FIRST PRINCIPLES OF CHEMISTRY.

UT potero, explicabo; nec tamen ut Pythius Apollo, certa ut sint et fixa, quæ
dixero: sed, ut homunculus, probabilia conjecturâ sequens.

TUSC. QUÆST. Lib. I. c. 9.

AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES

OF

CHEMISTRY

BY

EXPERIMENT.

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LITERARY AND PHILOSOPHICAL, AND NATURAL HISTORY SOCIETIES OF NEW YORK ; &C.

IN TWO VOLUMES.

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TO

Mʀ. JOHN DALTON, F.R.S., &c.,

M. GAY-LUSSAC, F.R.S., Mem. de l' Institut, &c.,

Sɪʀ HUMPHREY DAVY, Bart., P.R.S., &c.,

JACOB BERZELIUS, M.D., F.R.S., Kong. Vet. Acad. L., &c.,

WILLIAM HYDE WOLLASTON, M.D., V.P.R.S., &c.,

AND

WILLIAM PROUT, M.D., F.R.S., &c.,

TO WHOM

THE ATOMIC THEORY

IS INDEBTED FOR ITS ORIGINAL DEVELOPMENT

AND

FOR ALL THE IMPROVEMENTS WHICH IT HAS HITHERTO RECEIVED;

THIS ATTEMPT TO BRING THE SUBJECT

TO A STILL GREATER DEGREE OF SIMPLICITY AND PRECISION—

AS TO

THE BEST JUDGES OF ITS IMPORTANCE,

AND OF THE DIFFICULTIES TO BE SURMOUNTED,

AND MOST DISPOSED, IN CONSEQUENCE, TO VIEW

WITH INDULGENCE

ANY UNAVOIDABLE IMPERFECTIONS WHICH

THEY MAY PERCEIVE IN IT—

IS PRESENTED

BY THEIR SINCERE FRIEND AND HUMBLE SERVANT,

THE AUTHOR.

TO

THE STUDENTS

OF

MEDICINE AND CHEMISTRY

IN THE

UNIVERSITY OF GLASGOW.

GENTLEMEN,

A CONSIDERABLE portion of the work
which I now offer to the public, is already known to such
of you as attended my course of lectures during the last
three or four sessions. For I was in the habit of exhibit-
ing to you a table of the atomic weights of the different
bodies, as I succeeded in determining them, and of stating
to you the experiments by means of which the results
had been attained. I observed with pleasure the interest
which the better informed and more intelligent students
took in these investigations—while the numerous ap-
plications from various quarters for copies of my atomic
tables, satisfied me that many of my students had un-
derstood the discussions, and had fully appreciated their
importance.

I have been induced to lay the result of my investigations before the public, chiefly for two reasons, with which I think it requisite to acquaint you. The first of these is, the great advantage which medical practitioners will derive from a knowledge of the atomic weights of bodies, and of the weights of the integrant particles of the salts, &c., which they have occasion to employ in their prescriptions. This knowledge will be easily acquired by a perusal of the following pages; and it will enable those who possess it to avoid some very awkward blunders, into which I have observed too many practitioners, even of considerable celebrity, frequently to fall, to the no little inconvenience of their patients. Indeed, till the atomic theory was pretty completely investigated, even chemists themselves were not exempt from such mistakes; and I could point out, if I thought proper, some remarkable examples of men who would take it amiss if the world did not give them credit for possessing much chemical science, falling into mistakes that no student of mine, who took the trouble to follow and understand the lectures delivered on chemistry in the College of Glasgow, would run any hazard of committing. It was a wish to enable my students to recollect with ease this important collection of indispensable information, and to put it in the power of other medical students, who are strangers to the lectures which I deliver, to avail themselves of the benefits to be derived from the facts and the tables in the following pages, that constituted one of

the inducements which led me to lay the work before the world.

The second consideration which induced me to resolve upon publishing my atomical investigations, was one which more particularly concerns the medical students in the University of Glasgow. It was a wish on my part to shorten the discussions connected with the atomic theory, and with the composition of the salts, which I have hitherto thought it incumbent on me to introduce into my course of lectures. Henceforth, I shall have it in my power to refer you to the present publication for the proofs of the different fundamental points of importance. This will leave me much more time for illustration, and will enable me to make my future courses of lectures more entertaining and varied, without any diminution of the quantity of information which I have hitherto considered it as a point of duty to communicate. I shall be able too, hereafter, to enter more into detail respecting those parts of chemistry which are more intimately connected with the theory of medicine; for I need not observe to those gentlemen who have paid attention to the subject, that by far the most likely means of improving physiology, is a cautious application of chemistry to the investigation of the different constituents of the human body. An accurate knowledge of the chemical composition of every organ, and of the alterations produced on that organ by disease, would probably throw new and unex-

pected light upon the nature and treatment of many diseases. Physiology hitherto has been handled almost exclusively by the anatomists. These gentlemen have acted with a zeal and industry that cannot be too much admired. They have examined the anatomical structure of every organ of the human body; ascertained the changes to which it is liable from disease; and compared it with the analogous organs in all the inferior animals. A great deal of important knowledge has been the result of this active examination : yet, after the anatomists have exhausted all their ingenuity, it must be admitted that our knowledge both of the organs and functions is still very imperfcct. A new and more subtile species of anatomy remains still to be applied. Where the labours of the anatomist terminate, those of the chemist should begin. This chemical investigation of the animal body may be just said to be commencing at present : for it was not till the atomic theory was brought to considerable simplicity and perfection, that such an investigation was possible. It is easy to see that it must contribute pro-digiously to the advancement of physiological knowledge. I have been long anxious to lay before my students the general results already attained by these chemical investi-gations. But the preliminary discussions into which I was obliged to enter, left us too little time at the end of the session, to enter upon them; and after having been at no little pains in collecting and arranging the different facts from sources not easily accessible to students in

general, I have hitherto had the mortification to be obliged to pass them over, or at least to treat them in so general a way that my views could scarcely be understood. By referring my students hereafter to the facts contained in the following sheets, I shall have it in my power to shorten considerably the elementary part of my course, and be enabled to introduce at least a certain number of physiological lectures; by pointing out the general facts already ascertained, and the physiological consequences legitimately deducible from these facts. This is a branch of medical knowledge which has been much more attended to on the continent than in Great Britain. But from the intelligence and the zeal which the medical students in this country in general possess, I am satisfied that if the subject were once fairly started, it would become a favourite object of pursuit, and that it would advance to perfection with a degree of rapidity of which we can at present form but an imperfect idea.

PREFACE.

THE subject treated of in the following pages is of more importance than any other which can at the present moment occupy the attention of the chemist; since it is no other than an attempt to establish the fundamental principles of the science upon a sure and steady foundation. The analytical labours of the chemist and mineralogist depend upon these principles, and can only be accurate after their truth has been fully established. All the operations of the chemical manufacturer are equally dependant on them, and can only be prosecuted with perfect certainty and success by those who are acquainted with them. Several chemical manufacturers in this country have already availed themselves of the atomic theory to rectify their processes. This they have done to such an extent, that unless all the other manufacturers follow their example, they will find it impossible to compete with their more skilful rivals. One of the great objects of the present work is to reduce the whole doctrine of atoms to the utmost degree of simplicity and accuracy; so as to put it in the power of chemical manufacturers in general,

to avail themselves of it in order to bring their processes
to the requisite degree of precision.

Nor will the atomic theory prove less important to
apothecaries and druggists, and preparers of medicines.
It will point out the exact proportions of every substance
to be used, and will enable them to attain their object in
the most simple and direct manner, without any unprofit-
able waste by employing more or less of the different
substances than is just requisite for the intended object.
To them, and indeed to all medical men and medical
students, the knowledge of the atomic theory is of the
utmost consequence, and they will find the present publi-
cation of no little service to them. The tables contained
in this work ought to occupy a place in every laboratory,
and to lie upon the shop of every druggist, that he may
have it in his power to have recourse to them to regulate
all his processes.

The work which I now present to the public contains
the result of many thousand experiments, conducted with
as much care and precision as it was in my power to
employ. They have occupied the whole of my time
(except what was necessarily devoted to the duties of my
situation,) for the last five years. All those experiments
which I considered as fundamental, were repeated so
often, and varied in so many ways, that I repose the most
perfect confidence in their accuracy. I may therefore,

perhaps, venture to express a hope, that the reader will
not immediately judge them to be inaccurate, because they
do not exactly coincide with the analytical results of
other chemists. The processes of chemists have been so
much rectified and improved of late years, and so much
care is now generally bestowed upon experiments, that
we may rely upon the result (provided the data employed
be accurate) certainly within less than one per cent. I
believe indeed, that the error in many of Berzelius' analy-
ses does not exceed one thousandth part. But it is much
more difficult to obtain substances in a state of complete
purity than chemists in general are aware : it was in
reducing the different salts which I employed, to the
greatest possible degree of purity, that the greatest part
of my time was wasted. I have in all cases in which it
was in my power, deduced the atomic weights of bodies
from the rigid analysis of the neutral salts into which they
enter; because it is much easier to obtain neutral salts
pure, than any of the metallic bodies which constitute
their bases. Indeed, not a few of the metals have never
yet been exhibited in a state of absolute purity. Berzelius
has in general deduced the atomic weights of metals
from experiments on these bodies themselves. This I be-
lieve to be the principal reason why his atomic weights so
frequently differ a little from mine. For example, the atom
of zinc deduced from his experiments is 4·03225; while
the atomic weight obtained by me from the analysis of
sulphate of zinc is 4·25. The reason of this difference I

believe to be that the sulphate of zinc which I used was a pure salt, while zinc in the metallic state is never quite free from iron and some other impurities, all of which have a tendency to diminish its apparent atomic weight.

As the analysis of sulphate of zinc constitutes in some measure the foundation of the whole superstructure which I have endeavoured to rear, I made the analysis of it with the greatest possible care. My first analysis of it was inserted in the Annals of Philosophy, (second series) I. 247. But by some inadvertency, the quantity of water is stated at six atoms instead of seven, which is the true quantity. I cannot very well account for this mistake; for on looking back to my original analysis, I find it merely stated that 17 grains of sulphate of zinc were just decomposed by 13·25 grains of chloride of barium. Nothing is said about the state of the salt, which would enable us to account for the absence of an atom of water. But I have repeated the analysis of sulphate of zinc many times since the publication of that paper, and have made several of my practical students repeat it, and the uniform result has been seven atoms of water, and not six, as I there stated. If solutions of 17 grains of sulphate of zinc and 13·25 of chloride of barium be mixed, we shall find that the supernatant liquid, after the deposition of the sulphate of barytes, will become milky when mixed with sulphate of soda, showing that it still retains barytes,

and consequently, that 17 grains of sulphate of zinc do not contain so much as 5 grains of sulphuric acid.

I have been in the habit, ever since the atomic numbers given in the present work were determined, to calculate the experiments of other chemists by substituting for the data which they employed, the more correct data which I myself possessed, and I have frequently found that the experiments, when so calculated, came much nearer the truth than the experimenters themselves were aware of. This was remarkably the case with respect to Mr. Faraday's experiments to determine the constituents of the chlorides of carbon, for a knowledge of which we are indebted to that very ingenious and accurate chemist. The imperfect data which he employed has given his experiments the appearance of greater inaccuracy than the truth: for when the specific gravities and atomic numbers given in the following pages are substituted for those which he used, his experiments almost coincide with the theoretic quantities.

In this country, the atomic weights which I here present to the public, have been already very generally adopted, so far as they are known. But on the continent, the numbers and tables of Berzelius are in common use. Berzelius' numbers are in general very near approximations to the truth; though I am persuaded that in very few instances he has actually reached it. His tables

therefore, may be used without the risk of any great error, except those of the arseniates and phosphates, where the error is considerable ; but they consist of much more complex numbers than mine, and the atomic weights are all kept out of view by his method of giving the constituents in 100 parts of the compound bodies. On the score of facility and simplicity, I consider my numbers as much preferable: indeed, the theory of Berzelius is so complicated and intricate, that it would be surprising if it were a true representation of what takes place in nature.

A few of my determinations of the atomic weights of various bodies, were published in the Annals of Philosophy, during the years 1820 and 1821. But on perceiving that I had occasionally fallen into mistakes by stating results deduced from particular views of a subject, before I had been able to consider it in all its bearings, I thought it safer to refrain, till I had brought the investigation to a conclusion, and then to lay the whole at once before the public. This was the reason that induced me to discontinue my original plan of publishing my labours in periodical essays, in proportion as the atomic numbers were determined.

ADVERTISEMENT.

I HAVE been led by my desire of avoiding circumlocution, to make use of some terms in the following work, which may require explanation.

1. When the simple name of a compound occurs, it is to be understood that it is a compound of one atom of each constituent. Thus, oxide of zinc is a compound of one atom zinc and one atom oxygen. Sulphuret of bismuth, a compound of one atom bismuth and one atom sulphur. Sulphate of potash, a compound of one atom sulphuric acid and one atom potash.

2. When the acid which a salt contains is doubled, the doubling is denoted by prefixing the Latin word *bis* to the name. Thus, bisulphate of potash means a compound of two atoms sulphuric acid and one atom of potash. Biborate of soda is a compound of two atoms boracic acid and one atom soda.

3. When the base is doubled, this is denoted by prefixing the Greek syllable *dis*. Thus, disulphate of alumina is a compound of one atom sulphuric acid and two atoms alumina.

4. Three, four, &c. atoms of the acid are denoted by prefixing the Latin numerals, *ter, quater*,* &c. Three, four, &c. atoms of the base, by prefixing the Greek numerals, *tris, tetrakis,* &c.

5. When a metal is combined with oxygen in the proportion of two atoms metal to one atom oxygen, the compound is called a *suboxide*. Thus, suboxide of manganese is a compound of two atoms manganese and one atom oxygen, or, of one atom manganese and a half atom oxygen.

All the other terms employed will be understood without any farther explanation.

* The affix *quadro* having been already applied for this purpose by Dr. Wollaston, and having come into general use, I have thought it better to continue it than to use *quater*.

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OF

THE FIRST VOLUME.

CONTENTS.

AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES OF CHEMISTRY

BY EXPERIMENT.

CHAP. I.

HISTORICAL INTRODUCTION.

CHEMISTS appear at all times to have admitted that the constituents of compound bodies are constant, whether we consider the elements themselves, or their proportions. But it was not till Chemistry had made considerable progress, that any thing like an analysis of the salts could be attempted. Homberg, so far as I know, was the first person who thought of determining the composition of these bodies. He contrived a hydrometer for ascertaining the specific gravity of acids. This instrument was similar to the weighing bottle at present in common use for the same purpose. It enabled him to judge, from the specific gravity, how much stronger one acid

was than another.   But to estimate the quantity
of real acid contained in each of those liquids,
another process was necessary.   And he pro-
ceeded in this way : He took an ounce of salt of
tartar (carbonate of potash of the shops) and
saturated it with each of his acid liquids, deter-
mining the weights of each necessary to produce
the required effect.   The liquid was then eva-
porated to dryness, and the dry salt left was
weighed.   The augmentation of weight which
the ounce of salt of tartar had sustained, marked,
in his opinion, the weight of acid which had
combined with it.   For example : 1 ounce of
salt of tartar when saturated with nitric acid
becomes 1·45 ounces.   Hence he concluded that
saltpetre is a compound of

Potash	100 *
Nitric acid	45
	145

   In the same way he estimated the composition
of muriate of potash, sulphate of potash, acetate
of potash.   It is unnecessary to give the results
which he obtained, because Homberg, not having
been aware that salt of tartar contained carbonic
acid, increased the amount of the potash, and di-
minished that of the nitric acid by the whole quan-
tity of carbonic acid previously united with the

* Mem. Paris, 1699, p. 48.

potash. Of course, his results convey no idea whatever of the true composition of the salts which he attempted to analyze. We might, indeed, by subtracting the carbonic acid from the potash, and adding it to the acid, deduce the composition of these salts according to his experiments. These deductions being made, it will be found that saltpetre according to his experiments, is composed of

Potash   6 ,
Nitric acid   6·68
              ───────
              12·68

Numbers which, though not correct, constitute a pretty good approximation, and come much nearer the truth than the analysis of Kirwan, or even the more careful analyses of Berard or Wenzel.

The experiments of Plummer were made in the same way, and were subject to the same error.

In Dr. Black's celebrated Essay on Magnesia and Quicklime, he first pointed out the mistake of Homberg, and from some of his experiments deductions might be made respecting the constituents of some of the magnesian salts; but not being professed analyses, they have not attracted much of the attention of succeeding chemists.

Soon after the middle of the eighteenth century, attempts were made by different chemists

to analyze various chemical substances, especially by Bergman, who had acquired so great a reputation, that his opinions carried with them a high degree of authority, and his analyses were for some time considered as models of accuracy —a character to which they are by no means entitled.

Wenzel discovers the relative weight of acids and bases.

I. For the first accurate set of experiments on the composition of salts, we are indebted to Wenzel, a German chemist, who published in 1777, a small work entitled, *Lehre von der Verwandschaft der Körper*, or *Theory of the Affinities of Bodies.* He had been struck with a phenomenon which had already drawn some attention from chemists ; namely, that two neutral salts preserve their neutrality after mutually decomposing each other. Wenzel proved by a long series of very accurate analyses, that all the alkalies and earths bear the same ratio to all the acids. For example : if a given quantity of sulphuric acid be saturated by

9·75 barytes,
6·5   strontian,
6   potash,
4   soda,
3·5   lime,
2·5   magnesia,

the respective quantities of these earths and alkalies, which saturate a given quantity of each of the other acids, will be to each other as the

numbers 9·75, 6·5, 6, 4, 3·5, and 2·5. When nitrate of lime, and sulphate of potash decompose each other, the nitrate of potash, and sulphate of lime formed, are neutral, because the relative quantities of potash and lime, which saturate a given weight of nitric and sulphuric acid, are the same. If we represent nitric acid by 6·75, then 6 of potash and 3·5 of lime will just saturate that quantity of it; and 6 potash and 3·5 lime will just saturate 5 of sulphuric acid. Nitrate of lime (abstracting the water) is composed of

<div align="center">

Nitric acid   6·75
Lime   3·5
——
10·25

</div>

and sulphate of potash of

<div align="center">

Sulphuric acid   5
Potash   6
——
11

</div>

When 10·25 nitrate of lime and 11 sulphate of potash are mixed, a double decomposition takes place, and there are formed

<div align="center">

Nitrate of potash { Nitric acid   6·75
                { Potash   6
——
12·75

</div>

$$\text{Sulphate of lime} \begin{cases} \text{Sulphuric acid} & 5 \\ \text{Lime} & 3{\cdot}5 \end{cases}$$

$$\overline{8{\cdot}5}$$

And these new salts are neutral, because 6·75 nitric acid are neutralized both by 6 potash and 3·5 lime, and 5 sulphuric by 6 potash and 3·5 lime.*

It would appear a very extraordinary circumstance, if we were ignorant of the almost despotic power of fashion and authority over the minds even of men of science, that this luminous explanation of Wenzel, confirmed by the most accurate experiments which chemistry possessed, I do not say merely at the time when they appeared, but for many years after—experiments, which will even bear a comparison with those of Berzelius, made on purpose to demonstrate the truth of the very same principle which Wenzel first suggested—it would appear very extraordinary indeed, that neither the principle of Wenzel, nor the experiments by which it was confirmed, are noticed by any of the contemporary chemists, or seem to have attracted the smallest attention. Bergman was at that time in the height of his reputation. He published analyses of several of the salts, greatly inferior in point of accuracy to those of Wenzel. He, of course,

* I have not employed Wenzel's numbers to illustrate his opinions; but the more accurate numbers determined in the succeeding chapters of this work.

did not perceive the existence of the principle which Wenzel had investigated. Yet the analyses of Bergman and of other chemists, though less accurate, and inconsistent with the fact which had led Wenzel to his investigation, were adopted by chemists in general, and thus their attention was withdrawn from one of the most important steps which the science has ever made, and the great improvement itself was delayed for more than thirty years.

II. In the year 1792, Richter, who during the latter part of his life had the superintendence of the porcelain manufactory at Berlin, published a work entitled, *Anfangsgründe der Stochyometrie, oder Messkunst Chymischer Elemente, Elements of Stochyometry, or the Mathematics of the Chemical Elements.* This work consists of four thin volumes, which were printed at Breslau, during the years 1792, 3, and 4. It was followed by a periodical work, entitled, *Ueber die Neuern Gegenstände der Chymie, on the New Objects of Chemistry.* This work was begun in 1792,* and continued in twelve different numbers, or volumes, till the year 1807, the period of Richter's death. For he died on the 4th of May of that year.† In these works, he

The same opinions supported by Richter.

* In my copy, the date of the first part is 1799, but it is a second edition. The second part was printed at Breslau in 1793. Hence I infer, that the first part appeared in 1792.

† Gehlen's Jour. (second series) IV. 127.

endeavoured to give Chemistry a mathematical form. He examined the phenomenon observed by Wenzel, and explained it in the same way. He endeavoured to determine the relative capacity of saturation of the acids and bases, and attached a number to each, indicating this capacity. The following table exhibits these numbers.

Alumina	.	525	Fluoric acid	427
Magnesia	.	615	Carbonic .	577
Ammonia	.	672	Sebacic .	706
Lime .	.	793	Muriatic .	712
Soda .	.	859	Oxalic .	755
Strontian	.	1329	Phosphoric	979
Potash	.	1605	Formic .	988
Barytes	.	2222	Sulphuric	1000
			Succinic	1209
			Nitric .	1405
			Acetic .	1480
			Citric .	1683
			Tartaric .	1694

Richter's labours in this important field produced as little attention as those of Wenzel. Berzelius ascribes this to two causes. 1. The great inaccuracy of Richter's experiments, which indeed cannot for a moment be put in competition with those of Wenzel. 2. The violent discussion between the antiphlogistic and phlogistic system, which had originated about the year 1787, and had not completely subsided at the time of Richter's death. The last of these

reasons had, in all probability, the greatest influence.

But in Great Britain, where the importance of Richter's opinions were likely to have been early appreciated, another cause operated to prevent them from gaining much ground. The French revolution was at its acmé, when Richter began his Stochyometrical investigations, and all Europe was plunged into the bloodiest and most inveterate war, that has almost ever afflicted this part of the world. Great Britain soon became involved in the dispute, and gradually, not only bore the brunt of the war, but was, by degrees, deserted by all her allies, and at last left alone to wage war against all the world. Hence the intercourse between the men of science in Great Britain and on the continent was gradually interrupted. This, together with the little attention paid to German literature in this country, prevented us from being aware of the labours of Richter. My first knowledge of them was derived from a note in Berthollet's *Statique Chimique*, published in 1803, and I found it impossible to procure a copy till after the battle of Waterloo.

III. The notice in Berthollet's *Statique Chimique*, would probably have speedily drawn the attention of our countrymen to this most important department of chemistry, had not the genius of Dalton led him to a much more general view

Dalton's first views respecting the atomic theory.

of the subject, which has been usually called the atomic theory. I do not know when the ideas first occurred to him. In all probability they struck him by degrees, and were adopted in consequence of his own experimental investigations. I first visited him at Manchester, on the 26th of August, 1804, and on that day, he explained to me his notions respecting the composition of bodies. The ultimate particles of all simple bodies are, in his opinion, *atoms* incapable of farther division. These atoms (at least viewed along with their atmospheres of heat) are all spheres, and are all of them possessed of particular weights, which may be denoted by numbers. And he represented the atoms of the simple bodies by symbols. The following may be taken as a specimen of his method :

CHARACTERS.		RELATIVE WEIGHTS.
⊙	Hydrogen	1
⊕	Azote	5
◯	Oxygen	6·5
●	Carbon	5

BINARY COMPOUNDS.

◯⊙	Water	7·5
⊕◯	Nitrous gas	11·5
●⊙	Olefiant gas	6
⊕⊙	Ammonia	6
●◯	Carbonic oxide	11·5

TERNARY COMPOUNDS.

◯●◯	Carbonic acid	18

CHARACTERS.		RELATIVE WEIGHTS.
①O①	Nitrous oxide . . .	16·5
●⊙●	Ethers	
⊙●⊙	Carburetted hydrogen . .	7
O①O	Nitric acid	18

QUATERNARY COMPOUND.

OᴼO①O Oxy-nitric acid . . . 24·5
O

QUINQUINARY COMPOUND.

①O O①O Nitrous acid . . . 29·5
O

SEXTENARY COMPOUND.

●O● Alcohol . . . . 23·5
⊙●⊙

SEPTENARY COMPOUND.

O ①
⊙OO Nitrate of ammonia . . 31·5
①⊙

Such was the view of the subject, which Mr. Dalton had taken before the month of August, 1804. Unless my recollection fails me, Mr. Dalton's theory was originally deduced from his experiments on olefiant gas and carburetted hydrogen. He found both composed of carbon and hydrogen; but the carbon in each being considered as the same, he found the hydrogen in the latter gas twice as much as in the former. This induced him to determine the ratios of these constituents in numbers, and to consider the olefiant gas as a compound of 1 atom carbon

and 1 atom hydrogen; and carburetted hydrogen of 1 atom carbon and 2 atoms hydrogen. The idea thus conceived was applied to carbonic oxide, water, ammonia, &c. and numbers representing the atomic weights of oxygen, azote, &c. deduced from the best analytical experiments which chemistry at that time possessed.

In the third edition of my System of Chemistry, published in 1807, I introduced a short sketch of Mr. Dalton's theory, so far as I understood it.* The same year a paper of mine on oxalic acid was published in the Philosophical Transactions, in which I showed that oxalic acid unites in two proportions with strontian, forming an oxalate and a binoxalate; and that supposing the strontian in both salts the same, the oxalic acid in the latter is exactly twice as much as in the former.† About the same time Dr. Wollaston showed, that bicarbonate of potash contains just twice the quantity of carbonic acid that carbonate of potash does; and that there are three oxalates of potash, viz. oxalate, binoxalate and quadroxalate, the acids in which are to each other as the numbers

* Vol. III. p. 424.

† Berard, in a paper on the oxalates, which he published by way of correction of mine, though his results are in general more erroneous than my own, denies the existence of binoxalate of strontian. I have often made the salt, and regularly exhibit it to my students. It differs very much from the oxalate.

1, 2, 4. These facts gradually drew the attention of Chemists to Mr. Dalton's views, and induced several to adopt them, who were at first inclined to consider them as visionary. Among these I may mention Sir Humphrey Davy, who contributed so materially, a few years after, to confirm and extend this important theory.

In 1808 Mr. Dalton published the first volume of his New System of Chemical Philosophy. In the last chapter of that volume, consisting only of six pages, he gives us a concise view of his atomic theory; and in a plate at the end of the volume, he exhibits the symbols and atomic weights of 37 bodies, 20 of which were then considered as simple, and the other 17 as compound. In 1810, the second volume of this work appeared, in which he examined the combinations of oxygen with hydrogen, azote, carbon, sulphur, and phosphorus; and the combinations of hydrogen with carbon, sulphur and phosphorus; and showed that all these combined according to the laws of the atomic theory. He also examined the atomic weights and combinations of the alkalies and earths. The third volume of this most important work, though it has been printed for several years, the author, for reasons with which I am unacquainted, has thought proper to withhold from the public—and by so doing, has doubtless lost the right which he would have enjoyed, to

many curious discoveries, respecting the me-
talic combinations which he treated of in that
volume.

Mr. Dalton made choice of the atom of hy-
drogen for his unity. And in this he has been
followed by Dr. Henry of Manchester, and by
one or two chemical gentlemen in London.
But this method has been rejected by almost all
the British chemists, and by all the chemists,
without exception, in Europe and America.
The choice was unhappy, for very obvious
reasons. 1. Because the atom of hydrogen is
the most difficult of all to determine; and
chemists are not yet all agreed about its weight.
According to Professor Berzelius, it is only
0·0625; while the greater number of British
chemists consider it as 0·125, or twice as much
as Berzelius's estimate. Now, if we reckon the
atomic weight of hydrogen by unity, and commit
an error respecting its relation to that of other
bodies; this error will affect the atomic weights
of all other bodies, and will make them all either
too heavy or too light; whereas, if we make
choice of oxygen for our unity, any error re-
specting the atom of hydrogen will be confined
to that atom, and will not affect the accuracy of
the atomic weights of other bodies. 2. Hydro-
gen, so far as we know at present, combines
with but few of the other simple bodies; while
oxygen unites with them all, and often in vari-

ous proportions. Consequently very little advantage is gained by representing the atom of hydrogen by unity; but a very great one, by representing the atom of oxygen by unity. For it reduces the greater number of arithmetical operations, respecting these bodies, to the addition of unity; and we see at once, by a glance of the eye, the number of atoms of oxygen which enter into combination with the various bodies. Thus, if the atom of manganese be represented by 3·5, and the weight of the various oxides of that metal be as follows :

1 Suboxide	. .	4
2 Protoxide	. .	4·5
3 Deutoxide	. .	5
4 Tritoxide	. .	5·5
5 Manganesous acid	.	6·5
6 Manganesic acid	.	7·5

It is obvious at once that the

Suboxide contains	$\frac{1}{2}$ atom oxygen,
Protoxide	1
Deutoxide	1 $\frac{1}{2}$
Tritoxide	2
Manganesous acid	3
Manganesic acid	4

whereas, if we were to make the atom of hydrogen unity, these weights would be as follows :

Manganese	. .	28
Suboxide	. .	32

Protoxide	. .	36
Deutoxide	. .	40
Tritoxide	. .	48
Manganesous acid	.	56
Manganesic acid	.	64

Numbers, which would not suggest the number of atoms of oxygen contained in each, with the same facility.

But the ra-
tios should
be as sim-
ple as possi-
ble.
3. All the knowledge that we are likely ever to acquire of the atomic weights of bodies, is merely the ratios of these weights. Now, it is obvious, that ratios are much more easily observed, and much more easily employed, the smaller the numbers are, by which they are denoted. Thus the ratio of 38741 to 116223 is the same as that of 1 to 3. But how very inconvenient would the great number of figures be, compared with the simple number 1 : 3. It is therefore highly important in chemistry, that the atomic weights of bodies should be represented by the smallest possible numbers. Now, when we make the atom of oxygen unity, the atomic weights of all bodies are represented by numbers eight times less than they would be if the atom of hydrogen be unity. It has been represented by some persons, in favour of the atom of hydrogen being unity, that in that case the atomic weight of every body is a whole number; whereas, when oxygen is the unity, fractions are frequently unavoidable. And these fractions, it is said, ren-

der the atomic weights more complicated and unmanageable, than the greater size of the whole numbers deduced from hydrogen as a unity. But this view of the subject is quite erroneous. It will be shown in this work, that even when oxygen is made unity, nearly one half of all the atomic weights of bodies are whole numbers. And when fractions exist, they are always either 0·25, 0·5, or 0·75; except in four or five cases, when the fraction is 0·125, 0·375, or 0·625. If hydrogen be unity the atom of manganese is 28, while it is $3\frac{1}{2}$ if oxygen be unity. The atom of barytes on the former supposition is 78, on the latter $9\frac{3}{4}$. Now surely it will not be said that the fractional numbers are more unwieldy, or more unmanageable than the whole numbers; while in all cases of whole numbers the advantage on the side of the latter method is very great. Thus, if hydrogen be unity, the atom of uranium is 208, while if oxygen be unity it is only 26.

It was Dr. Wollaston that first suggested the representing of oxygen by unity. Berzelius, in his important investigations, adopted this method; and I did the same thing in the papers which I wrote on the Atomic Theory in the first series of the Annals of Philosophy. In the second series of the Annals, Mr. R. Philips has given a table of atoms according to the hydrogen scale.

Gay-Lus-
sac's theory
of volumes.

IV. For the next step in the progress of the atomic theory, we are indebted to Gay-Lussac. In the second volume of the Memoires D'Arcueil published in 1809, there appeared a paper by that acute chemist, *On the Combination of Gaseous Substances with each other.** In this paper he shows that the gases, considered in respect of their volumes, unite with each other in a very simple manner—one volume of one gas either combining with one volume, with two volumes, or with half a volume of the other. Thus one volume of carbonic acid gas combines with one volume and with two volumes of ammoniacal gas; fluoboric acid gas combines with one volume and with two volumes of ammoniacal gas; protoxide of azote is a compound of one volume azotic, and half a volume oxygen gas; deutoxide of azote of one volume of azotic, and one volume of oxygen gas, &c. He proved also in the same paper, that when gases unite, the alteration of volume which they sustain, is always very simple. Deutoxide of azote is composed of one volume of azotic, and one volume of oxygen gas united without alteration of volume. Carbonic acid is composed of one volume carbonic oxide, and half a volume of oxygen gas condensed into one volume, &c.

This very important view of the way in which gaseous bodies unite, threw a new and unex-

* Pag. 207.

pected light on chemical combinations. It has
contributed very materially to simplify and per-
fect the mode of analyzing compound gases. It
agreed admirably with the views of Mr. Dalton,
as Gay-Lussac hints in his paper; and might
have been employed by him in his investigations ;
and would have enabled him, had the specific
gravity of gaseous bodies been more accurately
known, at the time when he wrote, to have
determined the atomic weights of the acidifiable
combustibles with much more accuracy than he
did. But Mr. Dalton's first volume was pub-
lished, and probably the greater part of his se-
cond volume printed, before he had an opportu-
nity of seeing Gay-Lussac's paper. And when
he did see it, instead of welcoming it as an im-
portant addition to his own views, he set him-
self to show that Gay-Lussac's opinions were ill
founded. But the subsequent researches of
chemists have left no doubts about their accura-
cy ; and if Mr. Dalton still withholds his assent,
he is, I believe, the only living chemist who
does so.

V. When Professor Berzelius of Stockholm
thought of writing his elementary treatise on
Chemistry, the first volume of which was pub-
lished at Stockholm in 1808, he prepared him-
self for the task by reading several chemical
works, which do not commonly fall under the
eye of the chemist. Among others, he read the

Investigations and discoveries of Berzelius.

writings of Richter, and was very much struck
with the explanation there given, of the compo-
sition of salts, and the precipitation of metals by
each other.   It followed from the researches of
Richter, that if we are possessed of good analy-
ses of certain salts, we may, by means of them,
calculate with accuracy the composition of all
the others.   Professor Berzelius formed imme-
diately the project of analyzing a series of salts
with the most minute attention to accuracy.
While employed in putting this project in exe-
cution, Davy discovered the constituents of the
alkalies and earths; and Mr. Dalton's theory
came to his knowledge.   All this enlarged his
views as he proceeded, and induced him to em-
brace a much wider field than he had originally
contemplated.   His first analyses were unsatis-
factory; but by repeating them, and varying
the methods, he detected errors, improved his
processes, and finally obtained results, which
agreed exceedingly well with the theoretical
calculations.   These laborious investigations
seem to have occupied him several years.   The
first knowledge which we obtained of them in
this country, was in consequence of the publica-
tion of a letter addressed by Berzelius to M.
Berthollet, in the 77th volume of the *Annales
de Chimie*, about the beginning of the year 1811.
In this letter he gives an account of his methods
of analyses, together with the composition of 47

compound bodies. He shows that when a metallic proto-sulphuret is converted into a sulphate, the sulphate is always neutral; that an atom of sulphur is twice as heavy as an atom of oxygen; and that when sulphite of barytes is converted into sulphate, the sulphate is neutral, there being no excess either of acid or base. From these, and many other important facts, he finally draws this conclusion: " In a compound formed by the union of two oxides, the one which (when decomposed by the galvanic battery) attaches itself to the positive pole (the acid, for example,) contains 2, 3, 4, 5, &c. times as much oxygen, as the one which attaches itself to the negative pole, (the alkali, earth, or metallic oxide)." Berzelius' Essay itself appeared in the third volume of the *Afhandlingar i Fysik, Kemi och Mineralogie,* printed at Stockholm in 1810, where it occupies 114 pages. A translation of it was inserted almost immediately, in Gilbert's *Annalen der Physik,* and in the *Annales de Chimie;* but no English translation of this most important paper has ever been given to the public. In 1815, Berzelius applied his views to the mineral kingdom. His Essay was published in the fourth volume of the Afhandlingar, and an English translation of it by Mr. Black was soon after printed. And some years after, Berzelius himself got a French translation of it published in Paris. The fifth

volume of the Afhandlingar, published in 1818, is almost filled with papers on the same subject by Berzelius. His papers on the subject in that volume, amounting to nine—and all of them, especially the two last, are exceedingly important. The whole of these papers have appeared in the German Journals; and the greater number of them in the French and British Journals. In the 6th volume of the Afhandlingar, and in several of the latter volumes of the Memoires of the Stockholm Academy, this indefatigable experimenter has prosecuted the subject still farther. To him we are indebted for a much greater number of accurate analyses than to the whole chemical world put together. It is quite needless to observe how much the labours of Berzelius have contributed to the establishment of the atomic theory, and the immense progress which the science has in consequence made. In fact, we may almost say that it was by him that the theory was established. His analyses, in point of accuracy, infinitely surpass all those which had preceded him. He has embraced every department of chemistry with equal ardour, and every department lies under the deepest obligations to his indefatigable industry and profound sagacity.

Wollaston's scale of chemical equivalents. VI. In the year 1814, there appeared in the Philosophical Transactions, a description of a synoptical scale of chemical equivalents by Dr.

Wollaston. In this paper we have the equiva-
lents or atomic weights of 73 different bodies,
deduced chiefly from a sagacious comparison of
the previous analytical experiments of others,
and almost all of them exceedingly near the
truth. These numbers were laid down upon a
sliding rule by means of a table of logarithms,
and over against them the names of the sub-
stances. By means of this rule, a great many
important questions respecting the substances
contained on the scale may be solved. Hence
the scale is of great advantage to the practical
chemist, and of course ought to be found in
every laboratory. It will give, by bare inspec-
tion, the constituents of all the salts contained
on it, the quantity of any other ingredient
necessary to decompose, and the quantities of
the new constituents that will be formed. The
contrivance of this scale, therefore, may be con-
sidered as an important addition to the atomic
theory. It rendered that theory every where
familiar to all those who employed it. To it
chiefly we owe, I believe, the currency of that
theory in Great Britain; and the prevalence
of the mode which Dr. Wollaston introduced,
namely, of representing the atom of oxygen by
unity, or at least by ten, which comes nearly to
the same thing.

VII. In the year 1815, a paper appeared in
the 6th volume of the Annals of Philosophy

Prout's dis-
covery of
the relations
between the
atomic
weights.

by Dr. Prout, "On the Relation between the Specific Gravities of Bodies in their Gaseous State and the Weights of their Atoms." This paper displays a degree of sagacity that has seldom been exceeded in chemical investigations, and shows clearly that the author, if he chose, might rise to the highest eminence as a chemical philosopher. He proves, in the first place, that if air be a compound of 20 volumes of oxygen and 80 of azotic gas, then the specific gravities of these gases are

Oxygen 1·1111
Azotic 0·9722

He shows also, that the specific gravity of hydrogen gas is 0·0694 : that if we reckon the atomic weight of hydrogen 0·125, that of oxygen is unity. The following table exhibits the numbers which he determined for several simple bodies—and most of his determinations were the result of direct and very accurate experiments :

1 Oxygen	.	1
2 Azote	.	1·75
3 Hydrogen	.	0·125
4 Chlorine	.	4·5
5 Iodine	.	15·5
6 Carbon	.	0·75
7 Sulphur	.	2
8 Phosphorus	.	1·75
9 Calcium	.	2·5
10 Sodium	.	3

11 Iron	.	3·5
12 Zinc	.	4
13 Potassium	.	5
14 Barium		8·75

He observed that all these atomic weights are multiples of the atomic weight of hydrogen : indeed, that all of them are multiples of twice hydrogen, or 0·25, and most of them of 4 hydrogen, or 0·5. He observed also, that in general the specific gravity of the body in the gaseous state, may be obtained by multiplying its atomic weight by 0·5555, or half the specific gravity of oxygen gas ; because the atom of oxygen is represented by half a volume, but that of most other substances by a whole volume.

VIII. It was this admirable paper that satisfied me that new analytical investigations were still necessary to determine the atomic weights of bodies with perfect accuracy ; and I formed the project of attempting the investigation myself by direct experiment. This project it was not in my power to commence till the summer of 1819, because it was not till the end of the preceding summer that the college of Glasgow, to which I had recently been attached, could furnish me with a laboratory. Since that period I have devoted the whole of my spare time to the investigation ; and have resolutely withheld myself from entering upon several rather inviting fields, which have attracted general attention. My

Investigations of the author.

experiments have been very numerous, amounting
to many thousands. At first my progress was
very slow; because I was obliged to try many
methods of investigation before I hit upon one
sufficiently accurate for my purpose. But I
found the subject become easier as I proceeded,
and at last I acquired so much facility, that,
during the last four months, I have been able
to determine with tolerable accuracy the consti-
tuents of at least a hundred salts. My first ob-
ject was to satisfy myself whether Dr. Prout's
opinion, that the atomic weights of all bodies
are multiples of that of hydrogen, was correct;
because the establishment of its truth would at
once give a simplicity to the atomic numbers,
which had not been suspected, and would place
the science of chemistry in a new and much more
advantageous situation than it had ever oc-
cupied. The very numerous investigations,
which will be exhibited in the following pages,
will, I flatter myself, fully establish the truth of
Dr. Prout's sagacious conjecture. For every
substance, of which I could procure a sufficient
quantity to enable me to examine it fully, has
been found not only a multiple of the atomic
weight of hydrogen; but, if we except a few
compounds into which a single or odd atom of
hydrogen enters, they are all multiples of 0·25
or of two atoms of hydrogen.

After determining the atomic weights of all

the simple substances, and of many of their compounds, I next wished to examine the composition of a considerable number of salts, to see whether any law would develope itself respecting the quantity of water of crystallization which these bodies frequently contain. With this view a great number of salts were subjected to experiment; but the only obvious result is, that the number of atoms of water in salts, depends more upon the base than upon the acid : for the same base, in general, affects nearly the same number of atoms of water in its salts. But to this law there are many exceptions.

I now present the result of my investigations to the chemical public with considerable diffidence. For though I have been at the utmost pains to ensure accurate results; and often repeated what I considered as fundamental experiments eight or ten times, before I felt myself finally satisfied; yet the number of experiments gone through is so great, that it will be wonderful if, in some cases, I have not fallen into mistakes. I have made a point of relating my experiments (where I thought them fundamental) nearly as they were made : because, as I had no person to go over my calculations, which have been of necessity very numerous, though all of the simplest kind; it is very likely that I have not been always able to prevent the occurrence of some arithmetical errors in them.

And in all such cases the knowledge of the original experiments will put it in the power of the reader to calculate for himself, and to correct any errors into which I may have inadvertently fallen. The want of this attention in other writers has sometimes been severely felt by me, when an arithmetical error was conspicuous, without the requisite data for correcting it, or the means of knowing upon what number the error had fallen. Even the writings of Berzelius, though in general his numbers are very accurate, are not always free from this provoking uncertainty.

CHAP. II.

OF THE ATOMIC THEORY.

Two opinions have divided philosophers respect- Opinions respecting the ultimate elements of bodies. ing the nature of the ultimate elements of bodies, ever since they began to speculate on the subject. According to one party, these ultimate elements consist of *atoms*, or particles, incapable of farther division ; according to another, *matter* is infinitely divisible, and consequently no such atoms can exist. These two opinions divided the ancients ; and, after the revival of science in modern Europe, we find them equally dividing the philosophical world, and splitting it into sects. About the beginning of the last century, the infinite divisibility of matter was a favourite subject of discussion in Great Britain, and seems to have been universally adopted. Dr. Keil, in his Introduction to Natural Philosophy, devotes three lectures to this subject. In the first, he demonstrates the infinite divisibility of matter ; in the second, he answers the objections which have been advanced against the truth of the doctrine ; and in the third, he gives a number of examples of the extreme subtilty of matter, by showing how very minute a portion of certain substances may be made visible to the eye, or distinguished by the

Leibnitz considered them as *atoms*. sense of smelling.   Leibnitz, on the other hand,
adopted the opinion, that the ultimate elements
of bodies are atoms ; and, to obviate the mathe-
matical objections of those who had embraced
the doctrine of the infinite divisibility of matter,
he considered these atoms as unextended.   But
numerous absurd consequences were still deduci-
ble from this opinion of Leibnitz, which were
finally obviated by Boscovich ; who considered
the ultimate elements of bodies to be composed
of unextended atoms ; but demonstrated, in a
most ingenious manner, from the law of conti-
nuity, that mutual contact between these atoms,
or the bodies which they constitute, is impossi-
His view improved by Bosco-vich. ble.   According to the theory of Boscovich, the
latest and most complete and ingenious which
has been hitherto offered to the public, bodies
are composed of unextended atoms, indivisible
and homogeneous, possessing forces, which al-
ternate from repulsive to attractive, according to
the distance.   This theory has been viewed in a
favourable light by some of the most eminent
philosophers who have appeared since the The-
oria Naturalis of that mathematician was pub-
lished.   The opinion, that the ultimate principles
of bodies are atoms which are incapable of far-
ther division, seems, chiefly in consequence of
the authority of Boscovich, to have become the
prevailing opinion among the philosophers of the
present time.

With respect to the notion entertained by Boscovich, that the ultimate atoms of bodies are homogeneous, we are incapable at present of deciding whether it be well or ill founded. It is not likely that any of these ultimate elements has ever come under our inspection. All our simple bodies are most probably compounds. It is possible that the ultimate elements of bodies may be very few—it is even conceivable that they may be reduced to two ; but in what way all the variety of bodies with which we are acquainted, could be produced from one single kind of elementary body or atom, I cannot, for my own part, form any conception.

If the atoms of bodies be incapable of farther division or diminution, it seems requisite that we should adopt the opinion of Leibnitz, that these atoms are unextended. This notion involves us in a maze of metaphysical subtilties, through which Boscovich has piloted his way with infinite address. But such discussions being quite unsuitable to a system of chemistry, or to the science of chemistry in its present state, it will be better to avoid them altogether. By *atom*, then, in the following pages, I would be understood to mean, the ultimate particles of which any body is composed, without considering whether the farther division of these particles be possible or not. They differ from each other in weight ; but whether this difference be owing to

Meaning of the word atom *in this work.*

a difference in their size or specific gravity, or of
both together, I do not enquire.

The weights attached to the atoms of bodies,
and deduced from the combinations into which
they enter, merely express the ratios of the atomic
weights, and have no reference whatever to the
size or specific gravity of the atoms to which they
are attached.

If a body be simple, it seems reasonable to be-
lieve, that its atoms or ultimate particles, are in-
capable of farther diminution or division : and
consequently, that the supposition of the exis-
tence of half atoms involves an absurdity. Not-
withstanding this, I have in certain cases, in the
following pages, admitted the possibility of one
atom of one body, uniting with one and a half,
or with half an atom of another body. This ad-
mission has been viewed by many persons as im-
proper and absurd, and as even involving an
impossibility. I need hardly observe, that we
can get rid of these half atoms with the greatest
ease, by merely doubling the numbers represent-
ing the constituents of the compound. Thus, if
an atom of iron weigh 3·5, and an atom of oxy-
gen 1, and if we consider it as absurd to view
peroxide of iron as a compound of 1 atom of
iron, and $1\frac{1}{2}$ atom of oxygen ; we have only to
double 3·5, and 1·5, which are the two consti-
tuents of peroxide of iron. By so doing we get
$7 = 2$ atoms of iron, and $3 = 3$ atoms of oxygen,

and the peroxide of iron will be a compound of 2 atoms iron, and 3 atoms oxygen.

It is by no means unlikely, that this last method may represent the true composition of this oxide, and of the other compounds into which half an atom of oxygen, or of an acid or base, appears to enter. Nevertheless, I have been induced to represent the compound in the first way rather than the second ; because it gives us smaller and simpler numbers, and enables us better to see the connection between the compound in question, and other compounds of the same constituents. If we represent the atomic weights of iron and its oxides as follows,

Iron	.	.	3·5
Protoxide of iron	.		4·5
Peroxide of iron	·		5·0

we see at a glance that the protoxide is a compound of 1 atom iron + 1 atom oxygen ; and that the oxygen in the peroxide is to that in the protoxide, as 3 to 2. But if we represent these atomic weights by

Iron	·	.	3·5
Protoxide of iron	.		4·5
Peroxide of iron	.		10.0

by doubling the number of atoms in the peroxide, the relation between the oxygen, in the two oxides of iron, is much less evident. For the

sake of these advantages, which I consider as
considerable, I have been induced to introduce
half atoms in certain cases. But I would not
be understood to support the abstract idea of the
possibility of the existence of half atoms; but to
have been actuated by the arithmetical facilities
derived from the method which I have adopted.
Those who prefer theoretical considerations to
all such facilities, have only to double the atomic
weight of all bodies containing half atoms, and
they will get rid of the anomaly. The substances
containing a half atom of oxygen do not
amount to more than 7. A few occur contain-
ing half an atom of sulphur, and a few contain-
ing half an atom of acid.

Though the word *atom*, according to etymo-
logy, and indeed according to its usual accepta-
tion, implies a particle incapable of farther
diminution or division, I have been induced, for
the sake of shortness, to apply it in the following
pages with more latitude. When it is applied
to the ultimate particles of *simple* bodies, it is
taken in its usual and strict acceptation; but
when it is applied to a compound body, it is to
be understood as synonymous with *integrant
particle*. Thus, an atom of iron, may be con-
sidered as implying an ultimate particle of that
metal; but an atom of protoxide of iron means
merely an integrant particle of protoxide of iron,
which is a compound of 1 atom of iron and 1

atom of oxygen; and consequently contains in reality two atoms. I have seldom applied the term atom to any of the salts; but if it were so applied, it would denote a substance containing a considerable number of atoms. Thus, an atom or integrant particle of sulphate of ammonia, is composed of

1 atom sulphuric acid	5
1 atom ammonia	2·125
1 atom water	1·125
	8·25

An integrant particle of sulphuric acid contains 4 atoms; an integrant particle of ammonia contains 4 atoms; and an integrant particle of water contains 2 atoms. So that an atom, or integrant particle of sulphate of ammonia contains no fewer than 10 atoms.

I doubt not, that this loose mode of applying the term atom will appear to many of my readers an improper liberty, and quite inconsistent with the precision necessary in chemical discussions. But my reason for doing so was, that I am of opinion, that we are not at present acquainted with any truly simple bodies. All our simple bodies are most probably compounds; and many of them may be afterwards decompounded and reduced to more simple principles by the future labours of chemists. If this opinion be true, I could not have employed the term

atom at all, or at least I could not have applied
it to any of the bodies with which we are at
present acquainted. This consideration appears
to have induced several of the most distinguished
chemists, both in this country and in France, to
discard the term *atom* altogether. Thus, Dr.
Wollaston, instead of *atom*, employs the phrase
chemical equivalent, and Sir H. Davy employs
the term *proportion*. But I did not see any
reason for being so squeamish. The word *atom*
is more convenient, shorter, and more distinct
than any other word which I could think of.
And when it is understood to signify merely
integrant particle of the substance to which it is
applied, it cannot, I think, have any tendency to
mislead the reader.

2. Mr. Dalton, in the account of his atomic
theory, which he gave to the public at the end of
the first volume of his New System of Chemical
Philosophy, employs some terms which have
gradually got into general use, and which there-
fore require to be explained here.   These terms
are *binary*, *ternary*, *quaternary*, &c.

Binary, ter-
nary, &c.
explained.

1 atom of A + 1 atom of B = 1 atom of C, a binary compound.
1 atom of A + 2 atoms of B = 1 atom of D, a ternary
2 atoms of A + 1 atom of B = 1 atom of E, a ternary
1 atom of A + 3 atoms of B = 1 atom of F, a quaternary
3 atoms of A + 1 atom of B = 1 atom of G, a quaternary, &c.

Thus, protoxide of iron is a *binary* compound,
composed of 1 atom of iron + 1 atom of oxygen.

Carburetted hydrogen is a *ternary* compound, composed of 1 atom carbon and 2 atoms hydrogen : deutoxide of azote is a *ternary* compound, composed of 1 atom azote and 2 atoms oxygen. Ammonia is a *quaternary* compound, consisting of 1 atom azote and 3 atoms hydrogen ; sulphuric acid is a *quaternary* compound, composed of 1 atom sulphur and 3 atoms oxygen. Nitrous acid is a *quinquenary* compound, composed of 1 atom azote and 4 atoms oxygen. Nitric acid is a *sextenary* compound, composed of 1 atom azote and 5 atoms oxygen. After these illustrations the terms *septenary, octonary,* &c. will be understood without any farther explanation.

Mr. Dalton lays down the following rules, by which he thinks we should be guided in our opinions respecting chemical synthesis. Mr. Dalton's laws.

(1.) When only one combination of two bodies can be obtained, it must be presumed to be a *binary* one, unless some cause appear to the contrary.

(2.) When two combinations are observed, they must be presumed to be a *binary* and a *ternary*.

(3.) When three combinations are obtained, we may expect one to be a *binary* and the other two *ternary*.

(4.) When four combinations are observed,

we should expect one to be *binary*, two *ternary*, and one *quaternary*, &c.

(5.) A binary compound should be always specifically heavier than the mere mixture of its two ingredients.

(6.) A *ternary* compound should be specifically heavier than the mixture of a binary, and a simple, which would, if combined, constitute it, &c.

5th and 6th not accurate.

With respect to these rules, the first four appear unexceptionable, unless the third should be objected to ; but the fifth and the sixth do not appear to be warranted by a review of the compounds with which we are acquainted, compared with their constituents. It is in general true, that when two substances unite, they form a compound whose specific gravity is greater than the mean of that of the two constituents. But to this there are many exceptions. Deutoxide of azote has precisely the mean specific gravity of the two constituents. It has been demonstrated by Gay-Lussac, that it is composed of a volume of oxygen gas and a volume of azotic gas, united together without alteration of bulk. One volume protoxide of azote $+ \frac{1}{2}$ volume of oxygen gas united, will form 2 volumes of deutoxide of azote ; so that in the act of uniting, an expansion instead of a contraction takes place. The specific gravity of an alloy of 2 atoms tin

and 1 atom lead ought to be 9·321 ; but it amounts only to 8·817, showing that an expansion has attended the union of these metals, instead of a contraction.

3. Berzelius, in his different papers upon the atomic theory, and especially in his Essay on the Theory of Chemical Proportions, has made us aquainted with the rules that guided him in the conclusions which he has drawn respecting the atomic weights of the different bodies, and the number of atoms of which the compound bodies are composed. The most important of these laws are the following :

(1.) One atom of A may combine with 1, 2, 3, 4, &c. atoms of B. We do not know the limit ; but it rarely passes 5 atoms.

(2.) Two atoms of A may combine with 3 atoms of B. But this is a much rarer case than the preceding.

(3.) When an acid and a base unite, the oxygen in the acid is a multiple of that in the base by 1, 2, 3, &c. The only exceptions to this law, exist in the combinations of phosphoric, arsenic, and nitric acids with bases.

(4.) Oxides containing only 1 atom of oxygen, united to 1 atom of base, have very weak affinities for acids.

(5.) Oxides with 2 atoms of oxygen have very strong affinities for acids.

(6.) Oxides with 3 atoms of oxygen have weak

affinities for acids. Some of them possess rather
the properties of acids than of bases.

(7.) Most acids contain 3 atoms of oxygen;
but some contain 2, 4, 5, 6, 8 atoms.

The first two of these laws are unexcep-
tionable; being merely a statement of what
every person, who has attended to the combina-
tions of atoms with each other, must have ob-
served.

The third
law not uni-
versally
true.
The third law is not so obviously just, and will
require some consideration before it can be adopt-
ed. The greater number of the alkaline bases,
as will appear from the following pages, contain
only 1 atom of oxygen : and the neutral salts
being compounds of 1 atom acid, and 1 atom
base, it is clear that in all of them, the oxygen of
the acid will be a multiple of the oxygen of the
base; because every number is a multiple of
unity. Hence every acid, whether it contain 1,
2, 3, or more atoms of oxygen, must, in fact, con-
tain a number of atoms of that principle, equal
to the oxygen in the base, multiplied by the
number of atoms of oxygen in the acid. This
must necessarily be the case, because the oxygen
in every acid always amounts to a whole number
of atoms. Berzelius, indeed, considers almost all
the salifiable bases as containing two atoms of
oxygen. But he represents the neutral salts as
compounds of 1 atom base, and two atoms acid.
Now, whatever the number of atoms of oxy-

gen may be which an acid contains, it is obvious that the double of it must constitute an even number, or a number divisible by 2, and consequently a multiple of 2.

As far then as the neutral salts are concerned, Berzelius's law expresses nothing more, than that the salifiable bases are mostly protoxides—a pretty remarkable fact, though Berzelius himself was not aware of it. Even in the neutral phosphates, arseniates, and nitrates, and in the biphosphates, binarseniates, and binitrates, the same law will hold. It is only in the subsalts, and in those salts that contain peroxides united to an acid, that we can see whether this supposed law of Berzelius be general or not. For example, sulphuric acid contains 3 atoms of oxygen : now, it would be a very remarkable circumstance indeed, if no protoxide exist, of which 2 atoms are capable of uniting with 1 atom of sulphuric acid. There are but few subsalts known at present; yet when I come to treat of the salts, I think I shall be able to show examples of subsalts, which are inconsistent with Berzelius's supposed law. Peroxide of iron is a compound of 1 atom of iron, and $1\frac{1}{2}$ atom of oxygen ; consequently, whether it combine with 1 atom, 2 atoms, or 3 atoms, of sulphuric acid, it is obvious that the oxygen of the acid must be a multiple of the oxygen of the base : For $3 = 1 \cdot 5 \times 2$. But phosphoric acid is a compound of 1 atom phosphorus, and 2 atoms

of oxygen. Hence, Berzelius's law could not
hold with perphosphate of iron, unless it con-
sisted only of 1 atom peroxide of iron united to 3
atoms of phosphoric acid. We are acquainted at
present with but very few compounds of peroxides
with acids; yet, when I come to treat of the salts,
I think I shall be able to point out some which
are not combined according to Berzelius's law.
It would, therefore, be extremely hazardous to
employ this law as a guide to enable us to deter-
mine the quantity of oxygen united to bases.
This, Berzelius is frequently in the habit of do-
ing, and I think it has misled him in a variety of
cases. These I may perhaps notice more parti-
cularly hereafter.

4th, 5th, and 6th laws, founded on reviews peculiar to Berzelius. Berzelius's fourth, fifth, and sixth laws, are
founded entirely upon his own peculiar views re-
specting atomic combinations, and cannot, there-
fore, serve as guides to us. So far from being of
opinion that the combinations of 1 atom base, and
1 atom oxygen, constitute weak alkaline bodies,
I consider them as the strongest of all: for the
fixed alkalies, alkaline earths, and most of the
metallic oxides which constitute salifiable bases,
belong to this class of bodies.

To the oxides which Berzelius considers as
composed of 1 atom base, and 1 atom oxygen, I
give the name of *suboxides*, and believe them to
be compounds of 2 atoms base, and 1 atom oxy-
gen. They have but a weak affinity for acids;

though most of them combine, at least, with muriatic acid. Hitherto, only a few of these suboxides have been noticed by chemists, though it is likely that they will increase considerably hereafter.

It is unnecessary to make any observations upon Berzelius's seventh law; it expresses merely his opinion respecting the composition of acids. If the views which I have given in the following pages be entitled to any confidence, it will be seen that eleven of the acids contain three atoms of oxygen; namely,

7th law in the same predicament.

1 Oxalic	4 Arsenic	7 Succinic	10 Tungstic
2 Sulphuric	5 Molybdic	8 Benzoic	11 Fluoboric.
3 Chromic	6 Acetic	9 Formic	

Six contain only one atom of oxygen; namely,

| 1 Silica | 3 Hyposulphurous | 5 Columbic |
| 2 Phosphorous | 4 Oxide of tellurium | 6 Fluoric. |

Twelve contain two atoms; namely,

1 Carbonic	4 Sulphurous	7 Selenic	10 Uranitic
2 Boracic	5 Titanic	8 Antimonic	11 Uric
3 Phosphoric	6 Arsenious	9 Molybdous	12 Fluosilicic.

Two contain four atoms; namely,

Manganesic and citric.

Three contain five atoms; namely,

Hyposulphuric, tartaric, chloric.

One contains seven atoms; namely,

<div align="center">Perchloric;</div>

And one eight atoms; viz.

<div align="center">Saclactic.</div>

Rules by which the investiga- tions of the author were regulated.

4. I shall now briefly notice the considerations by which I have been regulated in the following investigations, and by which I have been led to fix upon the atomic numbers contained in this work.

(1.) The only useful information respecting the atoms of bodies, which we are likely to acquire, is that of the ratios which these weights bear to each other. Hence, the smaller the numbers employed to represent these atoms, the more useful will they be to the practical chemist.

(2.) Neutral salts (that is, salts which are neither acid nor alkaline) are probably composed of 1 atom of acid united to 1 atom of base. When the salt has acid qualities, it is probably a compound of 1 atom base, and more than 1 atom of acid. When it possesses alkaline qualities, it is probably a compound of 1 atom acid, and more than 1 atom of base : but to these rules there are many exceptions. Some acids have not the property of neutralizing the bases, in however great a proportion they are combined with them. This is the case with boracic acid ;—even a compound of 8 atoms of boracic acid, and 1 atom of

<div align="center">3</div>

soda, possesses alkaline characters. We cannot, therefore, determine the proportion between the atoms of acid and base in the borates, by their neu-trality. The same thing holds with the alkaline car-bonates, which always possess alkaline properties whatever be the number of atoms of carbonic acid they contain. On the other hand, there are several bases, as the oxides of copper and zinc, which do not destroy the acid properties of acids in how great a proportion soever they be combined with them. Such salts alway redden vegetable blues, and possess certain characters denoting the presence of an acid.

(3.) The weights of certain acidifiable bases were determined by their relation to oxygen. Thus it was found that 2 of sulphur is capable of combining with 1, 2, and 3 of oxygen. Hence, it was concluded, that 2 represents the atomic weight of sulphur, and that the atomic weights of the compounds of sulphur and oxygen are,

<div style="text-align:center">ATOMIC WEIGHT.</div>

1. 2 sulphur + 1 oxygen = 3 hyposulphurous acid.
2. 2   + 2   = 4 sulphurous acid.
3. 2   + 3   = 5 sulphuric acid.
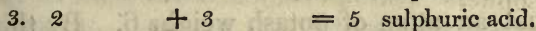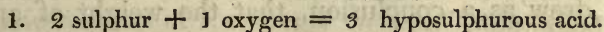
In like manner, 0·75 carbon unites with 1 and 2 of oxygen. Hence 0·75 represents an atom of carbon, and the atomic weights of the com-pounds of carbon and oxygen are,

1. 0·75 carbon + 1 oxygen = 1·75 carbonic oxide.
2.   + 2   = 2·75 carbonic acid.
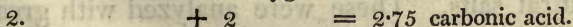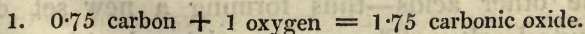
1·75 azote combines with 1, 2, 3, 4, 5 of oxygen. Hence

1. 1·75 azote + 1 oxygen = 2·75 protoxide of azote.
2. 1·75   + 2   = 3·75 deutoxide of azote.
3. 1·75   + 3   = 4·75 hyponitrous acid.
4. 1·75   + 4   = 5·75 nitrous acid.
5. 1·75   + 5   = 6·75 nitric acid.

(4.) After determining in this way, the atomic weights of some of the most common and important acids, I examined the neutral salts which these acids formed by uniting with the salifiable bases, and determined the proportion between the weights of the acid and base in each. From this I deduced the atomic weight of the base. Thus, knowing that the atomic weight of sulphuric acid is 5, and that sulphate of potash is a compound of

Sulphuric acid   5
Potash   6
                 ——
                 11

I drew as a conclusion, that the weight of an integrant particle of sulphate of potash is 11, and that an atom of potash weighs 6. By this method, I determined the atomic weights of most of the salifiable b as es.

(5.) I now combined some of the most common and important of these salifiable bases with the other acids—thus forming a new set of neutral salts. These were analyzed with great

care, and the ratio between the acid and base in them determined. From this I deduced the atomic weights of the other acids. Thus, knowing that the atomic weight of soda is 4, and that neutral anhydrous acetate of soda is composed of

Acetic acid	6·25
Soda	4
	10·25

I drew as a conclusion, that 10·25 represents the weight of an integrant particle of anhydrous acetate of soda, and that 6·25 is the atomic weight of acetic acid.

In this way, the atomic weights of all the acids and bases were determined from neutral salts, and they represent the ratios in which the acids and bases saturate each other, expressed in the smallest numbers consistent with the notion, that the atomic weight of oxygen is unity.

The methods employed to determine the atomic weights of the simple bodies, of which these acids and bases are composed, will be understood by perusing the different chapters of the following work.

CHAP. III.

OF THE SPECIFIC GRAVITIES OF OXYGEN
AND HYDROGEN GASES.

It is only of late years, that the great impor-
tance of an accurate knowledge of the specific
gravities of the gases has been fully appreciated.
Three different sets of experiments on the sub-
ject have been laid before the public. The first
was by Biot and Arago, which was published in
the *Memoires de l'Institute*, for 1806, p. 320.
They give a table of the specific gravity of a
few of the most important gases, and describe
the processes by which they were determined.
The next was a paper inserted by me in the
16th volume of the Annals of Philosophy. It
contained the specific gravities of 23 gases.
The experiments were made with every precau-
tion which I could think of, to secure me
against mistakes ; and I believe them to come
as near the truth as we can reach, with our pre-
sent means of operating. The third set was
by Messrs. Berzelius and Dulong, and published
in the *Annales de Chimie et de Physique*, for
1820.* They determined the specific gravity of
oxygen, hydrogen, carbonic acid, and azotic

Experiments already made to determine these gravities.

* Vol. XVI. p. 386.

gases with great care, and gave a table of the specific gravity of 21 bodies, calculated from these data, and the doctrines of Gay-Lussac, respecting the mode in which gases combine. These results of Berzelius and Dulong differed so much from mine as to excite my surprise; while the well known accuracy and dexterity of these gentlemen naturally induced me to distrust my former results, and to endeavour to verify them by new experiments. After a good many fatiguing trials made with every precaution that I could think of, I was unable to find any flaw in my former results, or to reconcile them with those of Berzelius and Dulong. I was satisfied that I could not approach any nearer the goal by the direct road. But another method of proceeding occurred to me, susceptible, I thought, of an unlimited approximation to the truth. This method applied only to oxygen and hydrogen gases. But these bodies constitute the keystone of the building. And were their specific gravities once determined with precision, we are enabled, by means of the atomic theory, to determine with accuracy the specific gravities of most of the other gases.

Method of the author.

I propose in this chapter to lay before the reader, a set of experiments which seem to me to settle the specific gravities of these two gases, without any error which can much exceed

the ten thousandth part of the whole. The accuracy of the process, indeed, is only limited by the delicacy of the balance made use of in the experiments. And my balance enabled me to weigh to within less than one hundred thousand part of the weight.

It has been demonstrated by Gay-Lussac and Humboldt, that water is a compound of oxygen and hydrogen gases, in the proportion of one volume of the former, to two volumes of the latter. It occurred to me that by a very careful analysis of water, the relation between the volumes and the weights of these gases might perhaps be determined. These experiments were made by means of zinc, and before their accuracy can be appreciated, it will be necessary to know the exact composition of the oxide of zinc. I shall therefore divide this chapter into three sections. In the first section, we shall determine the composition of oxide of zinc ; in the second, the specific gravity of oxygen gas ; and in the third, the specific gravity of hydrogen gas.

SECT. I.

OF THE COMPOSITION OF OXIDE OF ZINC.

I SHALL be under the necessity to state in this section a variety of facts, which may seem at first sight foreign to the subject in view ; but

which are requisite, in order to enable the reader to judge of the justice of the conclusions which are to be drawn. Some of the details may appear needlessly minute ; but I must request the reader's attention to them, because they constitute the foundation of the whole fabric which I mean to build.

The zinc of commerce does not answer for the experiments which I am going to describe. It is never quite free from carbon, which has a material effect in increasing the specific gravity of the hydrogen gas, obtained by dissolving it in sulphuric acid. It contains, likewise, small quantities of several other metals, and does not dissolve completely in sulphuric acid. The zinc which I used, was obtained by exposing common zinc to a white heat in a stone-ware retort, luted to a receiver nearly filled with water. At this temperature, the zinc is sublimed, and freed from all its impurities, except a trace of cadmium too minute to occasion any sensible error in the result of the experiments. The zinc thus distilled over, should be melted in a crucible, and poured upon the surface of a clean, smooth sandstone. We thus obtain it in a thin sheet, which can be easily broken into small pieces to suit the object in view.

Composition of oxide of zinc. 21·25 grains of this zinc were introduced into a small green glass retort, the weight of which had been previously determined. As much

6

very weak but pure nitric acid as was fully suf-
ficient to dissolve the whole zinc was introduced
into the retort.   As soon as the metal was all
dissolved, a receiver was applied to the retort
which was placed in hot sand, and allowed to re-
main till the whole liquid contents had distilled
over. The liquid in the receiver was saturated
with carbonate of ammonia, and boiled for some
time to see whether it contained any zinc; but
no precipitate appeared.

The retort, thus freed from its liquid contents,
was placed upon a charcoal fire, and kept for
about an hour in a dull red heat.   This com-
pletely decomposed the nitrate of zinc, which
existed at first in the retort, dissipated the
nitric acid, and left nothing behind but the
21·25 grains of zinc, now converted into an
oxide.   Being placed in the scales, the zinc, by
being oxydized, was found to have increased in
weight 5 grains.   Thus, it appears that oxide
of zinc is composed of

<div align="center">

Zinc   21·25
Oxygen   5
           ———
           26.25
</div>

or, dividing each constituent by 5 to bring them
to their lowest terms, of

<div align="center">

Zinc   4·25
Oxygen   1
           ———
           5·25
</div>

<div align="center">D 3</div>

As zinc combines with oxygen in only one proportion, it is reasonable to conclude that the oxide is a compound of 1 atom zinc and 1 atom oxygen. If this supposition be admitted, the atom of zinc is obviously $4\frac{1}{4}$ times heavier than the atom of oxygen. And if we represent the atomic weight of oxygen by unity, then the atomic weight of zinc will be 4·25 and the integrant particle of oxide of zinc will weigh 5·25; or in other words, 5·25 of oxide of zinc will just saturate an integrant particle of any acid with which it is capable of combining. The law holds with all acids; but I shall at present verify it only by referring to three acids; namely, the sulphuric, carbonic, and arsenic acids. It will be shown in the 5th, 1st, and 7th sections of the sixth chapter of this work, that the atomic weights of these acids are as follows :

Sulphuric acid .	5
Carbonic acid .	2·75
Arsenic acid .	7·75

Now, 5·25 of oxide of zinc will just saturate 5 of sulphuric acid, 2·75 of carbonic acid, and 7·75 of arsenic acid; or in other words, the sulphate, carbonate, and arseniate of zinc, supposing them anhydrous, are composed as follows :

1. SULPHATE OF ZINC.

Sulphuric acid .	5
Oxide of zinc .	5·25

2. CARBONATE OF ZINC.

Carbonic acid . 2·75
Oxide of zinc . 5·25

3. ARSENIATE OF ZINC.

Arsenic acid . 7·75
Oxide of zinc . 5·25

We shall verify this statement by a rigid analysis of these three salts.

1. SULPHATE OF ZINC.

Sulphate of zinc, or white vitriol, is a well known salt which crystallizes in beautifully transparent four-sided prisms, terminated by four-sided pyramids ; or if the crystallization be rapid, it assumes the form of long slender white needles. However carefully prepared, it always reddens vegetable blues. But it crystallizes also with an excess of acid. In that case, the crystals assume the form of large flat rhomboids, which are not altered by exposure to the air, and may be raised to the temperature of at least 500° without being deprived of their excess of acid.*

Analysis of sulphate of zinc.

---

* I am doubtful whether this salt constitutes a truly distinct species. I found its composition

$1\frac{1}{3}$ atom acid   6·66
1 atom oxide   5·25
8 atoms water   9·00

———————

20·91

or, it consists of one atom of the protohydrate of sulphuric acid, combined with three integrant particles of the neutral salt.

18·125 grains of the neutral sulphate of zinc were dissolved in distilled water, and precipitated by a solution of carbonate of soda. The precipitate was separated from the liquid by means of a double filter, consisting of two pieces of unsized and well washed printing paper, made previously of the same weight. The carbonate of zinc on the filter was washed with distilled water, till the liquid which passed through ceased to render muriate of barytes muddy. The filter was suspended in a linen bag above the sand bath, in a temperature of 85°, till it was apparently dry ; and it was finally left for some time in a temperature of about 212°. It was afterwards weighed by placing the two filters in opposite scales, and adding weights till the two scales were exactly counterpoised. The weight of the carbonate of zinc was exactly 8 grains. It was put into a platinum crucible, which was covered with a lid, and exposed for half an hour to a red heat. There now remained 5·25 grains of oxide of zinc.

Thus it appears, that 18·125 grains of sulphate of zinc, in crystals, contain 5·25 grains of oxide of zinc. It is still easier to prove that the sulphuric acid contained in this quantity of the salt weighs precisely 5 grains.

' But it will be necessary to state, in the first place, that when 15·5 grains of crystallized

muriate of barytes are exposed to a red heat,
they lose 2·25 grains of their weight, and are
converted into 13·25 grains of chloride of ba-
rium.   When 13·25 grains of chloride of barium
are dissolved in water, the solution contains just
9·75 grains of barytes.   Now, 9·75 represents
the atomic weight of barytes, which requires for
saturation exactly 5 of sulphuric acid.   And
14·75 parts of sulphate of barytes contain just
5 parts of sulphuric acid.

   A little distilled water was put into two small
cylindrical glass jars, and 18·125 grains of
crystallized sulphate of zinc were dissolved in
the one of these, and 13·25 grains of chloride
of barium in the other.   The two liquids being
mixed, a double decomposition took place, and
sulphate of barytes precipitated in the state of
a white powder.   This precipitate being col-
lected, washed, dried, and heated to redness,
weighed 14·75 grains, and therefore contained
exactly 5 grains of sulphuric acid.   A few
drops of the colourless liquid from which this
sulphate had precipitated, were put into a watch
glass, and a small quantity of muriate of barytes
mixed with it ; but it did not become in the
least muddy or even opal coloured, showing that
it contained no sensible quantity of sulphuric
acid.   For I find that 1 grain of glauber salt
(containing 0·2469 grain of sulphuric acid) dis-
solved in 12,000 grains of water, is sensibly

precipitated by muriate of barytes. Hence it is clear, that in the present experiment, the quantity of sulphuric acid remaining in the liquid could not amount to $\frac{1}{40502}$ of a grain. Indeed, as the quantity of liquid never amounted to 1000 grains, the sulphuric acid remaining in solution, could not be so much as $\frac{1}{486024}$ of a grain.

Another portion of this residual liquid being mixed with sulphate of soda, was not in the least altered, showing that the liquid contained no sensible portion of barytes. Thus it appears, that the barytes from 13·25 grains of chloride of barium, or 15·5 grains of muriate of barytes, just saturate the sulphuric acid in 18·125 grains of sulphate of zinc. Hence, this acid just weighs 5 grains.

We see therefore, that in neutral sulphate of zinc, 5·25 parts of the oxide are combined with 5 parts of the acid; which was the thing to be proved. These two constituents added together make 10·25, which subtracted from 18·125 leave 7·875 for the quantity of water of crystallization. It will appear afterwards that this is equivalent to 7 atoms of water. Sulphate of zinc in crystals, then, is composed of

1 atom sulphuric acid	5
1 atom oxide of zinc	5·25
7 atoms water	7·875

	18·125

So that 18·125 is the weight of an integrant particle of the crystallized salt. It was the knowledge of this that induced me to make choice of 18·125 grains of the salt. My first experiments were made upon a much larger quantity ; but I have often repeated them with 18·125 grains, and obtained the result just stated.

If the solution of neutral sulphate of zinc be White vi-
concentrated too much, it deposites, while still triol.
hot, an opaque crust upon the bottom of the vessel. This crust is very white, not so soluble in water as the crystals, and has not the least appearance of crystallization. It is neutral, though it reddens vegetable blues like the preceding salt; and being analysed in the same way as the crystallized sulphate, was found composed of

1 atom sulphuric acid	5
1 atom oxide of zinc	5·25
3 atoms water .	3·375

$$\overline{13·625}$$

So that an integrant particle of it weighs 13·625, and it differs from the crystals in containing only 3 atoms of water, instead of seven.

The white vitriol of the Germans consists of this second salt, while the sulphate of zinc manufactured in Great Britain consists of the former. The German white vitriol contains 24·77

per cent. of water, while the British sulphate of zinc contains 43·44 per cent.

2. CARBONATE OF ZINC.

Of carbonate of zinc. One of the experiments related while giving the analysis of sulphate of zinc, is sufficient to show the proportion of carbonic acid, which combines with 5·25 parts of oxide of zinc.   For 18·125 grains of sulphate of zinc, when decomposed by carbonate of soda, yielded a precipitate which, after being well washed and dried in the temperature of 212°, weighed 8 grains, and when exposed to a red heat, was reduced to 5·25 grains.   These 8 grains were carbonate of zinc.   The carbonic acid was dissipated by the red heat, and the oxide remained pure.   We see that 5·25 of oxide of zinc are converted into carbonate by uniting with 2·75 grains of carbonic acid.

When carbonate of zinc is dried in the open air, without exposure to any artificial heat, I have obtained it composed as follows :

1 atom carbonic acid	2·75
1 atom oxide of zinc	5·25
2 atoms water	2·25
	10·25

so that an integrant particle of it weighs 10·25. But the water is very easily dissipated—indeed,

so much so, that it is not easy to dry this car-
bonate without sustaining at least a partial loss
of the water.   But I have more than once suc-
ceeded in getting it with the exact atomic
proportions.   The carbonate of zinc occurs in
the mineral kingdom, sometimes anhydrous, and
sometimes containing 1 atom of water.

3. ARSENIATE OF ZINC.

This salt was obtained by the following pro-   Of arseniate
cess : 18·125 grains of the crystallized sulphate   of zinc.
of zinc, and 20·75 grains of arseniate of
soda were dissolved in separate portions of
distilled water, and the two solutions, after being
well mixed, were evaporated to dryness, and
the dry mass digested in distilled water.   A dou-
ble decomposition took place, and arseniate of
zinc separated in the state of a gelatinous looking
matter.   Being washed and dried in the open
air, it constituted a white powder, weighing 26·5
grains.   But when heated to redness, the weight
was reduced to 13 grains.   By a careful analysis
of this salt, I found that its constituents were

1 atom arsenic acid	7·75
1 atom oxide of zinc	5·25
8 atoms water	9·0
	——
	22·0

It would be easy to increase the number of
these examples ; but those given are sufficient

to show that the atomic weight of oxide of zinc is 5·25, and that it is a compound of 4·25 zinc and 1 oxygen. And this being the only object in view, we need not at present proceed any farther.

SECT. II.

OF THE SPECIFIC GRAVITY OF OXYGEN GAS.

VARIOUS statements of the specific gravity of this gas have been published by different chemists. The following table exhibits those which have been generally considered the most to be depended on.

Specific gravities of oxygen gas.	1·114 .	Saussure, Ann. de Chim. LXXI. p. 269.
	1·103 .	Biot and Arrago, Mem. de l'Institut. 1806, p. 320.
	1·089 .	Allen and Pepys. Phil. Trans. 1807.
	1·1117 .	Thomson, Annals of Philosophy, XVI. p. 163.
	1·1026 .	Berzelius and Dulong, Ann. de Chim. et de Phys. XV. 386.

It would be impossible to decide which of these determinations deserves the preference. The experiments were all made with care, and no doubt, sufficient precautions were taken to have the gas in a state of purity. I shall therefore proceed to relate the attempts which I have made to determine the specific gravity of oxygen gas in quite a different way.

A hundred grains of distilled zinc were put ^{Method of} into a small retort, nearly filled with a mixture of one part of sulphuric acid, and four parts of distilled water. The beak of the retort was immediately plunged into a water trough, and the hydrogen gas evolved, was received into a graduated glass jar. After an interval of twenty four hours, when the whole zinc had been long dissolved, and the apparatus and its contents had acquired the temperature of the room, the hydrogen gas evolved was measured. The experiment was twice repeated, and the quantity of gas obtained in both cases was exactly the same. The thermometer during both experiments stood at 48°. The barometer, during the first experiment, was at 30 inches; but during the second, at 29·6 inches.

The volume of gas extricated in the first experiment was 137·08 cubic inches. In the second experiment, 100·18 grains of zinc were dissolved, and the volume of the gas extricated was 139·284 cubic inches. Now, when we make the necessary corrections for the height of the barometer, and the excess of zinc dissolved, the quantity of gas evolved is reduced to 137·08 cubic inches, as in the first experiment.

These two experiments give us the volume of hydrogen gas evolved during the solution of 100 grains of pure zinc in dilute sulphuric acid. But the gas was saturated with moisture at the

temperature of 48°. Had it been dry, its volume would have been only 135·4755 cubic inches.* At the temperature of 60°, 135·4755 cubic inches of gas become 138·7551 cubic inches.†

Thus it appears, that when 100 grains of zinc are dissolved in dilute sulphuric acid, the hydrogen gas evolved, supposing it perfectly dry, and supposing the barometer to stand at 30 inches, and the thermometer at 60°, amounts to 138·7551 cubic inches. Now, it has been demonstrated long ago, by Lavoisier, that the hydrogen gas thus evolved is derived from the water with which the sulphuric acid is diluted. A portion of this water is decomposed; its oxygen unites to the zinc, and converts it to an oxide, while the hydrogen makes its escape in the state of gas. The other constituent of the water, then, the oxygen has united to the zinc.

---

* Let p = pressure of atmosphere = 30 inches mercury.

f = elasticity of vapour, at 48° = 0·351 inches mercury.

x = volume of dry gas at 48°.

It has been shown by Dalton, that

$$\frac{p\,x}{p-f} = 137 \cdot 08. \quad \text{Consequently}$$

$$x = \frac{137 \cdot 08\,p - 137 \cdot 08\,f}{p} \quad \text{and (substituting for } p \text{ and } f \text{ their values,)}$$

$$x = \frac{4064 \cdot 265}{30} = 135 \cdot 4755 \text{ cubic inches.}$$

† From the experiments of Guy-Lussac we learn, that air and all gases increase in bulk $\frac{1}{480}$ part for every degree of Fahrenheit's thermometer. Hence at 60°, the volume of the gas is $\frac{12}{496}$ greater than at 48°. Now, $\frac{12}{496}$ of 135·4755 is 3·2796. Adding this to 135·4755, the volume becomes 138·7551 cubic inches.

But if it were in the gaseous state, we know that its volume would be just half that of the hydrogen gas, or 69·3775 cubic inches. Thus it appears, that 100 grains of zinc, when converted into an oxide, unite with 69·3775 cubic inches of oxygen gas.

But from the facts established in the last section, it is evident, that 100 grains of zinc, when converted into an oxide, combine with 23·5294 grains of oxygen.* Hence, the weight of 69·3775 cubic inches of oxygen gas is 23·5294 grains. Consequently, 100 cubic inches weigh 33·915 grains.†

From the experiments of Sir George Shuckburgh Evelyn we learn, that 100 cubic inches of dry common air, under the same pressure, and at the same temperature, weigh 30·5 grains. And the specific gravity of common air being always reckoned unity, it is obvious that the specific gravity of oxygen gas must be 1·1111.‡

Thus we have obtained by a very simple process, which does not seem liable to any uncertainty, the very specific gravity of oxygen gas which Dr. Prout deduced from the supposition, that air is a mixture of four volumes azotic, and one volume oxygen gas; and which I adopted in

* 4·25 grains of zinc unite with 1 grain of oxygen, and 4·25 : 1 : : 100 : 23·5294.

† For 69·3775: 23·5294 : : 100 : 33 915.

‡ For 30·5 : 33·915 : : 1 : 1·1111 nearly.

the last edition of my System of Chemistry, and in my Essay on the Specific Gravity of the Gases. If we compare the table at the begining of this section, with the specific gravity now found, we will perceive the results of the different experimenters as follows :—

Saussure's, too high by	. .	$\frac{1}{370}$th part.
Biot and Arago's, too low by	.	$\frac{1}{139}$th part.
Allen and Pepys's, too low by	.	$\frac{1}{33}$d part.
Thomson's, too high by	. .	$\frac{1}{1832}$d part.
Berzelius and Dulong's, too low by		$\frac{1}{130}$th part.

There seems no reason to doubt that Biot and Arago, and Allen and Pepys, took the specific gravity of oxygen gas standing over water, and consequently saturated with moisture. Let us suppose the temperature at which their experiments were made to have been 60°, and let us see what influence the presence of moisture must have had upon the specific gravity of their gas.

Let p=pressure of the atmosphere, suppose 30 in. mercury.
    f=elasticity of vapour at 60°.=0·524 inch mercury.
    a=sp. gr. of dry oxygen gas=1·1111.
    b=sp. gr. of vapour at 60°.=0.00772.
    x=sp. gr. of moist oxygen gas at 60°.

It is well known that

$$x = \frac{p-f}{p} (a + b) = 1 \cdot 0992.$$

This is nearly the mean between the results of

Biot and Arago, and Allen and Pepys ;—Saussure's errors and my own, being in excess, can only be explained by a mistake in the weighing. My own, indeed, is accurate as far as my balance could enable me to go. The quantity of oxygen gas weighed, amounted to 20 grains, and the smallest weight I used was $\frac{1}{100}$th of a grain; consequently, I could only estimate the weight within $\frac{1}{2000}$th part : the three first decimal places I could depend on, but not upon the fourth ; accordingly the fourth decimal place was too high.

SECT. III.

OF THE SPECIFIC GRAVITY OF HYDROGEN GAS.

I GOT a thin glass flask blown, with a flat bottom and a narrow cylindrical mouth, into which the extremity of a bent glass tube was ground, so as to fit it accurately. The capacity of the flask was about 18 cubic inches ; the tube was 18 inches long, and the diameter of its interior cavity about the fifth of an inch. Its two extremities were bent nearly at right angles with the body, and turned different ways as here represented ; *a* being the end which was ground into the mouth of the flask. The whole

Method of determining the specific gravity of hydrogen gas,

E 2
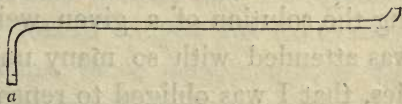
length of this tube was filled with small fragments
of fused muriate of lime, except the two extremi-
ties, which were stuffed full of amianthus, in
order to keep the muriate of lime in its place.
This flask was nearly filled with a mixture of sul-
phuric acid and distilled water, in the proportion
of about four parts of the latter to one part of
the former. It was accurately weighed by means
of an excellent balance, and the weight of the
tube with the muriate of lime, was also separately
determined. I then introduced into the flask, as
rapidly as possible, a known weight of distilled
zinc, in fragments; the tube with the muriate of
lime was fixed in its mouth; and it was immedi-
ately plunged up to the neck in a large trough of
water of the temperature of 48°, and left in that
situation till the zinc was all dissolved. The
flask was then wiped dry, put again in the bal-
ance, and the loss of weight which it had sus-
tained was ascertained;—at the same time, the
augmentation of weight of the tube with the
muriate of lime was determined.

The object of this experiment was to ascertain
the weight of a given volume of hydrogen gas;
for the experiments related in the last section
give us the volume of hydrogen gas evolved dur-
ing the solution of a given weight of zinc. It
was attended with so many unforeseen difficul-
ties, that I was obliged to repeat it ten times be-
fore I became aware of all the precautions

necessary to ensure success.   Unless the gas be extricated very slowly, the muriate of lime does not dry it sufficiently—indeed, I was never able to free it completely from moisture ; but a very simple calculation gave me the weight of the vapour which still adhered to it.   The tempera-ture of the liquid should be kept as low as possi-ble, not merely to moderate the fermentation, but to avoid the risk of sulphuric acid escaping along with the gas. When the flask was left in the air, the temperature continued to rise for more than an hour after the experiment began.   In one experiment it rose from 50° to 87°, in another, from 48° to 81° : the greater the quantity of zinc dissolved, the more accurate (cæteris paribus) was the experiment; but the quantity was unluckily very much limited by the small size of the flask.

It will be sufficient if I relate one experiment, during which, all the precautions that I could think of were taken ; and which, I have reason to believe, was very nearly accurate.

The quantity of zinc dissolved was 143 grains —the effervescence continued for 24 hours—the temperature never rose higher than 49°—the barometer stood at 30·1 inches, and the thermo-meter at 49°—the loss of weight was 4·3 grains.

It will be, perhaps, more perspicuous, if we suppose that 100 grains of zinc only were dis-solved.   On that supposition, the loss of weight

sustained was 3 grains, and the tube containing the muriate of lime, had increased in weight 0·163 grains.

From the experiments related in the last section, it follows, that the volume of hydrogen gas given out during the solution of 100 grains of zinc, supposing the barometer to stand at 30·1 inches, and the thermometer at 49°, amounts to 136·88 cubic inches.

The specific gravity of vapour at 49°, under a pressure of 30·1 inches of mercury, is 0·00533; and the weight of the vapour contained in 136·88 cubic inches of moist gas, is 0·00533 × 136·88 × 0·305 gr.=0·2225 grain; but the moisture retained by the muriate of lime was only 0·163 grain. It is obvious from this, that the hydrogen still retained 0·059 grain of moisture.

If from the weight lost, amounting to 3 grains, we subtract this 0·059 grain for moisture, the remainder, amounting to 2·941 grains, gives the true weight of the hydrogen gas exhaled, supposing it perfectly dry. Now, from the experiments related in the last section, we know that the volume of this gas, under the pressure of 30 inches of mercury, and at the temperature of 60°, is 138·7551 cubic inches.

Oxygen gas just sixteen times heavier than hydrogen gas. Thus it appears, that 138·7551 cubic inches of dry hydrogen gas (barometer 30 inches, thermometer 60°) weigh 2·941 grains : consequently, 100 cubic inches must weigh 2·119 grains. But

we have seen in the last section, that 100 cubic inches of oxygen gas weigh 33·915 grains; now

$$2·119 : 33·915 :: 1 : 16·005.$$

This approaches so nearly the ratio of 1 : 16, that it leaves no doubt that the specific gravity of oxygen gas is exactly 16 times greater than that of hydrogen gas. Consequently, the specific gravity of hydrogen gas is $\frac{1·1111}{16}$, or 0·0694; or exactly the specific gravity already deduced by Dr. Prout, from other considerations, and which I obtained experimentally, as may be seen in my Essay on the Specific Gravity of Gases.

That the proportion between the specific gravities of oxygen and hydrogen gases, is that of 16 : 1, is farther confirmed by an experiment of Berzelius and Dulong. They made dry hydrogen gas pass through a determinate weight of oxide of copper, heated to redness. The water thus formed was collected by means of dry chloride of calcium. The loss of weight sustained by the oxide of copper gave the weight of the oxygen in the water, while the weight of the hydrogen was denoted by the difference between the weight of the water and the oxygen : the mean of three trials gave the oxygen 889, and the hydrogen 111. Now 111 : 889 : : 1 : 8·009 ; and as water is a compound of 2 volumes hydrogen to 1 of oxygen, it follows, that the

specific gravity of hydrogen is to that of oxygen
gas as 1 : 16·018.*

In my experiment, the oxygen was more than
16 times heavier than the hydrogen gas by $\frac{1}{5000}$th
part—in that of Berzelius and Dulong it was a
little more. The mean of both (which must come
very near the truth) gives us the specific gravity
of hydrogen to that of oxygen gas, as 1 : 16·011.
That the true specific gravity of oxygen gas
is 1·1111, will be shown in the fifth chapter of
this work.†

The following table exhibits the most recent
specific gravities of hydrogen gas obtained by
experiment :

SP. GR. OF HYDROGEN GAS.

0·0732	. .	Biot and Arago.
0·0694	. .	Thomson.
0·0688	. .	Berzelius and Dulong.

It is obvious, when we compare these with the
above found specific gravity of hydrogen gas,
which must be exceedingly near the truth, that

* Ann. de Chim. et de Phys. xv. 389.

† I ought to mention that the weight of my flask filled with the dilute
sulphuric acid and zinc, was about 3000 grains, and that of the tube filled
with muriate of lime, about 1000 grains. My scales, loaded with double
that weight, turned sensibly with $\frac{1}{200}$th of a grain. Hence, I consider
myself as certain of the weight of the hydrogen gas to as many decimal
places as I have given in the text. I weighed so as to make myself sure
of the accuracy within $\frac{1}{100}$th of a grain :—Berzelius and Dulong deter-
mined the composition of water by an experiment nearly similar. Their
result does not tally exactly with mine, nor can I institute a comparison,
because they do not state the delicacy of their balance.

Biot and Arago's is too high by $\frac{1}{18}$th part, Berzelius and Dulong's too low by $\frac{1}{113}$th part,—while my results, owing probably to a fortunate accident, are, as far as they go, quite correct.

Water being a compound of 1 volume of oxygen gas, and 2 volumes of hydrogen gas, it is obvious, that it is composed of 8 parts, by weight, of oxygen, and 1 part of hydrogen.   There can be no doubt that water is a neutral compound, and that it consists of an atom of oxygen united to a determinate atomic quantity of hydrogen ; —but chemists are not yet quite agreed whether the hydrogen be 1 atom or 2 atoms.   Sir H. Davy and Professor Berzelius consider the hydrogen as amounting to two atoms, because there are 2 volumes of it united to 1 volume of oxygen ;—for they consider the volumes of these gaseous bodies as representing atoms.   On the other hand, Mr. Dalton, Dr. Wollaston, Dr. Prout, and indeed by far the greater number of chemists, consider water as a compound of 1 atom oxygen, and 1 atom hydrogen, founding their opinion upon the well known fact, that these two gases cannot be directly united in any other proportions than those which exist in water. *(margin: Composition of water.)*

If water contain only 1 atom of hydrogen, the atomic weight of this substance is obviously $\frac{1}{8}$th of that of oxygen, or 0·125; but if that liquid contain 2 atoms of hydrogen, then the atomic weight of hydrogen is only 0·0625.

It is of no great consequence which of these opinions be adopted; yet if we take a view of the various compounds into which hydrogen enters, we can have little hesitation in fixing upon 0·125 for its atomic weight. A few of these compounds may be noticed in this place. The evidence of the facts here stated will be laid before the reader in the subsequent chapters of this work.

<p style="margin-left:0">Atom of
hydrogen
weighs
0·125.</p>

1. It is now known that oxygen and hydrogen unite in two proportions. Water contains the smallest quantity, while the deutoxide of hydrogen, discovered by Thenard, contains the greatest quantity of oxygen. The composition of these bodies is as follows:

	OXYGEN.	HYDROGEN.
Water consists of	1 +	0·125
Deutoxide of hydrogen of	2 +	0·125

According to this way of stating the constituents, water is a compound of 1 atom oxygen, and 1 atom hydrogen; and the deutoxide of 2 atoms oxygen and 1 atom hydrogen. But if we state the constituents according to Berzelius's views,

	OXYGEN.	HYDROGEN.	
Water consists of	1 +	0·0625 × 2	or 2 atoms.
Deutoxide of	1 +	0·0625	or 1 atom.

Or, water is a compound of 1 atom oxygen and 2 atoms hydrogen; and the deutoxide of 1 atom oxygen and 1 atom hydrogen. Now, would it

not be a singular anomaly, if water, which is decomposed with considerable difficulty, should consist of 1 atom oxygen united to 2 atoms hydrogen, while the deutoxide, which parts with half its oxygen very readily, consists of 1 atom of oxygen united to 1 atom of hydrogen. This is not the case with other compounds. Bisulphate of potash may be deprived of half its sulphuric acid by exposure to a strong red heat; but the other half (which constitutes with potash the neutral compound) resists the highest temperature which we can apply.

2. Hydrogen unites with azote, carbon, phosphorus, and sulphur, as well as with oxygen, and with some of these bodies it unites in more than one proportion. But with none of these bodies does it ever combine in a smaller proportion than 0·125. Now, it would be a most extraordinary phenomenon, if never less than two atoms of this substance were to unite with an atom of other bodies. The following table exhibits the composition of a variety of bodies containing hydrogen.

			HYDROGEN.
Ammonia, composed of	1·75	azote	+ 0·125 × 3
Olefiant gas . . .	0·75	carbon	+ 0·125
Carburetted hydrogen .	0·75	————	+ 0·125 × 2
Phosphuretted hydrogen .	1·5	phosphorus	+ 0·125
Bihydroguret of phosphorus	1·5	————	+ 0·125 × 2
Sulphuretted hydrogen .	2	sulphur	+ 0·125

1·75, 0·75, 1·5, and 2 represent the atomic

weights of azote, carbon, phosphorus, and sul-
phur respectively, on the supposition that an
atom of oxygen weighs unity. It is obvious
from the table, that 0·125 hydrogen is the
smallest quantity of hydrogen that unites with
an atom of azote, carbon, phosphorus, or sul-
phur. Now, if 0·0625 were the atomic weight
of hydrogen, how comes it that it never unites
to any of these bodies in so small a quantity ?

But if 0·125 be the atomic weight of hydro-
gen and 1 of oxygen, since water is a compound
of 1 oxygen and 0·125 hydrogen, and is at the
same time a compound of 1 volume oxygen and
2 volumes hydrogen gases, it follows as a con-
sequence, that a volume of oxygen contains
twice as many atoms as a volume of hydrogen.
So that if we represent an atom of hydrogen by
a volume, we must represent an atom of oxygen
by half a volume.

It is obvious that the weight of an integrant
particle of water is 1·125 ; nor is this weight
altered, whether we consider it as a compound
of 1 atom oxygen and 1 atom hydrogen, or of
1 atom oxygen and 2 atoms hydrogen. For on
either supposition the atomic quantity of hydro-
gen must be represented by 0·125.

CHAP. IV.

OF THE ATOMIC WEIGHTS AND SPECIFIC GRAVITIES OF CHLORINE AND IODINE.

THESE two substances resemble each other in so many respects, that they ought to be classed together. Their analogy with oxygen is also very striking ; though they differ likewise in some circumstances ; the most remarkable of which is the property that they have of uniting with oxygen, and constituting with it an acid very similar in many respects to the nitric. I shall treat of each of these bodies in a distinct section.

SECT. I.

OF THE ATOMIC WEIGHT OF CHLORINE, AND THE SPECIFIC GRAVITY OF CHLORINE GAS.

IT has been demonstrated, that muriatic acid gas is a compound of equal volumes of chlorine gas and hydrogen gas, united together without any change of bulk. Hence, the knowledge of the specific gravity of dry chlorine gas at the temperature of 60°, and when the barometer stands at 30 inches, will give us the ratio be-

7

tween the atomic weights of chlorine and hydrogen.

Specific gravity of chlorine gas.

Now, I took the specific gravity of this gas three times successively, and found it always 1·500.* Many other considerations lead to the conclusion that this is very near the truth. Of these it may be sufficient to mention the following:

1. The specific gravity of muriatic acid gas was found by me from an average of three experiments, to be 1·284366. Now, the specific gravity of this gas is a mean between that of chlorine and hydrogen gases. Let

$$x = \text{sp. gr. of chlorine gas}$$
$$a = \text{sp. gr. of hydrogen gas}$$

We have $\dfrac{x + a}{2} = 1 \cdot 284366$. Consequently

$$x = 2 \cdot 568733 - 0 \cdot 0694 = 2 \cdot 499333.$$

Now, 2·499333 is only $\frac{1}{3731}$ part less than 2·5. This is a coincidence between the two experiments as near as the nature of the apparatus employed will admit of.

2. Gay-Lussac, in a table inserted in the first volume of the *Annales de Chimie et de Physique*, states the specific gravity of chlorine gas to be 2·470. Now, if his experiments were made with gas prepared over water, as was undoubtedly the case, his result approaches very nearly to mine, if we estimate the specific gravity of the

* Annals of Philosophy, xvi. 169.

dry gas, as will be obvious from the following simple calculation. Let

$x =$ sp. gr. of dry chlorine gas
$a =$ sp. gr. of vapour at $60^0 = 0·00772$
$p = 30$ inches mercury
$f =$ elasticity of vapour at $60^0 = 0·524$

then

$$\frac{p - f}{p}(x + a) = 2·47$$

The solution of this equation gives us $x = 2·507$. Thus it appears, that if Gay-Lussac made his experiments at the temperature of $60°$, the true specific gravity of his chlorine gas was $2·507$. If the temperature (as is most likely) was a few degrees above $60°$, then the true specific gravity of the gas would be exactly $2·5$, and his experiments would coincide with my own.

We may therefore, without hesitation, adopt $2·5$ as the true specific gravity of dry and pure chlorine gas.

As muriatic acid is a compound of equal volumes of chlorine gas and hydrogen gas, and as these gases unite in no other proportions, we cannot hesitate to consider muriatic acid as a compound of 1 atom chlorine and 1 atom hydrogen. The atom of chlorine, therefore, must bear the same relation to the atom of hydrogen, that the specific gravity of chlorine gas does to that of hydrogen gas. But chlorine gas is 36 times heavier than hydrogen gas; for $0·0694 \times$

Atom of chlorine weighs 4·5.

$36 = 2 \cdot 5$. The atomic weight of hydrogen is $0 \cdot 125$. Consequently that of chlorine is $0 \cdot 125 \times 36 = 4 \cdot 5$.

It is obvious too, that the volume of chlorine gas bears the same relation to the atom of chlorine that the volume of hydrogen gas does to the atom of hydrogen. If, therefore, we may substitute a volume of hydrogen gas for an atom, we may, in like manner, substitute the volume of chlorine gas for the atom of chlorine.

Proved
from the
chloride of
copper,

I. It is easy to show by simple and decisive experiments, that $4 \cdot 5$ is the true atomic weight of chlorine. Of these, it may be worth while to state one or two in this place.

1. An atom of copper, as will appear hereafter, weighs 4; an integrant particle of suboxide of copper weighs 9; and an integrant particle of black oxide, 5. Each of these oxides combines with muriatic acid. The protomuriate of copper is white, and the permuriate green. Both of these muriates crystallize, and both contain water of crystallization. When the muriates of copper are heated without the contact of air, they not only lose their water of crystallization; but the oxide of copper, and the muriatic acid lose respectively, the oxygen and the hydrogen which they contain. These two constituents unite together, and make their escape in the form of water, leaving behind a compound of chlorine and copper. In the suboxide

of copper there are two atoms of copper united to one atom of oxygen, and the protomuriate of copper is a compound of one integrant particle of muriatic acid, and two integrant particles of suboxide of copper, and the permuriate of one atom muriatic acid, and one atom black oxide of copper. Now, that this is the true constitution of these two salts, I have ascertained by a careful analysis of them.

These facts being understood, we are prepared for examining the chlorides of copper. Of these chlorides, there are two—the *protochloride*, obtained by heating the protomuriate in a close vessel; and the *deutochloride*, formed when the permuriate is treated in the same way.

Now, Dr. Davy analyzed the protochloride of copper, and found it a compound of

<div style="text-align:center">

Copper   8
Chlorine   4·5
———
12·5 *

</div>

Two atoms of copper weighing eight, 4·5 must represent the weight of an atom of chlorine.

I dissolved 5 grains of black oxide of copper in muriatic acid, and evaporated the solution to dryness. The chloride of copper was obtained in the state of a brownish yellow powder, and it weighed exactly 8·5 grains. Now, 5 grains of

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* Phil. Trans. 1812. p. 170.

black oxide are equivalent to 4 grains of metallic copper. So that the chloride was a compound of

Copper	4
Chlorine	4·5
	8·5

4·5 is evidently one atom of chlorine, and 4 one atom of copper. In this chloride one atom of copper is united with one atom of chlorine.

Thus it appears, that an atom of chlorine unites with either one atom or two atoms of copper; and that an atom of chlorine weighs exactly 4·5.

The chloride of mercury,

2. It will be shown hereafter, that an atom of mercury weighs 25. Now, mercury, like copper, combines with two proportions of chlorine, forming a *protochloride*, usually called *calomel*, and a *deutochloride*, usually called *corrosive sublimate*.

Calomel is composed of

Mercury	25
Chlorine	4·5
	29·5

and corrosive sublimate of

Mercury	25
Chlorine	9
	34 [*]

[*] See Annals of Philosophy, (second series) II. 127.

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We see that the first is a compound of one atom mercury and one atom chlorine, and the second of one atom mercury and two atoms chlorine. Here, as well as with copper, 4·5 represents exactly the weight of an atom of chlorine.

3. Silver is a metal, the atomic weight of which is 13·75. Dissolve 13·75 grains of pure silver in nitric acid; evaporate the solution gently to dryness, and re-dissolve the nitrate of silver in water; precipitate the silver by pouring into the liquid a solution of 7·5 grains of pure and dry common salt; collect the precipitate, wash it well, and fuse it on a piece of glass :—if the experiment be properly conducted, the chloride of silver, thus obtained, will weigh 18·25 grains.* Now, it contains exactly 13·75 grains of silver. Hence, it is composed of

And the chloride of silver.

Silver	13·75
Chlorine	4·5
	18·25

or in this compound, an atom of silver is combined with an atom of chlorine.

In all these examples, the atomic weight of chlorine is exactly 4·5.

4. It has been long known, that when chlo-

* The chloride of silver, while on the filter, must be washed with distilled water. This water should be very slightly acidulated with nitric acid. For want of this precaution, I was long unable to obtain the exact weight of chloride. The reason is, that distilled water often contains ammonia, which dissolves a little chloride.

rine gas is collected over water in temperatures below 40°, a number of green coloured crystals form. These crystals were considered as solid chlorine, till Sir. H. Davy showed, in 1810, that they were a compound of chlorine and water, or a hydrate of chlorine. During the severe winter of 1822-3, this hydrate was analyzed by Mr. Faraday, who found it to be composed of

Chlorine	27·7 or	4·5
Water	72.3	11·745
	100·0 *	

11·745 exceeds 10 atoms of water by 0·495, which is rather more than ⅓ of an atom. It was doubtless hygrometrical water. These crystals, then, must be considered as constituting a deca-hydrate of chlorine composed of

10 atoms water	11·25
1 atom chlorine	4·5
	15·75

II. Chlorine, according to the experiments of Sir H. Davy and Count Von Stadion, combines with no fewer than five proportions of oxygen, forming three oxides and two acids. The composition of these different compounds, which, with the exception of chloric acid, have been analyzed only by Davy and Von Stadion, is as follows :

* Annals of Philosophy, (second series) V. 304.

	CHLORINE.		OXYGEN.	ATOMIC WEIGHT.
1. Protoxide of chlorine.	1 atom	+	1 atom	5·5
2. Tritoxide of chlorine	1	+	3	7·5
3. Quadroxide of chlorine	1	+	4	8·5
4. Chloric acid	1	+	5	9·5
5. Perchloric acid	1	+	7	11·5 *

III. Hydrogen and chlorine, as far as we *Chlorine and hydrogen.* know at present, unite in only one proportion, constituting muriatic acid, the atomic weight of which is 4·625.

This acid is one of the most active and corrosive with which we are acquainted. It is very much used in chemical analyses, and indeed is altogether indispensable in a laboratory. When pure, it is a gas, the specific gravity of which is 1·28472, being exactly the mean between the specific gravities of chlorine gas and hydrogen gas.

I find that at the temperature of 69°, one cubic inch of water is capable of absorbing 417·822 *Liquid muriatic acid.* cubic inches of muriatic acid gas. The temperature of the liquid augments considerably, and its volume, when cooled down to the temperature of the air, is 1·3433 cubic inch. It is obvious from this, that 100 grains of acid of this strength contain 103 cubic inches of acid gas; and a cubic inch of this acid contains 311·04146

* The protoxide was analyzed by Davy, the tritoxide by Von Stadion, the quadroxide by Davy. It has not been ascertained whether or not the two last constitute really distinct substances. Chloric acid was first analyzed by Chenevix, and more correctly by Berzelius. Perchloric acid was discovered and analyzed by Von Stadion.

cubic inches of acid gas. Acid of this strength
has a specific gravity of 1·1958, and I find, by
saturating it with calcareous spar, that it con-
tains 40·39 per cent. of real acid, united with
59·61 of water. In winter I have obtained mu-
riatic acid of as high a specific gravity as 1·212.

All the tables hitherto published, exhibiting
the strength of muriatic acid of various specific
gravities, are very erroneous; because they were
constructed upon inaccurate data. I conceive,
therefore, that it will be worth while to exhibit
an accurate table of the specific gravity of this
acid of determinate strengths. My method of
proceeding was to saturate a given weight of
the acid with calcareous spar. Every 6·25 grains
of calcareous spar dissolved, indicated the pre-
sence of 4·625 grains of muriatic acid. Know-
ing the exact strength of one particular acid, it
was easy, by the addition of determinate weights
of water, to form acid of any inferior strength
wanted. I shall exhibit the specific gravity of
combinations of one atom of muriatic acid, with
a determinate number of atoms of water. The
strongest acid I could form, at the time that I
was employed in these experiments, was a com-
pound of one atom acid, and six atoms water.
Its specific gravity was 1·203, and it contained,
of course, 40·659 per cent. of real acid. This
acid is so volatile, that it can with difficulty be
preserved in warm weather. Indeed it frequently

forces out the stopper, while a quantity of mu-
riatic acid gas makes its escape.

TABLE EXHIBITING THE SPECIFIC GRAVITY OF MURIATIC
ACID OF DETERMINATE STRENGTHS.

Atoms of Acid.	Atoms of Water.	Acid in 100	Specific Gravity.
1	6	40·659	1·203
1	7	37·000	1·179
1	8	33·945	1·162
1	9	31·346	1·149
1	10	29·134	1·139
1	11	27·206	1·1285
1	12	25·517	1·1197
1	13	24·026	1·1127
1	14	22·700	1·1060
1	15	21·512	1·1008
1	16	20·442	1·0960
1	17	19·474	1·0902
1	18	18·590	1·0860
1	19	17·790	1·0820
1	20	17·051	1·0780

Muriatic acid, composed of 1 atom acid, and
16 atoms water, or that which contains 20·442
per cent. of real acid, seems to be the most inti-
mate combination of acid and water. For its
boiling point is a maximum, being 232°, accord-
ing to Dalton; while acid either weaker or
stronger than this boils at a lower temperature.
Indeed the boiling point of acid of the specific
gravity 1·203 is not higher than 107°.

The muriates, or the salts formed by the com-
bination of muriatic acid with the different bases,
deserve the particular attention of chemists in
many points of view. I shall devote a separate

F 4

chapter to the investigation of their constitution in a subsequent part of this work.

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SECT. II.

OF THE ATOMIC WEIGHT OF IODINE.

THE properties of iodine were investigated with such sagacity and success by M. Guy-Lussac and Sir H. Davy, that succeeding experimenters have had but little to add to the result of their investigations. I shall mention here the few particulars that I have had an opportunity of observing.

Specific gravity of iodine.

1. Gay-Lussac states the specific gravity of iodine to be 4·948 ; but I have reason to believe that this estimate is too high. I sublimed some iodine by exposing it in an eight ounce phial to a very low heat. By this method it may be obtained in pretty large octahedral crystals, approaching to the shape of the primitive form of sulphur. A number of these crystals were picked out, and their specific gravity taken. I found it 3·0844. The specific gravity of iodine, as originally prepared without any purification, is somewhat less, being only 2·915. This difference is owing to the presence of a very small quantity of water. The specific gravity of distilled water saturated with iodine is 1·00021— a sufficient proof of the

3

small quantity of this substance which water is capable of dissolving.

2. Gay-Lussac found that when iodine and zinc are heated together in a vessel hermetically sealed, and containing a sufficient quantity of water, a colourless solution is obtained, consisting of hydriodate of zinc. In this case he found that 100 parts of iodine combine with 26·225 parts of zinc.[*] Now 26·225 : 100 : : 4·25 (an atom of zinc) : 16·20. According to this experiment, 16·20 denotes the atomic weight of iodine. Gay-Lussac himself deduces from his experiment, that the atomic weight of iodine is 15·621 ; because he conceived that 26·225 of zinc combine with 6·402 oxygen, whereas the quantity of oxygen with which this weight of zinc combines, when oxydized, is only 6·170 parts.

This experiment of Gay-Lussac was repeated by Dr. Prout, who found that 50 parts of iodine combine with 12·9 parts of zinc.[†] According to this experiment, the atomic weight of iodine turns out 16·473, which is a little higher than that stated by Gay-Lussac.

3. I have repeated this experiment a good many times, but I did not obtain constant results, partly from the difficulty of preventing the loss of some of the iodine, and partly because the zinc was never perfectly pure. I therefore had recourse to another method, which I shall

Method of determining the atom of iodine.

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[*] Ann. de Chim. XCI. 24.　　　[†] Annals of Philosophy, VI. 323.

now explain. I formed a quantity of hydriodate
of potash, and by a careful analysis, satisfied
myself that it is composed of an atom of hydrio-
dic acid, united to an atom of potash. When this
salt is exposed •to a pretty strong heat in close
vessels, it gives out water, and is converted into
iodide of potassium. After a variety of trials, I
found that when 20·5 grains of this iodide of
potassium are dissolved in a small quantity of
distilled water, and the solution mixed with a
solution of 20·75 grains of dry nitrate of lead, a
double decomposition takes place : iodide of lead
is precipitated, and the residual liquid is trans-
parent and colourless, and neither altered by
sulphate of soda, nor by nitrate of lead, showing
that it contains no sensible quantity of oxide
of lead, or hydriodic acid. The residual liquid
being evaporated to dryness, furnished 12·75
grains of salt-petre. But 12·75 grains of salt-
petre (as will be seen in the next chapter) con-
tain 6 grains of potash, equivalent to 5 grains of
potassium. Consequently, the 20·5 grains of
iodide of potassium contained just 5 grains of
potassium. The remainder consisted of iodine.
From this it appears that iodide of potassium is
a compound of

Iodide of
potassium.

Potassium	5
Iodine	15·5
	20·5

5 being the atomic weight of potassium, and the iodide being a neutral compound, it is obvious that 15·5 must be the weight of an atom of iodine.

The above experiment was repeated, substitu- Iodide of zinc.
ting 19·75 grains of iodide of zinc, for the 20·5 grains of iodide of potassium. When solutions, containing respectively 19·75 grains of iodide of zinc, and 20·75 of nitrate of lead, were mixed together, I found it necessary to evaporate the mixture to dryness by means of a very gentle heat. Water being poured upon the yellow residue, was digested on it for some time. It was then tested with sulphate of soda, and with nitrate of lead, without being in the least affected by either of these re-agents, showing that it contained no sensible quantity of lead, or of iodine. Unless the original mixture of the two salts be evaporated to dryness, sulphate of soda is very apt to indicate the presence of lead—and if the evaporation be carried too far, or too great a heat be applied to the residual matter, the water poured upon it will acquire a yellow colour, and will contain distinct traces of iodine. If this be avoided, the liquid will contain simply a solution of nitrate of zinc.

From this experiment, which I have made several times successfully, it is obvious that 19·75 grains of iodide of zinc contain just an atom of iodine, or the quantity necessary to unite with

13 of lead, which exist in 20·75 of nitrate of
lead.   As the iodide of zinc is neutral, there
must be present in it just an atom of zinc, which
weighs 4·25.   Thus it appears that dry iodide of
zinc is composed of

Zinc	4·25
Iodine	15·5
	19·75

These experiments leave no doubt that the atom
of iodine weighs 15·5. This is the number which
Dr. Prout fixed upon, though from erroneous data.

   It is obvious also from these experiments, that
hydriodic acid is a compound of 1 atom iodine,
and 1 atom hydrogen.   For when hydriodate of
zinc is heated sufficiently, it is converted into
iodide of zinc.   It is evident that the oxide of
zinc by this treatment is deprived of its oxygen,
and the hydriodic acid of its hydrogen.   These
two substances combine together, and fly off in
the state of water.   Consequently, the atoms of
hydrogen in the acid must be just equal to the
number of atoms of oxygen in the oxide.   But
oxide of zinc contains only one atom of oxygen ;
consequently hydriodic acid contains only one
atom of hydrogen.

Hydriodic acid.   From the experiments of Gay-Lussac, which
I have often repeated, we learn that when hy-
driodic acid gas is left in contact with mercury,
the whole of its iodine is gradually absorbed, and

its volume is reduced to one half, consisting of hydrogen gas. Here it is clear that hydriodic acid is a compound of equal volumes of iodine vapour and hydrogen gas, united together without any change of volume. A volume of iodine vapour, then, bears the same relation to an atom, that a volume of hydrogen gas does to an atom. But the specific gravity of hydrogen gas is obtained by multiplying its atomic weight by half the specific gravity of oxygen gas, or by 0·5555. For 0·125 + 0·5555 = 0·0694. It will be shown in the 7th chapter of this work that this law is general. Consequently, to obtain the specific gravity of iodine vapour, we have only to multiply 15·5 by 0·5555. The product is 8·6111, which is the true specific gravity of iodine vapour.

The specific gravity of hydriodic acid is a mean between that of iodine vapour and of hydrogen gas, or 4·34027.

The atomic weight of hydriodic acid is 15·625.

Iodine combines both with oxygen and with chlorine, and forms with the former iodic acid, and with the latter chloriodic acid. I have not myself made any experiments to determine the atomic weight of these acids; but from Gay-Lussac's experiments it is evident, that iodic acid is a compound of one atom iodine, and five atoms oxygen. It must therefore weigh 20·5.

From the experiments of Sir H. Davy, I have
little doubt that chloriodic acid is a compound of
one atom iodine, and two atoms chlorine.   Con-
sequently, its atomic weight is 24·5.

CHAP. V.

OF THE ATOMIC WEIGHT OF AZOTE, AND
THE SPECIFIC GRAVITY OF AZOTIC GAS.

I SHALL begin this chapter with an account of the experiments to determine the true specific gravity of azotic gas. The specific gravity of common air is always reckoned unity, and we have seen in the third chapter of this work, that the true specific gravity of oxygen gas is 1·111. Now, as air is a mixture of oxygen and azotic gases, it is obvious that, in order to obtain the true specific gravity of azotic gas we have only to determine by rigid experiments what is the true ratio between the volumes of oxygen and azotic gases in common air. Many experiments have been made upon this subject; but chemists do not seem to have employed the requisite precautions to ensure a successful result.

1. In order to have common air in a state of purity, I collected a quantity of it from above the middle of a green field, at some distance from all houses. The hydrogen gas, which was employed to remove the oxygen, was prepared from a mixture of purified zinc, and pure sulphuric acid diluted with distilled water. The retort in which the gas was extricated, was quite

Composition of common air determined.

filled with this mixture, and a portion of the hy-
drogen gas was allowed to escape, before I be-
gan to collect it for use.   The eudiometrical
experiments were made while the hydrogen gas
was coming over, and it was taken for every ex-
periment directly from the beak of the retort,
and consequently, without standing any time in
contact with water.

A mixture of 100 volumes of air, and 42 vo-
lumes of this pure hydrogen gas, was fired by an
electric spark.   The diminution of bulk in three
successive experiments was precisely 60 volumes.
Now, the volume of oxygen gas in the 100 parts
of air employed is obviously $\frac{1}{3}$ of this diminution
of bulk.   But $\frac{1}{3}$ of 60 is 20.   Thus it appears,
that 100 volumes of air contain 20 volumes of
oxygen gas.   The remaining 80 volumes consti-
tute the azotic gas of air.   Air then is a mixture
of

$$20 \text{ volumes oxygen gas}$$
$$80 \text{ volumes azotic gas}$$
$$\overline{100}$$

or the 5th of the volume of common air is oxy-
gen gas, and four-fifths azotic gas.

If we employ less than 42 volumes of hydro-
gen gas to 100 of air, the combustion is not com-
plete.   Thus, when a mixture of 100 volumes
air and 40 volumes hydrogen is fired, the di-
minution of bulk amounts to 57 volumes, in-

stead of 60. The third of 57 is only 19, show-
ing that one volume of the oxygen gas pre-
sent had escaped combustion. When the
quantity of hydrogen gas is greater than 42 to
the 100 of air, the diminution of volume some-
what exceeds the truth, and it goes on increas-
ing till the volume of hydrogen gas is equal to
that of the air, beyond which I did not think it
worth while to carry the experiment. 50 vo-
lumes of air, and 50 of hydrogen gas, being mixed
and fired, the diminution of bulk was 32 vo-
lumes. The third of this is 10·66. This would
raise the bulk of oxygen gas in air to 21¼ per
cent. This diminution of the volume beyond
the proper quantity seems to be owing to the
formation of a small quantity of nitric acid or
ammonia. The best proportions are 100 volumes
air, and 42 volumes hydrogen gas ; with these we
always find the diminution of volume 60 indicat-
ing 20 per cent. of oxygen gas in air.

I likewise verified this analysis of air by means
of phosphorus : 100 volumes of air were left
standing for two days over mercury, with a stick
of phosphorus immersed in them. The glass jar
with the air was then removed to the water
trough, and well washed, to deprive it of any
phosphoric acid which might have a tendency
to alter its volume. And to facilitate the action
of the phosphorus, a little water was added, so
that the air was saturated with moisture at the

temperature in which the experiments were made. The following table exhibits a view of the results of these experiments.

No of Ex-periments.	Volumes of air.	Height of Barom.	Height of Thermom.	Residue.	Height of Barom.	Height of Thermom.
		INCHES.	DEGREES.		INCHES.	DEGREES.
1	100	30·33	61·5	82	30·08	62
2	100	30·08	62	80	29·8	62
3	100	29·80	62	81	29·5	60·5
4	100	29·5	60·5	78	29·99	59·5
5	100	29·99	59·5	79·75	30·07	60
6	100	29·99	60	80	29·94	61
7	100	29·94	61	80	29·7	60·5
8	100	29·70	60	81	29·5	58·5
9	100	29·5	58·5	79·5	29·6	58
10	100	29·54	58	80	29·55	58

Before we can draw any consequence from these experiments, we must determine by calculation the volume of the residues, supposing them perfectly dry, and supposing the barometer at 30 inches, and the thermometer at 60°. The following table shows what these volumes are.

No. of Ex-periments.	Volumes of Air.	Volumes of Residue.	Ratios of vol. of Air.	Ditto of vol. of Residues.
1	98·953	80·08	100	80·927
2	97·984	77·648	100	79·246
3	97·051	78·130	100	80·504
4	96·457	76·714	100	79·532
5	98·352	78·543	100	79·851
6	98·217	78·232	100	79·652
7	97·889	77·698	100	79·374
8	97·253	78·551	100	80·770
9	97·018	77·462	100	79·843
10	97·236	77·816	100	80·028
Mean - - - - - - - - -			100	79·9735

The last column shows the residue of dry gas,

from 100 volumes of dry air, supposing the barometer at 30 inches, and the thermometer at 60°. The mean of ten experiments gives the composition of dry air :

Azote	79·9735
Oxygen	20·0265
	100·0000

Now this is within $\frac{1}{1000}$ part of

Azote	80
Oxygen	20
	100

a degree of coincidence with the former experiments, as near as my method of proceeding enabled me to reach. It confirms very completely the preceding conclusions.

The proportion of the constituents of air in volume being thus known, it is easy to determine the specific gravity of azotic gas. Let $x =$ a volume of azotic gas, then

$$1\cdot111\dot{1} + 4\ x = 5 \quad \text{and}$$
$$x = \frac{3\cdot888\dot{8}}{4} = 0\cdot972\dot{2} = \text{specific gravity}$$

of azotic gas.*

---

* The specific gravity of oxygen and azotic gases might be deduced directly, from the known specific gravity of air; *viz.* 1·000, and the proportion of these two gases, *viz.* 80 azotic and 20 oxygen gas in 100 volumes of air, as Dr. Prout has already done, (Annals of Philosophy, VI. 322.)

<div style="text-align:center">

Let the atom of oxygen = 1

azote = 1·75

</div>

2. I have been thus particular in determining the specific gravity of azote, because it is a necessary element in the investigation of its atomic weight. We shall now determine the atomic weight of nitric acid, which is known to be a compound of azote and oxygen ; and it contains the greatest proportion of oxygen with which an atom of azote is capable of uniting. Nitric acid

Air is a compound of one atom of oxygen and two atoms azote ; or of

$$
\begin{array}{llll}
\text{Oxygen} & 1 & \text{or} & 22\cdot2\dot{2} \\
\text{Azote} & 3\cdot5 & & 77\cdot7\dot{7} \\
\cline{4-4}
& & & 100
\end{array}
$$

Let $x =$ specific gravity of oxygen　　$22\cdot2\dot{2} = a$

　　$y =$ 　　　　　　　　azotic gas　　$77\cdot7\dot{7} = b$

then $\dfrac{x + 4y}{5} = 1$ and $x = 5 - 4y$

and $x : 4y :: a : b$ and $x = \dfrac{4\,a\,y}{b}$

Hence $5 - 4y = \dfrac{4\,a\,y}{b}$ and $y = \dfrac{5\,b}{4\,a + 4\,b} = 0\cdot972\dot{2}$

and $x = 5 - 4y = 5 - 3\cdot8888 = 1\cdot111\dot{1}$

I have thought it better to proceed as I have done in the text, because the atomic weight of azote is most easily deduced from the specific gravity of azotic gas.

Berzelius and Dulong, in their paper on the specific gravity of gases, give us the specific gravity of oxygen and azotic gases, as follows :

$$
\begin{array}{ll}
\text{Oxygen} & 1\cdot1026 \\
\text{Azotic} & 0\cdot9760
\end{array}
$$

Now, as air is a compound of 4 volumes azotic and 1 volume of oxygen gas, it is obvious that $\dfrac{1\cdot1026 + 0\cdot9760 \times 4}{5} = $ specific gravity of common air. If we resolve the equation, we find the specific gravity of common air not 1, as it ought to be, but $1\cdot00132$; showing that the specific gravities of oxygen and azotic gases, as determined by these chemists, cannot be correct.

has the property of combining with the various
bases, and of forming salts distinguished by the
generic name of *nitrates*. Several of these nitrates
contain no water of crystallization, but consist of
the anhydrous acid united to the base; this is
the case with nitrate of lead and nitrate of po-
tash. I shall make use of nitrate of lead to de-
termine the atomic weight of nitric acid.

It will be shown in a subsequent chapter, that From ni-
the atom of lead weighs 13, and the atom of pro- trate of lead,
toxide of lead, which constitutes the base of ni-
trate of lead, 14. This salt is neutral, and con-
sequently consists of one atom of nitric acid uni-
ted to one atom of protoxide of lead. It is white,
opaque, has a strong lustre, and crystallizes in
octahedrons. Sometimes it may contain a little
water mechanically lodged between its plates;
but this is not the case when it is properly crys-
tallized; and it may be always rendered anhy-
drous by exposure for a few hours to a heat of
212°.

Sulphate of soda is a salt composed of one
atom sulphuric acid, one atom soda, and ten
atoms water :—but it is with great facility freed
from its water of crystallization. A few days'
exposure in a dry room is sufficient for the pur-
pose; or we may place it in the vacuum of an
air-pump, in a vessel raised an inch or two above
a flat plate filled with sulphuric acid. Twenty-
four hours of such a situation renders it quite

anhydrous; a moderate heat drives off the water
of crystallization with great facility; and we may
afterwards fuse it, to be absolutely certain that
all traces of water are removed.

When this salt is anhydrous, it is composed of

$$
\begin{array}{ll}
\text{1 atom sulphuric acid} & = 5 \\
\text{1 atom soda} & = 4 \\
\hline
& 9
\end{array}
$$

so that nine grains of it contain exactly five
grains of sulphuric acid.

The nature and constitution of these two salts
being understood, we are prepared to investigate
the weight of an integrant particle of nitric
acid.

I took two small glass vessels, containing each
a little distilled water; in the one, I dissolved
20·75 grains of pure nitrate of lead, and in the
other, 9 grains of anhydrous sulphate of soda.
These two solutions being mixed together, a
double decomposition took place; the sulphuric
acid and oxide of lead uniting together, and
forming an insoluble sulphate of lead, which fell
rapidly to the bottom, while the nitric acid and
soda remained in solution in the colourless li-
quid. As soon as the sulphate of lead had left
the liquid quite clear and transparent, a few
drops of it were put into two different watch
glasses; into one of these, I let fall a little of

the solution of muriate of barytes, and into the other, a little of the solution of sulphate of soda. But no precipitation, or even opalescence, was produced by either of these re-agents ; showing that the liquid contained no sensible quantity of sulphuric acid, or of oxide of lead.

From this experiment it follows, that the sulphuric acid in nine grains of anhydrous sulphate of soda, is just sufficient to saturate the oxide of lead in 20·75 grains of nitrate of lead ; but nine grains of anhydrous sulphate of soda contain five grains of sulphuric acid, which re-quires just fourteen grains of protoxide of lead to saturate it. Accordingly, if the sulphate of lead precipitated be washed, collected, and dried, without any loss, it will be found to weigh exactly nineteen grains. Thus, it is proved, that 20·75 grains of nitrate of lead contain 14 grains of protoxide of lead. So that nitrate of lead is composed of

Protoxide of lead	14
Nitric acid	6·75
	20·75

The salt being neutral, and 14 denoting an integral particle of protoxide of lead, it is clear that the atomic weight of nitric acid is 6·75.

3. The importance of an accurate knowledge And nitrate of silver.
of the atomic weight of nitric acid is so great,

that it may not be amiss to give an equally rigid
proof of what it really is, drawn from the com-
position of nitrate of silver, a salt very frequently
employed in chemical analyses.

Nitrate of silver is a white transparent salt,
which may be crystallized in beautiful rhom-
boids; but it most commonly assumes the form
of thin plates, which have been compared to
sword blades. It contains no water of crystalli-
zation, though sometimes a little may be me-
chanically lodged between the plates of the crys-
tals. From this it is easily freed, by fusing it in
a moderate heat, and keeping it for some time
in that state. The small cylinders of it sold by
apothecaries, under the name of *lunar caustic*,
are quite anhydrous. But I have never met
with them perfectly pure ; they usually contain
a little gold, which separates in flocks, when the
cylinder of nitrate of silver is dissolved ; and
not uncommonly, other impurities (particularly
nitre) are likewise present. For the experiment
which I am going to relate, the salt must not
only be anhydrous, but quite pure.

The atomic weight of silver, as will be shown
hereafter, is 13·75, and an integrant particle of
oxide of silver weighs 14·75. Consequently, if
the atomic weight of nitric acid be 6·75, as we
have found it to be from the analysis of nitrate
of lead, the constituents of nitrate of silver must
be

9

Nitric acid 6·75
Oxide of silver 14·75
_____
21·5

When common salt is fused, it is converted
into chloride of sodium, which is composed of

Chlorine 4·5
Sodium 3
_____
7·5

When 7·5 parts of chloride of sodium are dis-
solved in water, they combine with 1·125 of wa-
ter, and are converted into muriate of soda,
composed of

Muriatic acid 4·625
Soda . 4
_____
8·625

These facts being understood, we may pro-
ceed to the experiment. I dissolved 21·5 grains
of fused nitrate of silver, and 7·5 grains of fused
common salt, in separate portions of distilled
water, and mixed the solutions. A double de-
composition took place ;—the muriatic acid and
oxide of silver united together, and precipitated
in the form of a heavy, white, curdy matter ;
while the nitric acid and the soda remained in
solution, in the state of nitrate of soda. When

the precipitate had subsided, and left the super-
natant liquid quite clear, a few drops of it were
put into two separate watch glasses;—into the
one a little nitrate of silver was let fall, and into
the other a little common salt. The liquid was
not precipitated nor rendered opalescent by ei-
ther of these re-agents, showing, that it con-
tained neither muriatic acid nor oxide of silver.

From this experiment we see, that the muriatic
acid in 8·625 grains of muriate of soda, just sa-
turates the oxide of silver in 21·5 grains of nitrate
of silver. But 4·625 of muriatic acid require
just 14·75 of oxide of silver for saturation.
This is, of course, the quantity of oxide in 21·5
of fused nitrate of silver—the remainder, a-
mounting to 6·75, must be nitric acid. Thus
we have found the composition of nitrate of sil-
ver exactly agreeing with our hypothesis,—de-
monstrating that 6·75 is the atomic weight of
nitric acid.

When the muriate of silver, obtained in the
preceding experiment, is washed, dried, and
fused, it is converted into chloride of silver;
consequently,

4·625 muriatic acid become	4·5 chlorine.
14·75 oxide of silver become	13·75 silver.
19·375	18·25

Hence, if it be collected without any loss, which

is a difficult process, the weight, instead of be-
ing 19·375 grains, will only be 18·25 grains.

From these two experiments, we are entitled
to affirm, that the atomic weight of nitric acid is
6·75.

4. To demonstrate the true composition of Analysis of nitric acid, I shall employ nitrate of potash. nitre

This salt, when pure, contains no water of
crystallization; but a little water is often me-
chanically lodged between the plates of the crys-
tals. This water is easily dissipated by keeping
the salt for some time in a moderate heat; or
simply, by bringing it into fusion. The salt
upon which the following experiments were made
was pure, and perfectly anhydrous.

There is a particular temperature, higher than By heat;
600°, but I do not know how much, in which, if
saltpetre be kept, it allows a certain portion of
oxygen gas to escape and no more. When 127½
grains of nitre are kept in this temperature dur-
ing the requisite time, there are extricated 29½
cubic inches of pure oxygen gas; the weight of
the nitre is reduced to 117½ grains, and the salt
is no longer *nitrate of potash*, but *nitrite of pot-
ash;* for when acetic acid is poured on it, red
fumes are extricated, which is not the case with
saltpetre. Now, it will be shown in a subsequent
part of this chapter, that the atomic weight of *ni-
trous acid* (the acid in nitrite of potash) is 5·75. It
will appear immediately, that nitric acid is com-

posed of 5 oxygen and 1·75 azote ; consequent-
ly, 29½ cubic inches, weighing 10 grains, is the
fifth part of the whole oxygen in 127½ grains of
nitre. This makes the whole oxygen in 127½
grains of nitre to amount to 147·5 cubic inches,
or 50 grains.

But though I have made many attempts to
obtain the whole oxygen and azote in a given
weight of nitre, in the gaseous state, I have only
met with partial success.

I never succeeded in decomposing nitre in a
porcelain retort, without destroying the vessel
before the decomposition was completed. The
potash, as it is evolved, acts so powerfully upon
the vessel, at the high temperature which must
be kept up, that it soon makes its way through
it, and enables the gaseous products to escape.

When the nitre was mixed with twice its
weight of siliceous sand, I decomposed it with
facility in a common stone-ware retort ; but the
retort, in the high temperature to which it was
necessary to raise it, was pervious to the air.
This prevented me from determining with preci-
sion the proportion between the volumes of the
two gases evolved—and Wedgewood retorts,
though air tight, always cracked before the pro-
cess was completed. In general, the gaseous
products consisted of

<div align="center">

1 volume azotic gas
2·3 volumes oxygen gas

</div>

And the proportion of azotic gas was always found to increase with the length of the process. I came nearer the truth with a small quantity of nitre than with a large quanity—but I was never able to obtain the whole volume of gas which nitre is capable of giving out.

I next tried to decompose nitre by heating it, By char-coal; mixed with charcoal powder, in a copper tube. The tube was heated to redness, and the gaseous products collected over mercury. By this process, I obtained a greater volume of gas than nitre itself is capable of giving out;—in some cases, the volumes of the azotic gas and carbonic acid gas, evolved, were to each other as follows:

> 1 volume azotic
> $2\frac{1}{2}$ volumes carbonic acid.

But in general, the gas, unabsorbable by potash, bore a greater ratio to the carbonic acid gas than the preceding; and the longer the heat was continued, the greater was the quantity of unabsorbable gas evolved. There was always evolved, likewise, a very considerable quantity of water. It was impossible to doubt, that the charcoal (though I had previously heated it strongly in a wind furnace) contained both oxygen and hydrogen; and, when I substituted Kilkenny coal for charcoal, my results were not more satisfactory. With Kilkenny coal, the proportion of

water formed was greater, and of carbonic acid smaller, than when charcoal was used.

My next process was to mix together nitre and clean iron filings—to introduce the mixture into a copper tube—and to expose it to a red heat. In this process, the oxygen of the nitre united with the iron filings, while the azote was evolved in the gaseous state. Four experiments made in this way very nearly agreed with each other. I found, that 8·65 grains of nitre gave out four cubic inches of azotic gas, supposing the barometer to stand at 30 inches, and the thermometer at 60°. It will be more convenient to divide these quantities by 4 ; this will give, as a result, 1 cubic inch of azotic gas from 2·1625 grains of nitrate of potash.

Now, since the specific gravity of azotic gas is 0·9722, a cubic inch of it weighs 0·296527 grain ; and this is the weight of azote in 2·1625 grains of nitre.

But nitre is anhydrous : the atomic weight of nitric acid is 6·75, and of potash 6 ; consequently, nitrate of potash is composed of

Nitric acid	6·75
Potash	6
	12·75

And 2·1625 grains of nitre contain 1·144852 grain of nitric acid. The preceding experiments

give us the weight of azote in this quantity of nitric acid, and the remainder of the weight must be oxygen; consequently, nitric acid is composed of

Azote   0·296527 or 1·7477
Oxygen 0·848324 - 5

1·144852   6·7477

But there is obviously a slight inaccuracy in this analysis, for it gives us the atomic weight of nitric acid 6·7477, instead of 6·75, which we found above to be the true quantity. It is clear, that this error lies in the azote, which is a little too low, and not in the oxygen, which must constitute a whole number of atoms. Had I obtained from 8·65 grains of nitre 4·004 cubic inches of azotic gas, instead of 4 cubic inches, this error would not have existed. But my apparatus was not delicate enough to measure the gas evolved so exactly—I may, in reality, have obtained 4·004 cubic inches, without perceiving the slight difference in volume.

There can be no doubt, from these experiments, that the true composition of nitric acid is

Azote   1·75
Oxygen 5

6·75

Or it is composed of 1 atom of azote and 5

atoms of oxygen ; and an atom of azote weighs
1·75.

It appears from an experiment, which I have
stated above, that 8·65 grains of saltpetre con-
tain 4·004 cubic inches of azotic gas.   Now, as
nitre is a compound of 6 potash and 6·75 nitric
acid—and as nitric acid is a compound of 1·75
azote and 5 oxygen—it is obvious, that 8·65
grains of nitre contain

> Azote   1·187254 gr. or   4·00386 cubic inches,
> Oxygen 3·392155 -   - 10·00960 cubic inches.
> ————————
> 4·579410

Now, 4·00386 : 10·00960 :: 1 : 2·5.   So that the
constituents of nitric acid, when converted into
gases, consist of

> 1 volume azotic gas
> 2½ volumes oxygen gas.

But we have seen already, that half a volume of
oxygen gas is equivalent to an atom.   It is ob-
vious, that a volume of azotic gas is equivalent
to an atom ;—in this respect, azotic gas agrees
with hydrogen gas, chlorine gas, and the vapour
of iodine.

The specific gravity of azotic gas is obtained
by multiplying its atomic weight, 1·75, by 0·5555.
The product is 0·9722, which we have found to
be the true specific gravity of this gas.

Nitric acid is the compound of azote and oxy-
gen, which contains the maximum quantity of
oxygen. It is obtained by heating a mixture of Method of
sulphuric acid and nitre, in a retort, to which a nitric acid.
receiver is luted. When 6¼ parts of the strong-
est sulphuric acid of commerce are mixed with
12¾ parts of nitre, thoroughly freed from water,
and perfectly pure, the acid which comes over
is the strongest that can be procured. Its speci-
fic gravity is about 1·55, and it is a compound of
1 atom acid and 1 atom water, or it contains

<div style="text-align:center">

Real acid 85·714 parts
Water 14·286 parts
_____
100·000

</div>

When 12¼ parts of sulphuric acid are mixed with
12¾ parts of pure anhydrous nitre, the whole ni-
tric acid may be obtained without any loss; but
its specific gravity is only 1·4855, and it is a
compound of 1 atom real acid, and 2 atoms
water.

When nitric acid is quite free from nitrous
gas, it is colourless, and nearly as limpid as wa-
ter; but the presence of this gas gives it a yellow, Cause of its
a red, or a brown colour, according to its quan- colour.
tity. This gas greatly increases the volatility of
the acid, but its effect upon the specific gravity
is not so great as I had anticipated—the volume
of the acid being increased, nearly in proportion
to the quantity of gas absorbed.

The following table, from a set of experiments which I made with great care, exhibits the specific gravity of various atomic compounds of real nitric acid and water. The experiments were made, by adding given quantities of water to acid, of the specific gravity 1·4855, and taking the specific gravity of the mixture. The strongest acid which I was able to obtain from nitre, had the specific gravity 1·534. By determining the composition of this acid, and observing the rate at which the specific gravity diminishes with the proportion of water added, I concluded, that acid composed of 1 atom real acid, and 1 atom water, has the specific gravity 1·55.

Atoms of Acid.	Atoms of Water.	Acid in 100.	Specific Gravity.
1	1	85·714	1·55
1	2	75·000	1·4855
1	3	66·668	1·4546
1	4	60·000	1·4237
1	5	54·545	1·3928
1	6	50·000	1·3692
1	7	46·260	1·3456
1	8	42·857	1·3220
1	9	40·000	1·3032
1	10	37·500	1·2844
1	11	35·294	1·2656
1	12	32·574	1·2495
1	13	31·579	1·2334
1	14	30·000	1·2173
1	15	28·571	1·2012

The acid, composed of 1 atom of acid and 4 atoms of water, seems to be the most intimate, for its boiling temperature is the highest, being 248°—while acid, both stronger and weaker than

this, boils at a lower temperature. This is the strength of the acid usually met with in commerce ; it contains exactly 60 per cent. of real acid, and 40 per cent. of water. Acid, of the specific gravity 1·3692, contains just half its weight of water ;—it boils at the temperature of 243°. Acid of the specific gravity 1·3032, may be considered as just the reciprocal of acid of the specific gravity 1·4237, for it consists of 40 acid + 60 water ; whereas, the latter consists of 60 acid + 40 water. Its boiling point is 236°, or 12° lower than that of the acid, whose boiling point is a maximum. These boiling points were determined by Mr. Dalton.

I shall now take a view of the remaining compounds of azote and oxygen ;—these are *protoxide of azote*, *deutoxide of azote*, and *nitrous acid*. The knowledge of the atomic weight of azote, and the specific gravity of azotic gas, will enable us to make out the composition of these compounds without difficulty.

Other compounds of azote and oxygen.

1. Protoxide of azote, the *nitrous oxide* of Davy, is usually obtained by exposing nitrate of ammonia to a heat of about 400°, or a little higher—it is a colourless gas, having a sweetish taste, and water absorbs about three fourths of its volume of it. If you mix 100 volumes of pure dry protoxide of azote, with 100 volumes of dry hydrogen gas, and pass an electric spark through the mixture, a detonation takes place,

Analysis of protoxide of azote.

and some water is deposited upon the inside of the eudiometer. If the experiment be made when the barometer stands at 30 inches, and the thermometer at 60°, the residual gas will amount to 101·77 volumes. But this gas is saturated with humidity—if it were quite dry, its volume would be 100.*

Its constitution and atomic weight.

Thus it appears, that when protoxide of azote is mixed with its own volume of hydrogen gas, and fired, the gaseous residue, which is azotic gas, is just equal to the original volume of the gas—the hydrogen gas has disappeared and been converted into water—it must, therefore, have combined with a quantity of oxygen, which, had it been in the state of gas, would have amounted to half the bulk of the hydrogen gas. The constituents of protoxide of azote then are

1 volume of azotic gas $\Big\}$ condensed into one volume.
½ volume of oxygen gas

But a volume of azotic, and ½ a volume of oxygen gases, are each equivalent to an atom;— hence this gas is a compound of 1 atom azote + 1 atom oxygen, so that its atomic weight is 2·75.

* Let the volume of dry gas be x, and let $p = 30$; and $f = 0.524$. We have

$$\frac{p\,x}{p-f} = 101.77$$

The solution of this equation will give $x = 100$.

Its specific gravity is obviously obtained by adding together the specific gravity of azotic gas, and half the specific gravity of oxygen gas.

$$\begin{array}{ll} \text{Specific gravity of azotic} & = 0\cdot9722 \\ \tfrac{1}{2} \text{ specific gravity of oxygen} & = 0\cdot5555 \\ \hline & 1\cdot5277 \end{array}$$

I took the specific gravity of this gas three times successively, and obtained each time 1·5269. This is as near an approximation to the truth as I could reach with my balance—and is amply sufficient to satisfy us, that the specific gravity above deduced, from the known specific gravities, volumes, and condensation of its two constituents, is correct.

2. Deutoxide of azote, the *nitrous air* of Priestley, has been long known, and for many years constituted a favourite object of research among chemists. Sir H. Davy was the first person who attempted an accurate analysis of it. From his experiments (*Researches*, p. 122.) it was evident, that it consisted very nearly of equal volumes of oxygen and azotic gases. Gay-Lussac afterwards demonstrated, that its constituents are 1 volume of oxygen, and 1 volume of azotic gases, united together without any condensation. He heated some potassium in 100 volumes of this gas;—after the combustion was at an end, and the whole apparatus cooled down to the

Analysis of deutoxide of azote.

temperature of the apartment, the residual gas, which was pure azote, amounted to exactly 50 volumes,*—the potassium had absorbed the oxygen, which obviously constituted half the volume of the original gas. Now, since ½ a volume of oxygen gas is equivalent to an atom, and 1 volume of azotic gas to an atom, it is evident, that deutoxide of azote is a compound of 2 atoms oxygen, and 1 atom azote ; consequently, its atomic weight is 3·75.

Its consti-
tution and
weight.

The specific gravity of this gas is the mean between the specific gravity of oxygen and azotic gases, or 1·0416. For

Sp. gr. of oxygen gas 1·1111̇
Sp. gr. of azotic gas   0·9722̇

$$2 \,)\, 2·0833̇$$

1·0416̇ = sp. gr. of deutoxide of azote.

I took the specific gravity of this gas, prepared with as much care, to secure its purity, as possible. The mean of three trials, differing from each other only by unity in the fourth decimal place, was 1·04096. The small difference between this result and the preceding, deduced from theory, which does not exceed $\frac{1}{1488}$th part, is probably to be ascribed to the presence of a little azotic gas, with which it is extremely diffi-

* Mem. d'Arcueil. II. 216.

9

cult to prevent it from being contaminated, when the gas is prepared over water.

Berzelius and Dulong, in their paper on the Specific Gravity of Gases, state its specific gravity to be only 1·0010. But this statement cannot be accurate ; for it is inconsistent with the specific gravities of oxygen and azotic gases, which they themselves have given. According to them, the specific gravity of

Oxygen gas = 1·1026
Azotic gas = 0·9760
              —————
        2) 2·0786
              —————
        1·0393 = sp. gr. of deutoxide of azote, deduced from these data.

These gentleman have rated the specific gravity of deutoxide of azote a great deal too low.

If 1 volume of protoxide of azote, and half a volume of oxygen gas, were to unite and be reduced to ¾th of a volume, we should obtain a compound, having the constituents and specific gravity of deutoxide of azote. For

Sp. gr. of protoxide of azote = 1·5277
½ sp. gr. of oxygen gas   = 0·5555
                                 —————
                          2) 2·0833
                                 —————
                          1·0416 = sp. gr. of deutoxide of azote.

H 4

3. Nitrous acid is an orange coloured liquid,
which may be obtained in a state of purity, by
exposing dry nitrate of lead to heat in a retort,
while the receiver is surrounded with a mixture
of snow and salt.   It is a liquid, which, when
newly prepared, has an orange colour ; but I
have never been able to prevent it from acquir-
ing a green colour—a change produced by the
absorption of a very small quantity of water.
This acid was first obtained in a separate state by
Berzelius—Gay-Lussac first ascertained its na-
ture—Dulong analyzed it, by passing it through
red hot copper wire.   The oxygen united to the
copper, while the other constituent, the azote,
passed off in the state of gas.   By this method
of proceeding, he obtained its constituents as
follows :—

$$
\begin{array}{ll}
\text{Azote} & 1\cdot75 \\
\text{Oxygen} & 4\cdot178
\end{array}
$$

This is rather more than 4 atoms of oxygen
united to 1 atom of azote.   But that the true
composition of nitrous acid, is 1 atom of azote
and 4 atoms of oxygen, is obvious from the fol-
lowing experiment, which I have often repeated.

Introduce into a cylindrical glass tube, 18
inches long and 0·9 inch in its internal diameter,
shut at one end, filled with water, and standing
inverted over a water trough, 100 volumes of
common air ;—then let up to this air 100 vol-

umes of deutoxide of azote ;—the gaseous mix-
ture assumes an orange colour, and diminishes
rapidly in volume. When the gas has become
again colourless, and has ceased to diminish, its
bulk will be found to amount to 138 volumes.

To be able to understand what really takes
place in this experiment, we must recollect that
common air consists of 20 volumes oxygen gas,
and 80 volumes azotic gas ; and that the yellow
colour is occasioned by the combination of the
oxygen of the common air, with the deutoxide of
azote and the formation of nitrous acid. The
whole oxygen of the air disappears, and the
amount of the residual gas will enable us to judge
of the volume of deutoxide, with which it com-
bines.

The experiments were made over water at the
temperature of 60°. Had the air and deutoxide
been dry, instead of saturated with moisture, each
would have occupied only 98·253 volumes instead
of 100 ; so that the whole gaseous matter used,
had it been dry, would have occupied 196·506
volumes. The 138 volumes of residual gas, sup-
posing them dry, would be reduced to 135·589
volumes. This last quantity subtracted from
196·506 (the original volume) leaves 60·917 vol-
umes for the quantity absorbed or converted into
nitrous acid.

Now 98·253 volumes of common air, contain
19·65 volumes of oxygen, which, in order to be

converted into nitrous acid, must have combined
with 41·267 volumes of deutoxide of azote.
According to this experiment nitrous acid is
a compound of

> 19·65 volumes of oxygen gas
> 41·267 volumes deutoxide of azote

Or,

> 20 volumes oxygen gas
> 42 volumes deutoxide of azote

42 exceeds 20 × 2 only by 2 volumes—and these
2 volumes are absorbed by the air in the wa-
ter through which it was passed.   This air al-
ways causes a little of the deutoxide of azote
to disappear, and renders its absorption in all ex-
periments made in this way a little greater than
the truth.

From the preceding experiment, then, we may
conclude that nitrous acid is composed of

> 1 volume oxygen gas
> 2 volumes deutoxide of azote.

But we have seen, in a preceding part of this
chapter, that deutoxide of azote is composed of
1 volume of azotic and 1 volume of oxygen gas,
united, without any condensation.   It is obvious,
then, that nitrous acid is composed of

> 1 volume azotic gas
> 2 volumes oxygen gas.

But a volume of azotic gas being equivalent to an atom, and half a volume of oxygen gas equivalent to an atom, nitrous acid is obviously composed of

<div style="text-align:center">

1 atom azote
4 atoms oxygen

</div>

Hence its atomic weight is 5·75.

Such are the atomic weights and constitutions of all the known compounds of azote and oxygen. Azote appears likewise capable of uniting with chlorine and iodine; the compounds formed possess violently detonating properties, and have not hitherto been applied to any useful purpose. I have not myself made any experiments to determine the composition of these substances. Davy made some experiments on the chloride of azote, from which he deduced its constituents to be

<div style="text-align:center">

4 atoms chlorine = 18
1 atom azote = 1·75
────────
19·75

</div>

Gay-Lussac, from theoretical considerations, considers the iodide of azote to be a compound of

<div style="text-align:center">

3 atoms iodine = 36·5
1 atom azote = 1·75
────────
37·25

</div>

It would be very difficult to analyze it, for it de-

tonates on the slightest motion ; often, indeed,
spontaneously without any agitation whatever.

But azote enters into a combination with hy-
drogen, of considerable interest in a chemical
point of view, as it constitutes ammonia, or vola-
tile alkali, so much employed in chemical analy-
ses, and so often formed during the decomposi-
tion and putrefaction of animal substances.

Ammonia   Ammonia, in a state of purity, is a gaseous sub-
stance, easily obtained by heating a mixture of
sal-ammoniac and quicklime. $3\frac{1}{2}$ parts of pure
quicklime are sufficient to decompose $6\frac{3}{4}$ parts of
sal-ammoniac ; but it is better to add a consider-
able excess of quicklime.   Indeed, I always fill
the small retort in which the sal-ammoniac is
put with quicklime, which is of service by pre-
venting the two speedy extrication of moisture,
which stops the evolution of the gas.

Ammoniacal gas must be received over mer-
cury ; for it is the most absorbable of all the
gases by water, 1 volume of that liquid absorb-
ing 780 volumes of ammoniacal gas.

Analysis of   When pure dry ammoniacal gas in a glass
tube, standing over mercury, is exposed to a
continued series of electrical sparks passed
through it, decomposition takes place ; its volume
is just doubled ; and it is found to consist of a
mixture of one volume azotic and three volumes
hydrogen gas.   This experiment was first made
by M. Berthollet senior.   It was afterwards re-

peated with great care by M. Berthollet junior,
Sir H. Davy, and Dr. Henry.* What I have
just stated, is the obvious deduction from these
elaborate and difficult experiments. As in azo-
tic and hydrogen gases, volumes are equivalent
to atoms, it follows that ammonia is a compound
of

1 atom azote	=	1·75
3 atoms hydrogen	=	0·375
		2·125

So that its atomic weight is 2·125.

Its atomic
weight.

Ammoniacal gas has been shown to be a com-
pound of one volume azotic and three volumes
hydrogen gas, condensed into two volumes. Its
specific gravity, of course, will be obtained by
adding together the specific gravity of azotic
gas, and three times the specific gravity of hy-
drogen gas, and dividing the sum by two. This
gives us 0·59027 for the true specific gravity of
this gas.

Sir H. Davy took the specific gravity of this
gas with great care, and obtained for a result

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* Dr. Henry, in a paper on the Analysis of the Aeriform Compounds of
Nitrogen, printed in 1824, but not yet published, has repeated the analysis
of ammonia with still greater care, and has obtained results which scarcely
differ from those in the text. The ammoniacal gas was doubled by the
electric sparks, and the gas, thus increased in volume, was found a mixture
of one volume azotic and three volumes hydrogen gas.

Dr. Henry's analyses of protoxide of azote, deutoxide of azote, and nitric
acid, fully confirm the statements in the preceding part of this chapter.

0·590164. A set of experiments to determine the specific gravity of this gas, made with great care in my laboratory, gave (the mean of three trials) 0·59031. Davy found the specific gravity of this gas a little below the theoretical result, while I obtained it a little above it—but if we take the mean between these two specific gravities, we obtain 0·590237, which differs from the theoretical result by less than $\frac{1}{10000}$th part. There cannot be the least doubt that the atomic weight and specific gravity of ammoniacal gas have been determined with precision.

But as the exact knowledge of the composition of this substance is a most important point in the theory of chemistry, it will not be amiss to exhibit even a redundancy of evidence. I shall, therefore, add a few additional experiments.

Analysis of oxalate of ammonia. 1. Oxalate of ammonia is a neutral salt, which crystallizes in beautiful transparent prisms. It is not very soluble in water. Its constituents I have found, by a careful analysis, to be

1 atom oxalic acid	4·5
1 atom ammonia	2·125
2 atoms water	2·25
	8·875

8·875 grains of this salt were dissolved in a small quantity of distilled water. 6·25 grains of pure calcareous spar (equivalent to 3·5 grains of lime)

were dissolved in muriatic acid : the solution was evaporated to dryness, and the dry residual salt, constituting muriate of lime, was re-dissolved in a little water. The two solutions being mixed, a double decomposition took place, and oxalate of lime subsided to the bottom. As soon as the supernatant liquid had become quite clear, it was tested by oxalate of ammonia, and by muriate of lime ; but was not rendered muddy by either of these reagents,—showing that it contained no lime nor oxalic acid. From this it is obvious, that 8·875 grains of oxalate of ammonia contain just the quantity of oxalic acid requisite to saturate 3·5 grains of lime. Now, 3·5 being the atomic weight of lime, the oxalic acid in 8·875 grains of the oxalate must be the equivalent of an atom, or 4·5 ; for it will be shown afterwards that 4·5 is the atomic weight of oxalic acid.

The liquid from which the oxalate of lime had precipitated was neutral : hence the muriatic acid in the muriate of lime was just capable of saturating the whole ammonia in the 8·875 grains of oxalate of ammonia. Now, this muriatic acid weighed exactly 4·625 grains. And it will be shown in the next paragraph, that 4·625 grains of muriatic acid just saturate 2·125 grains of ammonia. This, therefore, is the quantity of ammonia in 8·875 grains of oxalate of ammonia.

We have thus determined the weight of acid and ammonia in 8·875 grains of oxalate of ammonia. The surplus weight being undoubtedly water, it is obvious that the constituents of oxalate of ammonia are

1 atom oxalic acid	.	4·5
1 atom ammonia	.	2·125
2 atoms water	.	2·25
		8·875

The atomic weight of ammonia in this salt is undoubtedly 2·125.

Of sal-ammoniac.

2. Sal-ammoniac, when newly sublimed, or when dried for some time upon the sand bath, is an anhydrous salt. It is neutral; and, therefore, a compound of one atom muriatic and one atom ammonia.

1 atom muriatic acid	.	4·625
1 atom ammonia	.	2·125
		6·75

6·75 grains of pure dry sal-ammoniac were dissolved in water; 21·5 grains of pure anhydrous nitrate of silver were dissolved in another portion of water, and the two solutions were mixed. A double decomposition took place, and chloride of silver precipitated. As soon as the residual liquid had become clear, it was tested by nitrate of silver and common salt. Neither of these

salts produced any effect, if we except an almost imperceptible opalescence which appeared when the common salt was added ; but there was no precipitate whatever, even after the liquid had stood a week. From this experiment it is obvious, that 6·75 grains of sal-ammoniac contain just 4·625 grains of muriatic acid ; for that is the quantity necessary to saturate the 14·75 grains of oxide of silver present in 21·5 grains of nitrate of silver. Hence the other constituent of the salt, the ammonia, must weigh 2·125, because that is the weight wanting to make up the full quantity of sal-ammoniac employed ; and, as sal-ammoniac is neutral, and 4·625 the atomic weight of muriatic acid, 2·125 must be the atomic weight of ammonia.

3. 13·5 grains of dry sal-ammoniac were wrapped up in blotting paper, and dropped into a retort filled with dichloride of lime, (Mr. Tennant's bleaching powder,) made into a thin paste with water. The whole retort and beak was then filled with water, and the beak of the retort was plunged into a water trough, under an inverted graduated jar, filled with water. As soon as the paper round the sal-ammoniac was sufficiently softened to allow the dichloride to come in contact with the salt, an effervescence took place, and azotic gas was disengaged. This is just the effect always produced when chlorine and ammoniacal gas come in contact. The lime which

Analysis of ammonia by chlorine.

was in excess in the salt decomposed the sal-
ammoniac; and the ammonia, as it was evolved,
came in contact with chlorine, and was decom-
posed; the hydrogen uniting with the chlorine,
and the azote being disengaged in the gaseous
state. The action is so violent, if the dry sal-
ammoniac be dropped at once into the retort,
that it is difficult to collect the whole gas; but
when the salt is wrapped in paper, the action
is slow, and the gas may be all collected with
the greatest facility. The azotic gas obtained in
this process was 11·7 cubic inches, at the tem-
perature of 47°, and when the barometer stood
at 29·93 inches. This is equivalent to 11·853
cubic inches of dry gas, of the temperature 60°,
and under a pressure of 30 inches mercury.

This constitutes the whole amount of the azo-
tic gas in 4·25 grains of ammonia, the quantity
contained in 13·5 grains of dry sal-ammoniac.
Now, 11·853 cubic inches of azotic gas weigh
3·5147 grains : Hence it follows, that the weight
of the other constituent, the hydrogen, is 0·7353
grain. Consequently, ammonia is composed of

Azote	1·7573	or	1 volume
Hydrogen	0·3676	—	2·94

2·1250

The small excess of azote in this experiment was
owing to a small admixture of common air with

the azote, in consequence of the gas standing 24 hours over the water.

The experiment was repeated seven times, in various ways, and the mean of the whole came exceedingly near 11·8 cubic inches of dry azotic gas from 13·5 grains of sal-ammoniac. This weighs 3·4993 grains, giving us the composition of ammonia as follows ;

Azote	1·74965	or	1 volume
Hydrogen	0·37535	—	3·0028

2·12500

This analytical result of direct experiment comes within less than $\frac{1}{1000}$th part of the theoretical estimate ; and, taken together with the preceding facts, can leave no doubt of the composition of ammonia.

CHAP. VI.

OF THE ATOMIC WEIGHTS OF THE ACIDI-
FIABLE COMBUSTIBLES.

THE simple bodies, which I have distinguished by the name of acidifiable combustibles, are the nine following :

1 Hydrogen,	4 Silicon,	7 Selenium,
2 Carbon,	5 Phosphorus,	8 Arsenic,
3 Boron,	6 Sulphur,	9 Tellurium.

I have already treated of hydrogen in the first chapter of this work. I shall endeavour in this chapter to establish the atomic weights, and to point out the principal combinations of the remaining eight. These bodies differ from all the other combustible substances in the property which they have of entering into gaseous compounds, either with hydrogen gas or fluoric acid, while none of the other combustible bodies enter into any gaseous combination whatever. An accurate knowledge of their atomic weights will be found important, not merely as connected with chemical analysis; but because it throws an important light on the relation between the atomic weight and the specific gravity of gaseous bodies.

SECT. I.

OF THE ATOMIC WEIGHT OF CARBON.

BRITISH chemists seem all agreed in opinion respecting the atomic weight of carbon. It is to the atom of oxygen as 6 to 8 ; consequently, if an atom of oxygen be reckoned unity, an atom of carbon must be represented by 0·75. Berzelius, who is followed by a great proportion of the chemists on the continent, considers the atomic weight of carbon to be 0·7533. As this number differs nearly 1 per cent. from 0·75, I have been at great pains to endeavour to determine which of the two is nearest the truth ; and I shall here describe a set of experiments which I made, with that specific object in view, with every possible attention to the most minute accuracy.

Carbonic acid gas contains its volumes of oxygen gas. It was established by the experiments of Lavoisier, and has been amply confirmed by succeeding experimenters, that when carbon is burnt in oxygen gas, the volume of the gas undergoes no alteration ; but it is converted into carbonic acid. It is obvious from this that, if we subtract the specific gravity of oxygen gas from that of carbonic acid gas, the remainder will give us the weight of carbon with which a volume of oxygen gas has united ; and, of course,

furnish us with the requisite data for determining the exact composition of carbonic acid gas.

We have three sets of experiments on the specific gravity of carbonic acid gas, which appear to have been made with great care. The following are the results obtained :

SP. GR. OF CARBONIC ACID GAS.

1·5196	.	by Biot and Arago.
1·52673	.	by my experiments.
1·5240	.	by Berzelius and Dulong.

These results differ too much from each other to enable us to deduce from them the composition of carbonic acid, with the requisite degree of precision ; nor have we any criterion by which we can discover which of the three results is nearest the truth. My own determination is the highest, and that of Biot and Arago the lowest. Now, if any error resulted from the impurity of the gas weighed, the probability is, that it would diminish the specific gravity somewhat ; for, common air, the only gas likely to contaminate the carbonic acid gas examined, is a good deal lighter. So far the probability of accuracy rather inclines to my own result ; but it is not sufficient to enable us to decide the point, far less to determine whether my own result be not in reality a little too low. This uncertainty suggested to me a method similar to that by which the specific gravities of oxygen and hydrogen gases

were determined in the first chapter of this work.
I shall now lay the result of these experiments
before the reader.

1. It is well known, that, when calcareous spar
or carbonate of lime is exposed to a white heat,
it loses its carbonic acid, and is converted into
quicklime. I exposed given quantities of very
pure crystallized calcareous spar, inclosed in a
platinum crucible, covered with a lid, to the
greatest heat of a wind furnace, in order to de-
termine the weight of carbonic acid which would
be driven off. The loss of weight in different
trials was not rigidly the same. However, by a
number of experiments, varied by uniting the
lime to sulphuric acid, and determining the
weight of sulphate of lime remaining after igni-
tion, I satisfied myself, that, when none of the
lime is lost, and when the carbonate is anhy-
drous, 100 grains of it, when deprived of its car-
bonic acid, lose exactly 44 grains. The remain-
ing 56 grains are lime. Carbonate of lime, then,
is a compound of

Carbonic acid		.	44	or	11
Lime	.	.	56	—	14
			100		25

It will appear afterwards, that the atomic
weight of lime is 3·5. Now, 14 : 11 : : 3·5 :
2·75 ; so that (if carbonate of lime be a com-

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pound of 1 atom lime and 1 atom carbonic acid)
the atomic weight of carbonic acid is 2·75. The
following experiment, which I have repeated
more than once, will show that this determina-
tion is rigidly exact.

2. I must begin by stating, what will be after- Atomic
weight of
carbonic
acid deter-
mined.
wards proved, that an atom of potash weighs 6.
This alkali combines in two proportions with car-
bonic acid, forming a *carbonate*, composed of 1
atom potash, united to 1 atom carbonic acid ;
and a *bicarbonate*, composed of 1 atom potash,
and 2 atoms carbonic acid. The latter of these
salts crystallizes in large transparent and perma-
nent crystals, not affected by exposure to the air.
It can easily be procured in this state in this
country, very nearly pure, being only occasion-
ally contaminated by a little lime and a little
iron. If we dissolve these crystals in distilled
water, filter the solution, evaporate it to dry-
ness, and expose the saline residue to a red heat,
we obtain anhydrous carbonate of potash in a
state of great purity. Dissolve 87½ grains of
this salt in water ; dissolve in muriatic acid 62½
grains of pure anhydrous carbonate of lime ; eva-
porate the solution to dryness, in a gentle heat,
to drive off the excess of acid ; and dissolve the
muriate of lime formed in distilled water. Thus
we have two solutions, containing each determi-
nate quantities of a particular salt : the first so-
lution, 87½ grains of carbonate of potash, and the

second, a quantity of muriate of lime equivalent to 62½ grains of carbonate. When these two solutions are mixed, a double decomposition takes place ; the lime and carbonic acid unite together, and precipitate in the state of carbonate of lime, while the muriatic acid and potash remain in solution, constituting muriate of potash. If we examine the clear residual liquid after the carbonate of lime has precipitated, we shall find in it no uncombined potash, and no carbonate of potash ; for, cudbear paper, dipped into it, is not in the least altered,—although a very minute quantity of uncombined alkali, or alkaline carbonate, gives it a violet stain. Neither does it contain any sensible quantity of lime ; for it is not in the least altered by the addition of a few drops of oxalate of ammonia. When the precipitated carbonate of lime is collected and dried, it weighs exactly 62½ grains, or is just equal to the original quantity of carbonate of lime employed—a clear proof that it contains all the lime and all the carbonic acid of the two salts.

This experiment will be more easily understood if we divide the quantities employed by 10. We thus get 8·75 grains of carbonate of potash, and 6·25 grains of carbonate of lime— each constituting an integrant particle of the anhydrous salt; for carbonate of potash is composed of

Carbonic acid   2·75
Potash   6
_____
8·75

And carbonate of lime of

Carbonic acid   2·75
Lime   3·5
_____
6·25

The carbonic acid was separated from this car-
bonate, and an atom of muriatic acid, weighing
4·625, was substituted in its place—forming mu-
riate of lime, composed of

Muriatic acid   4·625
Lime   3·5
_____
8·125

The 3·5 lime and the 2·75 carbonic acid united
together, and formed 6·25 carbonate of lime.
In the same way, the 6 potash and the 4·625
muriatic acid united together; and these respec-
tive quantities of acid and base exactly neutral-
ized each other : for both the carbonate of lime
and the muriate of potash were perfectly neu-
tral. It is clear from this experiment, that the
atomic weight of carbonic acid is just 2·75.

3. Two facts of great importance have been as-
certained by the preceding experiments; name-
ly, 1. That an atom of carbonic acid weighs
2·75. 2. That 100 grains of pure carbonate of
lime contain exactly 44 grains of carbonic acid.

The next object which engaged my attention was, to disengage the carbonic acid from 100 grains of calcareous spar, and collect it over mercury, in order to ascertain its volume. This experiment appears so easy, that the reader will be surprised to hear, that a considerable time elapsed, and many fruitless experiments were made, before I was able to make it with accuracy.

The first method that I tried was, to fill a graduated glass jar with mercury, to let up into it some muriatic acid, and then to introduce a given weight of calcareous spar. By this method the carbonic acid was extricated with great rapidity ; but the volume of gas obtained was always considerably greater than it ought to have been, judging from my previous knowledge of the specific gravity of carbonic acid gas. The reason I found to be, that a portion of the muriatic acid had been disengaged in the form of gas, had mixed with the carbonic acid gas, and had augmented its volume. Thus the gas from 100 grains of calcareous spar sometimes amounted to $109\frac{1}{2}$ cubic inches ; while I knew that the true volume of the gas, if pure, could not exceed $94\frac{1}{2}$ cubic inches.

I attempted to prevent this extrication of muriatic acid gas, by employing very weak muriatic acid for dissolving the calcareous spar ; but when the experiment was made in this way, the volume of carbonic acid gas extricated fell al-

ways a little below the truth. The reason I
found to be, that a portion of the carbonic acid
remained in the liquid muriatic acid, and did not
assume the gaseous form at all.

When acetic acid was used, the extrication of
gas went on very slowly, unless the carbonate of
lime was in powder ; and the gas extricated was
always below the true quantity, because it did
not all assume the elastic state.

Sulphuric acid did not answer well, because
the sulphate of lime formed was apt to screen
some of the calcareous spar from the action of
the acid, and thus to prevent the whole gas from
being obtained.

Oxalic, tartaric, and citric acids, could not be
used, for a similar reason. Nitric acid was ex-
cluded, because it acted on the mercury.

Foiled in my attempts to determine the vo-
lume of carbonic acid gas extricated from a given
weight of calcareous spar by the above method,
I had recourse to another, which succeeded per-
fectly.

To the beak of a small
retort, A, I cemented
a long glass tube, bent
at right angles, at *a*, *b*,
and B, and the upright
leg, B, C, of such a
length, that it reached
very nearly to the top of the graduated glass
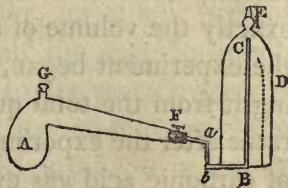
jar D, fitted at its top E with a stop cock.
The capacity of the retort was 36 cubic inches.
This apparatus was attached to a mercurial
trough, so that the jar D could be placed
over the upright tube B, C. The stop-cock F
being shut, I opened the stop-cock E, and with
my mouth sucked the air out of the jar till
only 5 cubic inches remained in it, over a co-
lumn of 8 inches of mercury; the stop-cock E
was then shut. I next took out the stopper G,
the stop-cock F remaining shut, and poured into
the retort a cubic inch of strong nitric acid.
100 grains of calcareous spar, in three or four
pieces were then dropped into the retort, and
the stopper being at the same instant put into
its place, the stop-cock F was opened. The
whole calcareous spar was speedily dissolved,
and the carbonic acid gas made its way into the
cylinder D. When the experiment was over, I
noted the volume of gas in the cylinder, the
height of the column of mercury below it (ge-
nerally about 1 inch), and the height of the ba-
rometer and thermometer at the time. Knowing
exactly the volume of air in the apparatus before
the experiment began, it was easy, by subtract-
ing it from the total quantity of air in the appa-
ratus after the experiment, to deduce the volume
of carbonic acid gas evolved. All the necessary
reductions being made, the volume of carbonic
acid gas evolved from 100 grains of calcareous

spar, supposing the barometer to stand at 30 inches, the thermometer at 60°, and the gas to be perfectly dry, amounts, from a mean of two experiments, both made with very great care, to 94·426 cubic inches.

Now, we have seen that the weight of this volume of carbonic acid gas is 44 grains. Consequently, 100 cubic inches of carbonic acid gas must weigh 46·5973 grains; but 100 cubic inches of air weigh 30·5 grains. We have, therefore, 30·5 : 46·5973 : : 1 : 1·52778 = specific gravity of carbonic acid gas.

Thus the specific gravity of carbonic acid gas, determined by ascertaining the volume of a given weight, amounts to 1·52778. By means of a nonius and a microscopic sight, I was enabled to measure the volume of gas with precision to the thousandth part of a cubic inch. My result, therefore, must be very near the truth. It is not, however, quite exact. But, by means of a law, which I shall explain more at length in the following chapter, we have it in our power to determine the specific gravity of this gas with mathematical accuracy; for, its atomic weight, multiplied by 0·5555, (half the specific gravity of oxygen gas,) is equal to its specific gravity. Now, we have seen that the atomic weight of this acid is 2·75 ; and 2·75 × 0·5555 = 1·5277, which is the true specific gravity of this gas. My estimate, deduced in the way just explained,

does not exceed this quantity by so much as $\frac{1}{700,000}$th part.

The specific gravity of carbonic acid gas being thus ascertained with rigid accuracy, we have only to subtract from it the specific gravity of oxygen gas, to know the weight of carbon united in it, with a volume of oxygen gas.

Sp. gr. of carbonic acid gas   1·5277

oxygen gas   1·1111

0·4166 = carbon

Thus we learn, that this acid is composed of

Oxygen   .   1·1111   or 2
Carbon   .   0·4166   or 0·75

2 denotes 2 atoms of oxygen; and 0·75 must be the atomic weight of carbon. Thus it appears, that carbonic acid is a compound of 2 atoms of oxygen, and 1 atom of carbon.*

The carbon in this gas is evidently in the state of vapour. If we consider the gas as a com-

---

* If the specific gravities of oxygen gas and carbonic acid gas were 1·1026 and 1·5240, as stated by Berzelius and Dulong, an atom of carbon would be 0·76438, a number considerably higher than the one pitched upon by Berzelius; for, 1·5240 — 1·1026 = 0·4214 = the quantity of carbon in a volume of carbonic acid; so that carbonic acid would be a compound of

Oxygen   .   1·1026   or 2
Carbon   .   0·4214   or 0·76438

It is obvious from this, that these specific gravities cannot be accurate.

pound of 1 volume oxygen gas and 1 volume carbon vapour, condensed into one volume, it is obvious that the specific gravity of carbon vapour is 0·4166. As is the case with hydrogen, azotic, and chlorine gases, a volume of it is equivalent to an atom.

II. Carbon enters into another gaseous combination with oxygen, namely, the gas distinguished by the name of *carbonic oxide*. The atomic weight of this gas is not of so much importance as that of carbonic acid, because we do not know any compounds of which it constitutes a part; but it will be worth while to determine it, because the knowledge of it will serve still farther to elucidate and confirm the preceding conclusions respecting the atomic weight of carbon.

Carbonic oxide was discovered by Dr. Priestley, but its nature was first ascertained by Mr. Cruikshanks. M. M. Clement and Desormes made a set of experiments on it nearly at the same time, or very soon after Cruikshanks, and came to the same conclusion with him : namely, that it is a compound of oxygen and carbon without any hydrogen.

I have never succeeded in obtaining it absolutely free from all admixture of carburetted hydrogen gas. Its specific gravity according to my trials is 0·9700. But, owing to the carburetted hydrogen which it contained, this result is too

low.   Berzelius and Dulong state its specific
gravity to be 0·9727.   This is rather too high ;
but it is a good deal nearer the truth than mine.

When 100 volumes of this gas are mixed with
50 volumes of oxygen gas, and an electric spark
passed through the mixture, combustion takes
place, both gases disappear, and a quantity of
carbonic acid gas is formed just equal to the ori-
ginal volume of the carbonic oxide gas employed.
This fact, which has been sufficiently established
by experiment, will enable us to determine the
true specific gravity of this gas, and likewise its
constituents and its atomic weight.

1. Since half a volume of oxygen gas added
to one volume of carbonic oxide gas constitutes
one volume of carbonic acid gas, it is obvious
that, if from the specific gravity of carbonic acid
gas, we subtract half the specific gravity of oxy-
gen gas, the remainder will be the specific gra-
vity of carbonic oxide gas.

Sp. gr. of carbonic acid gas   = $1 \cdot 527\dot{7}$
½ sp. gr. of oxygen gas   = $0 \cdot 555\dot{5}$
                                  ───────
                                  $0 \cdot 972\dot{2}$ = sp. gr. of
                                     carbonic oxide gas.

Thus we learn, that the specific gravity of this
gas is $0 \cdot 972\dot{2}$, or exactly the same with that of
azotic gas.   The specific gravity of it as given
by Berzelius and Dulong, exceeds the truth by
little more than $\frac{1}{2000}$ part.

2. It was observed in a former part of this chapter, that carbonic acid gas contains just its own volume of oxygen gas. But to convert a volume of carbonic oxide gas into a volume of carbonic acid gas, we must add half a volume of oxygen gas. It is evident from this, that a volume of carbonic oxide gas contains just the volume of carbon that carbonic acid gas does, but only half the volume of oxygen gas. It must therefore consist of one volume carbon vapour, and half a volume oxygen gas condensed into one volume.

1 volume carbon vapour weighs   0·4166

½ volume oxygen gas.   .   .   0·5555

———————

0·9722 = specific gravity of carbonic oxide gas.

3. A volume of carbon vapour being equivalent to an atom, and half a volume of oxygen gas to an atom, it is obvious that carbonic oxide is a compound of one atom carbon, and one atom oxygen. Hence its atomic weight is 1·75.

Thus we have two compounds of carbon and oxygen.

	CARBON.	OXYGEN.
Carbonic oxide composed of	1 atom +	1 atom
Carbonic acid . . .	1 +	2

The last of these only possesses acid properties. The first has no tendency whatever to unite with alkaline bases.

III. There are several gaseous combinations of carbon and hydrogen, which were long confounded under the general appellation of heavy inflammable airs. Their nature and constitution deserve to be pointed out, because they constitute the gaseous substances employed for giving light during the night; and they differ materially from each other in their illuminating powers. They may be divided into two species, which have been distinguished by the names of *olefiant gas*, and *carburetted hydrogen gas*.

Analysis of olefiant gas. 1. Olefiant gas was first examined by the Dutch chemists; but we are indebted to Mr. Dalton for an accurate knowledge of its composition. Its specific gravity, as determined by my experiments, is 0·9709; but Berzelius and Dulong found it as high as 0·9804. It will be seen immediately, that my result is about $\frac{7}{118}$th part too low; while that of Berzelius and Dulong is about $\frac{1}{118}$th part too high.

It was shown long ago by Mr. Dalton, and the observation was confirmed by my experiments, that one volume of olefiant gas requires for complete combustion, three volumes of oxygen gas, and the gas remaining after the combustion amounts to two volumes of carbonic acid gas. The knowledge of this fact will enable us to determine the specific gravity, the composition, and the atomic weight of this gas with rigid accuracy.

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(1.) Three volumes of oxygen gas being ne-
cessary to consume one volume of olefiant gas,
and only two volumes of carbonic acid gas being
formed, it is obvious that only two volumes of
the oxygen gas were employed in forming car-
bonic acid; the other volume of oxygen gas
must have been employed in forming water, and
it must have combined with a quantity of hydro-
gen, which, had it been in the gaseous state, and
uncombined, would have amounted to just two
volumes. The two volumes of carbonic acid
gas contain each a volume of carbon vapour.

Thus it appears, that one volume of olefiant
gas is composed of two volumes of carbon va-
pour, and two volumes of hydrogen gas con-
densed into one volume. Its specific gravity,
therefore, will be obtained by adding together
twice the specific gravity of carbon vapour, and
twice the specific gravity of hydrogen gas.

Twice the sp. gr. of carbon vapour   =   0·8333
Twice the sp. gr. of hydrogen gas   =   0·1388
                                          0·9722   =
                        specific gravity of olefiant gas.

Thus it appears that azotic gas, carbonic oxide
gas, and olefiant gas have the same specific
gravity.

(2.) In the case of carbon vapour and hydro-
gen gas, a volume is equivalent to an atom;—so
that olefiant gas is a compound of two atoms

carbon and two atoms hydrogen. This is the
same thing as one atom carbon and one atom
hydrogen. Consequently, this gaseous compound
ought to be distinguished by the name of *car-
buretted hydrogen*, had not that name, unfortu-
ately, been previously appropriated to a different
gas.

Five gases
exist com-
posed of
equal atoms
of carbon
and hydro-
gen.

But this combination of carbon and hydrogen,
atom to atom, in the gaseous state, deserves to
fix our particular attention. I believe that no
fewer than five different gases or vapours exist,
composed of these two substances in that pro-
portion, but coupled together in different ways.

First spe-
cies.

The first consists of

1 volume carbon vapour ⎫
1 volume hydrogen gas. ⎭ condensed into 1 volume.

Its specific gravity is 0·4861. One volume of
it requires for complete combustion, 1½ volume
of oxygen gas. After the combustion there re-
mains one volume of carbonic acid gas.

This peculiar gas has not yet been met with
by chemists ; but I see no reason to doubt its
existence. It probably exists occasionally as a
constituent of coal gas.

Second
species.

The second is *olefiant gas*, composed of

2 volumes carbon vapour ⎫
2 volumes hydrogen gas ⎭ condensed into 1 volume.

Its specific gravity is 0·9722. One volume of
it requires for complete combustion three vo-

lumes of oxygen gas. After combustion there remain two volumes of carbonic acid gas.

This gas is formed when alcohol and sulphuric acid, in the proportion of one part of the former to four of the latter, are heated. It exists also as a constituent of coal gas.

The third consists of

> 3 volumes carbon vapour ⎱ condensed into 1 volume.
> 3 volumes hydrogen gas ⎰

Its specific gravity is 1·4583. It requires 4½ times its volume of oxygen gas for complete combustion; and the residual gas consists of three volumes of carbonic acid gas.

Mr. Dalton discovered this gas as a constituent in the gas extricated, when whale oil is exposed to a red heat. This gas is employed for lighting houses, and even streets, under the name of *oil* gas.

The fourth consists of

> 4 volumes carbon vapour ⎱ condensed into 1 volume.
> 4 volumes hydrogen gas ⎰

Its specific gravity is 1·9444. It requires six times its volume of oxygen gas for complete combustion; and a volume of it, thus burnt, leaves four volumes of carbonic acid gas as a residue.

The vapour of sulphuric ether constitutes a gaseous body of this kind. But in this vapour there exists, likewise, a volume of the vapour

of water. Hence, the specific gravity of ether vapour is 2·5694 ; for it consists of

1 volume of quadro-carburetted hydrogen 1·9444
1 volume of vapour of water   .   .   0·6250
_____
2·5694 = sp. gr.
of ether vapour.

Fifth spe-
cies.

The fifth consists of

6 volumes carbon vapour ⎫
6 volumes hydrogen gas   ⎬ condensed into 1 volume.

Its specific gravity is 2·9166. It requires nine times its volume of oxygen gas to consume it completely: and when 1 volume of it is consumed in this way, there remain behind 6 volumes of carbonic acid gas as a residue.

I find, that the vapour of naphtha, from coal, constitutes a gaseous compound of this kind. It is not condensed by passing it through water; and is, I believe, what gives coal gas its peculiar smell.

These gaseous bodies are chiefly used for lighting the streets and illuminating houses. Now, it is obvious, that the quantity of light which they will emit while burning, will be proportional to the number of volumes of carbon condensed into 1 volume of the gas. Olefiant gas burns with great brilliancy ; but the vapour of naphtha will give three times as much light,

while the same volume of it is burning. This vapour, then, if we could get rid of the smell, would be the best substance for giving light ;— one obvious method would be, to take care that the whole of it is consumed, and that none escapes under the form of naphtha vapour.

2. Carburetted hydrogen gas can only be obtained pure, by stirring the mud at the bottom of stagnant waters, during hot weather. It was first accurately examined by Mr. Dalton. Soon afterwards, I published a set of experiments on it, in the first volume of the Wernerian Memoirs. I took its specific gravity at two different times, with great care. Gas, collected at Restalrig, near Edinburgh, had the specific gravity of 0·5554. The mean of the specific gravity of three specimens, collected in the neighbourhood of Glasgow, was 0·5576. It will be proper to state each of these trials, as the gas was collected at three different times.

Carburetted hydrogen analyzed.

<div style="text-align:center">

1st trial   0·5602
2d trial   0·5558
3d trial   0·5570

</div>

It is obvious that the gas was not of equal purity in each of these trials ;—it was purest in the second specimen, the specific gravity of which comes nearest that of my former experiments. The mean of the two gives us 0·5556, which is undoubtedly very near the truth. Berzelius and Dulong state the specific gravity of this gas to

be 0·5590 :—this nearly agrees with the specific gravity of the first specimen of gas collected by me near Glasgow.

It has been established by accurate experiments, that a volume of this gas requires, for complete combustion, two volumes of oxygen gas, and that the residual gas is one volume of carbonic acid. From this fact, it is easy to deduce the true specific gravity, the composition, and the atomic weight of this gas.

(1.) One volume of the oxygen gas must have gone to the formation of carbonic acid gas, and must have united with 1 volume of carbon vapour ;—the other volume of oxygen gas must have gone to the formation of water, and must have united with two volumes of hydrogen gas. Thus it appears, that the constituents of carburetted hydrogen gas, are one volume carbon vapour, and 2 volumes hydrogen gas, condensed into 1 volume. Hence, its specific gravity will be obtained by adding together the specific gravity of carbon vapour, and twice the specific gravity of hydrogen gas.

Sp. gr. of carbon vapour	= 0·4166
2 sp. gr. of hydrogen gas	= 0·1388

0·5555 = sp. gr.
of carburetted hydrogen gas.

Or its specific gravity is exactly half that of oxygen gas.

(2.) In the case of carbon vapour and hydrogen gas, we may substitute atoms for volumes. It is obvious, therefore, that this gas is a compound of 1 atom carbon, and 2 atoms hydrogen. And as an atom carbon weighs 0·75, and an atom of hydrogen 0·125, the atomic weight of this substance is unity, or the same as oxygen. Its specific gravity is only half that of oxygen gas; because, a volume of oxygen gas is equivalent to two atoms, while a volume of this gas is equivalent only to one atom.

3. There exists a third combination of carbon and hydrogen, which has come to our knowledge since coal gas was employed for lighting the streets. It was first noticed by Mr. Garden, who described some of its most remarkable properties, in the year 1820.* Soon after, I got from Mr. Cooper a considerable quantity of this substance, which I purified by sublimation, and subjected to a chemical examination. A valuable set of experiments on this substance was made by Dr. Kid, and published in the Philosophical Transactions for 1821;—he gave it the name of *Naphthaline.* I have only to refer the reader to this interesting paper for a satisfactory explanation of the formation and properties of this singular substance. But, as Dr. Kid made no experiments to determine its constituents, it may

Naphthaline, or sesquicarburetted hydrogen.

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* Annals of Philosophy, XV. 17.

be worth while to state here the results which I obtained. One grain and a quarter of naphthaline, in crystalline plates, was mixed with a sufficient quantity of oxide of copper, and exposed to heat in a copper tube—to which was attached a glass tube, filled with fragments of fused muriate of lime. The gas extricated was collected over mercury; it was pure carbonic acid; and measured under the mean temperature and pressure 8·85 cubic inches. The increase of weight of the muriate of lime was very nearly 1·125 grain. Now, 8·85 cubic inches of carbonic acid gas weigh very nearly 4·125 grains, and contain 1·125 of carbon; and 1·125 water contain 0·125 hydrogen. Now, 1·125 carbon = 1½ atom; while 0·125 hydrogen is an atom of hydrogen. Consequently, naphthaline is composed of

<div align="center">

1½ atom carbon 1·125
1 atom hydrogen 0·125
_____
1·25

</div>

It is, therefore, a sesquicarburet of hydrogen.

Dr. Kid states, that the specific gravity of naphthaline is a little heavier than that of water. I found its specific gravity only 0·7812 at 60°. But I am disposed to ascribe this apparent lightness to the pores which it contains;—for when digested in nitric acid, its specific gravity became 1·23. But this digestion alters its properties, and

converts it into a kind of acid, which has a yellow colour, and very different properties from the pure naphthaline.

SECT. II.

OF THE ATOMIC WEIGHT OF BORON

THE experiments of Davy, and of Gay-Lussac and Thenard, to determine the composition of boracic acid by the augmentation of weight which takes place when boron is converted into boracic acid, differ so much from each other, that it is impossible to put any confidence in either. Davy found that 30 grains of potassium were requisite to reduce a quantity of boracic acid capable of furnishing 2·375 grains of boron. Now, 30 grains of potassium when converted into potash, (as they were by the process) absorb 6 grains of oxygen. Hence, we have boracic acid composed of

Atom of boracic acid still doubtful.

Boron   2·375 or 1
Oxygen 6   - 2·52

He found farther, that 1 grain of boron, when converted into boracic acid, absorbs 5·125 cubic inches of oxygen gas, or 1·7368 grain. This gives us boracic acid composed of

Boron   1
Oxygen   1·7368

The mean of these two experiments gives us the composition of boracic acid as follows :

Boron   1
Oxygen   2·128

Now, I am persuaded that this comes nearer the truth than any other analytical results which have been given to the public.

The statement of Gay-Lussac and Thenard, that boron, when converted into boracic acid, only absorbs half its weight of oxygen, is most certainly extremely inaccurate. Davy's result, I believe to be about ⅛th part below the truth; but the result of the French chemists cannot be much less than ¾ths below the truth.

In the second volume of the second series of the Annals of Philosophy, I published a set of experiments on boracic acid,—from which I deduced 2·75 as the probable atomic weight of that acid. But my experiments, which consisted in the analysis of borax, were not quite conclusive, owing to the difficulty of collecting and weighing the whole of the boracic acid. I had not at that time examined *fluoboric acid gas* with the requisite attention. I have since found, that this curious combination furnishes us with the means of determining the atomic weight of boracic acid with rigid accuracy.

1. It will be proved in the 15th chapter of this treatise, that the weight of an atom of fluoric acid is 1·25. Fluoboric acid gas may be obtained by mixing together anhydrous boracic acid and pulverized fluor spar, and exposing the mixture to a red heat, in an iron tube—or simply, by heating in a retort (as was first discovered by Dr. John Davy), a mixture of 1 part boracic acid, 2 parts fluor spar, and 12 parts sulphuric acid. I collected a quantity of this gas, and took its specific gravity two different times, and obtained each time the very same result; namely 2·3709.

On causing the gas under examination to be absorbed by water, I observed that there was a slight deposite of silica, indicating a mixture of fluosilicic gas. By weighing this silica, I determined the volume of fluosilicic gas, and on deducting it, the specific gravity of the fluoboric acid gas was 2·38833. A careful examination of the water containing the fluoboric acid gas, enabled me to detect in it the presence of a small quantity of sulphuric acid ;—it was present to the amount of 0·8 grain in the hundred cubic inches of the gas. This being also deducted, the specific gravity of pure fluoboric acid gas became 2·3622.*

---

* Dr. Davy found the specific gravity of this gas 2·3709. This is the very specific gravity which I got—and a little above the truth, owing, doubtless, to a little fluosilicic or sulphuric acid, or both.

2. Dr. Davy found that fluoboric acid gas and ammoniacal gas, combine with each other in the three following proportions :

(1) 1 volume fluoboric gas
     1 volume ammoniacal gas $\Big\}$ forming a solid salt.

(2) 1 volume fluoboric gas
     2 volumes ammoniacal gas $\Big\}$ forming a liquid.

(3) 1 volume fluoboric gas
     3 volumes ammoniacal gas $\Big\}$ forming a liquid.

It will be shown in the 7th chapter of this treatise, that, in the greater number of gases, a volume of the gas represents an atom.   But in ammoniacal gas this is not the case ; two volumes of this gas are requisite to constitute an atom.   It is reasonable to conclude from this, that the second of the preceding compounds is the one consisting of an atom of each constituent.   We have it, therefore, in our power to determine the atomic weight of fluoboric acid from it.

1 volume fluoboric gas weighs 2·3622   or 4·2519.
2 volumes ammoniacal gas - 1·18055 - 2·125

2·125 is the weight of an atom of ammonia ; consequently, 4·2519 is the weight of an atom of fluoboric acid.   The law of Dr. Prout, which will be found to hold in the atomic weights of all bodies, shows us that this number is a very little too high.   The true atomic weight is undoubtedly 4·25 ; consequently, the true specific gravity

of fluoboric acid gas is 2·3611, which differs less than $\frac{1}{2000}$th part from the specific gravity which I actually obtained.

3. 4·25, then, is the atomic weight of fluoboric ^{Its compo-} acid, and 1·25 is the atomic weight of fluoric acid ; consequently fluoboric acid is a compound of

Fluoric acid	1·25
Boracic acid	3·00
	4·25

3, then, is the weight of an atom of boracic acid ; for Davy's experiments on the composition of boracic acid—Berzelius' analysis of borate of ammonia—and mine of borax—preclude the possibility of either more or less than an atom of boracic acid being united in fluoboric acid, with an atom of fluoric acid.

From Davy's analytical experiments, it is ^{Atom of} clear, that the atom of boron is 1 ; and that bo- ^{boron and} racic acid is a compound of

1 atom boron	1
2 atoms oxygen	2
	3

4. It occurred to me, that, by heating together ^{Ratio be-} anhydrous boracic acid and dry carbonate of ^{tween the weights of} potash, some light might be thrown on the ^{boracic and carbonic} atomic weight of boracic acid, by the quantity ^{acids.}

of carbonic acid driven off. A quantity of car-
bonate of potash was fused in a platinum cruci-
ble, which varied in different experiments, from
80 to 100 grains ; and 9 grains of anhydrous bo-
racic acid being added, the fusion was usually
continued from one hour to an hour and a half,
or in one case, two hours. The loss of weight
in the different experiments was not uniform.
The smallest loss amounted to 6·8 grains, and
the greatest to 8 grains. In these experiments
it is obvious, that the greatest loss of weight
must be nearest the truth. Even 8 grains, the
maximum loss of weight, is a little below the real
quantity of carbonic acid which ought to have
been displaced. The reason of the variation in
these results, and the difficulty of driving off the
full quantity of carbonic acid, I take to be, that
the boracic acid has a tendency to fall to the
bottom of the fused mass, and to remain at the
bottom. It is, therefore, difficult to bring the
acid and the carbonate into contact, and to keep
them in contact till the whole acid enters into
combination with the potash and displaces the
carbonic acid. I found that I succeeded best
when I placed the acid on the surface of the al-
kali.

But let us see what the atomic weight of bo-
racic acid will be, if we suppose 9 grains of it to
saturate as much potash as 8 grains of carbonic
acid. $8 : 9 : : 2{\cdot}75 : 3{\cdot}09375 =$ atomic weight

of boracic acid. This number comes near 3, which we have seen to be the true atomic weight of boracic acid; and serves still farther to show that the experiments from which I deduced 2·75 to be its atomic weight, were inaccurate.

5. Boracic acid, as it is usually obtained from borax by precipitation, is in white opaque scales, containing a considerable quantity of water. Sir H. Davy, Berzelius, and myself, endeavoured to determine the quantity of water present in these scales. The experiment is attended with a good deal of difficulty. I varied my method after I became aware that my first experiments were wrong, and endeavoured to prevent any volatilization of boracic acid, by mixing the hydrous acid with a considerable quantity of protoxide of lead. But I still found the loss of weight to amount to 44 per cent. The following are the results of Davy, Berzelius, and myself. The hydrate is composed of

Bihydrate of boracic acid.

	DAVY.	BERZELIUS.	THOMSON.
Real acid	57	56	56
Water	43	44	44

I am satisfied that Davy came nearest the truth, though I have not been able to discover the cause of my own failure. If the hydrous acid contain two atoms of water united to one atom of acid, its constituents should be

1 atom boracic acid	3	or 57·143
2 atoms water	2·25	42·857

5·25	100

which almost coincides with Davy's experiment.

6. Very few of the borates have hitherto been analyzed, and very few of them accurately. However, from Berzelius' analysis of borate of ammonia, I think we are entitled to conclude that the salt is composed of

1 atom boracic acid	3
1 atom ammonia	2·125
2 atoms water	2·25

7·375

Berzelius obtained

Boracic acid	2·659
Ammonia	2·125
Water	2·25

7·034

7. It was not till I had satisfied myself of the true atomic weight of boracic acid from the specific gravity and combinations of fluoboric acid, that I became acquainted with M. Arfwedson's method of analyzing the borates by means of fluor spar. He mixes the borate to be analyzed with a determinate quantity of fluor spar reduced to the state of a very fine powder, and exposes the mixture with the requisite

quantity of sulphuric acid to heat in a platinum crucible. The boracic acid is disengaged in the state of fluoboric acid, and the base of the borate remains combined with sulphuric acid. In the alkaline borates the base, when converted into a sulphate, is soluble in water, and may therefore be obtained in a separate state and its weight determined. I had recourse to this method, in order to determine the weight of soda in borax, my previous analysis of this salt having been obviously incorrect. (1.) 19 grains of borax being slowly raised to a red heat in a platinum crucible till they ceased to lose water, were found to have sustained a loss amounting almost exactly to 9 grains. (2.) 19 grains of borax, and 9·5 grains of very finely pounded fluor spar, intimately mixed together, were made up into a paste with sulphuric acid in a platinum crucible, and after digesting for 24 hours were exposed to a strong red heat. The matter remaining in the crucible was white, and weighed about 26 grains. This matter was digested in water, which dissolved the sulphate of soda, together with a little of the sulphate of lime. This water was mixed with oxalate of ammonia to throw down the lime. It was then filtered, evaporated to dryness, and the residual salt exposed to a red heat. It weighed within $\frac{1}{1000}$th part of 9 grains; indicating 4 grains of soda. Thus it appears, that 19 grains

of crystallized borax contain 4 grains of soda, and 9 grains of water. The 6 grains wanting to complete the whole weight, must represent the boracic acid in the salt. The reader will observe that the original weight of the ingredients put into the crucible (abstracting the water) was 19·5, consisting of

> 10   grains anhydrous borax
> 9·5 grains fluor spar
> ─────
> 19·5

The boracic acid of the borax, and the fluoric acid of the fluor spar, had been driven off together, and these acids had been replaced by sulphuric acid. Now, 9·5 fluor spar are composed of

> 7·0 lime
> 2·5 fluoric acid
> ─────
> 9·5

7 of lime require 10 of sulphuric acid for saturation. So that the sulphate of lime in the residue amounts to 17 grains. The remaining 9 grains are sulphate of soda, composed of

> 4 soda
> 5 sulphuric acid
> ─
> 9

But the original weight of anhydrous borax was 10, and it obviously contained 6 grains of bora-

cic acid. Thus, all the parts of this experiment confirm eac h other, and show that borax is a compound of

2 atoms boracic acid   6
1 atom soda   .   4
8 atoms water .   9
               —
            19

8. Arfwedson has analyzed boracite by a similar process, and it follows from his analysis, that the mineral is a biborate of magnesia, and consequently a compound of Of boracite.

2 atoms boracic acid   6
1 atom magnesia   2·5
               —
           8·5

This salt is perfectly anhydrous.

SECT. III.

OF THE ATOMIC WEIGHT OF SILICON.

THOUGH the experiments of Sir H. Davy have satisfied chemists that silica is a compound of oxygen, and a dark coloured combustible substance, like carbon or boron, to which the name of *silicon* or *silicium* has been given ; and though Berzelius has obtained silicon in a separate state ; yet as silica is the only known compound

into which it enters, the principal object of inquiry in this section will be into the atomic weight of *silica*. This inquiry is of great importance; because upon it the exact knowledge of the constitution of most stony bodies depends. I am of opinion that the atomic weight of silicon is precisely 2, and I shall proceed to state the evidence upon which that opinion is founded.

Proofs that the atom of silica weighs 2.

Analysis of silica by Berzelius

I. In the year 1810, Berzelius published a set of experiments, containing an analysis of silica which he made in the following manner :* He mixed together determinate proportions of iron filings, silica, and charcoal in a crucible, and exposed the mixture, properly covered, to the greatest heat of a blast furnace. The united action of the iron and charcoal decomposed the silica, and the silicon as it was evolved, entered into combination with the iron. The silicious iron thus formed was whiter, and had a smaller specific gravity than common iron. When dissolved in muriatic acid, it gave out a greater proportion of hydrogen gas than common iron, and this hydrogen gas contained a certain proportion of carbon. It left undissolved a quantity of silica. He dissolved a given weight of this iron in muriatic acid, collected the hydrogen gas evolved, and by burning it over lime water determined the quantity of carbonic acid formed, from which he deduced the carbon

* Afhandlingar. III. 117.

which the iron contained. The iron was then peroxydized, precipitated by ammonia, heated to redness, and weighed. The iron and carbon deducted from the original weight of the iron, gave the weight of the silicon which had been united with it. This silicon weighed 127 parts, but the *silica* obtained when the specimen was treated with muriatic acid, amounted to 335 parts. Now, $335 - 127 = 208 =$ the oxygen combined with 127 parts of silicon. But other experiments gave him silica composed of

Silicon   51·5 and 52·25
Oxygen   48·5 and 47·75

These experiments were repeated by Stromeyer,[*] who obtained for a result

Silicon   46·0069
Oxygen   53·9931

Now, the mean of these two sets of experiments gives us the composition of silica as follows :

Silicon   49·9189 or 0·9966
Oxygen   50·0811 — 1·0000

100·0000   1·9966 = atomic weight of silica, which approaches exceedingly near 2.

Gives
1·9966 for
the atom of
silica.

Berzelius, in his essay on Chemical Proportions, and in the second edition of his *Lärbok i*

Kemien, states the composition of silica as
follows :

Silicon	49·7 or	0·988
Oxygen	50·3	1·
	100·0	1·988 = atomic weight of silicon.

I do not know whether this new determination,
which approaches the ratio of equality much
more nearly than the number given by Berzelius
in his original paper, be the result of a new set
of experiments, or deduced from corrections
made upon the old ones. But the atomic
weight of silica deduced from it, is only $\frac{1}{166}$th
part less than 2. And I do not believe it to be
possible to operate in the way practised by Ber-
zelius and Stromeyer, without the risk of a still
greater error than $\frac{1}{166}$th part. I consider, there-
fore, this determination of Berzelius as a very
strong evidence in favour of 2 being the true
atomic weight of silica.

The com-
position of
natural sili-
cates.

II. Among the minerals which are found in
regular crystals, and which have been subjected
to chemical analysis, there are a good many con-
taining silica united chemically, and conse-
quently in definite proportions with different
bases. If these minerals were perfectly pure,
an accurate analysis of them would give us suffi-
cient data for determining the atomic weight of
silica. It will be worth our while to examine a
few of these compounds, that we may see how

nearly they agree in giving the same atomic weight to this substance.

1. TABLE SPAR.

This mineral, which is a *bisilicate of lime*, or Table spar a compound of two atoms silica and one atom of lime, occurs in the Bannat. It has been observed likewise in Ceylon, constituting a part of the cinnamon stone rock. It has a greyish white colour, and a foliated fracture in one direction only, from which it has got its name. We have four analyses of this mineral; one by Klaproth, a second by Stromeyer, a third by Rose, and a fourth by Bonsdorff.

The specimens analyzed by Klaproth and Stromeyer were from the Bannat; those by Rose and Bonsdorff were found in Finland.

According to Klaproth, the constituents of table spar are

Silica	50
Lime	45·9*
Water	5

100·9†

The constituents according to Stromeyer, are

* Klaproth reckons only 45; but he obtained 82 of carbonate of lime, which contains 45·9 lime.

† Beitrage, III. 289.

Silica	51·445
Lime	47·412
Protoxide of iron	0·401
of manganese	0·257
Water	0·076

99·591 *

Rose analyzed, in Berzelius' laboratory, a specimen of table spar from the village of Perheniemi in Finland, the constituents of which were

Silica	51·6
Lime	46·41
Oxide of iron, trace	
Actinolite	1·11

99·12 †

The specimen analysed by Bonsdorff was from Pargas in Finland; it had been mistaken for tremolite. Its constituents were

Silica	52·58
Lime	44·45
Magnesia	0·68
Protoxide of iron	1·13
Volatile matter	0·99

99·83 ‡

Before drawing any conclusion from these experiments, it may be proper to observe that in the Bannat, the table spar occurs in a rock consisting of garnets, blue limestone, and table spar.

* Untersuchungen, I. 356.   † Nordenskiöld's Bedrage, 1st part, p. 94.
‡ Annals of Philosophy, (second series) II. 300.

It is reasonable from this circumstance to expect, that the table spar analyzed by Klaproth and Stromeyer should contain a little too much lime, in consequence of the mixture of a small quantity of the blue limestone, with the portion of the mineral subjected to analysis. The iron and manganese, small quantities of which were detected by Stromeyer, no doubt originated from the garnets. The loss of five per cent. in Klaproth's analysis, which he ascribed to water, might possibly be owing to the presence of some blue limestone in the specimen.

The table spar from Perheniemi occurs in a limestone rock. This might lead to an excess of lime in the specimen analyzed by Rose. That from Pargas was mixed with pargasite and other varieties of horneblende, which might occasion a slight excess of silica in the specimen analyzed by Bonsdorff.

The iron, manganese, magnesia, &c. which occur in minute quantity in the mineral, may be neglected altogether as foreign matter. We shall attend only to the silica and the lime.

Let us suppose an atom of silica to weigh 2, and an atom of lime 3·5; and let us suppose table spar to be a bisilicate of lime : its constituents would be

$$\begin{array}{lll} \text{Silica} & 4 & \text{or} & 53\frac{1}{3} \\ \text{Lime} & 3\cdot5 & & 46\frac{2}{3} \end{array}$$

Now, Klaproth's analysis gives us

6

	Silica	$53\frac{1}{3}$
	Lime	48·96

Stromeyer's gives us

	Silica	$53\frac{1}{3}$
	Lime	49·153

Rose's gives us

	Silica	$53\frac{1}{3}$
	Lime	47·969

Bonsdorff's gives us

	Silica	$53\frac{1}{3}$
	Lime	45·086

In the three first analyses there is an excess of lime ; because the mineral analyzed was found in a limestone rock ; in the last analysis by Bonsdorff, there is an excess of silica, because the table spar was from a horneblende rock.   If we take a mean of all these analyses as likely to furnish a near approximation to the true composition of table spar, we obtain

Silica	53·333	or	3·905
Lime	47·792		3·5

It is obvious that this mean cannot be correct, because three of the specimens examined came from a limestone rock, and therefore were likely to contain an excess of lime, and only one from a horneblende rock, and likely to contain an excess of silica.   However, we see that even from this mean, we get 3·908 for the weight of two atoms of silica, or 1·9525 for the weight of one atom.

16

If we take the mean of the first three analyses which contain an excess of lime, we get 48·694 for the quantity of lime united with 53⅓ silica. And taking the mean of this quantity, and of 45·086, the lime united to the silica, according to Bonsdorff's analysis, we get 46·89 for the lime. This gives us table spar composed of

$$\begin{array}{lll} \text{Silica} & 53 \cdot 33\overset{.}{3} & \text{or} \quad 3 \cdot 936 \\ \text{Lime} & 46 \cdot 890 & - \quad 3 \cdot 5 \end{array}$$

By this constitution (which is as near the truth as the accuracy of the analysis will admit) two atoms of silica weigh 3·936, and consequently, the weight of one atom is 1·968.

Gives
1·968.

2. SILICATE OF ALUMINA, OR BUCHOLZITE.

Some years ago, a mineral was found in the Tyrol, to which Weiss gave the name of *fibrous quartz*, but Brandes, who analyzed it, distinguished it by the appellation of *bucholzite*. It has a white colour, interspersed with black spots; its texture is fibrous, and it has never been met with in crystals. Its constituents, according to the analysis of Brandes, are as follows:

Bucholzite

Silica	46
Alumina	50
Oxide of iron	2·5
Potash	1·5
	100·0 *

* Schweigger's Jour. XXV. 125.

Let us calculate the composition of this mineral, on the supposition that the silica is combined with three bases, atom to atom ; and that an atom of silica weighs 2, an atom of alumina 2·25, an atom of protoxide of iron 4·5, and an atom of potash 6.

1. 2·25 (an atom of alumina): 2 (an atom of silica) : :
      50 (alumina in the mineral) :   44·44
      = silica united to the alumina.

2. 4·5 (atom of protoxide of iron): 2 : : 2·5 (oxide in
      the mineral):   1·11
      = silica united to the iron

3. 6 (atom of potash) : 2 : : 1·5 (potash in the min-
      eral) :   0·50
      = silica united to the potash

                    Total silica in the mineral   =   46·05

This exceeds the quantity found by Brandes by only 0·05 grain—a quantity so small, that it might very easily be overlooked in an analysis. Let us, however, suppose, that the analysis is perfectly accurate, and let us deduce from it the atomic weight of the silica. About $\frac{1}{28}$th of the silica is united to the oxide of iron and the potash. Now, the 28th part of 0·05, the excess of silica, is nearly 0·002, which being deducted, leaves about 0·053. If we subtract this excess from the 44·444 of silica, supposed above to be united to the alumina, there will remain 44·391 grains. Hence, by Brandes' analysis of this mineral, silicate of alumina is composed of

<div style="text-align:center">

Silica   44·391 or 1·997595
Alumina 50   -   2·25

</div>

Thus the atomic weight of silica, from the analysis of bucholzite, comes out below 2; but the deficiency does not amount to $\frac{1}{800}$th part—a difference greatly within the limits of unavoidable error in such analyses.

3. NEPHELINE.

This mineral, which is found on Monte Somma, near Naples, has been long known to mineralogists. It crystallizes in six sided prisms, often bevelled at their extremities; it is hard enough to scratch glass, and has a specific gravity of 2·2741. From the late analysis of this mineral by Arfwedson, its constituents appear to be

<div style="text-align:center">

Silica	.	44·11
Alumina	.	33·73
Soda	.	20·46
Water	.	0·62
		98·92*

</div>

Let us suppose that in this mineral every atom of alumina is combined with an atom of silica; and every atom of soda with an atom and a half of silica, (this is a common mode of combination of soda with acids;)—and let an atom of silica weigh 2, an atom of alumina 2·25, and an atom of soda 4. Let us calculate the composi-

tion of nepheline according to these supposi-
tions :

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 33·73
      (alumina in mineral) :   .   .   .   29·98
      = silica united to the alumina.
(2.) 4 (atom of soda) : 3 (1½ atom silica) : : 20·46
      (soda in mineral) :   .   .   .   15·345
      = silica united to soda.

              Total silica   .   .   .   .   45·325

The silica in the mineral being only 44·11
grains, is less than the amount of the silica de-
duced from the above suppositions by 1·215 grain.
Let us admit the specimen analyzed by Arfwed-
son to have been perfectly pure, and the analy-
sis to have been accurate, and let us deduce
from it the atomic weight of silica.

It is obvious that nepheline must consist of 3
integrant particles of silicate of alumina, united
to 1 integrant particle of sesquisilicate of soda.
Of consequence, ⅓d of the deficiency belongs to
the sesquisilicate of soda. Hence, silicate of
alumina, according to Arfwedson's analysis, is
composed of

Gives
1·94582.
          Silica   .   29·17   or   1·94582
          Alumina .   33·73   -   2·25

The atom of silica deduced from this mineral
is less than when deduced from bucholzite.
The reason is, probably, that the substances with

which the nepheline is mixed, (hornblende, meionite, &c.) introduce a slight excess of alumina, or soda, by destroying the rigid purity of the mineral.

4. HEDENBERGITE, OR TRISILICATE OF IRON.

This mineral occurs in Marmor's mine, Tuna- Hedenberberg, Sweden, where it forms layers in white cal- gite
careous spar. It was described and analyzed by M. Hedenberg, in the year 1807.* It has a blackish green colour, a fibrous fracture, and it seems to consist of rhombs, having the same figure as calcareous spar ;—phosphoresces both by heat and friction ;—specific gravity, 3·154. The constituents assigned by Hedenberg, but corrected by Berzelius, are

Silica	.	.	40·62
Protoxide of iron	.	.	32·53
Water	.	.	16·05
Carbonate of lime	.	4·93
Oxide of Manganese	.	0·75
Alumina	.	.	0·37

95·25†

The carbonate of lime may be left out of view, because it is obviously derived from the rock in which the hedenbergite was found.

* Afhandlingar, II. 164. † Nouveau Systeme, p. 31.

Let us calculate the composition of hedenbergite, on the supposition that it is a trisilicate of iron ; that silica weighs 2, and protoxide of iron 4·5.

4·5 (atom of protoxide of iron) : 6 (3 atoms silica) : : 32·53 : 43·37 = silica united to the iron.

The quantity of silica united to the iron (on the supposition that an atom of it weighs 2) exceeds the quantity in the mineral by 2·75 grains ; but, in all probability, the oxide of manganese and the alumina supplied the place of the deficient silica.   Now, 0·37 alumina will go as far in saturating oxide of iron, as 0·328 of silica ; and 0·75 of protoxide of manganese will go as far as 0·333 of silica.   We may, therefore, subtract 0·66 from the deficient silica, thus reducing the deficiency to 2·09 grains.

If we suppose the analysis perfectly correct, the composition of trisilicate of iron deduced from it will be

Silica   .   41·28   or   5·7104
Protoxide of iron · 32·53   -   4·5

Gives
1·9035.

According to this analysis, 3 atoms of silica weigh 5·7104 ; hence the atom of silica is $\frac{5·7104}{3}$ = 1·9035.

5. DIOPTOSE, OR SESQUISILICATE OF COPPER.

Dioptose

This mineral, which was at first confounded

with the emerald, is usually crystallized in six-sided prisms, terminated by trihedral pyramids. It has a fine green colour, a foliated texture, and a specific gravity of 3·3. It is a conductor of electricity. From an analysis of this mineral by Lowitz, we learn that its constituents are

Silica	.	33
Peroxide of copper	.	55
Water	. .	12
		100

Let us calculate the constituents of this mineral on the supposition that it is a hydrated sesqui-silicate of copper; that an atom of silica weighs 2, an atom of oxide of copper 5, and an atom of water 1·125.

(1.) 5 (atom of oxide of copper) : 3 (1½ atom silica) : : 55 : 33 = the silica united to the oxide.
(2.) 88 : 12 (water in mineral) : : 8 : 1·0905 = water in the mineral, very nearly 1 atom.

Hence the mineral is composed of

1 integ. part. of sesquisilicate of copper $\left\{ \begin{array}{l} \text{silica } 33 \\ \text{oxide } 55 \end{array} \right\}$ 88

1 atom water . . . . 12·37

100·37

This mineral gives us exactly 2 for the atomic weight of silica. There is a slight deficiency in

the water, which could be probably accounted for, if we knew the previous treatment which the mineral had received.

6. SILICATE OF ZINC.

Silicate of zinc

This mineral was first accurately described and examined by Mr. Smithson. It is easily distinguished from the other *calamines*, by the property which it has of becoming electric when heated, which is peculiar to it. It is also very generally, if not always, in crystals.

According to Smithson's experiments, published in 1803, its constituents are

Silica	.	25
Oxide of zinc	.	68·3
Water	.	4·4
		97·7

Berzelius, who made an analysis of it, expressly with a view to elucidate the doctrine of definite proportions, found it a compound of

Silica	.	24·893
Oxide of zinc	.	66·837
Water	.	7·460
Carbonic acid	.	0·450
Oxides of lead and tin		0·276
		99·916 *

* Nouveau Systeme Mineral. p. 258.

An atom of oxide of zinc, as has been proved in the first chapter of this work, weighs 5·25. Now, if silica weigh 2, and this mineral be a silicate of zinc, we have 2 : 5·25 : : 24·893 : 65·344 = oxide of zinc united to the silica.

The oxide of zinc in the mineral exceeds this quantity by 1·493 grain, according to Berzelius' analysis. Let us see how far this excess can be accounted for.

1. The water in the mineral amounts, we see, to 7·460 per cent. Now, an atom of water weighs 1·125, and an integrant particle of anhydrous silicate of zinc 7·25 ; and 7·25 : 1·125 : : 90·237 (the silicate of zinc per cent.) : 14·002 = quantity of water, supposing the silicate to contain 1 atom water. Now, 14·002 being nearly double the quantity of water actually contained in the mineral, it is obvious that the silicate of zinc can contain only half an atom of water, which, in 100 parts of the mineral, amounts to 7·001. The quantity of water in the mineral is 7·460, which exceeds 7·001 by 0·459.

2. Besides the silica, then, there are two other substances contained in the mineral, both of which have the property of uniting to oxide of zinc. There are 0·459 grain of water, and 0·45 grain carbonic acid.

Now, 0·45 grain of carbonic acid requires 0·86 grain of oxide of zinc to form anhydrous carbonate ; but carbonate of zinc usually contains 1½

atom of water. This, united to a quantity of anhydrous carbonate, weighing 1·31 grain, a-mounts to 0·276 grain. There still remains 0·183 grain of water to be disposed of. It is probably united with oxide of zinc in the mineral, so as to form the common hydrate of zinc, composed of 1½ atom water, united to 1 atom of oxide of zinc. Now, 1·6875 (1½ atom of water) : 5·25 (an atom of oxide of zinc) : : 0·183 (water still unaccounted for) : 0·569 = oxide of zinc united to this water, in the state of hydrate.

3. Thus it appears, that 1·429 grain of oxide of zinc may have been in the state of carbonate, or hydrate of zinc, reducing the amount of the surplus to 0·064 grain—a quantity greatly within the limits of the unavoidable errors of analysis.

We are entitled, therefore, to consider silicate of zinc as a compound of

Gives 1·998.	Silica	24·893	or	1·998
	Oxide of zinc	65·408	-	5·25

Here the atomic weight of silica is about $\frac{1}{1000}$th part less than 2.

7. BISILICATE OF MANGANESE.

Bisilicate of manganese   This mineral is found at Longbanshytta, in Wermeland, Sweden; and it is said to occur

more abundantly at Catherinburgh, in Siberia. It has a rose red colour, and has never been observed crystallized ; but it has a foliated fracture, and natural cleavages, indicating a rhomboid for its primitive form. Its specific gravity, as determined by Hisinger, is 3·5384.

This mineral was analyzed by Ruprecht, and likewise by Napioni; but at a time when the chemical knowledge of manganese was not far enough advanced to admit of correct results. It was analyzed by Berzelius in 1806, and the constituents were published by him in the first volume of the *Afhandlingar* (p. 108). He repeated the analysis in 1817, with as much care as possible, and obtained the following constituents :

Silica	.	.	.	48
Deutoxide of manganese				54·42
Lime	.	.	.	3·12
Magnesia	:	:	:	0·22
With a trace of iron.				

105·76

Here the weight of the ingredients exceeds the weight of the original specimen by 5·76. The reason is obviously, that, in the mineral, the manganese exists in the state of protoxide; but it was converted into deutoxide in the course of the analysis. It will be shown hereafter, that protoxide of manganese weighs 4·5, and deutox-

9

ide 5. If we reduce the weight of the manga-
nese in that proportion, the constituents of the
mineral become

Silica	48
Protoxide of manganese	48·98
Lime . . .	3·10 *
Magnesia . . .	0·22
	100·3

Let us consider this mineral as a bisilicate of
manganese ; and let us calculate its composition,
on the supposition that an atom of silica is 2,
an atom of protoxide of manganese 4·5, an atom
of lime 3·5, and an atom of magnesia 2·5.

(1.) 4·5 (atom of protoxide manganese) : 4 (2 atoms
silica) : : 48·98 : 43·53 = silica united to man-
ganese . . . . 43·53

(2.) 3·5 (atom lime) : 4 : : 3·1 : 3·54 = silica united
to lime . . . . 3·54

(3.) 2·5 (atom magnesia) : 4 : : 0·22 : 0·35 = silica
united to magnesia . . . . . 0·35

Total silica united to the bases = 47·42

This quantity of silica is 0·58 grain less than
what was found in the mineral by Berzelius.
The quantity which he found is $\frac{1}{120}$th part more
than it ought to have been, supposing an atom
of silica to weigh 2. Let us, therefore, deter-

* Correcting Berzelius's estimate.

mine the atomic weight of silica, on the supposi-
tion that the constituents, as determined by
Berzelius, are rigidly accurate.

The bisilicates of lime and magnesia may be
omitted as foreign bodies. They contain about
$\frac{1}{12}$th of the whole silica; consequently, $\frac{1}{12}$th of
the surplus silica, or 0·05, must be subtracted.
The remainder is 0·53: let us add this to the si-
lica united to the protoxide of manganese. This
gives us bisilicate of manganese composed of

Silica	.	.	44·06 or 4·04798
Protoxide of manganese		48·98 -	4·5

Two atoms of silica weigh 4·04798; consequent- *Gives 2·024.*
ly, the weight of an atom will be 2·02399, which
exceeds 2 by rather more than 1 per cent.

8. KNEBELITE, OR SILICATE OF IRON AND
MANGANESE.

THIS ore has been described and analyzed by *Knebelite*
Dobereiner. It is grey, with spots of various
colours, occurs in amorphous masses, and has a
specific gravity of 3·714. According to Do-
bereiner's analysis its constituents are

Silica	.	.	32·5
Protoxide of iron	.		32
Protoxide of manganese			35

99·5

Let us calculate the composition of this mineral on the supposition that it is a silicate of iron and manganese ; and that the atomic weight of silica is 2, of protoxides of iron and manganese, each 4·5.

(1.) 4·5 (protoxide of iron atom) : 2 (atom of silica)
: : 32 : 14·2$\dot{2}$ = silica united to oxide of iron   14·2$\dot{2}$

(2.) 4·5 (atom of protoxide of manganese) : 2 : : 35 :
15·5$\dot{5}$ = silica united to the oxide of manganese   15·5$\dot{5}$

Total silica united with the bases = 29·7$\dot{7}$

The silica found in the mineral by Dobereiner exceeds this quantity by 2·72 grains. This excess might be ascribed to the presence of a certain quantity of trisilicate of manganese. Protoxides of iron and manganese having the same atomic weight, the silicates of these two bases should have the same weight. Hence, it is not unreasonable to suppose, that only 32 grains of the protoxide of manganese were in the state of silicate—the other 3 grains may have existed in the state of trisilicate. Now, 4·5 (atom of protoxide of manganese) : 6 (3 atoms silica) : : 3 : 4 = silica united to the 3 manganese. The constituents of the mineral may be thus stated :

Silicate of iron   .   46·2$\dot{2}$
Silicate of manganese   46·2$\dot{2}$
Trisilicate of manganese   7·00

99·4$\dot{4}$

This almost coincides with the analysis of Dobereiner.

But waving this probable explanation of the excess, let us calculate the atomic weight of silica, on the supposition that the mineral contains only simple silicates, and that the analysis is quite correct. The excess of the silica must be divided between the two silicates in the ratio of 14·22 : 15·55; or we must add 1·42 of it to the silica united to the manganese, and 1·3 to the silica united to the iron. This gives us silicate of iron composed as follows:

Gives 2·1827.

Silica . . 15·52 or 2·1827
Protoxide of iron 32 – 4·5

Let us now take a mean of the weight of an atom of silica, deduced from the analyses of the 8 minerals which we have just examined.

1 Table spar gives the atom of silica		1·96800
2 Bucholzite	. . .	1·997595
3 Nepheline	. . .	1·94582
4 Hedenbergite	. . .	1·90350
5 Silicate of zinc	. . .	1·99800
6 Dioptase	. . .	2·00000
7 Bisilicate of manganese	. .	2·02399
8 Knebelite	. . .	2·18270

Mean . . . . . 2·00245

Mean 2·00245.

This weight exceeds 2 only by $\frac{1}{1000}$th part. The atomic weight given by Berzelius, from his own

experiments, is below 2. But the weight just deduced is from a much greater number of experiments, and ought, therefore, to be much nearer the truth.

III. It occurred to me, that, as silica, when heated with carbonate of potash, has the property of disengaging the carbonic acid gas and uniting with the potash in its place, I might be able to form some estimate of the atomic weight of silica by mixing determinate quantities of it with pure dry carbonate of potash, exposing the mixture to a strong heat in a platinum crucible, and noting the loss of weight.

I found, in the first place, that carbonate of potash, obtained by exposing crystals of the bicarbonate to a red heat, lost no sensible weight though kept for a considerable time in a state of fusion. I found, in the second place, that, to make a successful experiment, it was necessary to employ, at least, eight times as much carbonate of potash as of silica. When less was employed, the loss of weight was always much too small. Twelve grains of pure silica in fine powder, and anhydrous carbonate of potash, were mixed together, and kept in a state of fusion for 13 hours in a platinum crucible. The loss of weight amounted to 16·67 grains.

It appears from this experiment, that 16·67 grains of carbonic acid are displaced by 12 grains of silica: but upon examining the cruci-

ble, I found that it had become lighter by 0·15 grain. Deducting this diminution, there remain 16·52 grains for the true quantity of carbonic acid expelled. Now 16·52 (the carbonic acid expelled) : 12 (the silica employed) : : 2·75 (the atomic weight of carbonic acid) : 1·99758 = the weight of an atom of silica.

Gives 1·99758 for the atom of silica.

From this experiment, which was several times repeated, the atom of silica appears to weigh 1·99758, which is very nearly $\frac{1}{1000}$th part less than 2;—the atomic weight of silica, deduced from the analysis of eight silicates, was a little above 2. As the deviations in these two different sets of experiments are on different sides, there is a chance that the mean of the two may come still nearer the truth.

Atomic weight of silica from the analysis of eight silicates . . . . . . 2·00245

Atomic weight of silica from heating silica and carbonate of potash . . . . 1·99758

Mean of both . . . . . 2·00001 Mean of both gives 2·00001.

This atomic weight is little more than $\frac{1}{200,000}$th part greater than 2.

IV. Silica enters into definite combinations with water, forming various hydrates. Some of these I have examined with care ; and they furnish satisfactory evidence that the true atomic weight of silica is 2.

1. When silica is fused with potash or car-

bonate of soda, and the fused mass digested in
hot water, we may either obtain a solution, or a
white insoluble flocky residue may be left, ac-
cording to the quantity of water which we em-
ploy. This flocky residue is a hydrate of silica,
which may be separated by the filter, washed by
repeated effusions of water, and dried in a tem-
perature which must not exceed 85° or 90°. In
summer, when the weather happened to be very
warm, I have repeatedly obtained an accurate
atomic hydrate of silica by drying it in the open
air; but in general, unless the temperature be
artificially raised, the silica retains a small excess
of water. This hydrate, when properly prepar-
ed, is composed of

Silica	. .	4
Water	. .	1·125
		5·125

Now, 1·125 is 1 atom of water, and 4 must be
just 2 atoms of silica; so that the hydrate is
a compound of 1 atom water, and 2 atoms si-
lica; and an atom of silica weighs exactly 2.

I shall relate two experiments which I made
to obtain this hydrate,—the first an unsuccessful,
and the second a successful one,—that the read-
er may be enabled to judge how great a surplus
of water the silica may retain.

About the middle of May, 1823, I fused a

quantity of silica, with thrice its weight of an-
hydrous carbonate of soda, and digested the fus-
ed mass in a small quantity of water, till the si-
lica assumed a flocky appearance. The whole
was then thrown upon a filter; and the silica was
washed repeatedly with distilled water, till no
traces of soda could be found in the washings.
In two days the filter with the silica became dry
enough to be handled. I placed the filter on
several folds of bloating paper, on a table in the
middle of my laboratory, where it was allowed
to remain for six weeks, without being disturbed.
It may be necessary to mention, that the weather
during the whole time was uncommonly cold ;
and I have reason to believe, that the tempera-
ture of the room scarcely ever exceeded 60°, if
it amounted to so much. When I returned to
Glasgow, on the 24th of June, the thermometer
in my laboratory stood at 57°. The silica, to
the eye and the feel, appeared perfectly dry ; it
weighed 43·23 grains. By exposure to a red
heat, it lost 10·55 grains, and was reduced to
32·68. Now, $32 \cdot 68 : 10 \cdot 55 :: 4 : 1 \cdot 2913 =$ wa-
ter combined with 4 silica. This exceeds 1·125
by 0·1663, which is rather more than $\frac{1}{7}$th of an
atom. This may be considered the greatest a-
mount of the excess which ever remains. I shall
now state the circumstances of the successful ex-
periment.

A quantity of silica obtained, precisely as in

the preceding experiment, after being sufficiently washed was left on the filter till it was dry enough to be moved. It was then placed (still on the filter) in a linen bag, which was suspended at some height above my sand bath, in a temperature of 85°, where it was left for several days, till it ceased to lose weight. By this treatment, the silica became a very white, dry powder, which weighed 38·4 grains. Being exposed to a red heat, the weight was reduced to 29·97 grains; so that it had been a compound of 29·97 silica, and 8·43 water. Now, 29·97 : 8·43 : : 4 : 1·125 = the water united to 4 of silica. Here we see that the silica and water were united in the true atomic proportions.   And this is an experiment which I have often made successfully.

2. If the silicated potash, or soda, be digested in a sufficient quantity of water, we may obtain a complete solution, which is neither precipitated by acids nor alkalies.   When this solution is concentrated by evaporation, it assumes the form of a transparent, colourless, tremulous jelly, consisting of silica and water, united together in the form of a hydrate.   If we throw this jelly upon the filter, and wash it with hot water till the alkali be completely removed, the silica remains in the state of a matter, so transparent and colourless, as scarce to be perceptible at first.   If we allow this jelly to dry on the filter till it ceases to feel wet, or to moisten bibulous paper, it still

retains a certain degree of transparency, and is not quite destitute of its gelatinous form. In this state it is a compound of

| 1 atom silica | . | 2 |
| 13 atoms water | . | 14·625 |

16·625

So that in this hydrate, though apparently quite dry and solid, more than $\frac{6}{7}$ths of the whole weight is water.

3. If we allow this solid mass of jelly to dry Hydrate of in the open air, without breaking it in pieces, it silica. gradually assumes a yellowish colour, somewhat similar to that of gum-arabic ; and even after an interval of several years, it is still semi-transparent. In this state it is very brittle, but hard, and breaks with a conchoidal fracture. It has a certain resemblance to common flint ; or rather it may be stated as an intermediate looking substance between flint and calcedony. This hydrate of silica, when successfully prepared, is composed of

| 1 atom silica | . | 2 |
| 1 atom water | . | 1·125 |

I have succeeded in preparing this hydrate, only by leaving it for a very long time (in general several years) in a warm and dry room. I shall state the result of an experiment made during the summer of 1823. A quantity of gelatinous

silica, prepared in the way just described, was left, unbroken, on the filter, for six weeks. Its weight was 13·63 grains. Being exposed to a red heat, it lost 5·13 grains; consequently, the anhydrous silica amounted to 8·5 grains, and the water to 5·13. Now, 8·5 : 5·13 : : 2 : 1·207 = water united to 2 silica. This exceeds the atomic proportion by about $\frac{1}{14}$th of an atom.

Other hydrates. 4. There are several other hydrates of silica, besides the three which I have just described. I have formed a hydrate, composed of

$$
\begin{aligned}
3 \text{ atoms silica} &= 6 \\
1 \text{ atom water} &= 1\text{·}125 \\
\hline
& 7\text{·}125
\end{aligned}
$$

I have obtained another, composed of

$$
\begin{aligned}
4 \text{ atoms silica} &= 8 \\
3 \text{ atoms water} &= 3\text{·}375 \\
\hline
& 11\text{·}375
\end{aligned}
$$

This great variety of hydrates renders it always indispensable in the chemical analysis of minerals to expose the silica to a red heat, in order to be sure of its true weight.

Conclusions. V. The details in this section have been somewhat tedious; but they were necessary to establish the true atomic weight of silica. Let us recapitulate the different results obtained.

1. Berzelius has concluded from his analysis of silicated iron, that the atomic weight of silica is 1·988. But the mean of the experiments of Berzelius and Stromeyer gives us for its atomic weight 1·9966.

2. The mean of the analysis of eight native silicates of different kinds gives us the atomic weight of silica 2·00245.

3. My decomposition of carbonate of potash by silica gives for its atomic weight 1·99758.

4. The analysis of the hydrates of silica gives its atomic weight exactly 2.

Even if we were to strike a mean from all these different estimations, the weight of an atom of silica would not deviate so much as $\frac{1}{1000}$th part from 2. But this method of proceeding would not be quite proper. The experiments on the hydrates being most easily made, and most susceptible of precise results, should have the greater effect in fixing our notions on the subject. Now, the hydrates make the atomic weight of silica precisely 2. Next to the hydrates, the greatest confidence seems due to the mean deduced from the analysis of the eight silicates; now, this mean differs from 2 by only $\frac{1}{1000}$th part. Upon the whole I am persuaded, that no unprejudiced person who peruses the preceding details can have any doubt that the true atomic weight of silica is 2.

Silica is a compound of silicon and oxygen.

N 3

Now, from the experiments of Berzelius, mentioned in the beginning of this section, it is clear that the weights of the silicon and oxygen are nearly equal. Since the atomic weight of silica is 2, and of oxygen 1, it is evident that the atomic weight of silicon is also 1. The true composition of silica is therefore

<div align="center">

1 atom silicon   1

1 atom oxygen   1

——

2

</div>

SECT. IV.

OF THE ATOMIC WEIGHT OF PHOSPHORUS.

PHOSPHORUS enters into chemical combinations both with hydrogen and oxygen; with the former it constitutes only gaseous, with the latter, only solid compounds. Its combinations with oxygen are *phosphorous* and *phosphoric acids*—combinations of great importance in the animal, and not without interest in the mineral kingdom. Let us first investigate the atomic weight of phosphoric acid. It will then be easy to determine the composition of phosphorous acid.

Atomic weight of phosphoric acid

1. Phosphoric acid forms soluble and crystallizable salts with the alkalies. Of these none is better known than phosphate of soda, which being employed as a medicine, is prepared by

trading chemists, and kept for sale in apothe-
caries' shops.

It crystallizes in rhomboids, has a cooling and
somewhat bitter taste, and effloresces when kept
in a dry atmosphere. I have met with this salt
consisting of 11 atoms, and likewise of 12 atoms
of water combined with one integrant particle
of anhydrous phosphate of soda. By far the
most common proportion of water, however, is
12 atoms. This difference in constitution, as
far as the aqueous part is concerned, probably
depends upon the way in which it has been kept.
It very speedily effloresces when exposed to the
air. Now, when got from the shops, we often
perceive white effloresced spots scattered through
the crystals. It is in such cases that the water
of crystallization is sometimes reduced to 11
atoms. We can never depend upon the water
of crystallization, unless the salt be quite trans-
parent. I think it best to make it anhydrous
by heating it red hot, and keeping it for some
time in a state of fusion in a platinum crucible.

7·5 grains of anhydrous phosphate of soda,
and 20·75 grains of crystallized nitrate of lead,
were dissolved in separate portions of distilled
water, care being taken not to employ more
water than was sufficient to dissolve the salts
completely. These two solutions being mixed
together, a double decomposition took place;
phosphate of lead precipitated in the state of a

white insoluble powder, while a transparent
colourless liquid remained, holding nitrate of
soda in solution.   A drop of this liquid was put
into a watch glass, and mixed with a drop of
solution of sulphate of soda.   No precipitation
or opalescence took place, showing that the li-
quid contained no sensible quantity of lead.
Another drop of the same liquid being put into
another watch glass, was tested in the same
manner with nitrate of lead, without being in
the least affected, showing the absence of any
sensible quantity of phosphoric acid.   This ex-
periment was repeated several times with exact-
ly the same result.

From the preceding experiment it is obvious,
that the oxide of lead in 20·75 grains of nitrate
of lead, just neutralizes the phosphoric acid in 7·5
grains of anhydrous phosphate of soda.   In like
manner, the nitric acid of the former salt just
neutralizes the soda of the latter.   But 20·75
grains of nitrate of lead are composed of

Nitric acid .	6·75
Protoxide of lead	14
	20·75

Numbers which are equivalent to the atomic
weights of nitric acid and protoxide of lead.

Fourteen grains of protoxide of lead require
for saturation, a quantity of phosphoric acid,
equivalent to an atom ; 6·75 grains of nitric

acid require exactly 4 grains of soda, which will be shown afterwards to be equivalent to an atom.

7·5 grains of anhydrous phosphate of soda, then, contain just 4 grains of soda. The remaining 3·5 grains must be the phosphoric acid of the salt. Thus, it appears, that anhydrou phosphate of soda is composed of

<div style="text-align:center">

Phosphoric acid 3·5
Soda . . 4·0
—
7·5

</div>

3·5 of phosphoric acid just saturate 4 of soda, Shown to be 3·5. and 14 of protoxide of lead, each of which numbers, represents the atomic weight of the respective bases ; consequently, 3·5 is the atomic weight of phosphoric acid.

2. Many attempts have been made by chemists to determine the composition of phosphoric acid by the rapid combustion of phosphorus. For when phosphorus burns with flame, it unites with the oxygen of the atmosphere, and is converted into phosphoric acid. Now, as both phosphorus and phosphoric acid are solids, it appears at first sight easy to determine the quantity of oxygen with which the phosphorus has combined, merely by weighing the phosphoric acid produced. But in reality, this method, though apparently easy, is not susceptible of perfect accuracy. Phosphorus can scarcely be obtained

in a state of complete purity, and we have no
means of appreciating the proportion of impuri-
ties with which it is contaminated. It can hardly
be burned completely in close vessels, always
leaving behind an orange coloured matter, which
deliquesces in the air, and is gradually acidified
spontaneously. It would be needless to relate
the experiments made in succession in this way,
by Lavoisier, Rose, myself, Dulong and Berze-
lius. Sir Humphrey Davy had the sagacity to
obviate some of the difficulties that had proved
most perplexing to his predecessors, and his ex-
periments came by far the nearest to the truth,
though they did not altogether reach it. It may
be worth while, therefore, to mention the result
of his researches on this difficult subject.

He inclosed the phosphorus in a separate tray,
which he introduced into the belly of a glass re-
tort ; by this contrivance, he was enabled to
give a stronger and longer continued heat to
the phosphorus. He found that 100 parts of
phosphorus, when converted into phosphoric
acid, unite with 135 parts of oxygen. Let us
deduce the atomic weight of phosphoric acid
from this composition.

It is obvious, that this acid is a compound of
one atom of phosphorus with one or more atoms
of oxygen. Were the quantity of oxygen only
one atom, the atomic weight of phosphoric acid
would be only 1·74. For 135 (the oxygen in

the acid) : 100 (the phosphorus in the acid) : : 1 (an atom of oxygen) : 0·74074 = atomic weight of phosphorus. But we have just seen that its true atomic weight is 3·5.

Let us suppose the quantity of oxygen to be two atoms. This would make the atomic weight of phosphoric acid 3·481. For 135 : 100 : : 2 : 1·4815 = atomic weight of phosphorus.

It appears from this, that phosphoric acid is a compound of two atoms oxygen, and one atom phosphorus; and that the atomic weight of phosphorus, according to the result of Davy's experiments, is 1·4815. But we have seen that phosphoric acid weighs 3·5; therefore, the atom of phosphorus must in fact weigh 1·5, or nearly 2 per cent. more than results from Davy's synthetic experiment. Hence, 100 phosphorus must combine with only 133⅓ of oxygen, to form phosphoric acid ; for 133⅓ : 100 : : 2 : 1·5. That this is the true composition of the acid will appear from the following experiments.

3. Phosphorus and hydrogen combine in two proportions, and form two gaseous compounds called *phosphuretted hydrogen*, and *bihydroguret of phosphorus ;* the former of which was first distinguished as a peculiar substance by M. Gengembre, the latter by Sir Humphrey Davy.

(1.) Phosphuretted hydrogen gas may be obtained pure, by putting fresh phosphuret of lime into a small retort, filling the retort with water,

and plunging its beak into a trough containing re-
cently boiled water, or water in which some deut-
oxide of azote has been agitated ; the gas is extri-
cated with considerable rapidity ; it is colourless,
has a smell somewhat similar to that of garlic, and
takes fire spontaneously when it comes in con-
tact with common air.   Water absorbs about 5
per cent. of its volume of it.   The specific gra-
vity of this gas from a mean of some very care-
ful experiments made in my laboratory, is
0·902735.   But I have elsewhere shown that its
true specific gravity is 0·90277 ;* which exceeds
the experimental result by an almost inapprecia-
ble quantity.

When phosphorus is heated in hydrogen gas,
a portion of phosphuretted hydrogen gas is
formed ; but the volume of the original gas is
not increased.   It is obvious from this, that a
volume of phosphuretted hydrogen gas contains
just a volume of hydrogen gas.   Hence, if from
the specific gravity of phosphuretted hydrogen
gas we subtract the specific gravity of hydrogen
gas, the remainder will represent the weight of
phosphorus united to a volume of hydrogen gas.

Sp. gr. of phosphuretted hydrogen gas	0·90277
——————————— hydrogen gas	0·06944
Phosphorus . . . . =	0·83333

* Annals of Philosophy, XVI. 262.

Thus it appears, that phosphuretted hydrogen gas is a compound of

| Hydrogen | 0·0694 | or | 0·125 |
| Phosphorus | 0·8333 | - | 1·5 |

But 0·125 represents the weight of an atom of hydrogen, and 1·5 must be the weight of an atom of phosphorus. The gas is obviously a compound of one atom hydrogen, and one atom phosphorus.

If we mix together one volume of phosphuretted hydrogen gas with either one volume or 1·5 volume of oxygen gas, combustion takes place, and the whole gaseous mixture disappears, being in the first case condensed into water and phosphorous acid, and in the second, into water and phosphoric acid. Let us analyze these combustions ; they will give us the composition of both phosphorous and phosphoric acids.

A volume of phosphuretted hydrogen gas may be considered as composed of one volume hydrogen gas, and one volume phosphorus vapour condensed into one volume—and a volume both of hydrogen gas and of phosphorus vapour is equivalent to an atom. The volume of hydrogen, in order to be converted into water, requires half a volume of oxygen gas. It is obvious from this, that phosphorous acid is a compound of one volume phosphorus vapour and half a volume of oxygen gas ; and phosphoric

acid of one volume phosphorus vapour and one volume oxygen gas. But one volume of phosphorus vapour, and half a volume of oxygen gas being each equivalent to an atom, it is obvious, that the constitution of these two acids is the following:

<div style="margin-left: 2em;">Atom of phosphorous acid.</div>

1. PHOSPHOROUS ACID.

1 atom phosphorus $= 1\cdot5$
1 atom oxygen   . $= 1$

$\overline{}$

         $2\cdot5 =$ atomic weight of acid.

2. PHOSPHORIC ACID.

1 atom phosphorus $= 1\cdot5$
2 atoms oxygen   . $= 2$

$\overline{}$

         $3\cdot5 =$ atomic weight of acid.

Thus an atom of phosphorous acid weighs $2\cdot5$, and an atom of phosphoric acid $3\cdot5$, which is precisely the weight deduced in the beginning of this section, from the analysis of phosphate of soda.

<div style="margin-left: 2em;">Subphosphuretted hydrogen gas.</div>

When this gas is allowed to stand for some days over mercury or water, it undergoes no sensible alteration in its volume, but deposites one-fourth of its phosphorus. When thus altered, it does not catch fire when mixed with common air, or oxygen gas; but combustion may be immediately induced, by letting up into it a little deutoxide of azote. When sulphur is sublimed

16

in it, no alteration takes place in its volume. For complete combustion, 1 volume of this altered gas requires 1·25 volume of oxygen gas. By the combustion, it is converted into water and phosphoric acid. Complete combustion cannot be induced with any smaller volume of oxygen gas. When we pass an electric spark through a mixture of 1 volume of the gas, and 0·75 volume of oxygen gas, a detonation takes place ; but the residual gas occupies very nearly 1 volume. On adding 0·5 volume of oxygen gas, a new combustion takes place, and the whole gaseous matter disappears. It would seem that, by the first combustion, the whole phosphorus is consumed, leaving the hydrogen very nearly pure. It is obvious, that half a volume of the oxygen gas was employed in converting the hydrogen of the gas into water. The remaining 0·75 volume of oxygen converted the phosphorus vapour into phosphoric acid ; but phosphorus requires its own volume of oxygen gas for this purpose. From this it is evident that the altered gas is a compound of

1 volume hydrogen gas	. .	0·0694
0·75 volume phosphorus vapour	.	0·6250
		0·6944

Hence it contains just nine times as much phosphorus as hydrogen, and its specific gravity is

0·6944, or ten times that of hydrogen; and its atomic weight is 1·25. We may distinguish this altered gas by the name of *sub-phosphuretted hydrogen*.

Bihydro-guret of phosphorus.

(2.) Bihydroguret of phosphorus was obtained by Davy, by heating crystallized phosphorous acid. When sulphur is heated in it, the volume of the gas is just doubled, and it is converted into sulphuretted hydrogen gas. Now, it will be shown in the next section, that sulphuretted hydrogen gas contains just its own volume of hydrogen gas. Hence it is obvious, that bihydroguret of phosphorus contains twice its volume of hydrogen gas.

This gas has a similar smell to phosphuretted hydrogen gas. It does not burn spontaneously when mixed with common air, or hydrogen gas; but combustion takes place readily, if an electric spark be passed through the mixture. For complete combustion, 1 volume of it must be mixed with 1·5, or with 2 volumes of oxygen gas. The gases disappear; and, with the smaller proportion of oxygen gas, we obtain phosphorous acid, with the greater phosphoric acid. From these facts it is obvious that the gas is a compound of

2 volumes hydrogen gas
1 volume phosphorus vapour } condensed into one volume.

Its specific gravity, therefore, must be the sum of twice the specific gravity of hydrogen

gas and the specific gravity of phosphorus vapour added together, or 0·9722. For,

Twice sp. gr. of hydrogen gas   = 0·1388
Sp. gr. of phosphorus vapour   = 0·8333

                            0·9722 = sp. gr. of the gas.

Bihydroguret of phosphorus is the fourth gas which we have met with, possessed of this specific gravity. The other three are azotic gas, carbonic oxide, and olefiant gas.

Thus it appears, that the composition and atomic weights of the various compounds of phosphorus with oxygen and hydrogen are as follows :

	PHOSPHORUS.	OXYGEN.	ATOMIC WEIGHT.
1. Phosphorous acid .	1 atom	+ 1 atom	2·5
2. Phosphoric acid .	1	+ 2	3·5
		HYDROGEN,	
3. Phosphuretted hydr.	1	+ 1 atom	1·625
4. Bihydroguret of phosph.	1	+ 2	1·75
5. Subphosphuretted hydr.	0·75	+ 1	1·25

Bihydroguret of phosphorus has both the specific gravity and atomic weight of azotic gas.

SECT. V.

OF THE ATOMIC WEIGHT OF SULPHUR.

SULPHUR forms three acid compounds with oxygen, distinguished by the names of *hyposul-*

phurous acid, sulphurous acid, and *sulphuric acid.*
Let us, in the first place, determine the atomic
weight of sulphuric acid, which is the most im-
portant of these compounds.

Atomic
weight of
sulphuric
acid.

I. 1. Sulphate of potash is a salt which usu-
ally crystallizes in pyramidal dodecahedrons,
though its primary form is an oblique four sided
prism; and it contains no water of crystalliza-
tion. 11 grains of sulphate of potash, and 13·25
grains of chloride of barium, were dissolved in
separate portions of distilled water : the two solu-
tions being mixed, a double decomposition took
place ; and sulphate of barytes, being insoluble,
immediately precipitated to the bottom. The
residual liquid, which was transparent and co-
lourless, was tested with sulphate of soda, and
with muriate of barytes ; but by neither of these
reagents was it in the least affected—showing
that it contained no sensible quantity either of
barytes or sulphuric acid.

From this experiment it follows, that the sul-
phuric acid in 11 grains of sulphate of potash
just saturates the barytes from 13·25 grains of
chloride of barium ; but the barytes from that
quantity of chloride is just 9·75 grains, which is
equivalent to the atomic weight of barytes.
When the sulphate of barytes formed in the pre-
ceding experiment was washed, dried, and ex-
posed to a red heat, its weight was exactly
14·75 grains; and of this weight, 9·75 grains

were barytes. Hence sulphate of barytes is com-
posed of

              Barytes   .   .   9·75
              Sulphuric acid .   5
                               ─────
                                 14·75

The salt being neutral, and 9·75 representing an
atom of barytes, 5 must represent the atomic
weight of sulphuric acid.

The potash in 11 grains of sulphate of potash
must weigh 6, which is equivalent to an atom ;
for it just saturates 4·625 grains of muriatic acid,
which is equivalent to an atom ; and we have
seen that the sulphuric acid in it weighs 5.
Consequently, sulphate of potash is a compound
of

          Sulphuric acid   .   5 = 1 atom.
          Potash   .   .   6 = 1 atom.
                             ──
                             11

2. Sulphuric acid is manufactured in this coun- Method of
try, by the combustion of sulphur, which con- manufac-
verts it into sulphurous acid gas. This gas passes
into large leaden chambers, the bottom of which
is covered with about 6 inches of water; to-
gether with the sulphurous acid gas, a quantity
of the vapour of nitrous acid passes into the
leaden chamber. These two acids have the pro-
perty of uniting together; and they form minute

crystals, which fall into the water at the bottom of the chamber. The moment they come in contact with that liquid, a decomposition takes place;—the sulphurous acid is converted into sulphuric acid, and the nitrous acid into deutoxide of azote. This last substance makes its escape in the gaseous state; but immediately comes in contact with the common air of the chamber, and is converted into nitrous acid, which, uniting with a new dose of sulphurous acid, falls again into the water. These decompositions and new formations continually go on as long as the air of the chamber contains oxygen gas and sulphurous acid. The water, when sufficiently impregnated with sulphuric acid, is drawn off from the bottom of the chamber, and concentrated as far as possible in leaden boilers. It is then put into glass or platinum retorts, and kept in a heat of at least 600°, till as much concentrated as possible.*

Composition of the acid of commerce.   Acid, thus prepared, is a clear, transparent, colourless liquid like water, with a certain degree of consistency, so as to adhere to the sides of a

---

* The acidulous water, when taken out of the leaden chambers, has a specific gravity of about 1·22. It is a compound of about 1 atom sulphuric acid, and 15 atoms water. It is concentrated in the leaden boilers till its specific gravity becomes 1·75. In this state it is nearly a compound of 1 atom acid, and 2 atoms water; the boiling point of acid of this strength is 435°. Beyond this strength it cannot be conveniently carried in leaden vessels, because its corroding action on the lead increases at a great rate as the boiling point rises.

phial like oil. When quite free from all impurity, its specific gravity (when as strong as possible) is 1·847 :—if it be heavier than this, it is contaminated with lead. The liquid, in this state, is a compound of 1 atom acid and 1 atom water. Now

$$
\begin{array}{r}
1 \text{ atom acid } = 5 \\
1 \text{ atom water} = 1{\cdot}125 \\
\hline
6{\cdot}125
\end{array}
$$

So that 6·125 parts of it contain 1·125 water and 5 of pure acid. Acid of this strength requires the highest temperature to boil it. Mr. Dalton states that its boiling temperature is 620°—but it is extremely difficult to determine such high temperatures with accuracy. I have satisfied myself, however, that the boiling point of this acid is above 600°.

If to 6·125 parts of this acid we add 1·125 parts of water, so as to form a compound of 1 atom acid and 2 atoms water, we obtain a liquid of the specific gravity of 1·78. Acid of this strength possesses the remarkable property of freezing at a higher temperature than acid of any other strength—its freezing point, according to the experiments of Mr. Keir, being 45°. Its boiling point, according to Mr. Dalton, is 435°.

3. Protosulphate of iron is a salt composed of

$$\begin{array}{ll}
\text{1 atom sulphuric acid} & = 5 \\
\text{1 atom protoxide of iron} & = 4\cdot5 \\
\text{7 atoms water} \qquad . & = 7\cdot875 \\
\hline
& 17\cdot375
\end{array}$$

So that an integrant particle of it weighs 17·375, and 4 integrant particles weigh 69·5 parts. If we expose 69·5 parts of this salt to a sufficient heat, it becomes white and loses 30·375 parts of water. Now, the whole water contained in 69·5 parts of this salt is obviously 31·5 parts; consequently, there still remains 1·125 parts of water united to the salt; and the salt thus heated is a compound of

$$\begin{array}{ll}
\text{4 atoms sulphuric acid} & = 20 \\
\text{4 atoms protoxide of iron} & = 18 \\
\text{1 atom water} \quad . \quad . & = 1\cdot125 \\
\hline
& 39\cdot125
\end{array}$$

When these 39·125 parts are put into an earthen-ware retort, and exposed to a strong heat, one half of the sulphuric acid, amounting to 10 parts, is decomposed into 8 parts of sulphurous acid, which flies off and is dissipated, and 2 parts of oxygen, which, uniting to the 18 parts of protoxide of iron, convert them into 20 parts of peroxide of iron. The remaining 10 parts of the sulphuric acid pass over into the receiver united to the 1·125 of water.

This is the process followed at Nordhausen in

Germany, by which the fuming sulphuric acid, which answers so well for dissolving indigo, is obtained. Its colour is always dark, and it is opaque. I do not know the reason of this opacity, but suspect the presence of some selenium in it, from some phenomena which I have observed. The specific gravity of this acid is 1·896. I find it, by a careful analysis, to be a compound of 2 atoms acid, and 1 atom water. Now

$$
\begin{array}{ll}
\text{2 atoms acid} & = 10 \\
\text{1 atom water} & = 1\text{·}125 \\
\hline
& 11\text{·}125
\end{array}
$$

So that an integrant particle of it weighs 11·125, and contains 1·125 parts water and 10 parts of pure acid.

4. When this acid is exposed to the air, it smokes, in consequence of its great avidity for moisture. It is much more volatile than the sulphuric acid of this country. When heated in a glass retort to which a receiver is luted, and surrounded with a mixture of snow and salt, one half of the acid passes over in a solid state, forming a snow white solid acid, like asbestus in appearance. What remains in the retort is a compound of 1 atom acid and 1 atom water—or it is precisely similar to the acid of this country. I have not been able to determine the specific gravity of this acid : its avidity for water is so great

Pure dry sulphuric acid.

that it smokes violently when exposed to the air, and is dissipated so speedily that it cannot be weighed. But, by dropping a piece of it into a known weight of water, and then determining the increase of the weight of the liquid, I was enabled (by throwing down the acid by means of muriate of barytes) to show that, when solid, it consists of pure acid, totally destitute of water. I have obtained it crystallized in flat rhomboids, quite transparent, the large faces deviating only a few degrees from 90°.

It is converted into vapour at a temperature which must be low, though I have not determined it with accuracy. The specific gravity of this vapour is 2·7777, that of common air being unity. One volume of it is capable of uniting with, and condensing, just 2 volumes of ammoniacal gas. A volume, therefore, is equivalent to an atom of the acid, for 2 volumes of ammoniacal gas are just equivalent to 1 atom of ammonia.

II. Let us now determine the atomic weight of *sulphurous acid.*

Composition of sulphurous acid.

1. This acid contains less oxygen than sulphuric ; for when the alkaline sulphites are dissolved in water, they are gradually changed into sulphates, while at the same time a quantity of oxygen gas is absorbed. Its atomic weight, then, is less than that of sulphuric acid.

2. Sulphurous acid is a gaseous compound,

which may be easily formed by burning sulphur in oxygen gas. Now, when we convert oxygen gas into sulphurous acid by this process, we do not produce any alteration in its volume, but we produce an increase in its specific gravity. Hence, it is obvious that, if from the specific gravity of sulphurous acid gas we subtract the specific gravity of oxygen gas, the remainder will give us the weight of sulphur united to a volume of oxygen gas. I have shown in a paper on the Specific Gravity of the Gases, inserted in the 16th volume of the Annals of Philosophy, (p. 256) that the true specific gravity of sulphurous acid is 2·2222̇; and we have seen that oxygen gas weighs 1·1111̇. Hence, it is obvious that sulphurous acid is composed of

$$
\begin{array}{ll}
\text{Sulphur} & 1\cdot1111\dot{} \\
\text{Oxygen} & 1\cdot1111\dot{} \\
\hline
& 2\cdot2222\dot{}
\end{array}
$$

Or of equal weights of each constituent. We may consider sulphurous acid gas as a compound of

1 volume oxygen gas $\left.\right\}$ condensed into 1 volume.
1 volume sulphur vapour

3. Sulphuretted hydrogen gas may be obtained by mixing together sulphuret of antimony and muriatic acid in a small retort, and applying the heat of a lamp. The gas may be collected over

Composition of sulphuretted hydrogen.

mercury. This gas has a fetid odour, and a
specific gravity of 1·1805 : it burns with a blue
flame ; and 1 volume of it, for complete combus-
tion, requires 1½ volume of oxygen gas. Water
is formed, and a quantity of sulphurous acid gas,
just equal to the volume of sulphuretted hydro-
gen gas, consumed.

This combustion is sufficient to enable us to
determine the composition of sulphuretted hy-
drogen gas. It may be proper to mention, in the
first place, that when sulphur is heated in hydro-
gen gas, the gas is partly converted into sul-
phuretted hydrogen ; but no alteration whatever
takes place in its volume. From this it is evi-
dent, that a volume of sulphuretted hydrogen
gas contains just a volume of hydrogen gas.

This being understood, let us proceed to ana-
lyze the composition of this gas from its combus-
tion with oxygen. One volume of it requires
1½ volume of oxygen gas, and forms water and a
volume of sulphurous acid gas. The half vol-
ume of oxygen gas went to the formation of wa-
ter and united with a volume of hydrogen gas :
the whole volume of oxygen must have gone to
the formation of sulphurous acid, and it must
have combined with a volume of sulphur vapour.

Thus, we see that sulphuretted hydrogen gas
is a compound of

  1 volume hydrogen gas } condensed into 1 volume.
  1 volume sulphur vapour

And we obtain its composition by stating the specific gravity of each constituent, for it must be a compound of

Hydrogen	0·0694	or	0·125
Sulphur	1·1111	-	2·000
	1·1805		2·125

No doubt, it consists of an atom of hydrogen united to an atom of sulphur;—0·125 is the weight of an atom of hydrogen, and 2 must, therefore, represent the atomic weight of sulphur.

Atom of sulphur.

3. We see from the composition of sulphuretted hydrogen gas, that a volume of sulphur vapour is equivalent to an atom, and a volume of oxygen gas is equivalent to 2 atoms. Now, sulphurous acid gas is a compound of 1 volume sulphur vapour and 1 volume oxygen gas ;—it is, therefore, a compound of 1 atom sulphur and 2 atoms oxygen. And, since an atom of sulphur weighs 2, the atomic weight of sulphurous acid is 4.

Atomic weight of sulphurous acid.

III. It would be easy to show, by a similar process of reasoning, that an atom of hyposulphurous acid weighs 3.

Thus, the atomic weights of sulphur and its acid compounds are as follows ·

WEIGHT OF ATOM.

Sulphur   2

Hyposulphurous acid   .   3
Sulphurous acid   .   .   4
Sulphuric acid   .   .   5
Sulphuretted hydrogen   .   2·125

	SULPHUR.	OXYGEN.
Hyposulphurous acid is a compound of	1 atom	+ 1 atom
Sulphurous	1	+ 2
Sulphuric	1	+ 3

		HYDROGEN.
Sulphuretted hydrogen . .	1	+ 1

The hyposulphuric acid of Gay-Lussac is formed
by the union of an integrant particle of sulphu-
rous and sulphuric acids with each other; conse-
quently, its atomic weight is 9; and it is a com-
pound of 2 atoms sulphur with 5 atoms oxy-
gen.

SECT. VI.

OF THE ATOMIC WEIGHT OF SELENIUM.

SELENIUM is so difficult to procure, that I have
been obliged to confine my experiments to very
minute quantities; not having had more in my
possession than about 40 grains, which did not
put it in my power to obtain satisfactory results.
For the investigation of its atomic weight, there-
fore, I must rely almost entirely upon the exper-
iments of Berzelius. Fortunately, his experi-

ments in general are made with so much precision that they furnish very good approximations.

Selenium forms with oxygen an acid, which has been distinguished by the name of *selenic acid*, and with hydrogen a gaseous compound, which has been called *selenietted hydrogen gas*.

1. Selenic acid combines with most bases in two proportions, and with a considerable number in three proportions, forming with them, salts distinguished by the names of *seleniates*, *biseleniates*, and *quadroseleniates*. Two seleniates have been analyzed by Berzelius : namely, *seleniate of soda*, and *seleniate of barytes*. Let us deduce from each of these analyses, the atomic weight of selenic acid.

(1.) Seleniate of soda does not crystallize readily, though it may be made to deposite crystalline grains. The biseleniate crystallizes more easily, and assumes the form of needles. Berzelius rendered a given weight of each of these salts anhydrous, mixed each with twice its weight of sal-ammoniac, and applied a subliming heat ; the selenic acid was sublimed and decomposed, and nothing remained but the base of each salt united to muriatic acid, or rather, in the state of chloride of sodium. 100 parts of seleniate of soda furnished $66\frac{2}{3}$ parts of common salt, equivalent to $35 \cdot 55$ soda. Hence, this salt is composed of

Selenic acid   64·44   or   7·25
Soda   35·55   -   4
                 ————
                 100

100 parts of biseleniate (anhydrous, but deprived also of a little of the acid) when treated in the same way, yielded 41⅔ parts of common salt, equivalent to 22·22 parts of soda.* Hence, the constituents of the salt are

Selenic acid   77·77   or   14
Soda   22·22   -   4
                 ————   ——
                 100   18

It is obvious that the first of these two salts contains one atom, and the second two atoms of selenic acid, united to an atom of soda. But the atomic weight of selenic acid resulting from the two analyses does not quite agree; according to the first analysis it is 7·25 ; according to the second 7.

And seleni-ate of ba-rytes.   (2.) Seleniate of barytes is insoluble in water, and can only be obtained in the state of a white powder. But biseleniate of barytes is soluble, and probably contains water of crystallization.

Two parts of anhydrous seleniate of barytes dissolved in muriatic acid, and precipitated by sulphuric acid, furnished 1·765 parts of sulphate of barytes equivalent to 1·1657 parts barytes. Hence, the salt is composed of

* Ann. de Chim. et de Phys. IX. 258.

Selenic acid   0·8343   or   6·9782
Barytes   1·1657   -   9·75

               2·0000

1271 parts of anhydrous biseleniate of barytes treated in the same way, yielded 785 parts of sulphate of barytes, equivalent to 518·9 parts of barytes. Hence, biseleniate is composed of

Selenic acid   752·1   or   14·132
Barytes   518·9   -   9·75

            1271·0 *

According to the result of the analysis of seleniate of barytes, the atomic weight of selenic acid is 6·9782; according to the analysis of the biseleniate, it is 7·066.

Though these results do not accurately correspond with each other, they, upon the whole, concur in rendering it very probable that the true atomic weight of selenic acid is 7. I consider the analysis of seleniate of barytes as susceptible of greater precision than that of the analysis of seleniate of soda. Now, the atomic weight of selenic acid, deduced from the mean of the analysis of seleniate and biseleniate of barytes, is 7·02211, which comes extremely near to 7.

2. I may state here a few attempts which I made to determine the atomic weight of selenic Attempts to determine the atom of selenic acid.

* Ann. de Chim. et de Phys. IX. 262.

acid, though they were not attended with the success which I had anticipated. 21·63 grains of crystallized selenic acid heated till they began to sublime, and therefore considered as anhydrous, were dissolved in water, and crystallized carbonate of soda in powder was added by small quantities at a time, till the liquid began to give a violet colour to cudbear paper. 43·43 grains of the carbonate were necessary to produce this effect. The liquid was now evaporated to dryness, and the dry residuum exposed to a temperature of about 600° on the sand bath, till it ceased to give out moisture. It weighed 30·4 grains. As it contained an excess of soda, the salt was again dissolved in water, and a few drops of muriatic acid being added, the whole was again evaporated to dryness. It now weighed 32⅔ grains, and, consequently, had increased in weight 2·266 grains.

This increase of weight was occasioned by the union of the muriatic acid with the surplus soda. No effervescence could be perceived, so that I had no evidence that any carbonic acid had been driven off. The salt having been exposed to heat, it is obvious, that the common salt was converted into chloride of sodium. The simplest way of determining its quantity, will be to consider it a compound of 3·5 muriatic acid and 4 soda. Now, 3·5 : 4 : : 2·266 (the augmentation of weight) : 2·59 = soda in the common salt. The common

salt then amounted to 4·856 grains; this subtract-
ed from 32·666 leaves 27·816 grains of biseleniate
of soda. Now, it contains 21·63 grains of selenic
acid. Hence, biseleniate of soda is composed of

Selenic acid	21·63	or	14
Soda	6·18	-	4
	27·61		

This experiment gave therefore 7 for the atomic
weight of selenic acid. But I consider this as
merely an accidental circumstance, because, on
repeating it a second time, the biseleniate was
found a compound of

Selenic acid	12·353
Soda	4

This would reduce the atomic weight of selenic
acid to 6·176. But this mode of experimenting
is not susceptible of the requisite degree of pre-
cision for deciding so delicate a point. Every
time the salt was evaporated to dryness, a little
selenium was separated, which prevented the
quantity of salt from remaining quite perma-
nent.

I attempted to determine the atomic weight
of selenic acid, by precipitating it from seleniate
of soda, by means of muriate of barytes. But
the precipitation produced by this salt is only
partial—a portion of selenic acid remaining in
solution even after a considerable excess of
muriate of barytes had been added.

Foiled in all these attempts, it would have been requisite in order to determine the atomic weight of this acid, to have had recourse to the direct analysis of some of the seleniates. But, besides that my stock of acid was exhausted, I had no reason to expect more accurate results from such an analysis, than those already obtained by Berzelius.

Upon the whole, I have little hesitation in fixing upon 7 as the true atomic weight of this acid.

2. The experiments made by Berzelius on selenietted hydrogen gas, will enable us easily to determine the atomic weight of selenium, from which the composition of selenic acid may be directly deduced.

This gas is colourless, has a smell somewhat similar to that of sulphuretted hydrogen gas, is very soluble in water, reddens vegetable blues, and precipitates metals from their solutions. To ascertain its constituents, Berzelius passed a current of it through a solution of acetate of silver; seleniet of silver was precipitated, which weighed when dry 1·888 parts. This seleniet he dissolved in nitric acid, and threw the solution, while boiling hot, into muriatic acid. By this contrivance, the seleniet was decomposed, and the silver thrown down in the state of chloride of silver. The chloride thus obtained, weighed 1·844. Now, chloride of silver is a

compound of 1 atom chlorine = 4·5, and 1 atom
silver = 13·75 ;—so that 18·25 grains of it con-
tain 13·75 grains of silver : consequently, 1·844
parts of this chloride must consist of

Chlorine	0·4546
Silver	1·3894
	1·8440

Now, this 1·3894 of silver constituted one of
the constituents of the 1·888 parts of seleniet of
silver ;—the only other constituent was the se-
lenium : consequently, seleniet of silver is com-
posed of

Silver	1·3894	or	13·75
Selenium	0·4986	-	4·9343
	1·8880		

13·75 being the atomic weight of silver, 4·9343
must represent the atomic weight of selenium.

The silver in the acetate, through which the
selenietted hydrogen gas was passed, was in the
state of an oxide composed of

1 atom silver	= 13·75
1 atom oxygen	= 1
	14·75

But in the seleniet it was in the metallic state :
the reason was, that the selenietted hydrogen
and the oxide of silver, had mutually decom-

posed each other.   The hydrogen of the gas had
united to the oxygen of the oxide, and formed
water—while the selenium and the silver combin-
ing together, formed the seleniet of that metal.
Seleniet of silvēr being a compound of 1 atom
silver and 1 atom selenium, and water of 1 atom
oxygen and 1 atom hydrogen, it is evident, that
selenietted hydrogen must be a compound of 1
atom hydrogen and 1 atom selenium.   Its con-
stituents, then, from the preceding analysis, must
be

> Selenium   4·9343
> Hydrogen   0·125

But if 7 be the atomic weight of selenic acid, it
is obvious that the atomic weight of selenium
must, in fact, be 5 instead of 4·9343 ; for sele-
nic acid must be a compound of

> 1 atom selenium
> 2 atoms oxygen :

And its weight could not be 7, unless the weight
of selenium were 5.

The true composition of selenietted hydro-
gen, then, must be

> Selenium   5   or 40
> Hydrogen   0·125 -   1
> ——
> 5·125

And the atomic weight of this gas must be
5·125.

It will be shown in the next chapter, that the specific gravity of most of the gases is obtained by multiplying their atomic weights by 0·5555, or half the specific gravity of oxygen gas. Now, $5·125 \times 0·5555 = 2·8522$, which must be the specific gravity of selenietted hydrogen gas.

SECT. VII.

OF THE ATOMIC WEIGHT OF ARSENIC.

ARSENIC has the property of combining with, at least, two proportions of oxygen, and of forming two well known and very poisonous compounds, distinguished by the names of *arsenious* and *arsenic acids*. It unites, likewise, with hydrogen gas, and forms a gaseous compound, the properties of which have been but imperfectly investigated. An examination of the acids of arsenic will enable us to determine the true atomic weight of this substance.

1. Arsenic acid is easily obtained, by dissolv- Atomic weight of ing white arsenic in nitric acid, mixed with a arsenic small quantity of muriatic acid, and evaporating acid. the solution to dryness. It is a white matter, soluble in water ; and the aqueous solution has a very sour taste. With most of the metallic oxides it forms compounds, insoluble in water ; but easily soluble in nitric acid ;—with ammonia,

P 3

potash, and soda, it unites in two proportions, and forms soluble compounds with each. Binarseniates of potash and soda crystallize readily —the former in four sided prisms—the latter in rhomboids. Binarseniate of soda contains rather more than 20 per cent. of water, being composed of

$$
\begin{array}{lll}
\text{2 atoms arsenic acid} & = & 15 \cdot 5 \\
\text{1 atom soda} & = & 4 \cdot 0 \\
\text{5 atoms water} & = & 5 \cdot 625 \\
\hline
& & 25 \cdot 125
\end{array}
$$

as I ascertained by a careful analysis.* When this salt is heated to about 500°, it loses the whole of its water of crystallization, melting at first into a liquid, and then falling down in the state of a white powder. At a red heat this powder melts into a transparent liquid, which is quite anhydrous.

If we add 18 grains of crystallized carbonate of soda to a solution of 25·125 grains of crystals of binarseniate of soda, and agitate the mixture till the whole soda be dissolved, and till the carbonic acid has made its escape, the liquid will be found incapable of reddening vegetable blues. Now, 18 grains of carbonate of soda contain just 4 grains of soda, which is equivalent to an atom.

* Or rather synthesis. The experiment, which is of importance, because it proves the inaccuracy of Berzelius's opinions respecting the composition of this acid, will be given at large in chapter XVIII. of this work.

It is evident, from this, that the rhomboidal crystals contain two atoms of arsenic acid united to 1 atom of soda; for 25·125 grains of them contain just 4 grains of soda, which is equivalent to an atom.

It has been already explained, that nitrate of lead is an anhydrous salt composed of

$$
\begin{array}{ll}
\text{1 atom nitric acid} & = \; 6\cdot75 \\
\text{1 atom protoxide of lead} & = \; 14 \\
\hline
& \;\; 20\cdot75
\end{array}
$$

Consequently, 41·5 grains contain 28 grains of protoxide of lead, which is equivalent to 2 atoms.

19·5 grains of anhydrous binarseniate of soda, and 41·5 grains of crystallized nitrate of lead, were dissolved in separate portions of distilled water. The solutions being mixed, a double decomposition took place; the arsenic acid and protoxide of lead united together, and precipitated in the state of an insoluble arseniate. The clear transparent colourless liquid remaining, after this salt had subsided, reddened vegetable blues; but it was exactly neutralized by the addition of 18 grains of crystallized carbonate of soda. The liquid thus neutralized was tested by sulphate of soda, and likewise by nitrate of lead; but the solutions of neither of these salts produced any sensible alteration; showing the absence both of lead and arsenic acid.

Now, it is evident from this experiment, that 19·5 grains of anhydrous binarseniate of soda contain exactly 4 grains of soda ;—for the 13·5 grains of nitric acid in 41·5 grains of nitrate of lead require 8 grains of soda to neutralize them. To accomplish this neutralization, (after the oxide of lead had been separated) it was necessary to add only 18 grains of carbonate, containing 4 grains of soda ; consequently, 4 grains had been already combined with it, and these 4 grains could only have been derived from the binarseniate of soda. 19·5 grains of anhydrous binarseniate of soda, then, are composed of

Arsenic acid	15·5
Soda	4·0
	19·5

These 15·5 grains of arsenic acid neutralized 28 grains of protoxide of lead, which are equivalent to 2 atoms ; consequently, 15·5 grains of arsenic acid must be equivalent to 2 atoms. Thus, we see that the atomic weight of arsenic acid is 7·75.

Composition of arsenic acid. 2. Let us now investigate the constitution of this acid.—Into a small green glass retort, previously weighed and the weight marked upon it with a diamond, 4·75 grains of clean metallic arsenic were introduced, and about an ounce of rather strong nitric acid was poured over it. A moderate heat being applied, the arsenic dissolved with

efferverscence. As soon as the solution was completed, a receiver was attached to the retort, the whole nitric acid was not only distilled off, but the heat was continued till the inside of the retort had become quite dry. By this process, the arsenic had been converted into arsenic acid, and its weight was exactly 7·75 grains.

From this experiment it is obvious, that arsenic acid is a compound of

Arsenic	4·75
Oxygen	3
	7·75

From this it appears, that the atomic weight of arsenic is 4·75, and that arsenic acid is a compound of 1 atom arsenic and 3 atoms oxygen.

Atomic weight of arsenic.

3. Let us now investigate the atomic weight of arsenious acid.—This is the substance known, in common language, by the name of *white arsenic*. It reddens vegetable blues, dissolves in water, and unites to bases; though it does not seem capable of neutralizing them. But the atomic weight, and the composition of this acid, is rendered evident by the following simple and easy experiment.

Atomic weight of arsenious acid.

6·75 grains of pure arsenious acid were put into a small retort, the weight of which had been previously determined; and there was poured over it, about an ounce of a mixture of

12 parts nitric acid of the specific gravity 1·25, and 1 part of muriatic acid of the specific gravity 1·2. The retort being exposed to a moderate heat, the arsenious acid was soon dissolved with effervescence ; but the heat was continued till all the liquid portion was distilled over into the receiver, and till the interior surface of the retort had become quite dry. The best way of drying the retort is to put it on the sand bath, and to cover the whole of it except the extremity of the beak, with sand of a temperature between 500° and 600°, and keep it in this situation for several hours. By this process the arsenious acid was converted into arsenic acid, and its weight was found to be exactly 7·75 grains.

From this experiment it is evident, that arsenious acid contains one atom of oxygen less than arsenic acid. Consequently, its atomic weight is 6·75 ; and it is a compound of one atom arsenic, and two atoms oxygen.

From the preceding investigation it is obvious, that an atom of arsenic weighs 4·75, and that the constitution and atomic weights of the acids of arsenic are as follows :

	ARSENIC.	OXYGEN.	ATOMIC WEIGHT.
Arsenious acid of	1 atom +	2 atoms	6·75
Arsenic acid - -	1 +	3	7·75

So that the constitution of these acids is the same as that of sulphurous and sulphuric acids.

4. It is exceedingly probable that there exists

an oxide of arsenic, composed of one atom arsenic and one atom oxygen, and, consequently, weighing 5·75. When very thin crusts of metallic arsenic are exposed to the air, they soon lose their metallic lustre, and crumble into a black powder. This black powder is probably the oxide in question; but it has not been particularly examined by modern chemists. When I was occupied with the experiments related in this section, I made some attempts to investigate its composition, but they were not successful, and I have not again had leisure to resume them.

5. Arsenic has the property, likewise, of combining with hydrogen gas, and of forming a gaseous compound, which was first discovered by Scheele, but has never yet been obtained in a state of purity. From our knowledge of the constitution of the other compounds of the combustible substances with hydrogen gas, however, there can be no difficulty in stating its leading properties from theory. *Arsenietted hydrogen.*

It is probably a compound of one atom arsenic and one atom hydrogen, and, consequently, its atomic weight must be 4·875.

From the analogy of the other gaseous compounds of hydrogen and a combustible, there seems little doubt that it is a compound of

1 volume arsenic vapour ⎫
1 volume hydrogen gas ⎬ condensed into 1 volume.

We will obtain its specific gravity in the gaseous

16

state by multiplying its atomic weight by 0·5555.
Now, 4·875 × 0·5555 = 2·7083 = specific gravity of arsenietted hydrogen gas.

The specific gravity of arsenic vapour ought to be 2·6388.

One volume of arsenietted hydrogen gas will require for complete combustion, either 1·5 volume, or two volumes of oxygen gas. In the first case, water and arsenious acid, and in the second case, water and arsenic acid will be formed.

SECT. VIII.

OF THE ATOMIC WEIGHT OF TELLURIUM.

THE atomic weights of all the acidifiable combustibles have now been investigated, except of tellurium, which is so scarce a substance, that I have never had it in my power to make any experiments upon it. But Berzelius has determined the composition of its oxide with his usual accuracy. We may therefore take advantage of his experiments to complete the series of the atomic weights of all the simple acidifiable combustibles.

According to Berzelius, tellurium unites with only one dose of oxygen, and forms an oxide which has the curious property of forming neutral salts, both with oxides and acids—so that

it possesses at once the characters of an acid and an alkali. Davy discovered that it forms a gas with hydrogen, similar in its properties to sulphuretted, phosphuretted, selenietted, and arsenietted hydrogen gases. But no experiments have been made to determine the specific gravity or composition of this gas.

1. Berzelius made two analytical experiments, from which the atomic weight of tellurium may be deduced.

(1.) He found that 100 parts of tellurium became 124·8 parts of oxide ; hence, oxide of tellurium is a compound of

<div style="text-align:right">Composition of oxide of tellurium.</div>

Tellurium	100	or	4·032
Oxygen	24·8	-	1

We see that the oxide of tellurium is a compound of one atom tellurium, and one atom oxygen. The atomic weight of tellurium by this experiment is 4·032, or rather less than one per cent. more than 4. Now, it is exceedingly difficult to make an experiment similar to the one by which Berzelius determined the composition of oxide of tellurium, without some loss. If the loss amounted to 0·2, which is no more than $\frac{1}{625}$th part of the whole, then the oxide of tellurium is composed as follows :

Tellurium	100	or	4
Oxygen	25	-	1
			$\overline{5}$

And the atomic weight of tellurium will be exactly 4, and that of the oxide 5.

Bitellurate of lead.

(2.) Berzelius found that 201·5 parts of fused tellurate of lead contained just the same weight of protoxide of lead, which 157 parts of sulphate of lead do.* But 157 parts of sulphate of lead contain 115·684 parts of protoxide of lead; hence, it follows, that tellurate of lead is composed of

Protoxide of lead	115·684	or	14
Oxide of tellurium	85·816	-	10·385
	201·500		

To reconcile this experiment with the former, the salt analyzed must have been a bitellurate, or a compound of two atoms oxide of tellurium and one atom protoxide of lead.

The atomic weight of oxide of tellurium from the above analysis is 5·1925.

This is rather higher than the weight deduced from the composition of oxide of tellurium. The former experiment being much simpler, and consequently, susceptible of greater accuracy than the latter, there can be no hesitation in preferring it, and, consequently, in fixing upon 4 as the true atomic weight of tellurium, and 5 as the atomic weight of oxide of tellurium.

Telluretted hydrogen.

2. We may deduce the specific gravity and constitution of telluretted hydrogen gas, with a

* Annals of Philosophy, III. 250.

great deal of probability, from the known consti-
tution of the other similar compounds.   If it be
a compound of

> 1 volume tellurium vapour ⎫
> 1 volume hydrogen gas   ⎭ condensed into 1 volume,

as is the case with all the others, and if a vo-
lume of tellurium vapour be equivalent to an
atom, then the atomic weight of telluretted hy-
drogen is 4·215, and its specific gravity 2·2916.

One volume of this gas will require, for com-
plete combustion, one volume of oxygen gas,
—one half of which will go to the formation of
water, and the other, to the formation of oxide
of tellurium.

CHAP. VII.

OF THE RELATION BETWEEN THE ATOMIC WEIGHTS AND SPECIFIC GRAVITIES OF GASEOUS BODIES.

Gay-Lussac, in a paper published in the second volume of the *Memoires d'Arcueil,* demonstrated, a good many years ago, that when gases combine with each other, one volume of the one gas either combines with one volume, or two volumes, or three volumes of the other. Dr. Prout, in a paper inserted in the sixth volume of the *Annals of Philosophy,* first pointed out the connection which existed between the specific gravity and the atomic weights of the gases ; and showed that, in general, the specific gravity is equal to the atomic weight multiplied by half the specific gravity of oxygen gas. I propose in this chapter to take a general view of the relation between the atomic weights and the specific gravities of all the known gases.

1. In the preceding chapters we have determined the atomic weights of all the simple bodies which are capable of assuming the gaseous form. Of these there are only four, which are gases in the uncombined state :—these are Oxygen,

Hydrogen, Chlorine, and Azote. There are seven simple bodies which are capable of combining with hydrogen, and forming with it a gaseous compound :—these are iodine, carbon, phosphorus, sulphur, selenium, arsenic, and tellurium. The two remaining bodies, boron and silicon, enter into gaseous combinations with fluoric acid,—a substance, the consideration of which is deferred till a future chapter ; though the specific gravity and atomic weights of the gases will be inserted in the following tables, for the sake of completing the series of gaseous bodies.

Gases whose specific gravity = atom × ·555.

2. We have seen that water is a compound of one volume of oxygen gas, and two volumes of hydrogen gas ; while, from the proportion in which hydrogen combines with all known bodies, there is every reason to consider two volumes of it as equivalent to an atom ; or if we choose, for the sake of simplicity, to represent an atom of hydrogen by a volume of the gas, then we must represent an atom of oxygen by half a volume of the gas. We have seen that chlorine and azote have the same relation between their atomic weights and their volumes that hydrogen has ; this is the case also with iodine, carbon, phosphorus, and sulphur, when in the state of vapour. The relation between the atomic weight and the volume of the vapours of selenium, arsenic, and tellurium, has not yet been determined by experiment ; but there seems no reason

to hesitate about extending the same law to
these bodies also.

Thus it appears, that the atomic weight of
oxygen is obtained by dividing the specific gra-
vity of oxygen gas by itself ; for $\frac{1\cdot111}{1\cdot111} = 1$; but
the atomic weights of the other gases and vapours
are obtained by dividing the specific gravity of
the gas or vapour by half the specific gravity of
oxygen gas, or 0·5555.*

The specific gravities of oxygen gas, hydrogen
gas, chlorine gas, and azotic gas, have been de-
termined with rigid accuracy in the preceding
chapters. The knowledge of the atomic weights
of the other bodies will enable us to determine
the specific gravities of the vapours and gases
of which they constitute parts, with equal ac-
curacy ; for we obtain these specific gravities by
multiplying the atomic weights by 0·5555.

The following table exhibits the atomic weights

* I need hardly point out to the reader, that the reason why the multi-
plicand of the specific gravity of the gases is $\frac{1}{2}$, or $\frac{1}{4}$th the specific gravity of
oxygen gas, instead of simply $\frac{1}{2}$ and $\frac{1}{4}$th, is, that the specific gravities and
the atomic weights are referred to different standards. The *specific gravity*
of atmospheric air is reckoned unity, and that of every other gas is referred
to it ; but the atomic weight of oxygen being unity, and that of all the
other gases referred to it, as far as atomic weights are concerned, it is ob-
vious, that when specific gravities are to be converted into atomic weights,
we must employ for our divisor half or $\frac{1}{4}$th the specific of oxygen gas, in
order to change one system into the other. All this trouble would be
saved, if we were to make the specific gravity of oxygen gas unity, as well
as its atomic weight.

and specific gravities of all the gases and vapours coming under this law.

I. *Gases whose specific gravity is equal to the atomic weight multiplied by* 1·1111.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Oxygen gas . .	1	1·1111
Fluosilicic acid . .	3·25	3·6111

II. *Gases and vapours whose specific gravity = atomic weight multiplied by* 0·5555.

1. SIMPLE GASES AND VAPOURS.

	Hydrogen gas . .	0·125	0·0694
	Carbon vapour . .	0·75	0·4166
5	Phosphorus vapour .	1·5	0·8333
	Azotic gas . . .	1·75	0·9722
	Sulphur vapour . .	2	1·1111
	Tellurium vapour . .	4	2·2222
	Chlorine gas . .	4·5	2·5
10	Arsenic vapour . .	4·75	2·6388
	Selenium vapour . .	5	2·7777
	Iodine vapour . .	15·5	8·6111

2. HYDROGEN, COMBINED WITH A SIMPLE BASE.

	Carburetted hydrogen .	1	0·5555
	Phosphuretted hydrogen	1·625	0·9027
15	Subphosphuretted hydrogen	1·25	0·6944
	Bihydroguret of phosphorus	1·75	0 9722
	Sulphuretted hydrogen	2·125	1·1805
	Telluretted hydrogen .	4·125	2·2916
	Arsenietted hydrogen .	4·875	2·7083
20	Selenietted hydrogen .	5·125	2·8522

3. OXYGEN, COMBINED WITH A SIMPLE BASE.

		ATOMIC WEIGHT.	SPECIFIC GRAVITY.
	Steam . . .	1·125	0·625
	Carbonic oxide gas .	1·75	0·9722
	Carbonic acid . .	2·75	1·5277
	Protoxide of azote .	2·75	1·5277
25	Nitric acid vapour .	6·75	3·75
	Sulphurous acid . .	4	2·2222
	Sulphuric acid vapour .	5	2·7777

4. OTHER COMPOUND GASES.

	Cyanogen . . .	3·25	1·8055
	Fluoboric acid . .	4·25	2·3611
30	Sulphuret of carbon .	4·75	2·6388
	Chlorocarbonic acid .	6·25	3·4722

The specific gravity of these 29 gases and vapours being obtained by multiplying the atomic weights of each by 0·5555, or half the specific gravity of oxygen, it is obvious, that in all of them a volume may be substituted for an atom; or, in other words, the specific gravities and atomic weights of all of them bear the same relation to each other. In oxygen gas and fluosilicic acid, on the contrary, an atom is represented by half a volume; so that, in the first set of gases, a volume contains twice as many atoms as in the second set.

3. There are five compound gases, whose atomic weights and specific gravities bear a different relation to each other from the gases in the pre-

Gases whose specific gravity = atom × 0·2777.

ceding table. The compound gases in the pre-
ceding table may be considered as consisting of
a volume, or a determinate number of volumes
of each constituent, so condensed, that a volume
of the compound gas bears the same relation to
a volume of oxygen gas, as a volume of hydrogen
gas does to a volume of oxygen gas ; but there
are four compound gases, which consist of a vo-
lume of each of the constituents united together,
without any condensation whatever. Conse-
quently, their specific gravities, instead of being
equal to the specific gravities of all their consti-
tuents added together, are only the means of the
specific gravities of the constituents. In reality,
therefore, the volumes of these gases may be
considered as doubled, with reference to their
atomic weights. These gases are *deutoxide of
azote, hydrocyanic acid vapour, muriatic acid,*
and *hydriodic acid.*

   (1.) Deutoxide of azote is composed of 1 vo-
lume of oxygen gas, and 1 volume of azotic gas,
united together, without any alteration of vo-
lume ; hence its specific gravity is the mean of
the specific gravities of oxygen and azotic gases,
or 1·0416.

   (2.) Hydrocyanic acid, muriatic acid, and hy-
driodic acid, are composed respectively of one vo-
lume of hydrogen gas, united to a volume of
cyanogen, chlorine, and iodine vapour, without
any condensation.

(3.) The constitution of ammoniacal gas is analagous to that of the four gases just mentioned. It is composed of 1 volume of azotic gas, and 3 volumes of hydrogen gas, condensed into two volumes ; so that its specific gravity, instead of being equal to the specific gravity of azotic gas, added to thrice the specific gravity of hydrogen gas, is only half that quantity, or 0·59027. Therefore, with respect to its atomic weight, its bulk is also doubled.

From what has been just stated, it must be obvious, that in these five gases the specific gravity will be obtained by multiplying the atomic weight of each by 0·2777, or ¼th of the specific gravity of oxygen gas.

The following table exhibits the atomic weights and specific gravities of these gases :

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Ammoniacal gas	2·125	0·59027
Hydrocyanic acid vapour	3·375	0·9375
Deutoxide of azote	3·75	1·04166
35 Muriatic acid	4·625	1·28472
Hydriodic acid	15·625	4·34027

It is obvious that a volume of oxygen gas contains four times as many atoms as a volume of any of these five gases. When we compare these five gases with each other, an atom may be substituted for a volume ; but when we compare them with the gases in the preceding table, two

volumes represent an atom, while 1 volume of
the second set of gases represents an atom. Thus,
when we wish to combine 1 atom of sulphurous
or carbonic acid with 1 atom of ammonia, we
must mix 1 volume of the acid gas with 2 vo-
lumes of the ammoniacal gas.

Protoxide
of chlorine.
4. The constitution of protoxide of chlorine
is different from that of both the preceding sets
of gases. It is composed (if Davy's experiments
be accurate) of 4 volumes of chlorine, and 2 vo-
lumes of oxygen gas, condensed into 5 volumes.
We obtain its specific gravity by adding together
four times the specific gravity of chlorine gas,
and twice the specific gravity of oxygen gas, and
dividing the sum by five ; this gives us 2·4444
for the specific gravity of this gas. As it is a
compound of 1 atom chlorine and 1 atom oxy-
gen, its atomic weight is obviously 5·5. Now,
the specific gravity of this gas is obtained by
multiplying its atomic weight by 0·4444, which
is $\frac{4}{9}$ths of the specific gravity of oxygen gas ; for
5·5 × 0·4444 = 2·4444. The reason of this is
obvious from the peculiar condensation which
the constituents of this gas undergo when they
combine.

Olefiant
gas.
5. Olefiant gas has not been inserted in the pre-
ceding tables ; it has been reserved for separate
notice, on account of the peculiarity of its na-
ture. Its specific gravity is 0·9722 ; and it is
obvious, from the phenomena of its combustion,

that it consists of 2 volumes of hydrogen gas, and 2 volumes of carbon vapour, condensed into one volume. Now, as in these two bodies atoms may be substituted for volumes, this gas is obviously a compound of 2 atoms hydrogen, and 2 atoms carbon. Hence its atomic weight is 1·75 ; but 1·75 × 0·5555 = 0·9722 ;—so that this gas coincides with the compound gases in the second table ; and it might have been inserted in the second division of that table, after carburetted hydrogen.

But the singularity of this substance, which is obviously a compound of 1 atom hydrogen and 1 atom carbon, is, that it seems capable of forming a variety of gases, differing from each other in the number of integrant particles of carburet of hydrogen, which a single volume contains. Gases seem to exist, containing 1 integrant particle, 2 integrant particles, 3 integrant particles, 4 integrant particles, and 6 integrant particles. Of course, the specific gravity of each of these gases will be different, though each is regulated by the law which determines the specific gravities of the compound gases in the second table. It may be worth while to exhibit the atomic weights and specific gravities of these gases.

	ATOMIC WEIGHT.	SP. GRAVITY.
Simple hydrocarburet . .	0·875	0·4861
Olefiant gas	1·75	0·9722
Oil gas, or tritohydrocarburet .	2·625	1.4583

16

	ATOMIC WEIGHT.	SP. GRAVITY.
Sulphuric ether vapour, containing		
4 volumes	3·5 .	1·9444
Naphtha vapour, containing 6 vols.	5·25 .	2·9166

The only one of these five gases not yet de-
tected is the first. But it may be looked for
among the inflammable gases produced from ve-
getable bodies, or from pit coal.

CHAP. VIII.

OF THE ATOMIC WEIGHTS OF THE FIXED
ALKALIES AND ALKALINE EARTHS.

THE atomic weights of the simple bodies which constitute the bases of the acids, have been determined in the preceding chapters. I propose in the five following chapters to investigate the atomic weights of the bases of the alkaline bodies, including under the term *alkali*, all bases which are capable of neutralizing acids.

The substances usually distinguished by the name of *fixed alkalies* and *alkaline earths*, are

1 Potash	4 Barytes	7 Magnesia
2 Soda	5 Strontian	
3 Lithia	6 Lime	

Sir H. Davy first showed that these bodies are compounds of oxygen, with certain white coloured solid metals, which have so strong an affinity for oxygen that they can with difficulty be preserved in the metallic state. Indeed, if we except potassium and sodium, the remainder, as far as utility is concerned, may be considered as still unknown; for they cannot be procured in such quantities as to be susceptible of useful applications. The fixed alkalies and alkaline

earths, on the contrary, which constitute the *oxides* of these metallic bases, are in constant use, and constitute some of the most important substances known to the chemist. They are the bases of the most common and useful salts, and an accurate knowledge of their atomic weights is of the utmost consequence to the progress of the science. The principal part of our attention will, therefore, be bestowed on the investigation of the atomic weights of these alkaline compounds. The knowledge of the atomic weights of the bases will follow as a kind of corollary from that of their compounds.

SECT. I.

OF THE ATOMIC WEIGHT OF POTASH AND POTASSIUM.

THERE are two salts of potash, which, when properly prepared, are destitute of water, and consist respectively of water united to nitric acid and sulphuric acid. These are nitrate of potash, and sulphate of potash.

Analysis of nitrate of potash. 1. Nitrate of potash crystallizes in six-sided prisms, terminated by six-sided pyramids. When kept red hot, the nitric acid is gradually dissipated, and pure potash remains behind. It may appear at first sight easy, by this means, to deter-

mine the composition of saltpetre ; for the loss of weight would indicate the quantity of nitric acid, while the residual matter in the crucible would be the potash ;—and if we were possessed of any vessel upon which red hot saltpetre would not act, and if potash were absolutely fixed in the fire, this method would be a good one ;—but I have not been able to obtain satisfactory results by decomposing this salt by heat.   The process, which answered best, was to triturate a given weight of saltpetre with twice as much siliceous sand, and to fuse the mixture in a platinum crucible.   When 12·75 grains of saltpetre were employed, the loss of weight approached very near 6·75 grains, though it always somewhat exceeded that quantity.

2. Sulphate of potash affords an easy method Of sulphate of potash. of determining the atomic weight of potash with precision.   Before relating the experiment by which this object was attained, it may be proper to remind the reader that the atomic weight of sulphuric acid is 5 ; and that 13·25 grains of chloride of barium yield a quantity of barytes just capable of neutralizing 5 grains of sulphuric acid.

11 grains of sulphate of potash, and 13·25 grains of chloride of barium, were dissolved in separate portions of distilled water.   The two solutions being mixed, a double decomposition took place, and sulphate of barytes precipitated

in the state of a white powder. The liquid, after it had recovered its transparency from the complete subsidence of this precipitate, was tested by sulphate of soda and muriate of barytes ; but neither of these reagents produced the least muddiness or opalescence, showing that the liquid contained neither barytes nor sulphuric acid. From this experiment it is evident, that the sulphuric acid in 11 grains of sulphate of potash, just saturates the barytes from 13·25 grains of chloride of barium. Consequently, it amounts to exactly 5 grains. So that sulphate of potash must be a compound of

$$
\begin{array}{lr}
\text{Sulphuric acid} & 5 \\
\text{Potash } . \quad . & 6 \\
\hline
& 11 \\
\end{array}
$$

Atomic weight of potash.

But since the salt is neutral, and since 5 is the weight of an integrant particle of sulphuric acid, it is plain that 6 must be the weight of an integrant particle of potash.

Of potassium.

3. The atomic weight of potash being known, it is easy from the experiments made on potassium to determine the atomic weight of that metal. From the experiments of Gay-Lussac and Thenard, it appears that when 100 grains of potassium are put into water, the metal combines with the oxygen of that liquid, and is converted into potash, while the hydrogen gas evolved

measures 116·38 cubic inches. This experiment was made by plunging a given bulk of potassium into water, and inferring the weight from the known volume and specific gravity of this metal. I have repeated it several times, employing various contrivances to enable me to weigh the potassium; but I was unable to obtain better results than those of the French chemists. I shall therefore employ them, as they are amply sufficient for the object I have in view.

The oxygen gas, which must have united with the 100 grains of potassium, must have amounted to $\frac{116·38}{2} = 58·19$ cubic inches; the weight of which is 19·72 grains. So that potash, according to these experiments of the French chemists, is composed of

Potassium	100	or	5·121
Oxygen	19·72	-	1
			6·121

The weight of an atom of potash, according to this experiment, is 6·121, and it is a compound of one atom potassium = 5·121, and one atom oxygen. Now, it is obvious, that this atomic weight of potash is a little too high; it should have been 6, and not 6·121. The reason undoubtedly is, that the hydrogen gas evolved was a little below the true quantity. Whoever will take the trouble to repeat the experiment, will be at no loss to account for this deficiency.

Berzelius took another method of determining the composition of potash. He placed a quantity of amalgam of potassium in water; the amalgam was speedily decomposed, the potassium being converted into potash, and dissolving in the water, while the running mercury remained behind. The potash thus formed was saturated with muriatic acid, the liquid evaporated to dryness, and the residual salt weighed. The difference between the weight of the amalgam and of the running mercury remaining, gave the weight of the potassium; while the weight of the muriate of potash formed, furnished the data for determining the weight of the potash. It is obvious, that the difference between the weight of the potassium and the potash, was the quantity of oxygen with which the potassium had combined. This experiment gave the constituents of potash as follows :

$$\begin{array}{lccc}
\text{Potassium} & 100 & \text{or} & 4\cdot889 \\
\text{Oxygen} & 20\cdot45 & \text{-} & 1 \\
\hline
& & & 5\cdot889
\end{array}$$

According to this experiment, an atom of potassium weighs 4·889, and an integrant particle of potash 5·889. This determination is a little below the truth, while that of the French chemists is a little above it.

The mean of the two gives 5·005 for the atomic weight of potassium. The true weight

is undoubtedly 5 ; and potash is a compound of
1 atom potassium = 5, and 1 atom oxygen = 1 ;
consequently, its atomic weight is 6, as we found
it to be by the experiment related near the be-
ginning of this section.

4. Potassium combines with an additional dose Peroxide of
of oxygen, and forms a solid yellow substance, potassium.
which has received the name of *peroxide* of
potassium.   From the experiments of Gay-Lus-
sac and Thenard, it appears, that 100 grains of
potassium, when converted into peroxide, com-
bine with 177 cubic inches of oxygen gas. Now,
this is just three times as much as the quantity
necessary to convert potassium into potash ; for
100 grains of potassium were found to absorb
58·19 cubic inches of oxygen gas when con-
verted into potash — and $\frac{177}{3} = 59$.   Peroxide
of potassium must, therefore, be composed of

$$
\begin{array}{ll}
\text{1 atom potassium} & = 5 \\
\text{3 atoms oxygen} & = 3 \\
\hline
& 8
\end{array}
$$

And an integrant particle of it must weigh 8.

It deserves attention, that this experiment of
Gay-Lussac and Thenard gives the atomic
weight of potassium different from their former
one.   For 59 cubic inches of oxygen gas weigh
20·38 grains ; so that potash is composed, ac-
cording to this experiment, of

Potassium   100   or 4·9068
Oxygen   20·38 - 1

                              —————
                              5·9068

The atom of potassium, by the first experiment, weighs 5·121; by the second 4·9068. The mean of the two is 5·0139; which approaches much nearer the truth than either of the experiments taken singly.

SECT. II.

OF THE ATOMIC WEIGHTS OF SODA AND SODIUM.

THE atomic weight of soda may be determined with the same precision, and nearly in the same manner, as the atomic weight of potash.

Composition of sulphate of soda.

1. Sulphate of soda is a well known transparent salt, which crystallizes with great facility. By a careful analysis of this salt I find its constituents as follows:

1 atom sulphuric acid   5
1 atom soda   .   4
10 atoms water   .   11·25

                         —————
                         20·25

The water of crystallization is not always exactly the same. I have found it amount to 11·28, which exceeds the true atomic quantity by 0·03

grain. This excess of water is mechanically lodged between the plates of the crystals;—it may be got rid of by reducing the crystals to powder, and pressing them between two folds of blotting paper. But, as the salt is very easily rendered anhydrous, it is better to employ it for the experiment which I am going to describe, in that state. It may be rendered anhydrous by placing it for some hours, in the vacuum of an air-pump, along with an open vessel of sulphuric acid—or by exposing it to a moderate heat in a platinum crucible.

Nine grains of anhydrous sulphate of soda, and 13·25 grains of chloride of barium, were dissolved in separate portions of distilled water. The two solutions being mixed, a double decomposition took place, and sulphate of barytes precipitated in the state of a white powder. As soon as the liquid had become transparent, it was tested with sulphate of soda and muriate of barytes, but was not rendered opalescent, nor in the least altered, by either of these reagents. It therefore contained no sensible quantity of barytes or sulphuric acid. From this experiment, it follows, that the sulphuric acid in 9 grains of anhydrous sulphate of soda is just saturated by the barytes from 13·25 grains of chloride of barium. Now, this quantity we know is exactly 5 grains; consequently, anhydrous sulphate of soda is composed of

Sulphuric acid 5
Soda . . 4
———
9

Atomic weight of soda.

Five being the atomic weight of sulphuric acid, and the salt being neutral, 4 must be the atomic weight of soda.

2. The atomic weight of soda being known, it is easy, from the experiments of Gay-Lussac and Thenard, to determine its composition, and to deduce the weight of an atom of sodium. 100 grains of sodium, when plunged into water, were immediately converted into soda, while 198·3 cubic inches of hydrogen gas were evolved. From this experiment, it follows, that when 100 grains of sodium are converted into soda, they combine with 99·15 cubic inches of oxygen gas, or 33·6 grains. This experiment gives us the composition of soda as follows :—

Atom of sodium determined.

Sodium   100   or 2·976
Oxygen   33·6   -   1
———
3·976

We see that soda is a compound of 2·976 of sodium and 1 of oxygen ; or of 1 atom sodium and 1 atom oxygen. The atom of sodium, by this experiment, is 2·976, and the atom of soda 3·976. This is a little below the truth ; for we have just seen that the true atomic weight of soda is 4 ; but the experiment is sufficient to satisfy us that

9

soda is a compound of 1 atom sodium and 1 atom oxygen ; and that an atom of sodium weighs 3.

Berzelius tried to determine the quantity of oxygen which converts a given weight of sodium into soda, by the same method which he followed in determining the composition of potash. The result obtained was, that soda is composed of

Sodium	100	or	2·896
Oxygen	34·52	-	1

3·896

This result deviates a little farther from the truth than that of Gay-Lussac and Thenard.

Sir H. Davy made a variety of experiments with the same object in view, and drew as a conclusion, that soda is a compound of from 75 to 73 sodium, and from 25 to 27 oxygen. One of his experiments gave him the composition of soda as follows :—

Sodium	100	or	3
Oxygen	33⅓	-	1

4

Now, this result agrees exactly with the atomic weight of soda, as determined in the first paragraph of this section.

There can be no doubt that the atom of sodium weighs 3—and that soda is a compound of 1 atom sodium and 1 atom of oxygen.

Peroxide of sodium.

3. Sodium, like potassium, combines with an additional dose of oxygen, and forms a solid of a greenish yellow colour, distinguished by the name of peroxide of sodium. From the experiments of Gay-Lussac and Thenard, it appears, that sodium in the peroxide is united with $1\frac{1}{2}$ times as much oxygen as in soda.* Hence, the peroxide is composed of

Sodium	3
Oxygen	1·5
	—
	4·5

So that the atomic weight of this peroxide is 4·5, and it is a compound of 1 atom sodium and $1\frac{1}{2}$ atom oxygen; or of 2 atoms sodium and 3 atoms oxygen. It is curious that soda has a tendency to combine in the same proportion, with several of the acids, that sodium does with oxygen.

SECT. III.

OF THE ATOMIC WEIGHTS OF LITHIA AND LITHIUM.

THOUGH *lithia* has been known for only a few years, and though it has been hitherto procured only in small quantities, yet its properties have

* Recherches Physico-Chem. I. 152.

been examined with so much care, and some of the salts which it forms have been analyzed with such accuracy, that its atomic weight has been ascertained with as much precision as that of any of the alkaline bases. I have examined several of the salts of lithia, but found the sulphate best adapted for a rigid determination of the atomic weight.

1. Sulphate of lithia crystallizes very well by spontaneous evaporation, even when the quantity of it is small. It forms four-sided rectangular prisms with square bases, which are not liable to deliquesce when exposed to the air. Its taste is saline, without any perceptible bitterness. It contains water of crystallization, which is easily driven off by exposing the salt to a heat of about 600°. Analysis of sulphate of lithia.

This salt was analyzed by Arfwedson, Vauquelin, and Gmelin, in an anhydrous state: but Stromeyer has stated both the saline constituents and the water of crystallization.

According to Arfwedson,* the constituents of this salt are

Sulphuric acid	68·41	or	5
Lithia	31·59	-	2·308

100·00

Vauquelin† states its constituents as follows:

---

* Ann. de Chim. et de Phys. X. 90.   † Ibid. VII. 287

R 4

Sulphuric acid	69·2	or	5
Lithia	30·8	-	2·225
	100·0		

The salt being neutral, and 5 being the atomic
weight of sulphuric acid, the corresponding
number for lithia must denote the weight of an
atom of that alkali, according to the determina-
tion of these chemists. Lithia, consequently,
according to the analysis of Arfwedson, weighs
2·308,—according to that of Vauquelin, its
weight is 2·225. The mean of these two ana-
lyses gives us 2·266 for the atomic weight of li-
thia. This approaches very near 2·25, which, as
I shall show immediately, is the true atomic
weight of lithia.

Gmelin's* analysis (when corrected) is as fol-
lows :—

Sulphuric acid	67·15	or	5
Lithia	32·85	-	2·416
	100·00		

The atomic weight of lithia derived from this
analysis, is higher than that given by Vauquelin,
or even by Arfwedson, amounting to 2·416.
But, if we compare Gmelin's analysis of car-
bonate of lithia with his analysis of the sulphate,
it will be evident that they cannot be quite ac-

* Gilbert's Annalen, LIX. 238.

curate. The fused carbonate he found a compound of

| Carbonic acid | 54·46 | or | 2·75 |
| Lithia | 45·54 | - | 2·2995 |

100·00

So that the atomic weight of lithia, by his analysis of the sulphate, is 2·416, while by the analysis of the carbonate it is only 2·2995. This discordancy would render it hazardous to employ Gmelin's analysis for the determination of the atomic weight of this alkali.

Stromeyer's analysis is more recent than those of the three above named chemists ; and it comes nearer the truth than any of the others.* 100 parts of the crystals contain (according to him) 13 parts of water, and the anhydrous salt (correcting the calculations) is a compound of

| Sulphuric acid | 68·977 | or | 5 |
| Lithia | 31·023 | - | 2·2488 |

100

The water, when reduced to the atomic proportions, is 1·083, or very nearly one atom.

2. I exposed 8·375 grains of very carefully prepared crystals of sulphate of lithia, to the temperature of 600°, in a platinum crucible, till

* Untersuchungen, I. 435.

the salt ceased to give out moisture. The loss of weight was exactly 1·125 grain, which is equivalent to 1 atom. The 7·25 grains of anhydrous salt were dissolved in a minimum of distilled water, and the liquid was mixed with a solution of 13·25 grains of chloride of barium. After the sulphate of barytes had subsided, the residual liquid was tested with sulphate of soda and muriate of barytes; but neither of these reagents produced any opalescence, showing that it contained neither barytes nor sulphuric acid. Consequently, the sulphuric acid in 7·25 grains of anhydrous sulphate of lithia amounts to exactly 5 grains. The remaining portion of the salt being lithia, it is obvious that the true composition of this salt is as follows :

Sulphuric acid	5	or	1 atom
Lithia . .	2·25	-	1 atom
Water . .	1·125	-	1 atom

8·375

Atom of lithia.

Thus, the true atomic weight of lithia is 2·25, and the sulphate contains an atom of each of its constituents.

Atom of lithium.

3. It was ascertained by Sir H. Davy, that lithia, like potash and soda, is a compound of a white coloured metal, called *lithium*, and oxygen. Though no experiments have been made to determine the proportion of these two constituents, there is no difficulty in ascertaining the true

composition of lithia, now that we know the atomic weight of this alkali and of oxygen. Potash and soda are each of them compounds of 1 atom of oxygen, with 1 atom of potassium and sodium respectively. We shall find that the composition of barytes, strontian, lime, and magnesia, is quite similar. It is reasonable to conclude from this, that lithia is likewise a compound of 1 atom oxygen and 1 atom lithium ; consequently, an atom of lithium must weigh 1·25, and lithia must consist of

1 atom lithium	1·25
1 atom oxygen	1
	2·25

SECT. IV.

OF THE ATOMIC WEIGHTS OF BARYTES AND BARIUM.

BARYTES has been employed in many of the preceding sections to determine the atomic weight of different bodies, in consequence of the property which it has of forming an insoluble compound with sulphuric acid. It has been already explained, that sulphate of barytes is a compound of

$$\begin{aligned} \text{Sulphuric acid} \quad & 5 \\ \text{Barytes} \quad & 9 \cdot 75 \\ \hline & 14 \cdot 75 \end{aligned}$$

From which it is obvious, that 9·75 must be the atomic weight of barytes ;—but a few additional observations may be requisite to prevent any obscurity from incommoding the progress of the reader.

Constituents of barytes.

1. When a current of chlorine gas is made to pass over red hot barytes, this gas is absorbed, while at the same time oxygen gas is evolved—and the barytes is changed into chloride of barium.   Sir H. Davy, to whom we owe this experiment, ascertained, that for every volume of chlorine gas absorbed by the barytes, half a volume of oxygen gas was evolved.   It is obvious that the oxygen gas was displaced from the barytes by the chlorine, and of consequence, the barytes was converted into barium.   Half a volume of oxygen gas and a whole volume of chlorine gas, being each equivalent to an atom, it is clear that barytes must be a compound of 1 atom barium and 1 atom oxygen ; consequently, an atom of barium weighs 8·75.

2. Muriatic acid was shown, in a preceding chapter, to be a compound of 1 atom of chlorine = 4·5 ; and 1 atom of hydrogen = 0·125 ; so that its atomic weight is 4·625.

3. Water was likewise shown to be a com-

pound of 1 atom oxygen and 1 atom hydrogen, and its atomic weight is 1·125.

4. An integrant particle of anhydrous muriate of barytes weighs 14·375 ; being composed of

$$\begin{array}{ll}\text{1 atom muriatic acid} & = 4\cdot625 \\ \text{1 atom barytes} & = 9\cdot75 \\ \hline & 14\cdot375\end{array}$$

5. When muriate of barytes is exposed to a red heat, it undergoes a double decomposition. The hydrogen of the acid and the oxygen of the base uniting together, constitute a particle of water, which is driven off by the heat, while the chlorine and the barium remain united together in the state of chloride of barium. For it is obvious, that 14·375 of muriate of barytes may be decomposed into

$$\begin{array}{ll}\text{1 atom water} & = 1\cdot125 \\ \text{1 atom chloride of barium} & = 13\cdot25 \\ \hline & 14\cdot375\end{array}$$

6. Whenever chloride of barium is dissolved in water it is again converted into muriate of barytes. A portion of the water is decomposed, the hydrogen of which converts the chlorine into muriatic acid, while the oxygen changes the barium into barytes.

7. Thus, it appears, that whenever muriate of barytes is exposed to a red heat, it is converted

into chloride of barium ; and that when chloride of barium is dissolved in water, it becomes muriate of barytes. We may, therefore, employ 13·25 grains of chloride of barium as an equivalent for 14·375 grains of muriate of barytes, and as capable of yielding 9·75 grains of barytes.

These things being understood and recollected, we are prepared for an experimental investigation of the atomic weight of barytes.

Atomic weight of barytes.

13·25 grains of chloride of barium, and 11 grains of sulphate of potash, were dissolved in separate portions of distilled water, and the two solutions were mixed together. A double decomposition took place, sulphate of barytes precipitated to the bottom of the vessel, while muriate of potash remained in solution. Both of these salts were quite neutral, and the solution contained no traces either of sulphuric acid or of barytes. The sulphate of barytes being collected weighed 14·75 grains ; the solution being evaporated to dryness, left 9·5 grains of chloride of potassium. Now, the weights of these two salts amount to 24·25 grains, which is just equal to the combined weights of the chloride of barium, and sulphate of potash employed in making the experiment.

11 grains of sulphate of potash contain 5 grains of sulphuric acid, which must exist in the 14·75 grains of sulphate of barytes. Consequently, that salt must be a compound of

Sulphuric acid   5
Barytes   9·75

——

14·75

The salt being neutral, and 5 being the atomic weight of sulphuric acid, it is plain that 9·75 must be the atomic weight of barytes.

Muriate of barytes is a white, pungent, and disagreeably tasted salt, which crystallizes in very short four-sided prisms with square bases. I find by a careful analysis of these crystals, that they are composed of

1 atom muriatic acid   =   4·625
1 atom barytes   =   9·750
1 atom water   =   1·125

——

15·5

If 15·5 grains of it be exposed to a red heat, they are reduced to 13·25 grains; so that the loss sustained, owing to the escape of water, is 2·25 grains. This loss is equivalent to two atoms of water; one of these atoms existed in the salt as water of crystallization; the other atom was formed by the muriate of barytes being converted into chloride of barium.

Gay-Lussac and Thenard ascertained that when anhydrous barytes is heated in oxygen gas, a portion of the gas is absorbed, and the barytes is converted into a peroxide. This peroxide is

Peroxide of barium.

grey ; but we have no data to determine how many atoms of oxygen it contains.

SECT. V.

OF THE ATOMIC WEIGHTS OF STRONTIAN AND STRONTIUM.

THE atomic weight of strontian is easily deter-mined by experiments of a similar kind with those related in the last section.   It will be suf-ficient if I describe one of them.

Atom of strontian determined.

1. Nine grains of anhydrous sulphate of soda, and ten grains of chloride of strontium, (that is, muriate of strontian, exposed to a red heat,) were dissolved in separate portions of water.   These two solutions being mixed together, a double decomposition took place.   Sulphate of strontian precipitated abundantly, and the residual liquid contained a quantity of common salt, which was perfectly neutral, as no change was produced on paper stained with litmus or cudbear.   This residual liquid being tested by muriate of bary-tes, did not give any indication of the presence of sulphuric acid.   Nor was it rendered in the least turbid by sulphate of soda, arseniate of soda, or chromate of potash, even when very much concentrated by evaporation.   Conse-quently, it contained no sensible quantity of strontian ; the sulphate of strontian being care-

fully collected and exposed to a red heat, weighed 11·5 grains. Now, it contained all the sulphuric acid in 9 grains of anhydrous sulphate of soda, which is just 5 grains. The remaining 6·5 grains must be strontian. Thus it appears, that sulphate of strontian is composed of

$$\begin{array}{ll} \text{Sulphuric acid} & 5 \\ \text{Strontian} \quad . & 6\cdot 5 \\ \hline & 11\cdot 5 \end{array}$$

5 being the atomic weight of sulphuric acid, and the salt being neutral, 6·5 must be the atomic weight of strontian.

The soda in 9 grains of anhydrous sulphate of soda amounts to 4 grains, which requires for saturation 4·625 grains of muriatic acid, equivalent to 4·5 grains of chlorine—and this must be the quantity of chlorine in 10 grains of chloride of strontium. If from 10 we subtract 4·5, the remainder is 5·5, which indicates the quantity of strontium in 10 grains of this chloride. This 5·5 of strontium, when converted into strontian in the sulphate, becomes 6·5. Hence, it is obvious that strontian is a compound of 1 atom oxygen, and 1 atom strontium; and that an atom of strontium weighs 5·5.

Muriate of strontian crystallizes in long needles, consisting of six-sided prisms, two opposite faces of which are broader than the other four. By

Atom of strontium.

Muriate of strontian.

a careful analysis of this salt, I have ascertained
its composition to be as follows :

$$
\begin{array}{lll}
1 \text{ atom muriatic acid} & = 4 \cdot 625 \\
1 \text{ atom strontian} & = 6 \cdot 5 \\
8 \text{ atoms water} & = 9 \\
\hline
& 20 \cdot 125
\end{array}
$$

So that an integrant particle of it weighs 20·125.
When 20·125 grains of these crystals are ex-
posed to a red heat in a platinum crucible, they
lose 10·125 grains of water, which is equivalent
to 9 atoms ; and there remain behind 10 grains
of chloride of strontium, which is equivalent to
the weight of an integrant particle of that chlo-
ride. Thus, muriate of strontian, like muriate
of barytes, loses 1 atom of water more than it
contains in the state of water. This atom is
produced by the double decomposition of the
muriate of strontian into an atom of water, and
an atom of chloride of strontium, precisely in
the manner explained in the last section, when
treating of the conversion of muriate of barytes
into chloride of barium by heat.

SECT. VI.

OF THE ATOMIC WEIGHTS OF LIME AND CALCIUM.

The salts of lime are either insoluble in water,
or they contain much water of crystallization, of

which they cannot be completely deprived, with-
out the risk of losing at the same time a portion
of their acid. On this account, the method
which I was obliged to employ in determining
the atomic weight of lime, was rather more com-
plicated than that which gave the atomic weights
of the other alkaline bodies contained in this
chapter; though it was equally decisive.

1. 6·25 grains of pure calcareous spar (kept Atomic
weight of
for twenty-four hours at a temperature higher lime deter-
mined.
than that of boiling water) were dissolved in
muriatic acid, and the solution evaporated to
dryness in a low temperature, in order to get
rid of all excess of acid. The muriate of lime,
thus rendered neutral, was re-dissolved in a
small quantity of distilled water. In another
portion of distilled water I dissolved 8·75 grains
of pure anhydrous carbonate of potash. These
two solutions being mixed, a double decomposi-
tion took place,—the lime and carbonic acid
precipitated in the state of carbonate of lime,
while the muriatic acid and potash remained in
solution in the state of muriate of potash.

The clear liquid remaining after the precipita-
tion of the carbonate of lime, produced no
change in the colour of cudbear pape and con-
sequently contained no sensible quantity of
carbonate of potash; and as it was not precipi-
tated by oxalate of ammonia, it contained no
sensible quantity of lime.

The carbonate of lime precipitated, being washed and dried, weighed just 6·25 grains, or exactly the same as the calcareous spar originally dissolved in the muriatic acid. It was obviously a compound of all the lime in 6·25 grains of calcareous spar, and all the carbonic acid in 8·75 grains of anhydrous carbonate of potash.

This carbonate of potash had been procured by exposing pure crystals of bicarbonate of potash to a red heat in a platinum crucible. It has been ascertained that this carbonate is anhydrous, and that it is a compound of

$$\begin{array}{ll} \text{1 atom carbonic acid} & = 2\text{·}75 \\ \text{1 atom potash} & = 6 \\ \hline & 8\text{·}75 \end{array}$$

From this it is obvious, that the 6·25 of carbonate of lime contained just 2·75 of carbonic acid, the remainder being lime, it is evident, that this carbonate is composed of

$$\begin{array}{ll} \text{Carbonic acid} & 2\text{·}75 \\ \text{Lime} & 3\text{·}50 \\ \hline & 6\text{·}25 \end{array}$$

2·75 being the atomic weight of carbonic acid, and the salt being neutral, 3·5 must be the weight of an atom of lime. It is clear likewise, that calcareous spar is a compound of one atom carbonic acid and one atom lime.

2. If a current of chlorine gas be made to pass through a quantity of lime heated to redness, this alkaline earth is decomposed, oxygen gas is disengaged, and chloride of calcium is formed. Sir H. Davy, to whom we are indebted for this experiment, ascertained that for every half volume of oxygen gas extricated, a whole volume of chlorine gas was absorbed. Now, these two being equivalent, respectively, to one atom, it is obvious that lime must be a compound of one atom oxygen and one atom calcium. Consequently, the atomic weight of calcium is 2·5.

3. Muriate of lime may be easily crystallized, by placing a concentrated solution of it under the exhausted receiver of an air pump, over a flat glass vessel containing a quantity of concentrated sulphuric acid. The crystals are large transparent four or six-sided prisms, usually striated longitudinally. They are composed of

1 atom muriatic acid		4·625
1 atom lime	. .	3·5
6 atoms water	.	6·75

14·875

When this muriate is cautiously exposed to a heat gradually raised to redness, it may be fused and converted into chloride of calcium with scarcely any loss of chlorine or muriatic acid. In that case it loses 7 atoms of water, 14·875 grains of the crystallized muriate being by this

treatment reduced to 7 grains of chloride of cal-
cium. I shall relate one experiment to show the
reader how near to these numerical results I
have been able to come. 12·5 grains of pure
calcareous spar (containing 7 grains of lime)
were dissolved in muriatic acid, in a plati-
num crucible, the weight of which had been
previously determined. The solution was slowly
evaporated to dryness, and the dry salt was
fused by exposing the salt to a red heat. The
fused salt was white and opaque, and weighed
13·98 grains, as nearly as could be determined.
Water being poured upon it, there remained
undissolved 0·17 grain of a white powder con-
sisting chiefly of carbonate of lime; but contain-
ing also one or two flocks of sulphate of lime,
apparently derived from a trace of sulphuric
acid, in the muriatic acid employed to dissolve
the calcareous spar. Now, 0·17 carbonate of
lime contain 0·095 lime = 0·0678 calcium, which
requires for saturation 0·122 chlorine, making
together 0·1898 chloride of calcium; which ex-
ceeds the 0·17 grain of carbonate of lime by very
nearly 0·02 grain; making (as near as I could
determine) almost exactly 14 grains.

Now, these 14 grains contained 2 atoms chlo-
rine = 9, and 2 atoms calcium, which must
amount to 5. So that the atomic weight of cal-
cium is obviously 2·5; and lime is a compound
of 1 atom oxygen and 1 atom calcium.

SECT. VII.

OF THE ATOMIC WEIGHTS OF MAGNESIA AND
MAGNESIUM.

THE atomic weight of magnesia may be deter-
mined in the same way as that of the fixed alka-
lies. For sulphate of magnesia, which crystallizes
in four-sided prisms with square bases, and is per-
fectly neutral, may be rendered anhydrous by
heat, without losing any of its acid.

1. 7·5 grains of anhydrous sulphate of mag- Atom of
nesia, and 13·25 grains of chloride of barium, determined.
were dissolved in two separate portions of dis-
tilled water. The two solutions being mixed
together and agitated, a double decomposition
took place, sulphate of barytes precipitated,
while muriate of magnesia remained in solution.
The supernatant liquid, after the sulphate of
barytes had subsided, was perfectly neutral.
Being tested by sulphate of soda, and muriate of
barytes, it did not become in the least muddy by
the addition of either of these reagents, showing
that it contained neither barytes nor sulphuric
acid. Hence, the sulphuric acid in 7·5 grains
of anhydrous sulphate of magnesia just saturates
the barytes from 13·25 grains of chloride of ba-
rium—so that it amounts to precisely 5 grains.
The remainder of the salt consisting of magne-

sia, it is evident that anhydrous sulphate of magnesia is a compound of

$$
\begin{array}{lr}
\text{Sulphuric acid} & 5 \\
\text{Magnesia} & 2\cdot5 \\
\hline
& 7\cdot5
\end{array}
$$

The salt being neutral, and 5 being the atomic weight of sulphuric acid, it is plain that $2\cdot5$ must represent the atomic weight of magnesia.

Composition of sulphate of magnesia.

2. By a careful analysis of the crystallized sulphate of magnesia, I have ascertained that it is a compound of

$$
\begin{array}{lrl}
\text{1 atom sulphuric acid} & = & 5 \\
\text{1 atom magnesia} & = & 2\cdot5 \\
\text{7 atoms water} & = & 7\cdot875 \\
\hline
& & 15\cdot375
\end{array}
$$

So that an integrant particle of it weighs $15\cdot375$. When $15\cdot375$ grains of these crystals are heated properly, the whole water may be driven off without the loss of any sulphuric acid or magnesia;—for the weight of the anhydrous salt is exactly $7\cdot5$ grains. $15\cdot375$ grains of crystallized sulphate of magnesia just precipitate all the barytes contained in a solution of $13\cdot25$ grains of chloride of barium.

Muriate of magnesia.

3. Muriate of magnesia is a deliquescent salt; but it may be obtained in large transparent crys-

tals, which by a careful analysis I find composed
as follows :

<div style="margin-left: 3em">

1 atom muriatic acid = 4·625
1 atom magnesia   = 2·5
5 atoms water .   = 5·625

                      ————
                       12·75

</div>

If it could be rendered anhydrous without the
loss of its acid, it would doubtless be reduced
to chloride of magnesium, weighing only 6
grains; but this cannot be done; for when
the muriate is heated, not only the water, but a
considerable portion of the acid flies off and
leaves the magnesia. I may state an experi-
ment, however; because it seems to show that a
chloride of magnesium might be formed, if the
requisite precautions were taken. It was the
only successful trial that I made, though my ex-
periments amounted to five or six. 15·31 grains
of pure anhydrous carbonate of magnesia, equiva-
lent to 7·29 grains of magnesia, were dissolved
in muriatic acid, and the solution being evapo-
rated to dryness, the muriate of magnesia was ex-
posed to an incipient red heat, with every pre-
caution which I could devise to prevent the
escape of the muriatic acid. The salt thus treated
weighed 13·3 grains, and had a whitish colour.
Water being poured upon it, the greater part
was dissolved with the evolution of much heat,

and there remained undissolved 3 grains of pure magnesia. Now, if we suppose the 10·3 grains which dissolved, to have been previously in the state of chloride of magnesium, they must have consisted of

Magnesium	2·575
Chlorine	7·725

10·300

And 2·575 grains of magnesium are equivalent to 4·29 grains of magnesia. Now, 4·29 + 3 = 7·29, which is the amount of the magnesia originally present in the carbonate employed. It would appear that in this experiment a chloride of magnesium was obtained.

Atom of magnesium.

It is obvious, if the preceding experiment deserves any confidence, that magnesia is a compound of

1 atom magnesium	1·5
1 atom oxygen	1·0

2·5

And this is corroborated by the following experiment originally made by Sir H. Davy. When magnesia is heated, and a current of chlorine gas passed over it, oxygen is given out, and the magnesia is converted into chloride of magnesium. Now, for every volume of chlorine absorbed, half a volume of oxygen gas is given out. This shows that magnesia contains only 1

atom of oxygen. Consequently, the weight of an atom of magnesium must be 1·5.

From the details contained in the different sections of this chapter, it is evident that the fixed alkalies and alkaline earths are all analagous substances, being each a compound of one atom of a metallic basis, and one atom of oxygen. Potassium, sodium, and barium combine with two doses of oxygen; though this has not been shown to hold with the other four bases contained in this chapter, yet it is probable, from the striking analogy between the properties of all these bodies, that they will be found hereafter to be in the same predicament.

Lithia is the lightest, and barytes the heaviest of these bodies. It may be worth while to subjoin a tabular view of the atomic weights of the metallic bases and the alkalies, arranged according to the weight.

BASES.	ATOMIC WEIGHTS.	ALKALIES.	ATOMIC WEIGHTS.	
Lithium	1·25	Lithia	2·25	Table of
Magnesium	1·5	Magnesia	2·5	the atoms of the alka-
Calcium	2·5	Lime	3·5	line metals
Sodium	3	Soda	4	and alka- lies.
Potassium	5	Potash	6	
Strontium	5·5	Strontian	6·5	
Barium	8·75	Barytes	9·75	

CHAP. IX.

OF THE ATOMIC WEIGHTS OF THE EARTHS PROPER.

THERE are four substances, which are now considered as metallic oxides, but which were long distinguished by the name of *earths proper.* When pure, they have the form of white tasteless powders,—insoluble in water, though capable of forming solid hydrates with that liquid. They combine readily with the acids, and form salts, which redden vegetable blues, and are decomposed by exposure to a red heat. These four bodies are *alumina, glucina, yttria,* and *zirconia.* We shall devote this chapter to the investigation of the atomic weights of these bodies.

SECT. I.

OF THE ATOMIC WEIGHT OF ALUMINA.

In a paper inserted in the Annals of Philosophy (Second Series), Vol. III. p. 61. I gave the result of a very laborious analysis of alum, from which I drew, as a conclusion, that the atomic weight of alumina was 2·25. Since that time, Mr.

R. Philips has published some experiments on the
sulphate of alumina, from which he considers it
most probable that the atomic weight of alu-
mina is 3·375. This opinion, from a man of Mr.
Philips' precision and extensive chemical know-
ledge, induced me to repeat the whole of my
experiments, and to extend my researches as far
as possible, in order to throw as much light as I
could upon this very important, but difficult sub-
ject. I shall in this section lay the result of my
experiments before the reader.

Methods of
determin-
ing the
atom of
alumina. There are three methods, by means of which
we may hope to come to an accurate conclusion
respecting the atomic weight of alumina. 1*st*. It
enters as a constituent into a great number of
crystallized minerals, which appear to be definite
combinations of acids and bases. By a rigid
analysis of these minerals in a state of purity,
and by our knowledge of the atomic weights
of all the other constituents, we may determine
the quantity of alumina which unites with a deter-
minate weight of the acid in the mineral, which
will give us the atomic weight of alumina, or
at least an approximation to it. 2*d*. Several arti-
ficial salts exist, containing alumina as one of the
constituents. A precise analysis of these salts,
in a state of purity, must lead to an accurate de-
termination of the saturating power of alumina,
and consequently give us its atomic weight. 3*d*.
Alumina enters into definite combinations with

water, and forms a variety of hydrates ; a precise analysis of which will also throw considerable light upon the atomic weight of alumina. Let us see what number we shall obtain for the atomic weight of alumina, deduced in each of these ways.

I. The number of minerals containing alumina as an essential constituent is very considerable. The acid substance with which it is most commonly combined is silica. It occurs, indeed, combined with phosphoric acid, fluoric acid, and mellitic acid ; but the mode of analyzing such combinations is still too imperfect to render it safe for us to trust to them for determining a point of such importance. Beryl would be an excellent mineral for our purpose, were it not that the atomic weight of glucina has not been yet determined with sufficient precision to allow us to employ it in investigating the atomic weight of alumina. I shall, therefore, satisfy myself with the following mineral species, all of which have been analyzed with much care, and in a state of as great purity as possible ; but I have investigated the atomic weight of alumina from a much greater number of species, and have obtained very nearly the same result as from the species which we are going to examine.

1. From the composition of minerals.

1. NEPHELINE.

Nepheline   It was stated in p. 177 of this work, that from the late analysis of nepheline, by Arfwedson, its constituents are as follows :

Silica	.	44·11
Alumina	.	33·73
Soda	.	20·46
Water	.	0·62

$$98·92$$

It was shown that nepheline is a compound of 3 integrant particles of silicate of alumina, and 1 integrant particle of sesquisilicate of soda. It was shown that the portion of silica united to the alumina was 29·17 grains.   Now,

29·17 (the quantity of silica) : 33·73 (the alumina) : : 2

Gives   (atom of silica) : 2·3126 = atom of alumina.
2·3126.

2. KARPHOLITE.

Karpholite   This rare mineral occurs in the Schlacken-wald in Bohemia, and was named by Werner, from the resemblance of its colour to straw.   It occurs in very fine needles, which usually diverge from a point.   Its specific gravity is 2·923 ; it seems to be rather soft.   Stromeyer,* from a very careful analysis of this mineral, has given its constituents as follows :

* Untersuchungen, I. p. 410.

Silica	.	.	.	36·154
Alumina	.	.	.	28·669
Deutoxide of manganese				19·160
Peroxide of iron	.		.	2·290
Lime	.	.	.	0·271
Fluoric acid		.	.	1·470
Water	.	.	.	10·780

$$98·794$$

It appears from Professor Stromeyer's experiments on this mineral, that it is usually mixed with particles of fluor spar. To the presence of this spar in minute quantities, I have no doubt that the lime and the fluoric acid found by Stromeyer owe their origin. It is true that the lime and fluoric acid were not found in the same proportions as they exist in fluor spar ; for I shall show, in a subsequent chapter of this work, that fluate of lime is a compound of

Fluoric acid	1·25
Lime	.	3·5

$$4·75$$

But the accurate analysis of this mineral is attended with so much difficulty, that much greater errors than those here suspected have been committed by the most expert analysts.

The manganese was obtained, and weighed by Stromeyer, in the state of deutoxide ; but it must have existed in the mineral, in the state of

protoxide. Now, the atomic weight of protoxide
of manganese is 4·5, and of deutoxide 5.   If we
reduce the manganese in the mineral in this pro-
portion, the quantity of protoxide will be 17·244
grains.   •

The peroxide of iron is probably foreign to
the constitution of the mineral, and may have
been introduced by percollation.

Now, if we suppose every atom of alumina to
be united to an atom of silica, and every atom of
protoxide of manganese to be united to $1\frac{1}{2}$ atom
of silica, we shall obtain data for calculating the
constituents of the mineral.   We shall consider
an atom of silica as 2, an atom of alumina as
2·25, and an atom of protoxide of manganese
as 4·5.

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 28·669
    (alumina in the mineral) : 25·483 = silica united to
    the alumina.

(2.) 4·5 (atom of protoxide) : 3 (atom and half of silica)
    : : 17·244 (protoxide in the mineral) : 11·496 = si-
    lica united to the manganese.

But 25·483 + 11·496 = 36·979, which exceeds
the whole silica found in the mineral by 0·825
grain ; but $\frac{1}{32}$ of the silica is united to the man-
ganese : consequently, 0·257 of this excess
must be referred to that portion of the silica.
There remains 0·568, which must be subtracted
from the 25·483 grains of silica, given by theory

as united to the alumina; so that the quantity of silica actually united with the alumina, according to Stromeyer's analysis, is 24·915. Now,

24·915 : 28·669 : : 2 (atom of silica) : 2·3013 = atomic weight of alumina.

<div style="text-align:right">Gives
2·3013.</div>

3. HARMOTOME.

This mineral, which occurs in a state of great purity in the lead mine at Strontian, in Argyleshire, was found, by Klaproth, to be composed of the following constituents:

<div style="text-align:right">Harmo-
tome</div>

Silica	. .	49
Alumina	. .	16
Barytes	. .	18
Water	. .	15
		——
		98

Let us consider this mineral as a compound of 3 integrant particles of trisilicate of alumina, and 1 integrant particle of bisilicate of barytes. Then,

(1.) 2·25 (atom of alumina) : 6 (three atoms silica) : : 16 (alumina in the mineral) : 42·666 = silica united to alumina.

(2.) 9·75 (atom of barytes) : 4 (two atoms silica) : : 18 (barytes in the mineral) : 7·384 = silica united to barytes.

But 42·666 + 7·384 = 50·05 ; and this exceeds the silica found in the mineral by 1·05 grain.

The silica united to the barytes being $\frac{1}{7}$th of the whole, $\frac{1}{7}$th of this excess must be referred to that portion. There remains 0·9, which must be subtracted from the 42·666 grains of silica, given by theory as united to the alumina. This being subtracted, leaves 41·766 for the silica actually combined with the alumina, according to Klaproth's analysis. Now,

Gives
2 2985

41·766 : 16 : : 6 : 2·2985 = atomic weight of alumina.

4. MEIONITE.

Meionite

Of this mineral, which occurs most abundantly on Monte Somma, near Naples, but which has been found also in other places, and indeed is probably identical with scapolite, we have several very careful analyses.*

According to the experiments of Dr. L. Gmelin of Tubingen, its constituents are as follows :†

Silica	.	.	40·8
Alumina	.	.	30·6
Lime	.	.	22·1
Soda, with some lithia			2·4
Oxide of iron		.	1·0
Carbonic acid and loss		.	3·1

100·0

---

* The mineral analyzed by Arfwedson, from which Berzelius has taken his notion of the composition of meionite, was obviously a leucite.

† Schweigger, XXV. 36.

By comparing this analysis with the two follow-ing, it will appear probable that the alkali, oxide of iron, and carbonic acid, are merely accidental ingredients; and that silica, alumina, and lime, are the only essential constituents.

Let us consider meionite as a compound of 2 integrant particles of silicate of alumina and 1 integrant particle of silicate of lime; and let us calculate its constitution.

(1.) 2·25 (atom of alumina) : 2 (atom of silica) : : 30·6 (alu-mina in the mineral) : 27·2 = silica united to alu-mina.

(2.) 3·5 (atom of lime) : 2 : : 22·1 : (lime in the mineral) : 12·62 = silica united to the lime.

But 27·2 + 12·62 = 39·82. Now, the silica actually found in the meionite exceeds this by 0·98 grain.

The silica united to the lime amounts to $\frac{1}{3\cdot15}$th of the whole; consequently, $\frac{1}{3\cdot15}$th of 0·98 or 0·311, belongs to the silica united to the lime. There remains 0·669, which being added to the 27·2, makes 27·869 for the silica united to the alumina in meionite by Gmelin's analysis. Now

27·869 : 30·6 : : 2 : 2·196 = atomic weight of alumina.

Professor Stromeyer analyzed some very pure specimens of meionite from Monte Somma, and found the constituents as follows:[*]

Silica   .   .   .   40·531
Alumina   .   .   .   32·726
Lime   .   .   .   24·245
Potash with some soda   1·812
Oxide of iron   .   .   0·182
                                        ─────────
                                        99·496

Here the alkali differs both in quantity and kind
from that found by Gmelin, and the oxide of
iron is not quite ⅕th of the quantity obtained by
that chemist. Let us calculate the composition
of this mineral, on the same supposition as we
made when calculating the result of Gmelin's.

(1.) 2·25 : 2 : : 32·726 : 29·08 = silica united to the alu-
    mina.
(2.) 3·5 : 2 : : 24·245 : 13·854 = silica united to lime.

But 29·08 + 13·854 = 42·934, which exceeds
the silica found in the mineral by 2·403 grains.
The silica united to the lime is $\frac{1}{3·09}$th of the
whole. Now $\frac{1}{3·09}$th of 2·403 is 0·777, which be-
ing subtracted from 2·403 leaves 1·626 to be
taken from the 29·08, making 27·454 for the
amount of the silica actually united to the alu-
mina. Now,

27·454 : 32·726 : : 2 : 2·3841 = atomic weight of alumina.

Professor Strömeyer likewise analyzed a spe-
cimen of meionite from Sterzing in the Tyrol,
and found its constituents as follows :*

* Untersuchungen, I. 590.

Silica . . .	39·915
Alumina . .	31·970
Lime . . .	23·856
Potash with some soda	0·894
Protoxide of iron .	2·242
Protoxide of manganese	0·174
Water . . .	0·949

100·000

The variation in the proportion of alkali and oxide of iron is equally conspicuous in this analysis. Let us calculate the constitution of the mineral on the former supposition.

(1.) $2·25 : 2 : : 31·97 : 28·417 =$ silica united to alumina.
(2.) $3·5 : 2 : : 23·856 : 13·632 =$ silica united to lime.

But $28·417 + 13·632 = 42·049$, which exceeds the quantity of silica present in the mineral by 2·134 grains.

The silica united to the lime is $\frac{1}{3·08}$th of the whole. Now $\frac{1}{3·08}$th of $2·134 = 0·69$; and $2·134 —0·69 = 1·444$, which must be subtracted from the 28·417, leaving 26·973. And

$26·973 : 31·97 : : 2 : 2·3705 =$ atomic weight of alumina.

We have obtained three different atomic weights of alumina, namely,

1. From Gmelin's analysis . . .	2·1960
2. From Stromeyer's analysis of Monte Somma meionite	2·3841
From ditto of Tyrol meionite . .	2·3705

3) 6·9506

Mean . . . 2·3168

Gives
2·3168.

T 4

5. SCAPOLITE.

Scapolite   We have a very careful analysis of this mineral in a state, apparently, of great purity, by Mr. Nordenskiöld.[*] He found its constituents as follows:—

Silica	.	.	43·83
Alumina	.	.	35·43
Lime	.	.	18·96
Water	.	.	1·03
			99·25

The only difference between the composition of meionite and scapolite seems to be, that the former contains only 2 integrant particles of silicate of alumina united to 1 integrant particle of silicate of lime, while the latter contains 3.

Let us calculate the constitution of this mineral on the same supposition as of meionite:

(1.) $2·25 : 2 : : 35·43 : 31·049 =$ silica united to alumina.
(2.) $3·5 : 2 : : 18·96 : 10·834 =$ silica united to lime.

Now, $31·049 + 10·834 = 41·883$, which is less than the silica found in the mineral by $1·947$ grain. Of this surplus, ¼th, or 0.487 must be united to the lime—the remaining $1·460$ grain must be added to the $31·049$, making $32·409$. And

Gives $32·409 : 35·43 : : 2 : 2·0580 =$ atomic weight of alumina.
2·0580.

* Bidrag till Närmare Kännedom af Finland's Mineralier och Geognosie, p. 63.

6. SCOLEZITE.

This mineral was analyzed with great care by
Gehlen and Fuchs, who, from a mean of many
trials, state its constituents as follows:

Silica	.	.	.	46·4
Alumina	.	.	.	25·7
Lime	.	.	.	14·2
Water	.	.	.	13·6
				100·0

I have analyzed various specimens of scolezite;
but only one of them was quite free from soda,
and its constituents were almost exactly the same
as those found by Gehlen and Fuchs. In the
other specimens the quantity of soda varied from
0·5 to 1·5 per cent.; showing that the mineral
contained a mixture of natrolite.

Let us suppose that scolezite is a compound of
3 integrant particles of silicate of alumina and 1
integrant particle of trisilicate of lime, with 3
atoms of water, and let us see what its constitu-
ents will be on that supposition.

2·25 : 2 : : 25·7 : 22·844 = silica united to alumina.
3·5 : 6 : : 14·2 : 24·3428 = silica united to lime.

Now, 22·844 + 24·3428 = 47·1868, which sur-
passes the silica actually found in scolezite by
0·6868.

The silica united to the lime is $\frac{1}{1·93}$ of the

whole; and $\frac{1}{1\cdot95}$d part of 0·6868 = 0·3557. This being subtracted from 0·6868 leaves 0·3311, which must be taken from 22·844, leaving 22·513 for the silica actually combined with the alumina in the mineral. And

Gives
2·2831.

22·513 : 25·7 : : 2 : 2·2831 = the atomic weight of alumina.

7. BUCHOLZITE.

Bucholzite From the account of this mineral given in page 175 of this work, it appears that its constituents, according to Brande's analysis, are as follows:

Silica	.	.	.	46
Alumina		.	.	50
Oxide of iron	.	.	.	2·5
Potash	.	.	.	1·5
				100·0

And that the silica united to the alumina in this mineral is 44·391 grains. Now,

Gives
2·2527.

44·391 : 50 : : 2 : 2·2527 = an atom of alumina.

8. LEUCITE.

Leucite This mineral, which abounds so much in the neighbourhood of Mount Vesuvius, and which always occurs crystallized, was found by Arfwedson to be composed of

Silica	.	.	.	56·1
Alumina	.	.	.	23·1
Potash	.	.	.	21·15
Oxide of iron		.	.	0·95
				101·3

Let us calculate the composition of this mineral, on the supposition that each of the three bases are combined with two atoms of silica, constituting as many bisilicates :

(1.) 2·25 : 4 : 23·1 : 41·066 = silica united to alumina.
(2.) 6 : 4 : : 21·15 : 14·1 = silica united to potash.
(3.) 4·5 : 4 : : 0·95 : 0·844 = silica united to iron.

Now, 41·066 + 14·1 + 0·844 = 56·01, which is less than the silica actually found in the mineral by 0·09 grain.

The silica united to the potash and the iron amounts to $\frac{1}{3·748}$th of the whole. The $\frac{1}{3·748}$th of 0·09 is 0·024, which, being subtracted, leaves 0·066 to be added to 41·066, in order to have the silica actually united to the alumina in the mineral, it will amount to 41·132 grains. And

41·132 : 23·1 : : 4 : 2·2464 = atomic weight of alumina. Gives 2·2464.

9. THOMSONITE.

This mineral, which hitherto has been found only in the Kilpatrick hills, near Glasgow, and which had been considered as a mesotype, has been constituted into a new species by Mr. Brooke, on account of the peculiar form of its primary crystal. I made a very careful analysis of this mineral,* and found its constituents as follows :

Thomson-ite

* Annals of Philosophy, XVI.

Silica	.	.	.	36·8
Alumina	.	.		31·36
Lime	.	.	.	15·4
Magnesia	.	.		0·2
Peroxide of iron		.		0·6
Water	.	.	.	13·0

$$97·36$$

Let us consider it as a compound of three integrant particles of silicate of alumina and one integrant particle of silicate of lime, together with $2\frac{1}{2}$ atoms of water; and let us calculate its composition according to that opinion.

(1.) $2·25 : 2 : : 31·36 : 27·875 =$ silica united to alumina.
(2.) $3·5 : 2 : : 15·4 : 8·8 =$ silica united to lime.

Now, $27·875 + 8·8 = 36·675$, which is less than the silica found in the mineral by $0·175$ grain.

The silica united to the lime is $\frac{1}{4}$th of the whole. Now, $\frac{3}{4}$ths of $0·175 = 0·132$, which must be added to the $27·875$, in order to have the silica actually united to the alumina in the mineral; this makes $28·007$. And

Gives
2·2395. $28·007 : 31·36 : : 2 : 2·2395 =$ atomic weight of alumina.

10. NATROLITE.

Natrolite   This mineral, which corresponds with the *mesotype* of Brooke, was analyzed with great care by Gehlen and Fuchs. They found its composition, from a mean of many experiments, as follows:

Silica	.	.	.	48
Alumina		.	.	26·5
Soda	.	.	.	16·2
Water	.	.	.	9·3

$$100·0$$

I analyzed a beautifully crystallized and pure specimen, which I received from Mr. Heuland, and found its composition almost identical with the preceding analysis.

Let us calculate the composition of this mineral, on the supposition that it is a compound of 3 integral particles of silicate of alumina, and 1 integrant particle of trisilicate of soda, with 2 atoms of water.

(1.) $2·25 : 2 : : 26·5 : 23·555$ = silica united to alumina.
(2.) $4 : 6 : : 16·2 : 24·3$ = silica united to soda.

Now, $23·555 + 24·3 = 47·855$, which is less than the silica found in the mineral by 0·145 grain. One half of the silica being united to the lime, it is obvious that, in order to have the true quantity of silica united to the alumina in natrolite, we must add 0·0725 to the 23·555 grains, given by theory. And

$23·6275 : 25·7 : : 2 : 2·1754$ = atomic weight of alumina. Gives 2·1754.

11. FELSPAR.

Felspar consists essentially of silica, combined Felspar

with alumina of potash. It has been often ana-
lyzed; but the different results obtained do not
well agree with each other. The reason is, that
felspar almost always occurs in granite, which is
a compound roek; and the other constituents,
doubtless, mix themselves with it in greater or
smaller proportions. According to the analysis
of felspar by Rose, which is one of the latest
and most careful that have been made, the con-
stituents of felspar are as follows:

Silica	. . .	66·75
Alumina	. . .	17·50
Potash	. . .	12·00
Lime	. . .	1·25
Oxide of iron	. .	0·75
		98·25

Let us suppose that all the bases are combined
with silica, and in the state of trisilicates, except
potash, which is a quadrosilicate; and let us
calculate its constitution according to that sup-
position.

(1.) $2\cdot25 : 6 : : 17\cdot5 : 46\cdot666 =$ silica united to alumina.
(2.) $6 : 8 : : 12 : 16 =$ silica united to potash.
(3.) $3\cdot5 : 6 : : 1\cdot25 : 2\cdot143 =$ silica united to lime.
(4.) $4\cdot5 : 6 : : 0\cdot75 : 1 =$ silica united to oxide of iron.

Now, $46\cdot666 + 16 + 2\cdot143 + 1 = 65\cdot809$, which
is less than the silica in the mineral by $0\cdot941$.
The silica united to the potash, lime, and iron,

amounts to $\frac{1}{3.43776}$th part of the whole. And the $\frac{1}{3.43776}$th part of $0.941 = 0.273$, which being taken from 0.941 leaves 0.668, which must be added to the 46.666 given by theory. Now

$47.334 : 17.5 : : 6 : 2.2183 =$ atomic weight of alumina.   Gives 2.2183.

12. ALBITE.

Albite is a name given to a mineral which was   Albite long confounded with felspar. Eggertz * first pointed it out as a distinct mineral ; it was after-wards analyzed by Stromeyer from Chesterfield in North America, by whom it received the name of *kieselspath*.† Mr. Brookes has called it *cleavelandite*.‡ Rose has given a minute descrip-tion of the crystals of this mineral, which differ a good deal from those of felspar.

Stromeyer found an uncrystallized specimen from North America composed of

Silica	.	.	70.676
Alumina	.	.	19.801
Soda	.	.	9.056
Lime	.	.	0.235
Oxide of iron and manganese	0.111

99.879

Rose found the specific gravity of albite to vary from 2.608 to 2.619. The constituents of the crystals he found

* Afhandlingar, V. p. 27.   † Untersuchungen, p. 300.
‡ Introduction to Crystallography, p. 459.

Silica	.	68·46
Alumina	.	19·30
Soda	.	9·12
Lime	.	0·68
Oxide of iron		0·28
		97·84[*]

Let us suppose the bases combined with silicon in the state of trisilicates, and let us calculate the composition on that supposition from Rose's analysis.

(1.) $2·25 : 6 : : 19·3 : 51·466 =$ silica united to alumina.
(2.) $4 : 6 : : 9·12 : 13·68 =$ silica united to soda.
(3.) $3·5 : 6 : : 0·68 : 1·165 =$ silica united to lime.
(4.) $4·5 : 6 : : 0·28 : 0·373 =$ silica united to protoxide of iron.

Now, $51·466 + 13·68 + 1·165 + 0·373 = 66·684$, which is less than the silica in the mineral by 1·776 grain. It is not improbable that, if the loss, amounting to rather more than two per cent., and which was more likely to fall upon the bases than the silica, had not taken place, this excess of silica would not have occurred in our calculation. But let us see what the atomic weight of alumina will be, supposing the analysis accurate.

The silica united to the soda, lime, and oxide of iron is $\frac{27}{71}$ part of the whole; and $\frac{27}{71}$ part of $1·776 = 0·655$, which being taken from 1·776

leaves 1·121 to be added to the 51·466 given by theory. Now, $52·587 : 19·3 : : 6 : 2·202 =$ ato- ^{Gives} mic weight of alumina.

The 12 preceding minerals constitute a suffi-cient number to enable us to approach pretty nearly to the atomic weight of alumina. That weight comes out somewhat differently from each mineral. This may be partly occasioned by small errors in the analyses; but it is owing chiefly to impurities existing in the specimens analyzed, the presence of which we have no means of determining. If a mineral contains mixed with it some silica, or a portion of any stone containing more silica than itself, the ato-mic weight of the alumina will come out too high. The contrary will be the case, when the mineral contains an excess of alumina, or of a stone containing more alumina than the speci-men now under examination. An accurate knowledge of the rock from which the specimen was taken, and of the minerals accompanying it, might throw some light upon the foreign matter most likely to be present. But this has not yet been sufficiently attended to ;—meanwhile, it is probable, that the errors in the atomic weight of alumina, resulting from these foreign matters, will be on different sides in different analyses ; consequently, the mean atomic weight from all the twelve analyses given above will come near the truth. Let us therefore see what

atomic weight of alumina will be derived from
that mean.

1.	Nepheline gives the atomic weight					2·3126
2.	Karpholite	.	.	.	.	2·3013
3.	Harmotome	.	.	.	.	2·2985
4.	Meionite	.	.	.	.	2·3168
5.	Scapolite	.	.	.	.	2·0580
6.	Scolezite	.	.	.	.	2·2831
7.	Bucholzite	.	.	.	.	2·2527
8.	Leucite	.	.	.	.	2·2464
9.	Thomsonite	.	.	.	.	2·2395
10.	Natrolite	.	.	.	.	2·1754
11.	Felspar	.	.	.	.	2·2183
12.	Albite	.	.	.	.	2.2020

12)26·9046

Mean gives
2·24205.   Atomic weight of alumina   .   2·24205

The reader will observe that the greatest
atomic weight of alumina is deduced from meion-
ite, and amounts to 2·3168, which is very far
short of 3·375, the atomic weight pitched upon
by Mr. Phillips. The least weight is 2·0580,
which is derived from scapolite.

Upon the whole, the atomic weight of alu-
mina derived from the constitution of these min-
erals, though it would be hazardous to consider
it as quite exact, cannot be very far from the
truth ;—and it differs from 2·25 by a very small
2. From
the analysis
of alum. fraction.

II. The aluminous salt most easily obtained

in a state of purity, and in regular crystals fit for examination, is *alum*. Of this triple salt there are several species ; for it consists of a certain number of integrant particles of sulphate of alumina combined with sulphate of potash, or sulphate of soda, or sulphate of ammonia, or sulphate of magnesia, and perhaps of some other soluble sulphate which I have not tried. The crystals of alum consist of regular octahedrons, and neither the figure nor the taste of the salt is altered by substituting any of the above named sulphates for the others. The species of alum which I chose as upon the whole of easiest analysis, and capable of being obtained with the greatest facility, was the common alum of this country, composed of sulphuric acid, alumina, potash, and water, or of sulphate of alumina and sulphate of potash, united together with a certain quantity of water of crystallization. As the analysis of this salt was attended with considerable difficulty, but was made with the utmost possible attention to precision, it will be proper to give a somewhat detailed account of it.

1. 60·875 grains of pure alum crystals were dissolved in hot water, and the liquid was mixed with a solution of 53 grains of chloride of barium. A double decomposition immediately took place, and sulphate of barytes precipitated to the bottom : when the supernatant liquid had become transparent and colourless, it was tested by sul-

phate of soda and muriate of barytes, but was
not affected by either; showing that it contained
no sensible quantity of barytes or sulphuric acid.
It follows from this experiment, that the sulphu-
ric acid in 60·875 grains of alum is just saturated
by the barytes from 53 grains of chloride of
barium. But 53 is equal to 13·25 × 4; and
13·25 grains of chloride of barium require just
5 grains of sulphuric acid to saturate all the ba-
rytes which they yield. It is obvious from this,
that 60·875 grains of alum contain exactly 20
grains of sulphuric acid.

2. 60·875 grains of alum crystals were put
into a platinum crucible, which was left for an
hour on a hot sand bath. After it had been re-
duced to the state of burnt alum by the loss of
its water of crystallization, it was introduced
into a wind furnace, and kept for an hour in a
bright red heat. The loss of weight sustained
was 43·62 grains.

The alum thus treated, was digested in dis-
tilled water, and then thrown upon the filter.
The alumina left upon the filter was washed
till the liquid which passed through ceased to
precipitate muriate of barytes. The liquid which
passed through the filter was concentrated on
the sand bath, and then precipitated by muriate
of barytes. The sulphate of barytes obtained,
after being washed, dried, and heated to redness,
weighed 13·28 grains, which is equivalent to

4·504 grains of sulphuric acid; if we add this to the original loss, we obtain 48·124 grains for the amount of the water and sulphuric acid in 60·875 grains of alum. Deducting the 20 grains of sulphuric acid which we know to be present, there remain 28·124 grains for the water of crystallization.

But an integrant particle of water weighs 1·125, and 1·125 × 25 = 28·125. From this it is obvious, that 60·875 grains of alum contain 28·125 grains of water, which is equivalent to 25 atoms.

3. 60·875 grains of alum crystals were exposed in a platinum crucible to the heat of the sand bath, and afterwards to a dull red heat for an hour. Distilled water was poured upon the residual matter in the crucible in successive portions, and digested on it till it ceased to take up any thing; this water being evaporated to dryness, left 11 grains of sulphate of potash. Hence, 60·875 grains of alum contain 6 grains of potash. We see, too, that one-fourth of the sulphuric acid is united to the potash : the remaining three-fourths must be in combination with the alumina.

4. To obtain the alumina, 60·875 grains of alum were dissolved in distilled water, and to the solution was added the quantity of carbonate of potash just necessary to saturate 15 grains of sulphuric acid. The experiment was repeated

with carbonate of soda and carbonate of ammo-
nia. Six experiments made in this way gave the
mean quantity of alumina from 60·875 grains of
alum, equal to 6·746 grains ; but the true quan-
tity is obviously 6·75 grains : because this small
addition is necessary to complete the weight of
the alum.

From the preceding detail it is evident that
alum is composed of

> Sulphuric acid   20
> Alumina   .   6·75
> Potash   .   6
> Water   .   28·125
> ————
> 60·875

One integrant particle of the sulphuric acid is
united to the potash, and three to the alumina.
It is obvious from this, that 6·75 must represent
the weight of three atoms alumina. Consequent-
ly, the weight of alumina is $\frac{6.75}{3} = 2.25$.

Atomic
weight =
2·25.

The composition of alum may be stated some-
what differently. For it is obviously composed
of

> 3 atoms sulphate of alumina   = 21·7⁵
> 1 atom sulphate of potash   = 11
> 25 atoms water   .   .   = 28·125
> ————
> 60·875

The analysis of alum just given was made by

me during the course of the summer of 1821,
and was repeated so frequently that I considered
myself as quite certain of its accuracy. But
after Mr. Phillips published his experiment on
sulphate of alumina, and his suspicion that
3·375 was the true weight of an atom of alu-
mina, I resolved to repeat the whole again.
This I accordingly did during the summer of
1823. The result which I obtained may be con-
sidered as absolutely identical, for the only dif-
ferences took place in the second decimal place;
and the ratios of the constituents of alum de-
duced from this second analysis, did not de-
viate $\frac{1}{1000}$th part from those of the preceding
analysis.

If the weight of alumina were 3·375 instead
of 2·25, we should obtain from 60·875 grains of
alum no less than 10·125 grains of alumina, in-
stead of 6·75, which I obtained; so that I must
have lost more than 30 per cent. of the alumina;
which, from the care with which the experiment
was made, I consider as impossible.

But my analysis of alum is corroborated and
confirmed by the analysis of this salt made pre-
viously by Berzelius. When we correct his
statements by means of the more accurate data
given in this work, his analysis of alum is as
follows :*

* Ann. de Chim. LXXXII. 258.

Sulphuric acid	33·85	or	20·6060
Alumina .	10·86	-	6·5958
Potash .	9·90	-	6·0266
Water .	45·00	-	27·3940
	99·61		60·6224
Loss . .	.	.	0·2526
			60·8750

According to this analysis, 3 atoms of alumina weigh 6·5958. Consequently, the weight of the atom of alumina is 2·1986, which is a little less than the result of my analysis of alum.

In a subsequent chapter of this work, when I come to treat of the salts of alumina, it will be seen that the atomic weight of alumina just given, is corroborated by many other aluminous salts which have been subjected to examination.

Mr. Phillips' experiment respecting the atom of alumina

Mr. Phillips' opinion, that the atomic weight of alumina is 3·375, seems, as far as I can judge, to be founded on the following experiment. He found that when moderately diluted, sulphuric acid was digested for a long time upon an excess of recently precipitated alumina, till it refused to take up any more;—the liquid, when filtered, had a tendency to precipitate a peculiar sulphate of alumina in white flocks;—the liquid, when dropped into water, rendered it milky, and a white sediment was deposited. He analyzed

this sulphate of alumina, and found it composed
of

Sulphuric acid   40
Alumina   .   40·83*

This he considers as inconsistent with 2·25 being
the atomic weight of alumina. But if 3·375 be
the atomic weight of that earth, he conceives
that his salt was a compound of

2 atoms sulphuric acid   10   or   40
3 atoms alumina   . 10·125 - 40·5

_____

20·125

But this is not the only view of the subject
which may be taken.

I may observe, in the first place, that alumina Explained.
is a much weaker base than any of the other
earths or alkaline bodies treated of in the pre-
ceding chapter. Now, it is a remarkable cir-
cumstance, which has been particularly illustrated
by Berzelius, that weak bases have the property
of combining in a much greater number of pro-
portions with acids than strong bases. I have
ascertained by experiment that alumina and
sulphuric acid may be united in three propor-
tions; namely,

1 atom acid + 1 atom alumina
1 atom acid + 2 atoms alumina
1 atom acid + 3 atoms alumina

* Annals of Philosophy (second series) IV. 280.

The first of these salts constitutes common sulphate of alumina, and it is an essential constituent of alum. The third of these salts is the mineral found in Sussex and other places, and known by the name of aluminite. For Stromeyer has shown that it is a compound of 1 atom sulphuric acid, 3 atoms alumina, and 9 atoms water. If potash be poured into a boiling hot solution of alum, an earthy precipitate falls, precisely similar in its nature with the substance which chemists formerly called *alum saturated with its earth.* This precipitate is a compound of 1 integrant particle of sulphate of potash, and 3 integrant particles of trisulphate of alumina, as was first proved by Riffault.* I find that the second of these salts, to which I give the name of disulphate of alumina, may be obtained by a process similar to the one followed by Mr. Phillips ; but not carried so far. It is soluble in water, and still possesses an astringent and sweetish sour taste.

Mr. Phillips' salt was a mixture or compound of disulphate of alumina and trisulphate of alumina, in the proportion of 3 atoms of the former salt to 1 atom of the latter. It was the trisulphate which precipitated when the solution was poured into water; and it was its tendency to fall down that explains the phenomena which

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* Ann. de Chim. et de Phys. XVl. 355.

Mr. Phillips considers so unaccountable. I need hardly observe that

	SULPHURIC ACID.		ALUMINA.
3 atoms disulphate contain	15	+	13·5
1 atom trisulphate . .	5	+	6·75
Total . . .	20	+	20·25

Now, this is equivalent to

Sulphuric acid   40
Alumina   40·5

—the very theoretic proportions which Mr. Phillips deduces from an erroneous atomic weight of alumina.

III. When alumina is precipitated from an alkaline solution, collected on a filter, well washed, and allowed to dry spontaneously on the filter in a dry warm room, a hydrate is obtained, composed of equal weights of alumina and water. This is an experiment which I have frequently made in Edinburgh and in London, where I was in the habit of working in a room elevated considerably above the ground; but in Glasgow, where my laboratory is in a ground floor situated in a clay soil, and consequently rather damp, I have found it much more difficult to obtain correct results, at least during the summer of 1823, which was uncommonly cold and wet, when I was occupied with this investigation. I shall relate one experiment which I made with consi-

3. From the hydrates of alumina.

derable care,—it will show how near the truth I
was able to come.

Bihydrate.   1. A quantity of alumina left upon the filter
in a temperature not exceeding 60°, for a couple
of months, was found to weigh 36·66 grains.
Being strongly ignited in a platinum crucible,
the weight was reduced to 17·85 grains. The
loss of weight, therefore, was 18·81 grains,
which gives the amount of the water in the hy-
drate.   Now, 17·85 : 18·81 : : 2·25 : 2·42624,
which exceeds 2 atoms of water by 0·17624 ;—
and this excess of water I find it difficult to get
rid of in a damp room. If we were to consider
the water in this hydrate as amounting to exactly
2 atoms, and to calculate the atomic weight of
alumina on that supposition, we have 18·81 :
17·85 : : 2·25 : 2·1352 = atomic weight of alu-
mina.   But the analysis of alum, given in a pre-
ceding part of this section, shows that there is
really an excess of water.   Besides, I have fre-
quently obtained a hydrate of alumina composed
exactly of equal parts of alumina and water,
showing that the atomic weight of alumina is
exactly 2·25, and that this hydrate contains 2
atoms water.

Hydrate.   2. When the bihydrate of alumina is dried in
a temperature of about 100°, it is reduced to the
state of a hydrate—at least very nearly, for I
have not always been able to obtain exactly the
atomic proportions, though the deviation was

small. I shall state one or two of the experiments numerically, that the reader may judge of the approximation.

(1.) 18·92 grains of alumina, dried on the filter in a temperature of 100°, being exposed to a strong red heat, were reduced to 13·49 grains; consequently, the water driven off amounted to 5·43 grains. Now,

$$13\cdot49 : 5\cdot43 :: 2\cdot25 : 0\cdot9055 = \text{ratio of water.}$$

(2.) 20 grains of alumina, which had been left upon a filter for three months, in a temperature which, during the day, was usually 85°, though during the night it was lower, as the fire was allowed to go out, being exposed to a strong red heat, was reduced to 13·45 grains; and, consequently, it had lost 6·55 grains. Now,

$$13\cdot45 : 6\cdot55 :: 2\cdot25 : 1\cdot099 = \text{ratio of water.}$$

It appears from this experiment, that by a great length of time the alumina may be brought into the state of a hydrate, consisting of 1 atom alumina and 1 atom water; for 1·099 is only a very little less than 1·125, the weight of an atom of water.

Such are the results which I have obtained respecting the atomic weight of alumina. They all conspire to show that it is very nearly 2·25, and that it cannot by any means amount to a

number nearly so high as 3·375. Indeed, from the constitution of alumina, there seems no reason to doubt that 2·25 is the true atomic weight of this earth.

Atom of aluminum.

The probability is, that alumina is a protoxide of aluminum. On that supposition, the atomic weight of aluminum will be 1·25.

SECT. II.

OF THE ATOMIC WEIGHT OF GLUCINA.

Though glucina has been known to chemists for more than twenty years, we are in possession of very few experiments from which we can deduce its atomic weight. Berzelius, so far as my knowledge extends, is the only person who has analyzed some of the salts of glucina with a view of determining its capacity of saturation, from which the atomic weight is easily deduced. Before relating the experiments which I have made to ascertain the atomic weight of this substance, it will be interesting to state the experiments of Berzelius, by which, in fact, my own were directed.

Analysis of sulphate of glucina by Berzelius.

1. Berzelius dissolved a quantity of glucina in an excess of sulphuric acid—evaporated the solution till the acid began to escape—and then washed it in alcohol to get rid of the excess of

sulphuric acid. The sulphate of glucina thus obtained was dissolved in water. The solution was mixed with carbonate of ammonia to precipitate the glucina, and heat was applied till the ammonia ceased to be disengaged. The glucina thus obtained, being well washed and heated to redness, weighed 0·553 parts : the liquid thus freed from glucina was precipitated by muriate of barytes. The sulphate of barytes, after being washed and heated to redness, weighed 5, which is equivalent to 1·6949 of sulphuric acid.*

Thus it appears, that the sulphate of glucina, formed by the above process, is composed of

Glucina   0·553   or   3·2627
Sulphuric acid 1·6949 -   10

Considering this salt as a bisulphate, Berzelius dissolved a portion of it in water and digested it over a quantity of carbonate of glucina free from ammonia. By this digestion he obtained a gummy looking liquid. Part of this being mixed with water, a white matter precipitated, (doubtless glucina) and the liquid being filtered, was decomposed by carbonate of ammonia and muriate of barytes precisely as the former salt. The glucina obtained weighed 1·001, and the sulphate of barytes 4·549, equivalent to 1·5573 sulphuric acid. Thus it appears, that the new

* Berzelius' Attempt, &c. p. 134.

16

gummy like sulphate of glucina was composed of

$$
\begin{array}{lcc}
\text{Glucina} & 1\cdot001 & \text{or} & 3\,2139 \\
\text{Sulphuric acid} & 1\cdot5573 & - & 5
\end{array}
$$

A portion of the gummy liquid, obtained as above described, was heated over a spirit lamp till it became dry, when it resembled *burned alum*. After ceasing to give out water from the heat of a spirit lamp, Berzelius exposed 2·5 parts of it to a red heat; the glucina left weighed 1·24 parts. Berzelius, considering the salt as perfectly dry, concludes it was composed of

$$
\begin{array}{lcc}
\text{Glucina} & 1\cdot24 & \text{or} & 4\cdot92 \\
\text{Sulphuric acid} & 1\cdot26 & - & 5 \\
\hline
& 2\cdot50 &
\end{array}
$$

It is obvious that the second of these three salts is neutral, being composed of one atom of acid and one atom of glucina. The first is a bisulphate, or a compound of two atoms acid and one atom glucina, while the third is a sulphate composed of one atom acid, and 1½ atom glucina.

These three analyses, however, are not absolutely correct; for the atomic weight of glucina differs a little in each.

$$
\begin{array}{lr}
\text{By the first it is} & 3.2627 \\
\text{second} & 3\cdot2139 \\
\text{third} & 3\cdot2800 \\
\hline
& 3)9\cdot7566 \\
\hline
\text{Mean} \quad = & 3\cdot2522
\end{array}
$$

This mean of 3·2522 must be exceedingly near the truth; as near, probably, as it is possible to come with our present analytical means by a direct analysis. I consider myself entitled to conclude from it, that the true atomic weight of glucina is 3·25. I leave out the two last decimal places, because they would destroy the law pointed out by Dr. Prout, which we have seen to hold in all the other atomic weights of bodies;—namely, that these weights are all multiples of 0·125, the atomic weight of hydrogen.

2. Berzelius likewise analyzed the muriate of glucina; and, although the muriates are not so easily analyzed with accuracy as the sulphates, it will be well worth our while to state the result of the analysis as constituting an exceedingly good approximation. The bimuriate of glucina was a crystallizable salt : but when the excess of acid was expelled, he obtained only a gummy like mass. This matter was dissolved in water, the solution filtered, and the glucina was thrown down by carbonate of ammonia, and the muriatic acid by nitrate of silver. The glucina weighed 0·626, and the chloride of silver 3·392, which is equivalent to 0·85962 of muriatic acid. According to this analysis, muriate of glucina is composed of

Glucina	0·266	or	3·3681
Muriatic acid	0·85962	-	4·625 *

The atomic weight of glucina deduced from this
analysis is 3·3681, which is a little higher than
that from the sulphate.   But the preponderancy
of evidence is entirely in favour of 3·25, the
weight deduced from the sulphates of glucina.

Composi-
tion of
emerald.

3. The *emerald* or *beryl* is the mineral from
which glucina was originally obtained, and in-
deed, we are scarcely in possession of any other
quarry from which this earth can even at present
be procured.   It is usually crystallized in six-
sided prisms, and has all the marks of being a
chemical compound.   Its constituents are silica,
alumina, and glucina, with mere traces of some
metallic oxides, which seem to act the part of
colouring matters.   It will be worth our while
to see what atomic weight will be deduced for
glucina from the constituents of this mineral.

Vauquelin and Klaproth published good ana-
lyses of emerald and beryl; but it will be better
to employ for our calculations the analysis by
Berzelius, which is much later, and which, from
the improvements introduced into the art of
analyzing minerals, is probably nearest the truth.
According to Berzelius, the constituents of this
mineral are as follows : †

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* Berzelius' Attempt, &c. p. 134.   † Afhandlingar, IV. 192.

Silica	68·35
Alumina	17·60
Glucina	13·13
Oxide of iron	0·72
Oxide of tantalum	0·27
	100·07

Let us consider the emerald as a compound of two atoms of trisilicate of alumina, and one atom of trisilicate of glucina, and let us see what the quantity of silica will be, supposing the atomic weights of alumina and glucina to be 2·25 and 3·25 respectively.

(1.) 2·25 (atom of alumina) : 6 (3 atoms silica) : : 17·6 (alumina in mineral) : 46·933 = silica united to alumina.

(2.) 3·25 (atom of glucina) : 6 : : 13·13 : 22·422 = silica united to glucina.

Now, 46·933 + 22·422 = 69·355, which exceeds the silica in the mineral by 1·005 grain. The silica united to the alumina is very nearly two-thirds of the whole; consequently, two-thirds of this surplus belongs to that portion of the silica. There remain 0·335 grain, which must be deducted from the 22·422. The remainder, 22·087, is the silica actually united to the glucina in the mineral. Now, 22·087 : 13·13 : : 6 : 3·5668 = atom of glucina.

2. EUCLASE.

There is another mineral, containing glucina, Composition of euclase.

X 2

namely *euclase ;* the constituents of which, according to the analysis of Berzelius, are as follows :

Silica	43·32
Alumina	30·56
Glucina	21·78
Oxide of iron	2·22
Oxide of tin	0·70
	98·58

Let us calculate the constitution of this mineral, on the supposition that it is composed of two atoms silicate of alumina, one atom of silicate of glucina, and a small quantity of bisilicate of iron, probably accidentally present.

(1.) $2·25 : 2 :: 30·56 : 27·164 =$ silica united to alumina.
(2.) $3·25 : 2 :: 21·78 : 13·403 =$ silica united to glucina.
(3.) $4·5 : 4 :: 2·22 : 1·973 =$ silica united to iron.

Now, $27·164 + 13·403 + 1·973 = 42·540$, which is less than the silica in the mineral by 0·98 grain. Two thirds of the silica are united to the alumina;—consequently, only one third of 0·98 or 0·33 is to be added to the 13·403, making 13·733 grains for the silica united to the glucina. And

$13·733 : 21·78 :: 2 : 3·1719 =$ atomic weight of glucina.

From these two minerals we obtain two different atomic weights of glucina, the first too high, and the second too low. The probability

is, that the mean of the two will give an atomic weight not very far removed from the truth.

Atomic weight from beryl   3·5668
                     euclase   3·1719
                              ─────────
                           2)6·7387
                              ─────────
      Mean   .   .   =   3·36935

This result, though too high, is much nearer the truth than that derived from the analysis of beryl alone.

4. I shall now relate the experiments by which I satisfied myself that 3·25 is the exact atomic weight of glucina.

(1.) I prepared a quantity of bisulphate of glucina precisely in the same way as had been previously done by Berzelius: 18·875 grains of this salt were put into a platinum crucible, and exposed for some time to a strong red heat:— there remained 3·25 grains of pure glucina.

(2.) 18·875 grains of the same salt, and 26·5 grains of chloride of barium, were dissolved in separate portions of distilled water. These two liquids being mixed, a double decomposition took place—sulphate of barytes falling to the bottom, while muriate of glucina remained in solution. This liquid, as soon as it had become transparent, was tested by sulphate of soda and muriate of barytes; but was not affected by either of these reagents, showing that it contained no sensible

quantity either of barytes or sulphuric acid. From this experiment, we see that the quantity of sulphuric acid in 18·875 grains of bisulphate of glucina just saturates the barytes from 26·5 grains of chloride of barium ; and consequently, amounts to exactly 10 grains.

(3.) Thus it appears, that 18·875 grains of bisulphate of glucina contain 3·25 grains of glucina and 10 grains of sulphuric acid ;—the rest must be water : consequently, the constituents of the salt are

Sulphuric acid	10
Glucina . .	3·25
Water . .	5·625
	18·875

Now, 10 is equivalent to 2 atoms of sulphuric acid, and 5·625 to 5 atoms of water. And comparing this analysis with those of Berzelius, no doubt can remain that 3·25 represents the weight of an atom of glucina.

Atom of glucina.

We have no data to determine the atomic weight of glucinum. But analogy leads to the supposition, that glucina is a compound of 1 atom glucinum and 1 atom oxygen—on that supposition an atom of glucinum will weigh 2·25.

Atom of glucinum.

SECT. III.

OF THE ATOMIC WEIGHT OF YTTRIA.

THOUGH yttria has been known for almost twenty years, the minerals in which it occurs have been hitherto met with only in Sweden; and even in that country, they are so scarce as hardly to be procured, except in pieces too small to admit of the extraction of a quantity of yttria sufficiently large to enable us to make experiments on the composition of the salts which it forms. Thus circumstanced, I have been necessarily confined to experiments made upon a very few grains of this earth; and though they were conducted with the most scrupulous attention to accuracy, I was not able to draw any satisfactory conclusions from them. I am, therefore, under the necessity of deducing the atomic weight of this earth from the experiments of Berzelius. Fortunately, this illustrious chemist is so remarkably accurate in his experiments, that they are sure to furnish an exceedingly good approximation.

1. Berzelius put 100 parts of dry carbonate of yttria into a small retort, a glass tube connected with the beak of which, was filled with dry mu-

Analysis of carbonate of yttria.

X 4

riate of lime.   Heat was applied and continued
till the retort began to soften.   By this process
the water was driven off and united to the muriate
of lime, the weight of which it had increased by
12·82 parts.   The yttria, thus freed from water,
was heated to redness in a platinum crucible, in
order to drive off the carbonic acid :—by this
process its weight was reduced to 57·7 parts.
From this analysis, it appears that carbonate of
yttria is composed of

Carbonic acid	29·48	or	2·75
Yttria	57·70	-	5·3825
Water	12·82	-	1·1959

100·00*

This analysis gives us 5·3825 for the atomic
weight of yttria.   But the water in the salt,
which obviously ought to amount to 1 atom, is a
little too high.   The probability is, that the wa-
ter absorbed by the muriate of lime would retain
a little carbonic acid.   If we divide the 42·3
parts which make up the carbonic acid and wa-
ter in the ratio of 2·75 : 1·125—which must have
been the true proportion of those bodies, on the
supposition that the salt was a chemical com-
pound,—we shall have the constituents of this
carbonate as follows :

* Annals of Philosophy, III 359.

Carbonic acid	30·019	or	2·75
Yttria	.	57·700	-	5·285
Water	.	12·281	-	1·125

100·000

This brings the atomic weight of yttria to 5·285, a number which must come pretty near the truth.

2. Berzelius dissolved 2·8 parts of pure yttria in sulphuric acid—evaporated the solution to dryness—and heated the residual sulphate till it ceased to give out acid vapours. It now weighed 5·392 parts. From this experiment he concluded, that anhydrous sulphate of yttria is composed of

Of sulphate of yttria.

Sulphuric acid	2·592	or	5
Yttria	.	.	2·8	-	5·4012

5·392*

By this experiment the atomic weight of yttria comes out 5·4012. But we have no satisfactory evidence that the salt was neutral, except that it was still soluble in water. I am disposed to think that a very small portion of the acid had been driven off: for if we suppose the constituents of the salt to have been

Sulphuric acid	2·685
Yttria	.	.	2·8

5·485

* Annals of Philosophy, III. 359.

—that is to say, had the acid been 0·093 more, then the atomic weight of yttria would have been 5·25.

3. Klaproth found that yttria precipitated from muriatic acid, and dried in the open air after being well washed, was a hydrate composed of

Yttria	.	.	.	69
Water	.	.	.	31
				100

For 100 parts of it when heated to redness lost 31 parts of its weight. Now, 31 : 69 : : 2·25 : 5·008 = atomic weight of yttria, supposing the hydrate to contain just 2 atoms water.

Thus we have got three atomic weights of yttria.

(1.) From the carbonate	.	.	5·285
(2.) From the sulphate	.	.	5·4012
(3.) From the hydrate	.	.	5·008
		3)	15·6942
Mean	. . . .		5·2314

This mean must be very near the truth : we may, therefore, adopt 5·25 as the true atomic weight of yttria in order to make that weight accord with Dr. Prout's law.

4. Gadolinite, the mineral in which yttria was first discovered, has been likewise analyzed with

great care by Berzelius, who found its constitu-
ents as follows :

Silica	. .	25·80
Yttria	. .	45·00
Protoxide of cerium		16·69
Protoxide of iron		10·26
Volatile matter		0·60

98·35 *

Let us calculate the composition of this mineral,
on the supposition that the yttria and oxides
of cerium and iron are respectively in the state
of silicates, and that the atomic weights of all
of these constituents are as follows :

Silica	. .	2
Yttria	. .	5·25
Protoxide of cerium		7·25
Protoxide of iron		4·5

(1.) 5·25 (atom of yttria) : 2 (atom of silica) : : 45 (yttria in
the mineral) : 17·14 = silica united to yttria.

(2.) 7·25 (atom protoxide of cerium) : 2 : : 16·69 : 4·302 =
silica united to the oxide of cerium.

(3.) 4·5 (atom of oxide of iron) : 2 : : 10·26 : 4·56 = silica
united to the oxide of iron.

Now, 17·14 + 4·302 + 4·56 = 26·002, which ex-
ceeds the silica found in the mineral by 0·2002
grain.

The silica united to the oxides of cerium and
iron being one third of the whole, it is ob-

* Afhandlingar, IV. 225.

vious, that one third of this surplus, or 0·0667 belongs to that portion; we have, therefore, 0·1335 grain to subtract from the 17·14, to obtain the quantity of silica in the mineral, actually united •to the yttria. It amounts to 17·0065. And

17·0065 : 45 : : 2 : 5·2921 = atomic weight of yttria.

5. There is another mineral, which was discovered by Berzelius at Finbo in Sweden, and analyzed with great care, namely, the yttrocerite, which he found composed as follows :

Lime	50
Yttria	8·1
Protoxide of cerium	16·45
Fluoric acid	25·45
	100·00*

Let us suppose the lime and yttria in this mineral to be in the state of neutral fluates, and protoxide of cerium in the state of a bifluate, and let us calculate the composition, on the supposition that the atom of fluoric acid is 1·25, which will be proved in a subsequent chapter.

(1.) 3·5 (atom of lime) : 1·25 (atom of fluoric acid) : : 50 (lime in the mineral) : 17·857 = fluoric acid united to lime.

(2.) 5·25 (atom of yttria) : 1·25 : : 8·1 : 1·928 = fluoric acid united to yttria.

(3.) 7·25 (atom of oxide of cerium): 2·5 (2 atoms fluoric acid) : : 16·45 : 5·672 = fluoric acid united to oxide of cerium.

* Afhandlingar, IV. 151.

Now, $17 \cdot 857 + 1 \cdot 928 + 5 \cdot 672 = 25 \cdot 457$, which exceeds the fluoric acid found in the mineral by 0·007 grain. But $\frac{92}{100}$ part of the fluoric acid are united to the lime and the cerium, so that only $\frac{8}{100}$ of 0·007 or 0·00056 grain require to be subtracted from 1·928, to have the fluoric acid actually united to the yttria, according to the analysis. This amounts to 1·9224. And

$$1 \cdot 9224 : 8 \cdot 1 : : 1 \cdot 25 : 5 \cdot 2668 = \text{an atom of yttria.}$$

6. There is still another mineral, namely, the *Yttrotantalite.* yttrotantalite, which appears to consist essentially of oxide of tantalum and yttria united together. But the other constituents vary so much, that no greatreliance can be put on the analyses hitherto given, the specimens appearing all exceedingly impure. There are three varieties, which differ a good deal from each other in the proportions of their constituents. The first variety has a black colour, and was found by Berzelius composed of

Oxide of tantalum	57
Tungstic acid .	8·25
Yttria . .	20·25
Lime . .	6·25
Oxide of iron .	3·50
Oxide of uranium	0·50

$$95 \cdot 75 \, *$$

* Afhandlingar. IV. 267.

The second variety, which is yellow, was composed of

Oxide of tantalum	60·124
Tungstic acid	1·044
Yttria	29·780
Lime	0·500
Oxide of iron	1·155
Oxide of uranium	6·622
	99·225

The third variety, which is dark brown, was composed of

Oxide of tantalum	51·815
Tungstic acid	2·592
Yttria	38·515
Lime	3·260
Oxide of iron	0·555
Oxide of uranium	1·111
	97·848

It must be obvious from a bare inspection of these three analyses, that the ratios between the oxide of tantalum and the yttria differ too much in each, to enable us to deduce from them any information, either respecting the atomic weights of yttria or oxide of tantalum;—not to mention the tungstic acid, the lime and the oxide of uranium, which are still more variable. But a comparison of the atomic weight of yttria, deduced from the analyses of gadolinite and yttrocerite, with the weights deduced from the car-

9

bonate, sulphate and hydrate of yttria, leave Atom of yttria. little doubt that the true atomic weight of this earth is 5·25.

Analogy is in favour of the notion, that yttria Of yttrium. is a compound of one atom of yttrium and one atom of oxygen ; on that supposition, the atomic weight of yttrium will be 4·25.

SECT. IV.

OF THE ATOMIC WEIGHT OF ZIRCONIA.

WE have no good data for calculating the atomic weight of zirconia. The best at present in our possession, are derived from the composition of the zircan and hyacinth, which have been repeatedly analyzed by Klaproth and Vauquelin. The constituents of this mineral, as deduced from their analyses, are as follows :

Zirconia	69·0	65	64·5	70	64·5	66	Analyses of
Silica	26·5	33	32·5	25	32	31	zircon.
Oxide of iron	0·5	1	1·5	0·5	2	2	
	96·0 *	99 †	98·5 ‡	95·5 §	98·5 ‖	99¶	

The great difference in these results renders it probable that none of the analyses is quite cor-

* Klaproth Bectrage, I. 222.　† Ibid. III. 271.　From Norway.
‡ Ibid. V. 130.　From the Circars.　§ Ibid. I. 231.　From Ceylon.
‖ Vauquelin, Jour. de Min. No. XXVI. 106.　¶ Vauquelin, Ibid.

rect. Indeed, neither Klaproth nor Vauquelin succeeded in freeing the zirconia completely from iron. But if we deduce the atomic weight of zirconia from these analyses, supposing the minerals to be simple silicates of zirconia mixed with a little silicate of iron, then the atomic weight of zirconia will be as follows :

From first analysis	5·247
From second	3·987
From third	4·043
From fourth	5·645
From fifth	4·134
From sixth	4·370
	6)27·426
Mean	4·537

A careful examination of a collection of hyacinth crystals, which I was favoured with some years ago by Mr. Heuland, serves, in some measure, to explain the reason of these anomalies. Besides crystals of zircon, I found among them likewise crystals of spinell, garnet, quartz, and some green fragments having the colour of emerald,—besides some black grains, apparently octohedral iron ore. It was doubtless owing to the presence of some of these foreign crystals that the alumina, which I observed in a former analysis of the hyacinth, is to be ascribed. Pure and regular crystals of hyacinth seem composed of

Zirconia	.	.	.	75
Silica	.	.	.	25
Oxide of iron	.	.	0·5

100·5

If we suppose the iron foreign, and the mineral a simple silicate, then the atomic weight of zirconia would be 6, which, from experiments immediately to be mentioned, I believe to be its true weight.

There is another mineral containing zirconia, which was discovered by Sir Charles Giesecke, at Kangerdluarsuk in Greenland ; and to which Professor Stromeyer, to whom we are indebted for a knowledge of its composition, gave the name of eudialite. It was found by Giesecke on the west coast of Greenland, in the same bed that contains the sodalite, and intimately mixed with that mineral and with hornblende. It is sometimes amorphous, and sometimes crystallized in rhomboidal octahedrons, with their edges truncated : it has a rose red, or rather a hyacinth red colour : it is hard enough to scratch glass, but is easily scratched by pyrope : it is easily reduced to powder, and the powder has a red colour : the specific gravity is 2·90355, according to Stromeyer : it is, therefore, considerably lighter than the pyrope, to which it bears a certain degree of resemblance. The specimen of this mineral in my possession, and for which I am indebted to the liberality of Sir Charles Giesecke,

Composition of eudialite.

exhibits a tendency to split into rhomboidal frag-
ments :—the fracture is flat, conchoidal, and
slightly splintery.   Before the blow pipe it melts
easily into a green coloured bead : it dissolves
with great faĉility in nitric or muriatic acids,
and gelatinizes like mesotype or apophyllite.
This solution and gelatinization takes place even
when the eudialite has been previously heated
to redness.   The constituents of this mineral,
from a mean of several careful analyses of it by
Stromeyer, are as follows :*

Silica	. . .	53·325
Zirconia	. . .	11·102
Lime	. . .	9·785
Soda	. . .	13·822
Protoxide of iron	.	6·754
Protoxide of manganese		2·062
Muriatic acid	. .	1·034
Water	. . .	1·801

99·685

The great number of constituents in this mineral
renders it very ill adapted for determining the
atomic weight of zirconia.   Let us suppose that
the muriatic acid is in combination with soda in
the mineral :—it will constitute 1·676 parts of
common salt, and the remaining soda will amount
to 13·13.   Let us now calculate the composition
of eudialyte, on the supposition that all the bases

* Untersuchungen, I. p. 438.

are combined with silica in the state of trisilicates, except the soda, which must be in the state of bisilicate; and let us consider the atomic weight of zirconia as 6, that of lime as 3·5, that of soda as 4, and that of protoxide of iron and manganese as 4·5.

(1.) 6 (atom of zirconia) : 6 (3 atoms silica) : : 11·102 : 11·102 = silica united to the zirconia.

(2.) 3·5 (atom of lime) : 6 (3 atoms silica) : : 9·785 : 16·77 = silica united to the lime.

(3.) 4 (atom of soda) : 4 (2 atoms silica) : : 13·13 : 13·13 = silica united to the soda.

(4.) 4·5 (atom of protoxide) : 6 (3 atoms silica) : : 8·816 : 11·75 = silica united to the protoxide of iron and manganese.

Now, 11·102 + 16·77 + 13·13 + 11·75 = 52·752. This is less than the whole silica in the mineral by 0·573. As the silica in combination with the zirconia constitutes $\frac{1}{48}$ of the whole, it is obvious, that, in order to have the quantity of silica united to the zirconia in the eudialite, we must add $\frac{1}{48}$ of 0·573 = 0·12 to 11·102, which will raise it to 11·222. This gives us

11·222 : 11·102 : : 6 : 5·9358 = atomic weight of zirconia,

according to the constitution of this mineral. Though this number be under 6, yet it approaches fully as near it as could be expected from so complicated a mineral; which, probably, was not free from some admixture both of sodalite and hornblende.

I shall now relate the experiments which I made to determine the saturating power of zirconia, and the quantity of water with which it is capable of combining.

(1.) A quantity of pure carbonate of zirconia was dissolved in muriatic acid, the solution was precipitated by ammonia, and the earth, after being well washed, was left for several weeks upon the filter in a temperature, which, during the day, was very nearly 85°; though it was a good deal lower during the night. The hydrate thus obtained had a greyish yellow colour, a certain degree of semitransparency, and broke with a fracture resembling that of glue. It was exposed to a strong red heat for nearly an hour, in order to drive off the water. I found that this hydrate was a compound of

Zirconia	. . .	6
Water	. . .	8·885

Now, 8·885 differs very little from 9, which represents the weight of 8 atoms of water. This leads to the inference, that the atomic weight of zirconia is 6, and that the hydrate was a compound of 1 atom zirconia and 8 atoms water.

(2.) Another quantity of zirconia, precipitated from the muriate, was well edulcorated and dried on the filter by means of steam, at the temperature of 212°. The hydrate thus obtained was decomposed in a strong red heat, and was found to be composed of

Zirconia	.	.	.	6
Water	.	.	.	1·125

Now, 1·125 represents an atom of water. Hence, the hydrate was a compound of 1 atom zirconia and 1 atom water; and this experiment also leads to the conclusion that an atom of zirconia weighs 6.

(3.) 11·85 grains of pure muriate of zirconia, not in crystals, but formed by dissolving zirconia in muriatic acid, and evaporating the solution to dryness in a low temperature, were dissolved in water, and the zirconia thrown down by ammonia. When properly washed and dried, and heated to redness, it weighed 4·331 grains. The liquid thus freed from zirconia, was neutralized by nitric acid, and the muriatic acid thrown down by nitrate of silver. The chloride of silver, after fusion, weighed 13·59 grains, equivalent to 3·444 grains of muriatic acid. From this experiment it follows, that muriate of zirconia is composed of

Muriate of zirconia.

Muriatic acid	3·444	or	4·625
Zirconia .	4·331	-	5·815
Water .	4·075	-	5·437

4·625 denotes the weight of an atom of muriatic acid—5·437 approaches pretty near to 5·625, the weight of 5 atoms of water—5·815 represents the atomic weight of zirconia, according to this experiment:—it is a little less than 6, the atomic weight deduced from the hydrates. I

am disposed to ascribe this to a slight excess of muriatic acid in the salt. My quantity of zirconia was not sufficient to give me muriate of zirconia in crystals.

These experiments are not quite decisive; but they lead to the conclusion, that the atomic weight of zirconia is 6.

CHAP. X.

OF THE ATOMIC WEIGHTS OF IRON, NICKEL, COBALT, MANGANESE, AND CERIUM.

These metals are very nearly related to each other, both in their atomic weights and in the proportions of oxygen with which they combine. Each of them forms at least two oxides, the first containing an atom of oxygen, and the second an atom and a half of oxygen united to an atom of the metal; and both of these oxides, at least in the case of iron and manganese, is capable of combining with acids. One of these metals, I mean manganese, unites with two, if not three, additional dozes of oxygen, forming an oxide neither possessing alkaline nor acid properties, and one or two oxides capable of combining with bases, and consequently, possessing the characters of acids.

SECT. I.

OF THE ATOMIC WEIGHT OF IRON.

Protosulphate of iron, or *green vitriol*, is a salt which has been long known, and manufac-

Analysis of protosulphate of iron.

Y 4

tured for the use of dyers and other artists.   It
crystallizes in four-sided oblique prisms with a
rhombic base, is transparent, has a light green
colour, and a sweetish astringent taste.   It may
be obtained perfectly pure from the copperas
manufactories ; or by dissolving the salt of com-
merce in boiling water, filtering the solution
while hot, and allowing it to crystallize by cool-
ing.   I employed this salt to determine the
atomic weight of protoxide of iron, and I shall
now state the method by which I proceeded.

1. 17·375 grains of pure dry crystals of proto-
sulphate of iron were dissolved in water, and
mixed with a solution of 13·25 grains of chloride
of barium.   A double decomposition immediate-
ly took place, and sulphate of barytes precipi-
tated to the bottom of the vessel.   When the
liquid had become clear after the subsidence of
this sulphate, it was tested by means of sulphate
of soda, and muriate of barytes ; but was not
affected by either of these reagents, showing that
it neither contained barytes nor sulphuric acid.
From this experiment it is evident, that the
barytes from 13·25 grains of chloride of barium,
just saturates the sulphuric acid in 17·375 grains
of crystallized protosulphate of iron.   Conse-
quently, 17·375 grains of protosulphate of iron
contain exactly 5 grains of sulphuric acid.

2. 17·375 grains of crystallized protosulphate
of iron were exposed for some time in a plati-

num crucible to a heat of between 500° and 600°. The loss of weight was 7·6 grains.

Now, as 17·375 grains of this salt contain just 5 grains of sulphuric acid, which is equivalent to the weight of an atom, the water of crystallization ought likewise to be a determinate number of atoms. Now, 7·875 grains would be equivalent to 7 atoms. And the water actually found was 7·6 grains, which is only 0·275 grains, or ¼th of an atom less than 7 atoms.

But all the water cannot be separated from this salt by heat, without at the same time decomposing and separating a portion of the sulphuric acid. Sulphurous acid begins to be disengaged, and sulphuric acid in a liquid state (and therefore containing water) trickles down the sides of the retort.

It is easy to show that the water which remains behind, and which comes over united to the sulphuric acid, is exactly ¼th of an atom. For the sake of explanation, I shall take for granted what will be proved in the subsequent part of this section ; namely, that an atom of iron weighs 3·5, an atom of protoxide of iron 4·5, and an atom of peroxide of iron 5.

When protosulphate of iron, freed from as much water of crystallization as possible, is strongly heated, the protoxide of iron which it contains is converted into peroxide at the expense of the sulphuric acid, which gives off one

atom of oxygen to the iron, and then flies off
in the state of sulphurous acid.   Now, 1 atom
of oxygen will convert 2 atoms of protoxide of
iron into peroxide.   It is obvious from this, that
one half of the ♦sulphuric acid is decomposed,
and that the other passes over in the state of
fuming sulphuric acid.   Now, this fuming acid
I have carefully analyzed, and I find it a com-
pound of

$$
\begin{array}{ll}
\text{2 atoms sulphuric acid} & = 10 \\
\text{1 atom water} \qquad . & = 1{\cdot}125 \\
\hline
& 11{\cdot}125
\end{array}
$$

Let us suppose that a quantity of protosul-
phate of iron, equivalent to 4 integrant particles,
or 69·5 grains (17·375 × 4) of the crystals, are
treated in this way.   By exposing them to a heat
of about 600°, they lose 30·375 grains, or the
whole of the water, except one atom.   There
remain 39·125 grains, composed of

$$
\begin{array}{ll}
\text{4 atoms sulphuric acid} & = 20 \\
\text{4 atoms protoxide of iron} & = 18 \\
\text{1 atom of water} & = 1{\cdot}125 \\
\hline
& 39{\cdot}125
\end{array}
$$

When a strong heat is applied to this residuum,
half the sulphuric acid, or 10 grains, is decom-
posed into

$$
\begin{array}{ll}
\text{2 atoms of sulphurous acid} & = 8 \\
\text{2 atoms of oxygen} & = 2 \\
\hline
& 10
\end{array}
$$

The 8 grains of sulphurous acid fly off in the state of gas, and the 2 grains of oxygen unite with the 18 grains of protoxide of iron, and convert them into 20 grains of peroxide. The remaining 10 grains of sulphuric acid, united to the atom of water, are driven off in the state of fuming sulphuric acid, and weighing 11·125 grains.

From this statement it is obvious, that when 17·375 grains of protosulphate of iron are thus treated, 7·59375 grains of water (or 7 atoms — ¼th atom) will be driven off; 2½ grains of sulphuric acid will be converted into 2 grains of sulphurous acid (which will fly off) and half a grain of oxygen, which will convert the 4½ grains of protoxide into 5 grains of peroxide. The remaining 2½ grains of sulphuric acid united with 0·28125 grains of water, (the ¼th atom still remaining) will be driven off in the state of fuming sulphuric acid.

From the preceding exposition it is plain, that after all the water has been driven off, which can be made to leave 17·375 grains of protosulphate of iron by a moderate heat, one fourth of an atom, or 0·28125 grain still remains. Hence, the whole water of crystallization amounts to 7·6 + 0·28125 = 7·88125 grains. This comes so near 7·875 grains, which is the equivalent of 7 atoms, that there can be no doubt that 7 atoms is the true quantity of water present. The small excess (only 0·00625 grain) was owing to a com-

mencement of decomposition, for the whole of the salt thus treated was not soluble in water.

Thus it appears that 17·375 grains of protosulphate of iron contain

<div align="center">

1 atom sulphuric acid = 5

7 atoms water . = 7·875

_____

12·875

</div>

The 4·5 grains, wanting to make up the whole 17·375, are obviously protoxide of iron; and, as the salt is neutral, 4·5 must denote the atomic weight of protoxide of iron.

3. The preceding analysis of protosulphate of iron is rigidly exact; but it proceeds upon assumptions which require to be proved. It will now be requisite to state the experiments by which I satisfied myself that 3·5 is the true atomic weight of iron.

35 grains of pure iron were put into a small retort, with dilute sulphuric acid. A complete solution took place; and the volume of the hydrogen gas evolved (reduced to the mean temperature and pressure) was 59 cubic inches. Consequently, the iron must have combined with a quantity of oxygen, which, had it been in the gaseous state, would have amounted to $\frac{59}{2}$, or 29·5 cubic inches, which weigh almost exactly 10 grains. From this it is obvious, that when 3·5 grains of pure iron are dissolved in dilute sul-

phuric acid, they combine with 1 grain of oxy-
gen. Now, by this solution, the iron is convert-
ed into protoxide; consequently, protoxide of
iron is composed of

Iron	.	3·5
Oxygen	.	1
		4·5

1 being the atomic weight of an atom of oxy-
gen, 3·5 must be the weight of an atom of iron;
and the atomic weight of protoxide of iron is
obviously 4·5.

4. Iron and sulphur unite together in two
proportions, forming the *protosulphuret* and *per-*
sulphuret of iron. The former is called by mi-
neralogists *magnetic pyrites*, because, when in
powder, it is attracted by the magnet. The lat-
ter is called *cubic pyrites*, because it usually
crystallizes in cubes. The protosulphuret of iron
may be formed artificially, by mixing together
iron filings and sulphur, and exposing the mix-
ture for some time to a red heat, in a well cover-
ed crucible. The mixture fuses, and the excess
of sulphur is gradually driven off, and protosul-
phuret of iron remains. This sulphuret, when
in crystals, has a yellow colour, the metallic
lustre, and a specific gravity of about 4½.

When it is reduced to powder, and digested
for a sufficient length of time in nitric acid, the

Sulphuret of iron analyzed.

sulphur is converted into sulphuric acid, while the iron at the same time is oxydized. If the solution, thus changed, be mixed with a sufficient quantity of muriate of barytes, sulphate of barytes precipitates; the weight of which enables us to determine the proportion of sulphur which the protosulphuret of iron contains. 100 grains of protosulphuret, treated in this way by Berzelius, yielded him 269 grains of sulphate of barytes.*   This weight exceeds the truth a little; because a portion of the oxide of iron is precipitated along with the sulphate of barytes, sufficient to give it a reddish yellow colour. When the oxide of iron is precipitated, in the first place, by means of ammonia, and the requisite precautions taken to prevent any of the sulphuric acid from remaining in combination with this precipitate, the sulphate of barytes is perfectly white, and weighs almost exactly 267·37 grains. Now, 267·37 grains of sulphate of barytes contain almost exactly 36·36 grains of sulphur. Thus it appears that 100 grains of protosulphuret of iron contain 36·36 grains of sulphur. Consequently, the constituents of the protosulphuret are

Sulphur	36·36	or	2
Iron .	63·64	-	3·5002

<div align="center">——</div>

<div align="center">100·00</div>

It is obvious that this protosulphuret is a com-

* Ann. de Chim. LXXVIII. 126.

pound of 1 atom sulphur and 1 atom iron ; and, consequently, that an atom of iron weighs 3·5. These observations apply only to protosulphuret of iron formed artificially. The native protosulphuret, when dissolved in muriatic acid, always deposites a little sulphur. Hence, it contains either a small mixture of persulphuret of iron or of sulphur.

Now, it is possible to convert protosulphuret May be converted of iron into neutral protosulphate of iron, by into protosulphate of careful digestion in a sufficient quantity of dilute iron. nitric acid. Hence it follows, that the sulphur and iron have the same ratio to each other in protosulphuret and protosulphate of iron ; namely, the ratio of 2 to 3·5. When 2 of sulphur are converted into sulphuric acid, they become 5 ; and when 3·5 of iron are converted into protoxide, they become 4·5, as is obvious from what has been stated above. Hence it is clear, that 17·375 grains of protosulphate of iron must contain exactly 4·5 grains of protoxide of iron ; as the quantity of sulphuric acid has been shown to be 5 grains. Thus the proportion of acid, oxide, and water in 17·375 grains of protosulphate of iron has been rigidly made out ; and the component parts of the salt are as follows :

1 atom sulphuric acid	5
1 atom protoxide of iron	4·5
7 atoms water	7·875

17·375

Experi-
ments of
Berzelius
to deter-
mine the
atom of
iron.

5. Berzelius has fixed the atomic weight of iron at 3·39215, or (as the number should have been) 3·393. His conclusion is founded upon the following experiment: 100 grains of iron were dissolved in muriatic acid, and the hydrogen gas evolved being burned over lime water, a quantity of carbonate of lime precipitated, which weighed 4·125 grains. Now, this is equivalent to 0·495, or very nearly half a per cent. of carbon. The solution was boiled with nitric acid, to peroxidize the iron; it was then precipitated by caustic ammonia. The precipitate, being washed, dried, and calcined, weighed 143·5 grains; but, if 99·5 grains of iron yielded 143·5 grains, it is evident that 100 grains would have yielded 144·2 grains.* Thus it follows, that peroxide of iron is a compound of

Iron	100	or	3·393
Oxygen	44·2	-	1·5

But this experiment does not seem susceptible of complete accuracy, unless it were made upon iron in a state of perfect purity; for we are not certain that all the carbon is converted into carburetted hydrogen gas. The strong smell of the gas evolved indicates the presence of some oily or bituminous substance, which may be partly deposited before the combustion of the hydrogen gas. Besides, different experimenters have ob-

* Ann. de Chim. LXXVIII. 230.

tained different results in this way. I made two experiments with great care. In one, 100 iron were converted into 142·6 of peroxide; in another, into 144·75 grains.*

Hassenfratz found that 100 grains of iron, calcined on a cupel, were converted into 142·224 grains of peroxide.† In another experiment, 100 iron, when thus treated, became 145 peroxide.

Bucholz, by an experiment similar to that of Berzelius, obtained 142 grains of peroxide from 100 grains of iron.‡

Gay-Lussac, from 100 grains of iron, obtained 142·35 grains of peroxide.§

The mean of all these experiments gives 43·303 for the quantity of oxygen which unites with 100 of iron. Hence, peroxide of iron according to these experiments is composed of

Iron	100	or	3·463
Oxygen	43·303	-	1·5

Now, 3·463, the atomic weight of iron deduced from these experiments, approaches nearer to 3·5, the weight deduced from the experiments above described, than to Berzelius' number.

6. I determined the atomic weight of the peroxide of iron in the following manner : 7·5 grains of cubic pyrites, very carefully selected,

Atom of peroxide of iron determined.

* Nicholson's Journal, XXVII. 378.   † Ibid. XXVI. 149.
        ‡ Ibid. XXV. 353.   § Ann. de Chim. III. 356.

were reduced to a coarse powder, and digested
in dilute nitric acid till the whole was dissolved.
An excess of caustic ammonia was then poured
into the solution, by which the peroxide of iron
was thrown down. It was collected on a double
filter, washed, dried, and exposed to a red heat.
It weighed exactly 5 grains. The residual li-
quid, thus freed from iron, was concentrated, in
order to drive off the excess of ammonia. It
was then mixed with a sufficient quantity of mu-
riate of barytes to throw down all the sulphuric
acid. The sulphate of barytes, thus obtained,
being washed, dried, and heated to redness,
weighed 29·5 grains, equivalent to 4 grains of
sulphur. From this experiment it is evident,
that persulphuret of iron is composed of

$$
\begin{array}{ll}
\text{Sulphur} & 4 \\
\text{Iron} & 3·5 \\
\hline
& 7·5
\end{array}
$$

or two atoms sulphur and 1 atom iron. But
during the experiment the 3·5 of iron were con-
verted into peroxide, which weighed 5. Hence
it is obvious, that peroxide of iron is composed
of

$$
\begin{array}{llll}
\text{Iron} & 3·5 & \text{or} & 1 \text{ atom} \\
\text{Oxygen} & 1·5 & - & 1\frac{1}{2} \text{ atom} \\
\hline
& 5
\end{array}
$$

Consequently, when 100 parts of pure iron are converted into peroxide they become 142·857.

7. Peroxide of iron has the property of combining with water, and forming with it a perhydrate. This compound is found native, and constitutes what the Germans call *brauneisenstein*. D'Aubuisson first showed it to be a perhydrate of iron. Very frequently it is mixed with a little oxide of manganese and silica. This is almost always the case with the variety called hematite. But when the perhydrate is pure, it is a compound of

1 atom water .	1·125
1 atom peroxide of iron	5
	———
	6·125

A portion of this water is very easily dissipated : hence, unless very carefully examined, the portion of water will turn out rather less than an atom.

8. I found, many years ago, that when 100 parts of iron are oxydized by passing the steam of water over them at a red heat, they combine with 29·7528 parts of oxygen.[*] Bucholz analyzed iron by the same process, and found that 100 grains of the oxide thus obtained, when converted into peroxide by nitric acid, became 110 grains. Hence, he inferred that 100 oxy-

Ferroso-ferric oxide of Gay-Lussac

---

dized by steam, combine with 29·87 grains of
oxygen.* This is nearly the same result as I
obtained. But from the subsequent experi-
ments of Gay-Lussac it would appear that iron,
oxydized in this manner, unites with more oxy-
gen than was found either by Bucholz or my-
self. He found the oxide composed† of

$$\begin{array}{lccc}
\text{Iron} & 100 & \text{or} & 3\cdot5 \\
\text{Oxygen} & 37\cdot8 & - & 1\cdot323
\end{array}$$

Now, 1·323 is very nearly $1\frac{1}{3}$ oxygen. Hence,
it would appear that this supposed oxide is a
compound of 1 atom iron $+ 1\frac{1}{3}$ atom oxygen.
Now, this is just the proportion of oxygen which
would result from the combination of 1 inte-
grant particle of protoxide, and 2 integrant
particles of peroxide of iron ; for

$$\begin{array}{llll}
\text{1 atom protoxide is composed of} & 3\cdot5 \text{ iron} & + 1 \text{ oxygen} \\
\text{2 atoms peroxide of} & . & . & 7 & + 3 \\
\hline
\text{Total} & . & . & . & 10\cdot5 & 4
\end{array}$$

And $\frac{10\cdot5}{3} = 3\cdot5$; and $\frac{4}{3} = 1\frac{1}{3}$. So that such a
compound would obviously consist of 1 atom of
iron, and $1\frac{1}{3}$ atom oxygen.

When this oxide of Gay-Lussac is dissolved
in sulphuric acid, and alcohol poured upon the
sulphate, a solution of persulphate of iron is ob-

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* Nicholson's Jour. XXV. 353.   † Ann. de Chim. LXXX. 164.

tained, while protosulphate remains undissolved.
From this and several other facts stated by Gay-
Lussac in his Memoir, it is evident that this
substance cannot be considered as a peculiar
oxide, but as a combination of protoxide, and
peroxide in the proportions above stated.

From the phenomena which appear during
the manufacture of Prussian blue, there are
strong reasons for considering the iron which
that pigment contains as in the state of Gay-
Lussac's oxide, or as a mixture or compound of
1 part of protoxide with 2 parts of peroxide.
For if we attempt to make Prussian blue by
means of persulphate of iron at once, we get
a pigment apparently of the finest colour; but
so intense that it appears quite black when dry.
The manufacturers always find it necessary to
employ protosulphate of iron. The Prussian
blue, when first thrown down, is an exceedingly
light blue powder. This powder is continually
washed with water for a fortnight or three
weeks. The shade gradually deepens during
the washings, and when it is judged sufficiently
deep, the water is drained off and the pigment
allowed to dry.—From my knowledge of this
process, I am disposed to think that protoxide
and peroxide of iron are capable of uniting in
the proportion of 1 atom of the former to 2
atoms of the latter. But, with the exception of
Prussian blue, I am not aware of any combina-

tion into which this compound is capable of
entering.

SECT. II.

OF THE ATOMIC WEIGHT OF NICKEL.

THE atomic weight of nickel and its protoxide
may be determined without much difficulty from
the sulphate, which I find to be a compound of
1 integrant particle of sulphuric acid, 1 inte-
grant particle of protoxide of nickel, and 7 inte-
grant particles of water. This salt has a fine
grass green colour, and crystallizes in four-sided
rectangular prisms. Its taste is astringent, but
not strong, and it is very soluble in water.

Sulphate
of nickel
analyzed.

1. 17·125 grains of the crystals of this salt
were dissolved in water, and mixed with a solu-
tion of 13·25 grains of chloride of barium. A
double decomposition took place, and sulphate
of barytes precipitated. The clear residual li-
quor being tested by sulphate of soda and mu-
riate of barytes, was not affected by either,
showing that it contained neither barytes nor
sulphuric acid. It is obvious from this experi-
ment, that 17·125 grains of crystallized sulphate
of nickel contain just the quantity of sulphuric
acid necessary to saturate the barytes from 13·25
grains of chloride of barium ; that is to say, ex-
actly 5 grains of this acid.

2. When 17·125 grains of crystallized sulphate of nickel are exposed to a heat of 600° for half an hour, they lose 6·25 grains of their weight, or rather more than 5½ atoms of water. But at this temperature the salt does not lose its green colour, and consequently, still retains water. When 17·125 grains of the salt are exposed to a low red heat, they lose their green colour, and in general, diminish in weight 8 grains. But the salt which has been thus treated, is not completely soluble in water, though very nearly so: hence, a small portion of its acid has been disengaged. From this experiment, which I have often made, it appears that the water of crystallization in 17·125 grains of sulphate of nickel is not quite so high as 8 grains. In one experiment in which the heat was applied with much caution, the loss of weight was 7·8 grains, and the salt was completely soluble in water. It is obvious from this, that the water of crystallization in 17·125 grains of sulphate of nickel lies between 7·8 and 8 grains. Now, 7·875 grains of water are equivalent to 7 atoms of that liquid : and as the quantity of acid in this weight of salt is just 5 grains, equivalent to an atom, we can have no doubt that the true quantiy of water is likewise equivalent to 7 atoms, or 7·875 grains.

Five acid and 7·875 water, make 12·875, which Atom of protoxide of nickel. being subtracted from 17·125 leaves 4·25, which must be the weight of protoxide of nickel, and

must likewise (since the salt is neutral) indicate the atomic weight of protoxide of nickel. Thus it appears, that sulphate of nickel is composed of

1 atom sulphuric acid	5
1 atom protoxide of nickel	4·25
7 atoms water	7·875
	17·125

There is no reason to doubt that this oxide is a compound of 1 atom nickel and 1 atom oxygen. An atom of nickel, therefore, must weigh 3·25.

Atom of nickel.

3. Besides the protoxide of nickel there is another oxide, having a black colour, which was first pointed out by Thenard, and which he obtained by passing a current of chlorine gas through water, having protoxide of nickel suspended in it. A portion of the oxide dissolves in the muriatic acid evolved, while another portion assumes a black colour and is converted into peroxide. It will be obvious, from the account given below of the constitution of this oxide, that ⅓d of the protoxide of nickel must be dissolved and converted into muriate of nickel, while ⅔ds become peroxide of nickel and remain undissolved.

Atom of peroxide of nickel.

When peroxide of nickel is dissolved in ammonia, an effervescence takes place, owing to the escape of azotic gas: for the peroxide is converted into protoxide at the expense of the hydrogen of the ammonia. An effervescence also

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takes place when this oxide is digested in acids : the excess of oxygen flies off in the state of gas, and the protoxide thus formed unites with the acid. From some experiments of Rothoff, quoted by Berzelius,* it would appear that the oxygen in peroxide of nickel is to that in the protoxide as 3 to 2. If this be the case, the atomic weight of peroxide of nickel will be 4·75, and it will be a compound of

1 atom nickel . .	3·25
1½ atom oxygen . .	1·5
	4·75

If this supposition be well founded, 47·5 grains of peroxide of nickel, when dissolved in sulphuric acid, will lose 5 grains, or 14·754 cubic inches of oxygen gas.

SECT. III.

OF THE ATOMIC WEIGHT OF COBALT.

THE sulphate of cobalt, when pure, crystallizes in small red rhombic prisms, very similar to the crystalline form of protosulphate of iron. It may be exposed to an incipient red heat, and

* Annals of Philosophy, III. 355.

deprived of the whole of its water of crystalliza-
tion without losing any of its acid.

1. 9·25 grains of anhydrous sulphate of cobalt
were dissolved in water, and the liquid mixed
with a solution of 13·25 grains of chloride of ba-
rium.   A double decomposition took place ; sul-
phate of barytes precipitated, and the clear re-
sidual liquid being examined, was not affected
by sulphate of soda or muriate of barytes—show-
ing that it contained neither barytes nor sulphu-
ric acid.   From this experiment it is obvious,
that 9·25 grains of anhydrous sulphate of cobalt
contain exactly 5 grains of sulphuric acid : the
remaining 4·25 grains must be protoxide of co-
balt.   Consequently, this salt is composed of

$$
\begin{array}{lc}
\text{Sulphuric acid} & 5 \\
\text{Protoxide of cobalt} & 4\cdot 25 \\
\hline
 & 9\cdot 25
\end{array}
$$

The salt being neutral, and 5 being the atomic
weight of sulphuric acid, 4·25 must be the atomic
weight of protoxide of cobalt.

2. When 17·125 grains of crystallized sulphate
of cobalt are exposed to an incipient red heat in
a platinum crucible, they lose 7·875 grains of
their weight.   Now, this is equivalent to 7 atoms
of water.   It is obvious from this experiment,
that sulphate of cobalt is composed precisely as
sulphate of nickel, or of

1 atom sulphuric acid	5
1 atom protoxide of cobalt	4·25
7 atoms water . .	7·875
	17·125

3. There seems no reason to hesitate about considering this oxide as a compound of 1 atom oxygen and 1 atom cobalt. On that supposition, the atomic weight of cobalt will be 3·25, the same as the atomic weight of nickel.

<div style="text-align: right; font-size: small;">Atom of cobalt.</div>

4. If protoxide of cobalt be a compound of 1 atom cobalt and 1 atom oxygen, it follows, that 100 parts of this oxide are composed of

Cobalt	.	.	76·47
Oxygen	.	.	23·53
			100·00

Now, when the protoxide of cobalt is precipitated from an acid, edulcorated and dried in the open air, it absorbs oxygen during the drying, and is converted into a black powder, which is the *peroxide* of cobalt. This peroxide dissolves with effervescence in muriatic acid, while chlorine gas is disengaged. When heated, it gives out oxygen gas ; and, from the experiments of Rothoff, as stated by Berzelius,[*] it appears, that when 111 grains of peroxide of cobalt are heated, they are converted into 100 grains of protoxide : so that

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* Annals of Philosophy, III. 356.

100 grains of protoxide become peroxide by uniting with 11 grains of oxygen. But 11   2 = 22, which approaches very near the oxygen in 100 grains of protoxide.

Atom of peroxide of cobalt.   From this we see that the oxygen in the protoxide is to that in the peroxide as 2 to 3. Consequently, the atomic weight of peroxide of cobalt must be 4·75, and it must be a compound of

1 atom cobalt	3·25
1½ atom oxygen	1·5
	4·75

Thus its composition and weight agree with those of peroxide of nickel; like that peroxide, it does not appear capable of uniting with acids, nor of entering into any permanent combinations like the peroxide of iron.

SECT. IV.

OF THE ATOMIC WEIGHT OF MANGANESE.

THE atomic weight of the protoxide of this metal may be made out from the protosulphate in the same way as the protoxide of iron, nickel, and cobalt. Protosulphate of manganese, when pure, forms large transparent crystals, having a beautiful flesh colour, and the shape of a very oblique rhombic prism, the faces of which meet

at angles of about 148° and 32°. Its taste is somewhat similar to that of Glauber's salt, but rather more disagreeable ; and like that salt, it acts as a cathartic when taken to the extent of about half an ounce. It is very soluble in water, but is not altered by exposure to the air, whether the atmosphere be dry or moist.

1. 15·125 grains of these crystals were dissol- Sulphate of
ved in water, and the liquid mixed with a solu- manganese
tion of 13·25 grains of chloride of barium. A analyzed.
double decomposition took place, and when the sulphate of barytes had subsided, the residual liquid was neither affected by sulphate of soda nor muriate of barytes. From this experiment it follows, that 15·125 grains of protosulphate of manganese contain exactly 5 grains of sulphuric acid.

2. When 15·125 grains of protosulphate of manganese are heated in a platinum crucible, they melt, and the water of crystallization is gradually dissipated. But it is scarce possible, by this process, to drive off the whole water of crystallization without allowing some of the acid at the same time to escape. Dr. John, from 15·125 grains of this salt, drove off 5·345 grains of water. I repeated this experiment with great care, and found that I could disengage 5·48 grains of water from 15·125 grains of the salt. But if the heat was raised high enough to produce a greater diminution of weight, a portion of the salt was

altered in its appearance, and rendered inso-
luble.

Five atoms of water weigh 5·625, which weight
exceeds 5·48 by only 0·145, or about the eighth
part of an atom. There is no reason to doubt
that the aqueous portion of this salt constitutes
a determinate number of atoms; and since
15·125 of the salt contain exactly one atom of sul-
phuric acid, the atomic weight of the water
must exist also in the same quantity. Now, the
results just stated point out unequivocally that
five atoms of water are united in it with an inte-
grant particle of anhydrous protosulphate. Thus
it appears, that 15·125 grains of protosulphate
of manganese contain 5·625 grains of water.

3. The five grains of sulphuric acid and the
5·625 grains of water make together 10·625
grains. This quantity, subtracted from the ori-
ginal weight, leaves 4·5, which must denote the
quantity of protoxide of manganese present.
Thus it appears, that protosulphate of manganese
is composed of

Sulphuric acid	5
Protoxide of manganese	4·5
Water . . .	5·625
	15·125

Atom of
protoxide
of manga-
nese.

As the salt is neutral, and as 5 is the weight of
an atom of sulphuric acid, 4·5 must be the
atomic weight of protoxide of manganese.

Thus it appears, that protoxide of manganese and protoxide of iron have the same atomic weight. If protoxide of manganese be a compound of one atom manganese and one atom oxygen, (as there is the strongest reason for believing) then an atom of manganese weighs 3·5, or the same as an atom of iron.

4. Manganese occurs most commonly in the state of a black coloured oxide, which has been long employed to deprive glass of its colour, and is at present consumed in great quantities by the bleachers and the preparers of the bleaching powder. This black oxide is most commonly impure; but it occurs occasionally crystallized in small needles, which have the form of rhombic prisms, and the lustre and colour of iron, though rather darker. I have met with specimens of this kind perfectly pure. When 11 grains of this pure oxide are kept for some time in a low red heat in a platinum crucible, they lose exactly one grain of their weight, which consists of pure oxygen gas. By this exposure to heat, the metallic lustre disappears, and the mass assumes a brownish black colour. The powder thus formed is a peculiar oxide of manganese; for it dissolves without effervescence in sulphuric and in muriatic acid, and forms dark red coloured solutions. This sulphate and muriate do not crystallize;—indeed, when the muriate is heated, chlorine gas is evolved, and

Native black oxide.

9

the common colourless protomuriate of manganese obtained. But the red sulphate of manganese may be concentrated without losing its colour. Sulphurous acid, or nitrous acid, instantly renders it colourless, by depriving it of the excess of oxygen which it contains above the protosulphate.

Deutoxide of manganese.

Thus, besides the protoxide of manganese, there are two other oxides, both of which are *black*. I determined the composition of the brownish black oxide in the following way : A quantity of carbonate of manganese, which I knew to contain exactly 45 grains of protoxide, was dissolved in nitric acid in a platinum crucible ; the solution was evaporated to dryness, and the crucible with its contents was then exposed to a red heat : by this means, the nitric acid was decomposed, and driven off, and a black shining powder obtained, which weighed exactly 50 grains. This black powder possesses the same properties with the brownish black powder obtained by exposing native black oxide of manganese to a low red heat—for it forms the same red coloured solutions with sulphuric and muriatic acids, which are rendered colourless by sulphurous acid, or when heated with sugar.*

* When carbonate of manganese is exposed to a red heat, it assumes a brown colour ; but is not converted into deutoxide, unless it be previously mixed with nitric acid. A quantity of carbonate containing 4·5 grains of protoxide of manganese, when thus treated, instead of weighing 5 grains as it would do if it were converted into deutoxide, only weighs 4·8 or

Thus it appears, that 45 protoxide of manganese become 50 deutoxide; or, 4·5 protoxide become 5 deutoxide: but 4·5 is the atomic weight of protoxide of manganese, and it contains 1 atom of oxygen. Five, therefore, must be the atomic weight of deutoxide; and it is obviously a compound of

1 atom manganese	3·5
1½ atom oxygen	1·5
	5·0

It is, therefore, similar in its composition to the peroxide of iron. As its colour is either a brownish black, or a shining black, according to the mode of preparing it, we cannot with propriety distinguish it by its colour; and shall, therefore, henceforth give it the name of *deutoxide of manganese*.

5. The composition of deutoxide of manga-

perhaps 4·83; showing that it is still partly in the state of protoxide. This is the *oxydum manganoso-manganicum* of Arfwedson, which he considers as composed of

1 atom protoxide	4·5
2 atoms deutoxide	10
3)14·5	

4·8333 = atomic weight of the compound.

When the black oxide is exposed to too high a temperature, it becomes analogous to this in its composition, showing that it is partly converted into protoxide.

nese being known, it is easy, from what has been already said, to determine the composition of the native black oxide employed by manufacturers : 11 black oxide, when heated to redness,

lose 1 of oxygen, and become 10 deutoxide ; or, which is the same thing, 5·5 black oxide, when deprived of 0·5 oxygen, become 5 deutoxide; consequently, the atomic weight of native black oxide is 5·5, and it is obviously composed of

1 atom manganese	3·5
2 atoms oxygen	2
	5·5

This is an oxide not analogous to any of the known oxides of iron, nickel, or cobalt. It has been hitherto distinguished by the name of *peroxide of manganese ;* but, as there is reason to believe that manganese forms at least one, if not two additional oxides, it will be better henceforth to call it *tritoxide of manganese.*

6. Scheele, many years ago, made a curious experiment with the tritoxide of manganese. He mixed it with caustic potash, and exposed it to a heat sufficiently strong to melt the alkali. The fusion being kept up for some time, a dark green, or blackish mass was formed, which was soluble in water. By degrees, a yellow powder precipitates from this solution, and the liquid assumes a *blue* colour ; some time after, the co-

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lour becomes *violet*, and then *red ;* and, finally,
black oxide of manganese precipitates, and the
liquid loses all colour. In consequence of this
curious succession of colours, the liquid thus ob-
tained used to be distinguished by the name of
mineral chameleon. We may employ saltpetre
instead of potash, and the process will succeed
equally well. When the liquid had assumed a
red colour, Chevillot and Edwards* concentrat-
ed it by evaporation, and obtained a red colour-
ed salt in needles. This salt is neutral, and is
composed of potash, united to an oxide of man-
ganese, which possesses acid properties, and
which, consequently, is different from the three
oxides, which have been already noticed.

This red salt has received the name of *man-* Manganate
of potash.
ganate of potash. It possesses some singular
properties. It crystallizes in four-sided rectan-
gular prisms, has the diamond lustre, a purple
colour, and a taste at first sweet, and similar to
that of walnuts, but which leaves a very disa-
greeable impression in the mouth. When these
crystals are heated, in contact with hydrogen
gas, they set it on fire. They detonate violently
with phosphorus, set fire to sulphur, antimony,
and arsenic, and rival chlorate of potash itself in
their power of supporting combustion. The acid
cannot be separated from this salt without de-

* Ann. de Chim. et de Phys. VIII. 337.

composition. Sulphuric acid disengages it from
the potash ; but when we endeavour to separate
the sulphate of potash by evaporation, the red
colour disappears, and tritoxide of manganese
precipitates. •

Forchham-
mer's mode
of obtaining
manganesic
acid.

But Dr. Forchhammer succeeded by a very
ingenious process in obtaining *manganesic acid*
in a separate state, or at least combined merely
with water. He mixed together tritoxide of
manganese and crystallized nitrate of barytes,
and exposed the mixture to a heat just sufficient
to produce the fusion of the salt. Great care, he
says, must be taken not to drive off the water of
crystallization, otherwise the process does not
succeed.* The nitric acid is gradually decompos-
ed. The tritoxide of manganese unites with more
oxygen, is converted into an acid, and combines
with the barytes, as that alkali is disengaged.
After the process is finished, the mass must be
digested in water, which dissolves any pure ba-
rytes, or nitrate of barytes, that may be present ;
but does not touch the compound of barytes and
acid of manganese, which is insoluble in that
liquid. To this insoluble residuum Dr. Forch-
hammer added the quantity of sulphuric acid
just capable of saturating all the barytes which
it contained. The acid of manganese in the

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* I have not attempted to repeat this process, because I have never met
with any nitrate of barytes that contained any water of crystallization. As
far as my observations go, the salt is always anhydrous.

mass is immediately resolved into two substances, tritoxide of manganese, and manganesic acid. The former remains mixed with the sulphate of barytes; but the latter dissolves in water, and gives that liquid a beautiful red colour.

7. When tritoxide of manganese and nitre are heated, the solution is at first green, and it gradually passes into red, while, at the same time, a quantity of deutoxide of manganese precipitates. When an acid is poured into the green coloured solution, it becomes red; an alkali, on the other hand, renders the red coloured solution green. When alcohol, or any animal or vegetable substance, is added to the red solution, deutoxide of manganese precipitates; while, at the same time, the red colour is destroyed.

Dr. Forchhammer is of opinion, from these and similar phenomena, that there are two acids of manganese, which he calls *manganous* and *manganesic* acids—the former containing the least, and the latter the most oxygen. The manganous acid exists in the green coloured liquid, which is a compound of that acid and potash; while the red salt is a compound of manganesic acid and potash.

8. To determine the composition of manganous acid, Dr. Forchhammer prepared a quantity of the manganite of potash, and decomposed it by the addition of a solution of nitrate of lead. A dark coloured precipitate fell, consisting of a

His method of analyzing manganous acid,

combination of peroxide of lead and deutoxide of manganese; and this precipitate he considered as containing all the oxygen and all the manganese which existed in the manganous acid. This precipitate, being washed and dried, was mixed with bisulphate of potash, and exposed to a heat capable of fusing it in a retort. The oxygen gas given out was collected and measured; its weight was 0·1303 parts. The salt in the retort was dissolved in water (the lead remaining behind in the state of sulphate); the manganese, was precipitated by carbonate of soda, and exposed to a red heat. The deutoxide obtained by this process weighed 0·282 parts.

Now, deutoxide of manganese is (as we have seen) a compound of 3·5 manganese + 1·5 oxygen; consequently, 0·282 parts of this oxide contain

Manganese .	0·1974
Oxygen .	0·0846
	0·2820

If to this portion of oxygen we add the 0·1303 parts driven off by heat, we shall have manganous acid composed of

Manganese	0·1974	or	3·5
Oxygen	0·2149	-	3·8103
	0·4123		

Now, 3·8103 approaches nearly to 4 atoms of oxygen—from which it would appear, that manganous acid is a compound of 1 atom manganese and 4 atoms oxygen; and that its atomic weight is 7·5. But Dr. Forchhammer concludes (though I do not see the force of his reasoning), that, in reality, manganous acid contains only 3 atoms of oxygen, united to 1 atom of manganese. Its atomic weight, on that supposition, will be 6·5.

Dr. Forchhammer's process of experimenting And manganesic and reasoning, by which he made out the com- acid. position of manganesic acid, is very ingenious, but rather abstruse. I shall endeavour to lay a simple view of it before the reader :—Through a solution of manganite of potash, he passed a current of carbonic acid gas. By this process the manganite was converted into manganate of potash ; while, at the same time, 0·136 parts of deutoxide of manganese were thrown down. The manganate was then decomposed, by means of alcohol ; 0·214 parts of deutoxide of manganese were precipitated. Now, by the first process, the manganesic acid formed contained all the oxygen in the manganous acid, except what remained in the portion of the deutoxide separated. The whole deutoxide separated was 0·136 + 0·214 = 0·350; and this was the quantity of deutoxide contained in the manganous acid. The manganesic acid contained only 0·214 parts; and with these 0·214 parts

there was combined just as much oxygen as with the 0·350 parts in the manganous acid.

But manganous acid is composed of 5 deutoxide of manganese + 1·5 oxygen; consequently, 0·350 are composed of 0·245 deutoxide + 0·105 oxygen; and manganesic acid is a compound of

| Deutoxide of manganese | 0·214 |
| Oxygen . . | 0·105 |

Deutoxide of manganese is a compound of 3·5 manganese + 1·5 oxygen; consequently, 0·214 deutoxide consists of 0·1498 manganese + 0·0642 oxygen. By adding together the 0·105 oxygen and the 0·0642, we obtain 0·1692 for the whole oxygen in manganesic acid, combined with 0·1498 of manganese. Thus it appears, that manganesic acid is a compound of

Manganese	0·1498	or	3·5
Oxygen	0·1692	-	4·620
	0·3190		

If we make the same allowance for excess of oxygen that Dr. Forchhammer made in the case of manganous acid, manganesic acid may be considered as a compound of 1 atom manganese and 4 atoms oxygen, which would make its atomic weight 7·5.

It would appear from the preceding investigation, that oxygen and manganese combine in no

fewer than 5 proportions, and form 5 oxides, the composition of which is as follows :

		MANGANESE.	OXYGEN.	
1	Protoxide	3·5	+ 1	Oxides of manganese.
2	Deutoxide	3·5	+ 1·5	
3	Tritoxide	3·5	+ 2	
4	Manganous acid	3·5	+ 3	
5	Manganesic acid	3·5	+ 4	

9. Berzelius describes an oxide of manganese containing less oxygen than any of the preceding. It was obtained by leaving metallic manganese for more than a year in a phial not very closely corked. It fell into a dark coloured powder, which, according to Berzelius' analysis, or rather calculation, was a compound of

Manganese	.	.	100
Oxygen	.	.	10·666

I have had no opportunity of making any experiments on this supposed oxide: but, if it exist, it must be a compound of 3 atoms manganese with 1 atom oxygen. This would consist of

Manganese	10·5	or	100
Oxygen	1·0	-	9·5238

which differs but little from the estimate of Berzelius.

10. Dr. John found, that when metallic manganese is put into water, that liquid was slowly   Suboxide of manganese.

decomposed ;—hydrogen gas being evolved, while the manganese lost its metallic lustre and assumed a green colour : 80 parts of manganese thus treated, became 92 parts of the new oxide. Now, 80 : 12 : : 3·5 : 0·525. Hence it would appear that this oxide, which I have not had an opportunity of examining, is a compound of 1 atom manganese and half an atom of oxygen; or of

2 atoms manganese	. .	7
1 atom oxygen	. . .	1
		——
		8

This oxide is incapable of uniting with acids; but Dr. Forchhammer has made a set of experiments to show that it combines with sulphur, and that it constitutes the mineral found in Transylvania and Cornwall, and considered at present as a sulphuretted oxide of manganese. It seems, however, proved that the Transylvanian ore is a sulphuret of manganese.

I think the existence of the supposed protoxide of manganese of Berzelius exceedingly doubtful. But I see no reason to doubt the existence of the suboxide of John—though that chemist was mistaken in considering it as the basis of the salts of manganese. The real basis is the substance which I have here distinguished by the name of protoxide, and which contains just twice as much oxygen as the suboxide of John.

Of all the substances hitherto examined, manganese is capable of uniting with the greatest number of doses of oxygen.

SECT. V.

OF THE ATOMIC WEIGHT OF CERIUM.

CERIUM has not hitherto been obtained in the metallic state ; but it has been ascertained that it combines with two proportions of oxygen, and forms two oxides ; both of which possess alkaline properties, and are capable, of consequence, of combining with acids, and of constituting the bases of a variety of salts.

The only person who has hitherto attempted to determine the atomic weight of this metal and its oxides, is M. Hisinger. His deductions were made from an analysis of the protomuriate of cerium. A quantity of this salt was dissolved in water, and the muriatic acid thrown down by nitrate of silver. The chloride of silver, after fusion, weighed 1·819, equivalent to 0·4609 parts of muriatic acid. The solution having been freed by muriatic acid from the excess of silver which it contained, was mixed with carbonate of ammonia to throw down the protoxide of cerium. This oxide, after being heated to redness in a close vessel, weighed 0·684 parts.* From this

Muriate of cerium analyzed by Hisinger.

* Annals of Philosophy, IV. 355.

analysis it follows, that protomuriate of cerium
is composed of

Muriatic acid	0·4609	or	4·625
Protoxide of cerium	0·684	-	6·862

As the salt was neutral, the conclusion to be
drawn from this analysis is, that the atomic
weight of protoxide of cerium is 6·862.

But I think there is reason to suspect that the
muriatic acid in this analysis is somewhat over-
rated, and the protoxide of cerium somewhat un-
derrated :—at least, I generally find, that when
nitrate of silver is poured into the solution of a
metalline salt, the chloride obtained contains
traces of the metal previously in combination
with the muriatic acid. In order to obtain cor-
rect results from the analysis of a metalline mu-
riate, the metallic oxide should be thrown down
in the first place, by means of an alkaline car-
bonate or pure alkali ; and after the metallic ox-
ide has been separated by the filter, the liquid is
to be neutralized by nitric acid, and the muriatic
acid thrown down by nitrate of silver.—These
considerations induced me to make the following
experiments in order to determine the atomic
weight of protoxide of cerium.

Experi-
ments of
the author.
1. A quantity of oxalate of cerium was ex-
posed to a red heat, in order to destroy the acid
which it contained. The peroxide of cerium
thus obtained, was dissolved in muriatic acid,
and the liquid was repeatedly evaporated to dry-

ness with an excess of acid till it became quite colourless. Carbonate of ammonia was then mixed with it in sufficient quantity to throw down the protoxide of cerium in the state of a carbonate. The carbonate of cerium, when allowed to dry in the open air, was a very light, bulky, white, tasteless substance, in small scales or plates, somewhat resembling the appearance of earthy talc. It was dissolved in dilute sulphuric acid till the acid refused to take up any more. The solution was colourless, and on being sufficiently concentrated deposited protosulphate of cerium in small crystals, which had the form of six-sided prisms, and some of them seemed to be three-sided prisms; but they were too small to admit of any thing like an accurate measurement of their angles.

This salt has a flesh colour, a sweet taste, with a slight degree of astringency, and the property of reddening vegetable blues. It is pretty soluble in water; though the precise degree was not determined.

2. 15·625 grains of these crystals were dissolved in distilled water, and the liquid mixed with a similar solution of 13·25 grains of chloride of barium. A double decomposition took place, sulphate of barytes precipitated, and the residual liquid was not affected by sulphate of soda nor muriate of barytes. Hence, it contained no sensible quantity of sulphuric acid, or

barytes.   From this experiment it follows, that
15·625 grains of protosulphate of cerium con-
tain 5 grains of sulphuric acid.

3. 15·625 grains of the crystals of protosul-
phate of cerium were exposed for an hour on
the sand bath to a heat of about 500° or rather
more.   The loss of weight was 3·125 grains;
and this loss was not increased though the heat
was continued for twenty four hours.   The salt
thus treated, had become white.   It still red-
dened vegetable blues, and was completely solu-
ble in water.   Hence, the loss of weight must
be ascribed to the escape of water.   Now, the
weight of three atoms of water is equivalent to
3·375 grains.   This exceeds the loss of weight,
actually sustained by the salt, by 0·25 grains,
equivalent to $\frac{1}{13}$th of an atom.   The salt being
as neutral as possible, and 15·625 grains of it
containing 5 grains of sulphuric acid, which is
equivalent to an atom, the same weight of salt
must contain a determinate number of atoms of
water; and it is obvious, that the true quanti-
ty of water must be 3 atoms, or 3·375 grains.
I found that the salt could not be rendered per-
fectly anhydrous without at the same time losing
a portion of its acid.

4. Five sulphuric acid, and 3·375 water added
together make 8·375, which being subtracted
from 15·625, the total quantity of salt used,
leaves 7·25, which must represent the weight of

protoxide of cerium in the salt, and must also be the atomic weight of that protoxide.

From the preceding analysis the reader will perceive, that protosulphate of cerium is composed of

1 atom sulphuric acid	.	5
1 atom protoxide of cerium		7·25
3 atoms water	. .	3·375

15·625

7·25, then, is the true atomic weight of protoxide of cerium, which is a little higher than the number deduced from Hisinger's analysis of the muriate of cerium. The probable reason for this difference has been already hinted at.

Atom of protoxide of cerium.

5. According to Hisinger's experiments the oxygen in the protoxide of cerium is to that in the peroxide as 2 to 3. My stock of cerium was not sufficient to enable me to make a similar set of experiments on peroxide of cerium. But there is every reason to confide in the ratios which Hisinger has deduced from his analyses; all of which, having been made in the same way, would be subject to the same errors, which would not affect the ratios between the two oxides, though it had an effect upon their absolute weights. It is easy from these ratios to deduce the atomic weights and composition of cerium and its oxides, as follows:

Of peroxide of cerium.

	ATOMIC WEIGHT.	CERIUM.	OXYGEN.
Cerium	6·25		
Protoxide	7·25 composed of	1 atom +	1 atom
Peroxide	7·75	1	+ 1½

Action of reagents.

6. The following experiments to determine the effects of reagents on protomuriate of cerium, though they contain little novelty, are perhaps worth recording ; because the salts and all the reagents used were exceedingly pure.

1. Prussiate of potash—A chalky white precipitate.
2. Gallic acid and infusion of galls—O.
3. Oxalic acid—A copious white precipitate.
4. Oxalate of Ammonia—Ditto, redissolved by agitation.
5. Tartaric acid—O.
6. Tartrate of potash—A copious white precipitate.
7. Bitartrate of potash—O.
8. Phosphoric acid—A white precipitate.
9. Phosphate of soda—Abundance of white flocks.
10. Carbonate of ammonia—A milk white flocky precipitate.

CHAP. XI.

OF THE ATOMIC WEIGHTS OF ZINC, CADMIUM, LEAD, TIN, BISMUTH, COPPER, MERCURY, AND SILVER.

THESE eight metals possess several properties in common by which they are distinguished from all the other metals. 1. They all possess a cer- Characters of the me-tals treated of in this chapter. tain degree of malleability; for bismuth, by far the most brittle of them all, may be dimpled by a blow of the hammer; and zinc, the next in order, is very malleable at a temperature some-what above that of boiling water. 2. They all melt at rather low temperatures, when compared with the melting point of most of the other metals; for copper, which requires the greatest heat to melt it, may be fused in a common fire urged by bellows. It requires some care to keep a silver crucible red hot in a common fire with-out fusing it. The other six melt in a heat be-low redness. Indeed, mercury requires so very little heat to melt it, that it remains always fluid even in our coldest winter weather. 3. Their oxides are easily decomposed by heat and char-coal, so that there is no difficulty in obtaining

these bodies in the metallic state, and, compara-
tively speaking, in a state of considerable purity.
4. When the last seven of these metals are held
in solution by an acid (particularly sulphuric, or
muriatic, when these acids form soluble salts
with the metallic oxide) if we introduce into the
solution a plate of zinc, the metal previously in
solution is thrown down in the metallic state,
while a corresponding portion of the zinc is dis-
solved in its place. A plate of cadmium intro-
duced into a solution of any of the six metals
placed after it in the title of this chapter, will
also throw it down in the metallic state, while a
corresponding portion of the cadmium enters
into solution. In like manner a plate of lead
will throw down any of the five metals after it
in the metallic state. A plate of tin will throw
down any of the four metals after it; a plate of
bismuth, any of the three metals after it; a plate
of copper either of the two metals after it; and
mercury will throw down silver in the metallic
state.

But silver is incapable of throwing down any
of the other metals mentioned in the title of
this chapter, though it is itself thrown down by
them all. Mercury throws down silver, but
none of the others; copper throws down mer-
cury and silver, but none of those that precede
it. The same remark applies to every particular
metal; it throws down all those which are placed

after it in the title of the chapter, but none of those that are placed before it.

Iron has likewise the property of throwing down all the metals belonging to this chapter, except zinc, in the metallic state. When a plate of zinc is put into a solution of iron, the iron falls very slowly in the state of peroxide. Copper is a good precipitant of mercury and silver; zinc precipitates cadmium, tin, and copper very well from muriatic acid, and lead very well from acetic acid.

The reader will recollect that the atomic weight of zinc was established in the first section of the first chapter of this work. The knowledge of it was necessary in order to enable us to determine the specific gravities of oxygen and hydrogen gases, upon which the whole doctrine of atomic proportions ultimately depend. The weight of an atom of zinc is 4·25; it combines with only one proportion of oxygen, and forms one oxide, the atomic weight of which is 5·25.

Atom of zinc.

SECT. I.

OF THE ATOMIC WEIGHT OF CADMIUM.

CADMIUM is still a very scarce metal; but by the kindness of Mr. Harepath, I was favoured

with a quantity of the matter which adheres to
the roof of the room in which zinc is smelted in
Bristol. This sublimate contains about ten per
cent. of cerium ; by extracting it, I have had
it in my power to examine the constitution of
its different salts. Stromeyer, to whom we are
indebted for our knowledge of this metal, has
analyzed several of its salts, and ascertained how
much the metal increases in weight when it is
converted into an oxide : and from the well
known precision of this excellent chemist, we
have every reason to expect that the results of
his analyses will give us the atomic weight of
this metal, at least exceedingly near the truth.
It will be proper, therefore, in the first place to
state his experiments.

M. Stromeyer analyzed the carbonate, sul-
phate, nitrate, muriate, phospate, and borate of
cadmium. He has not yet published the details
of his analyses ; or at least, the second volume of
his *Untersuchungen,* in which they will probably
be found, has not yet reached Great Britain.
This puts it out of our power to judge of the
accuracy of the data which he employed in his
calculations. Under this uncertainty, I shall
make choice of the sulphate to determine the
atomic weight of cadmium, because I know
from other analyses which he has published in
detail, that he employs the constituents of sul-
phate of barytes as given by Berzelius, which,

though not rigidly exact, approach exceedingly near the truth.

According to Stromeyer, sulphate of cad- mium has a good deal of resemblance to sulphate of zinc in its appearance. Its crystals are four-sided rectangular prisms, which are very soluble in water, and effloresce rapidly when exposed to the air. Heat easily drives off the water of crystallization; but the salt may be exposed to a red heat without losing any of its acid; this makes it easy to determine its water of crystallization. The constituents of this salt as determined by Stromeyer are

Sulphuric acid	.	28·5230
Oxide of cadmium		45·9564
Water	.	25·5206
		100 *

Now, these numbers bear to each other the same ratios as the following:

Sulphuric acid	.	5
Oxide of cadmium		8·0567
Water	.	4·454

It will be obvious to the reader that 5 is the number which denotes the atomic weight of sulphuric acid; 4·454 is so near 4·5, which represents the weight of four atoms of water, that we

* Gilbert's Annalen, LX. 202.

B b 3

can have no doubt that four atoms is the exact quantity of water in an integrant particle of the salt. It is more than probable that the 0·046, which is wanting to complete the weight of the four atoms of water, has been given to the oxide of cadmium. Hence, it is likely that the constituents of the salt should have been stated as follows :

1 atom sulphuric acid	=	5
1 atom oxide of cadmium	=	8·0107
4 atoms water	=	4·5

8·0107 denote the weight of an atom of oxide of cadmium, according to this analysis—a number approaching 8 so nearly, that we can have no hesitation in making choice of 8 as the true atomic weight of this oxide. For it is obvious from the great number of atoms already investigated, as well as to be investigated, that all the atomic weights of simple bodies are multiples of 0·25. Now, 8 is such a multiple; while neither 8·0567 nor 8·0107 is so.

To determine the composition of sulphate of cadmium with the requisite exactness, I prepared a quantity of very pure crystals, by crystallizing a rather concentrated solution of the salt under the exhausted receiver of the air-pump over sulphuric acid. The crystals were large, flat, four-sided prisms, apparently rectangular, but from their efflorescing property, I was not able to measure their angles by the reflecting goniometer. In most of them, the edges were

truncated, rendering the prism hexagonal, and it was terminated at both extremities by an elongated hexagon. These crystals, after four successive crystallizations, still reddened vegetable blues. Hence, I conclude that oxide of cadmium, like oxide of zinc, is incapable of completely neutralizing sulphuric acid. The taste of the salt has some resemblance to that of sulphate of zinc ; but it is rather more acrid and disagreeable.

Guided by the analysis of Stromeyer given above, I dissolved 17·5 grains of these crystals, dry, but quite free from efflorescence, in water, and mixed the solution with one of 13·25 grains of chloride of barium. After the sulphate of barytes had subsided, the supernatant liquid was tested by sulphate of soda and muriate of barytes, but it was not affected by either. From this we see that 17·5 grains of crystallized sulphate of cadmium contain just 5 grains of sulphuric acid.

17·5 grains of the same crystals, heated very cautiously to redness in a platinum crucible, lost just 4·5 grains, which is equivalent to 4 atoms of water.

The acid and water in 17·5 grains of sulphate of cadmium amounting to 9·5 grains, it is obvious, that the 8 grains wanting to make up the whole weight must be oxide of cadmium ; and that the true composition of the salt is

1 atom sulphuric acid   5
1 atom oxide of cadmium   8
4 atoms water   .   4·5
                                        _____
                                        17·5

I placed an exceedingly concentrated solution
of sulphate of cadmium, along with sulphuric
acid, under the exhausted receiver of an air
pump.   Instead of crystallizing, the liquid de-
posited a white, hard, shapeless crust, similar in
appearance to enamel.   When a solution of 15·25
grains of this crust was mixed with a solution of
13·25 grains of chloride of barium, a double de-
composition took place ; and after the sulphate
of barytes had subsided, the supernatant liquid
was tested with sulphate of soda and muriate of
barytes, but was not affected by either.   Hence
the constituents of this crust are

1 atom sulphuric acid   5
1 atom oxide of cadmium   8
2 atoms water   .   2·25
                                        _____
                                        15·25

Sulphate of zinc has the property of being de-
posited in the same way, as was shown in the
first section of the third chapter of this work.

Several of the other salts of cadmium were
likewise analyzed.   The results, which will be
seen in a subsequent chapter, all coincide to

show that 8 is the atomic weight of oxide of Atom of oxide of cadmium.
cadmium.

As cadmium unites with only one dose of oxygen, it is obvious that the oxide is a compound of one atom cadmium and one atom oxygen; consequently, the atomic weight of cadmium must be 7. This is corroborated by Stromeyer's experiments. He found that 100 cadmium, when oxydized, were converted into 114·352 of oxide of cadmium. Therefore, oxide of cadmium is composed of Atom of cadmium.

<div style="text-align:center">
Cadmium 100   or   6·9677
Oxygen   14·352 -   1
</div>

6·9677, the atomic weight of cadmium, deduced from this experiment, approaches very nearly to 7, the number deduced from the sulphate. That it should be rather less than 7 is not surprizing; for cadmium is so volatile a metal, that it is not easy to expose it to heat, without some loss.

Stromeyer likewise formed and analyzed some alloys of cadmium. They deserve our attention, because they serve to corroborate the accuracy of the atomic weight which has been assigned to cadmium.

The alloy of cadmium and platinum is a compound of Alloy of cadmium and platinum.

<div style="text-align:center">
Platinum   46·02   or   12
Cadmium   53·98   -   14·07
</div>

<div style="text-align:center">
100·00*
</div>

* Gilbert, LX. 209.

It will appear hereafter, that the 12 represents the atomic weight of platinum.   14·07 must denote two atoms of cadmium ; for the alloy consists obviously of 1 atom of platinum, united to 2 atoms of cadmium.   The atom of cadmium, deduced from this alloy, is 7·035.

Amalgam of cadmium.

The amalgam of cadmium is composed of

Cadmium	21·7391	or	6·944
Mercury	78·2609	-	25
	100		

25 is the atomic weight of mercury, so that the amalgam is a compound of 1 atom mercury, and 1 atom cadmium.   The atomic weight of cadmium, deduced from this amalgam, is 6·944.

The atom of cadmium, deduced from a mean of these two alloys, is 6·9895 ; and if we deduce the atomic weight of this metal from a mean of these four sets of experiments of Stromeyer, which is the most likely way to come at the truth, we obtain 7·00085.   Now, this approaches so very near 7, that the most scrupulous chemist cannot hesitate about adopting 7 as the true atomic weight of this metal ; so that the experiments of Stromeyer, even without mine, are sufficient to establish that important point.

Thus it appears that an atom of cadmium weighs 7, and an atom of oxide of cadmium 8. Sulphuret of cadmium, when digested in nitric

acid, is converted into sulphate of cadmium. It is, therefore, a compound of one atom sulphur and one atom cadmium, and its atomic weight is 9.

SECT. II.

OF THE ATOMIC WEIGHT OF LEAD.

I HAVE already in a former section of this work described an experiment, from which the atomic weight of protoxide of lead is easily deduced. Nitrate of lead crystallizes in white opaque octahedrons, and is quite anhydrous. 20·75 grains of it are just decomposed by 11 grains of anhydrous sulphate of potash; and the sulphate of lead obtained weighs exactly 19 grains. Now, these 19 grains contain 5 grains of sulphuric acid; so that the salt must be a compound of

Sulphuric acid . 5
Protoxide of lead 14
———
19

The salt being neutral, and 5 representing the weight of an atom of sulphuric acid, 14 must represent the weight of an atom of protoxide of lead. *Atom of protoxide of lead.*

If it be a compound of 1 atom lead and 1 atom oxygen, then an atom of lead weighs 13; and that 13 is the true weight of an atom of lead *Atom of lead.*

will appear from the following experiment : 15
grains of pure galena or sulphuret of lead were
reduced to powder, and digested with nitric acid
in a small retort, the weight of which had been
previously ascertained, and marked upon it with
a diamond.   By this process the galena was gra-
dually converted into sulphate of lead.   When
the conversion was completed, the nitric acid
was distilled off, and the retort was kept in a
heat of above 600°, till it became quite dry in
the inside ; it was then allowed to cool, and the
weight of the sulphate of lead thus formed was
exactly 19 grains.   Now, 5 of these grains are
sulphuric acid, containing 2 grains of sulphur ;
consequently, 2 represents the quantity of sul-
phur in 15 grains of sulphuret of lead.   The re-
mainder of the weight being lead, it is obvious
that sulphuret of lead is composed of

$$
\begin{array}{lr}
\text{Lead} & 13 \\
\text{Sulphur} & 2 \\
\hline
& 15
\end{array}
$$

2 represents the weight of an atom of sulphur,
and 13 is obviously the atomic weight of lead.

2. Besides the protoxide, or yellow oxide of
lead, there are two other oxides of this metal ;
namely, the *red oxide*, or *deutoxide*, and the
brown oxide, or *peroxide*.

Composi-
tion of red
lead.   The beautiful pigment called *red lead*, is a

9

mixture of deutoxide and protoxide in variable proportions. In some very beautiful red lead, I have found the proportion of protoxide amount to nearly one-half of the whole weight. If we digest red lead in acetic acid, we dissolve the protoxide, and leave the deutoxide untouched ; it has a dark red colour, and is destitute of the beauty which characterizes red lead. Various experiments have been made to determine the additional quantity of oxygen necessary to convert the protoxide of lead into deutoxide. I made a set of experiments on the subject about twenty years ago ;* but as I was not aware at that time, of the mixture of protoxide present in the pigment, I did not, of course, attempt to separate it, and consequently underrated the proportion of oxygen which it contained. Even Berzelius, though aware of the existence of the protoxide of lead in red lead, does not seem to have succeeded in removing the whole of it. But the proportion of oxygen, which he assigns to this oxide, though below the true quantity, affords a sufficient approximation to enable us to determine the composition of the deutoxide of lead.

9·835 parts of deutoxide, when heated to redness, gave out 0·29 parts of oxygen, and left 9·545 parts of protoxide of lead.† According to

* Nicholson's Jour. VIII. 289.

† Afhandlingar, III. 168, or Ann. de Chim. LXXVIII. 14. But there is a typographical error in the French translation.

this experiment deutoxide of lead is composed of

<div style="text-align:center">

Protoxide of lead   9·545   or   14
Oxygen   .   0·290   -   0·43

</div>

Atom of deutoxide of lead.

The following experiment, which I made with great care, will show that the true composition of deutoxide of lead is 14 protoxide + 0·5 oxygen. 29 grains of deutoxide of lead were digested in dilute, but pure nitric acid, till all action was at an end ; the whole was then thrown on a double filter, and the peroxide of lead remaining undissolved was well washed and thoroughly dried in a temperature of nearly 500° —it weighed 15 grains. Hence it follows, that the protoxide dissolved by the acid weighed 14 grains. Thus, 29 grains of deutoxide of lead were resolved into

<div style="text-align:center">

Protoxide of lead   .   .   14
Peroxide of lead   .   .   15
        —
        29

</div>

But it will be shown immediately that 15 represents the atomic weight of peroxide, and that it is a compound of 1 atom lead and 2 atoms oxygen. Protoxide of lead is a compound of 1 atom lead and 1 atom oxygen : hence it follows, that 29 deutoxide of lead are composed of

<div style="text-align:center">

2 atoms lead   = 26   or 1 atom lead   13
3 atoms oxgen =   3   -   1½ atom oxygen   1·5
          —   ——
          29   14·5

</div>

Deutoxide of lead does not seem capable of entering into any chemical combination ;—it is, therefore, in the present state of our knowledge, comparatively insignificant as a chemical substance.

3. The peroxide of lead is a flea brown coloured powder, which was discovered by Scheele. It may be obtained by digesting nitric acid on red lead. A portion of the deutoxide is reduced to the state of protoxide, and dissolves in the acid, while the oxygen given off by it uniting to another portion converts it into peroxide. If the deutoxide be pure, it is evident from the experiment stated above, that just one half of the lead is dissolved and the other half converted into peroxide.

Atom of peroxide of lead.

I found long ago, that 100 grains of this oxide, when exposed to a red heat, left 91 grains of protoxide.* Now, if the 9 grains of loss be considered as oxygen, it will follow from this experiment, that peroxide of lead is composed of 100 lead + 18·34 oxygen, or of lead 13 + oxygen 2·384. But when I made these experiments I was not aware that metallic oxides are apt to retain water : the peroxide which I employed had been merely dried in the open air, and consequently, was not quite anhydrous. The loss of weight was partly water and partly oxygen ;

* Nicholson's Journal, VIII. 288.

consequently, my estimate of the quantity of oxygen in this oxide was too high.

Berzelius dried the peroxide of lead in a temperature at which tin melted. He found, that 5 parts of the oxide thus dried, lost, when exposed to a red heat, 0·325 parts;—the residue, which weighed 4·675 parts, being digested in acetic acid, left 0·13 parts of sulphate of lead and silica.* It follows from this experiment, that peroxide of lead is composed of

$$
\begin{array}{lccc}
\text{Protoxide of lead} & 4\text{·}545 & \text{or} & 14 \\
\text{Oxygen} & 0\text{·}325 & - & 0\text{·}973 \\
\hline
 & 4\text{·}87 & &
\end{array}
$$

No doubt the true composition is

$$
\begin{array}{lc}
\text{Protoxide of lead} & 14 \\
\text{Oxygen} & 1 \\
\hline
 & 15
\end{array}
$$

The atomic weight is 15, and the oxide is a compound of 1 atom lead = 13, and 2 atoms oxygen = 2.

Thus, the constituents of the three oxides of lead are as follows :

	LEAD.	OXYGEN.			ATOMIC WEIGHT.
Protoxide	1 atom	+ 1 atom	.	.	14
Deutoxide	1	+ 1½	.	.	14·5
Peroxide	1	+ 2	.	.	15

* Af handlingar, III, 170., or Ann. de Chim. LXXVIII, 16. The French translation is unintelligible, because a sentence is left out.

4. When thin plates of pure lead are intro- Chloride of lead.
duced into dry chlorine gas, the gas is gradually
absorbed and the lead converted into a white
matter, which is a chloride of lead. This chlo-
ride is easily obtained by mixing together solu-
tions of nitrate of lead and of common salt :
small brilliant crystals precipitate, which, when
heated in a close vessel, melt and assume the
form of a greyish matter, formerly distinguished
by the name of *plumbum corneum.* I find, by a
careful experiment, that 13 grains of lead, when
converted into chloride, weigh 17·5 grains.
Hence, it is obvious that this chloride is com-
posed of

<div style="text-align:center">

1 atom lead   . .   13
1 atom chlorine . .   4·5
<u>   </u>
17·5

</div>

SECT. III.

OF THE ATOMIC WEIGHT OF TIN.

TIN is a metal which forms two different oxides, Oxides of tin.
when it combines with oxygen. The *protoxide*
may be obtained by dissolving tin in strong mu-
riatic acid (taking care to exclude all access of
atmospheric air to the inside of the small retort in
which the process is going on). When the muri-
atic acid is saturated with the tin, the liquid must

be poured at once into a glass vessel containing as much caustic potash or soda as will saturate the whole muriatic acid in combination with the protoxide. A black powder falls, which is protoxide of tin ; it may be separated by a filter, edulcorated and dried. When in combination with acids, this oxide has a great tendency to combine with more oxygen, and to be converted into peroxide ; but when in a separate state, and dry, I have kept it for years in a common phial, without observing any alteration in its colour.

The peroxide of tin has a yellowish colour. It may be obtained by digesting tin in nitric acid, and gradually raising the temperature to redness. The acid is decomposed and driven off, while the peroxide of tin remains behind in a state of purity.

Both of these oxides form salts with muriatic acid ; but my attempts to determine the atomic weight of tin, by a rigid analysis of these salts, did not succeed. The following experiment, however, which I have several times repeated, gives the composition of peroxide of tin, from which it is easy to deduce the atomic weight of this metal.

Atom of peroxide of tin.   7·25 grains of pure tin were put into a platinum crucible, and dissolved in a sufficient quantity of very dilute nitric acid. The solution was slowly evaporated to dryness, and the crucible gradually raised to a red heat. The peroxide of

tin formed in this way weighed 9·25 grains; hence it is evidently a compound of

$$
\begin{array}{lll}
\text{Tin} & . & 7\cdot25 \\
\text{Oxygen} & . & 2 \\
\hline
& & 9\cdot25
\end{array}
$$

But 2 denotes 2 atoms of oxygen; consequently, 7·25 must be the weight of an atom of tin. Peroxide of tin obviously weighs 9·25, and is a compound of 1 atom of tin and 2 atoms of oxygen.

2. The experiments of Berzelius* leave no doubt that the protoxide of tin contains just half the oxygen in the peroxide. It is, therefore, a compound of 1 atom tin and 1 atom oxygen, and its atomic weight is 8·25. Atom of protoxide.

3. Tin combines with two proportions of chlorine, as well as of oxygen, and forms two chlorides. The protochloride is most easily formed pure, by amalgamating together tin and mercury, mixing the amalgam with a sufficient quantity of calomel; and exposing it in a glass tube to a heat at first low, but gradually raised high enough to expel all the mercury and the calomel. 7·25 grains of tin treated in this way, left 11·75 grains of protochloride. Hence this chloride is obviously composed of Chlorides of tin.

---

* Nicholson's Journal, XXXV. 122.

$$
\begin{array}{lll}
\text{1 atom tin} & . & 7 \cdot 25 \\
\text{1 atom chlorine} & . & 4 \cdot 5 \\
\hline
& & 11 \cdot 75
\end{array}
$$

This chloride is a grey matter, having a resinous lustre and fracture. When put into chlorine gas, it catches fire, and is converted into per-chloride.

Fuming li-
quor of Li-
bavius.

4. The perchloride of tin has been long known under the name of *fuming liquor* of Libavius. It may be obtained by mixing together amalgam of tin and corrosive sublimate, and distilling with a very moderate heat. A colourless liquid comes over at first, consisting chiefly of water ; then the fuming liquor rushes all at once with such rapidity, that I have more than once lost the whole product of the distillation. Dr. John Davy found that this perchloride may be obtained likewise by mixing together concentrated permuriate of tin and sulphuric acid, and distilling with a gentle heat.

This perchloride gives out very copious and dense fumes when exposed to the air, in consequence of its great avidity for moisture. Adet found, that when three parts of it are mixed with one part of water, the whole condenses into a solid state. I see no reason to doubt that this perchloride, when in a state of purity, is a compound of 1 atom tin and 2 atoms chlorine ; and that its atomic weight is $16 \cdot 25$;—but I have not

been able to verify this opinion by direct analy-
sis. I made three experiments upon fuming li-
quor of Libavius, prepared very carefully in my
laboratory. The quantity of chlorine found in
each did not exactly correspond; but the mean
of all the three gave for the constituents of the
chloride

1 atom tin . .	7·25
2¼ atoms chlorine	9·112
	16·362

The analysis of this compound by Dr. John
Davy* gave very nearly the same result; or,
rather, he found a somewhat greater proportion
of chlorine, viz. 9·18 parts united to 7·25 of tin.
It would seem from these analyses, that fuming
liquor of Libavius, when prepared by means of
amalgam of tin and corrosive sublimate, is apt to
contain an excess of chlorine.

I find that permuriate of tin in crystals is
composed of

1 atom peroxide of tin .	9·25
2 atoms muriatic acid .	9·25
3 atoms water . .	3·375
	21·875

When this salt is mixed with sulphuric acid, and

C c 3

distilled by a gentle heat, the perchloride obtained would probably be neutral ; but I have not tried to prepare it in this way.

5. The sulphurets of tin, which are two in number, likewise furnish decisive evidence of the atomic weight of tin.

The protosulphuret of tin may be obtained by melting together tin and sulphur in a glass tube, and keeping up the heat till the excess of sulphur is sublimed. When 7·25 grains of pure tin are thus converted into sulphuret, the weight of the new compound is 9·25. Hence it is a compound of

1 atom tin . .	7·25
1 atom sulphur .	2
	9·25

The persulphuret has been long known by the name of Mosaic gold. It is under the form of light scales, of a brownish yellow colour, and great beauty and lightness. It is soluble in nitromuriatic acid, and likewise in potash ley. The analysis of this sulphuret of tin by Dr. John Davy is sufficient to prove that it is a compound of

1 atom tin . .	7·25
2 atoms sulphur .	4
	11·25

for he found the constituents by analysis to be[*]

Tin	.	100	or	7·25
Sulphur	.	56·25	-	4·078

SECT. IV.

OF THE ATOMIC WEIGHT OF BISMUTH.

In order to determine the atomic weight of bis-
muth with accuracy, it is requisite to employ
that metal in a state of purity.   The bismuth of
commerce is usually contaminated with iron, and
almost always contains some sulphur.   To obtain
pure bismuth, I dissolved a quantity of the bis-
muth of commerce in nitric acid.   The crystals
of nitrate of bismuth being thrown into water,
were decomposed, and a white powder, consist-
ing chiefly of hydrated oxide of bismuth, fell to
the bottom.   This hydrate was well washed,
dried upon the filter, and reduced to the me-
tallic state, by heating it in a covered crucible
with black flux.

1. Nine grains of bismuth purified in this way, Atom of
were put into a platinum crucible, and dissolved oxide of
in nitric acid.   The solution was evaporated to bismuth.
dryness by a gentle heat, which was afterwards
gradually raised till the crucible became percep-

* Phil. Trans. 1812, p. 199.

C c 4

tibly red hot. By this means, the acid was driven off, leaving behind it the bismuth reduced to the state of an oxide. It weighed exactly 10 grains, and consequently, the metal, when oxydized, had combined with one-ninth of its weight of oxygen. Hence, oxide of bismuth is composed of

Bismuth	9
Oxygen	1
	10

But 1 being the weight of an atom of oxygen, it is obvious that 9 must be the atomic weight of bismuth; and the atomic weight of oxide of bismuth is 10.

This metal combines with only 1 atom of oxygen, and forms only one oxide.

Chloride of bismuth.   2. The chloride of bismuth may be formed by mixing together bismuth in powder, with corrosive sublimate in a glass tube, and exposing the mixture to a heat, at first low, but gradually raised to the boiling point of mercury, or a little higher. The excess of corrosive sublimate and the reduced mercury, are gradually volatilized, leaving the chloride of bismuth in a state of purity. It is a solid substance, having a granular texture, a greyish white colour, and a silky lustre. I mixed 9 grains of pure bismuth in powder, with 40 grains of corrosive sublimate in a test tube. This test tube, with a cork fitted

to it, was left for three or four days on the sand
bath ; at first the heat applied did not exceed
that of boiling water, but the tube was brought
gradually towards the hottest part of the sand
bath, till the temperature was at last between
600° and 700°. Finally, it was raised high
enough to drive off all the mercury and the cor-
rosive sublimate which had escaped decomposi-
tion ; the weight of the chloride of bismuth was
within $\frac{1}{10}$th of a grain of 13·5 grains. The loss
of $\frac{1}{10}$th of a grain, I ascribe to the volatilization
of a small portion of the chloride, which it is
very difficult to avoid. If we compare this ex-
periment with the preceding, it will be obvious
that the chloride of bismuth is a compound of

1 atom chlorine	4·5
1 atom bismuth	9
	13·5

3. The atomic weight of bismuth deduced Sulphuret of bismuth.
from the oxydation of the metal, is still farther
confirmed by the sulphuret. This sulphuret
occurs native, and may be easily formed artifi-
cially, by heating together bismuth and sulphur,
and keeping up the heat till the excess of the
sulphur is driven off. Nine grains of pure bis-
muth converted into a sulphuret in this way, in
a green glass tube, became eleven grains of
sulphuret, showing that the sulphuret is a com-
pound of

                    1 atom bismuth   9
                    1 atom sulphur   2
                                         ——
                                         11

The previous analyses of sulphuret of bismuth
by Dr. John Davy and Mr. Lagerhjelm almost
coincide with this experiment of mine. Dr.
John Davy * found it a compound of

                    Bismuth   9
                    Sulphur   2·007

M. Lagerhjelm obtained †

                    Bismuth   9
                    Sulphur   2·0268

Dr. John Davy's experiment was conducted
nearly in the same way as my own: he em-
ployed 100 grains of bismuth—I presume the
bismuth of commerce. Now, the presence of
a very small portion of iron in this bismuth,
would account for the slight excess of sulphur,
which scarcely exceeds one third per cent. La-
gerhjelm's analysis is not quite so near the truth
as Dr. Davy's.

4. Vauquelin, in a set of experiments, pub-
lished a number of years ago, upon the quantity
of sulphur with which the metals combine when
heated or fused with that substance, states that
he found sulphuret of bismuth composed of‡

* Phil. Trans. 1812. p. 200.   † Annals of Philosophy, IV. 357.
            ‡ Ann. de Mus. d'Hist. Nat. XV. 9.

Bismuth 68·25 or 9
Sulphur 31·75 - 4·186

100·00

If this sulphuret of Vauquelin exist, (for I have not succeeded in my attempts to form it artificially,) it is evidently a bisulphuret, or a compound of two atoms sulphur with one atom of bismuth.

SECT. V.

OF THE ATOMIC WEIGHT OF COPPER.

COPPER forms two oxides; the *red oxide*, which occurs native, and does not seem capable of combining with acids; and the *black*, which constitutes the basis of all the cupreous salts. It was shown long ago by Chenevix, and his experiments have been amply confirmed by succeeding researches, that the black oxide contains exactly twice as much oxygen as the red; and I shall show immediately, that if we reckon the weight of an atom of copper to be 4, then the composition of these oxides is as follows : Oxides of copper.

COPPER. OXYGEN.
1. Red oxide   8 + 1 or 2 atoms copper + 1 atom oxygen.
2. Black oxide 4 + 1 or 1 atom copper + 1 atom oxygen.

I shall therefore distinguish the black oxide by

the name of *oxide of copper ;* while to the red
oxide we shall apply the term *suboxide,* indicat-
ing that it is a compound of two atoms copper
and one atom oxygen.   Such suboxides in gen-
eral are incapable of constituting permanent salts
with acids.

As the black oxide of copper constitutes the
basis of all the cupreous salts, the knowledge of
its atomic weight is of most importance in a
chemical point of view.   We may employ the
common sulphate of copper, as a good instru-
ment for determining the atomic weight of this
oxide; because being manufactured to a con-
siderable extent, and employed both in medi-
cine and the arts, it may be easily procured in a
state of purity.   It has a fine blue colour, an ex-
ceedingly disagreeable cupreous taste, reddens
vegetable blues, and crystallizes in oblique four-
sided prisms, the faces of which are inclined to
each other at angles of 124° and 56°.

Analysis of
sulphate of
copper.
1. When a solution of 15·625 grains of these
crystals in water, is mixed with a solution of
13·25 grains of chloride of barium, a double de-
composition takes place, sulphate of barytes pre-
cipitates, and the supernatant liquid is neither
affected by sulphate of soda nor muriate of ba-
rytes.   Hence, it follows, that 15·625 grains of
this salt contain just 5 grains of sulphuric acid.

2. If the whole oxide of copper be precipita-
ted from 15·625 grains of blue vitriol, and col-

lected without loss, it will weigh exactly five grains. This experiment is not easily made, be-cause we have no good precipitant of oxide of copper. But I have accomplished it in various ways. If we throw down the oxide of copper by caustic potash, we obtain very nearly five grains, though I have never got the exact amount in this way. In general, the oxide of copper thus procured weighs about 4·9 or 4·95 grains. When the copper is thrown down by sulphuret-ted hydrogen, or by hydrosulphuret of ammonia, the precipitate, when collected without loss, and sufficiently dried, weighs 8 grains, and when dis-solved in aqua regia, and precipitated by muriate of barytes, the sulphate of barytes obtained weighs 29·5 grains, indicating 10 grains of sul-phuric acid, equivalent to 4 grains of sulphur ; consequently, the copper in 15·625 grains of blue vitriol weighs exactly 4 grains.* This, coupled with the amount of the precipitate by means of caustic potash, leaves no doubt that the true weight of the oxide of copper in 15·625 grains of blue vitriol is 5 grains ; and that it is a compound of

* If we precipitate the copper from 15·625 grains of sulphate of copper by means of a plate of zinc, taking care in the first place, to acidulate the solution of the salt with a little sulphuric acid, to prevent the copper from adhering to the zinc ; the precipitated copper, if it be dried without allow-ing it to absorb oxygen, will weigh exactly four grains. This experiment is not easily made, because the copper while drying has a tendency to absorb oxygen, But it is easy in this way to obtain a very near approxi-mation.

9

Copper   4   or   1 atom
Oxygen   1   -   1 atom

3. The only other constituent of blue vitriol being water, it is obvious that the salt is a compound of

1 atom sulphuric acid   5
1 atom oxide of copper   5
5 atoms water   5·625
                          ————
                          15·625

Disulphate of copper.   4. There exists another sulphate of copper, which I formed by the following process : 31·25 grains of blue vitriol were dissolved in water in a retort, and the solution was mixed with 10 grains of peroxide of copper. The retort was put upon the sand bath in such a position that it was kept boiling several hours every day, taking care to add fresh water in proportion as that liquid was dissipated; and this was continued till all the oxide of copper had totally disappeared. This happened in about a couple of months ; at the same time the liquid lost its blue colour, while a green coloured powder was deposited. The liquid being tested for copper by ammonia, was found to contain none. It is obvious, therefore, that the green powder contained all the acid and oxide of copper in 31·25 grains of blue vitriol, together with the additional 10 grains of oxide added. The green powder, therefore, was a compound of

Sulphuric acid   10   or   5
Oxide of copper   20   -   10

This powder was tasteless, insoluble in water, and produced no effect on vegetable blues. It was obviously a compound of 1 atom acid, and 2 atoms oxide, or it was a disulphate of copper.

5. Sulphuret of copper is easily formed by heating together copper filings and sulphur. The combination takes place suddenly when the mixture has reached a certain temperature, and the sulphur from being in a liquid state becomes suddenly solidified. This explains the reason of the ignition which takes place, and which attracted so much of the attention of the Dutch chemists. The first person who attempted to determine the composition of this sulphuret with the requisite precision was Berzelius. He found that 10 parts of copper, when converted into sulphuret, became 12·56 parts.* Now, 10 : 2·56 : : 8 : 2·048 ; so that according to this experiment, sulphuret of copper is composed of

Copper   8
Sulphur   2·048

The copper of commerce, which Berzelius probably employed in his experiment, is not quite pure. I believe it is often contaminated with some protoxide of copper, and always with some other

*Afhandlingar, III. 187.
16

metals. I prepared some very pure copper on purpose, and found that 8 grains of it, when converted into sulphuret in a green glass tube, became exactly 10 grains. Hence, it follows that this sulphuret is a compound of

Copper	8
Sulphur	2
	10

2 is an atom of sulphur and 8 is two atoms copper. So that this compound is a disulphuret of copper.

Sulphuret of copper.

Besides these two sulphurets of copper, a third seems to exist in combination with protosulphuret of iron; for M. Henry Rose found copper pyrites to be a compound of

Copper	34·4
Iron	30·47
Sulphur	35·87
	100·74
Silica	27
	101·01*

The excess of 1 per cent. was probably in the sulphur. But let us suppose the result to be exact, the above numbers are equivalent to

* Ann. de Chim. et de Phys. XXV. 197.

Copper	4·000	or	1 atom
Iron	3·543	-	1 atom
Sulphur	4·170	-	2 atoms

It is obvious, that copper pyrites is a compound of

1 atom sulphuret of copper	6
1 atom sulphuret of iron	5·5
	11·5

Thus, there are three sulphurets of copper; namely,

	COPPER.			SULPHUR.	
1. Disulphuret composed of	2	atoms	+	1	atom.
2. Sulphuret	1	atom	+	1	atom.
3. Bisulphuret	1	atom	+	2	atoms.

6. If 100 grains of peroxide of copper be dissolved in muriatic acid, and 80 grains of copper filings be added to the solution, and the whole agitated in a well stopped phial nearly filled by the mixture, the copper filings are instantly dissolved without the evolution of any gas, and the liquid, which has become black and opaque, is found to contain a solution of suboxide of copper in muriatic acid. This experiment, for which we are indebted to Mr. Chenevix, but which I have frequently repeated, demonstrates the composition of suboxide of copper: for 100 grains of oxide of copper are composed of

Atom of suboxide of copper.

Copper   80
Oxygen   20

─────

100

So that by the addition of 80 grains, the copper in the liquid is exactly doubled, while the oxygen with which it is combined remains the same as at first.   Hence, suboxide of copper is obviously composed of

Copper   160   or   16   or   8
Oxygen   20   -   2   -   1

It is a compound of 2 atoms copper and 1 atom oxygen, and its atomic weight is 9.

Chloride of copper.   7. Chlorine and copper combine in two proportions, and form two chlorides analogous in their composition to the two oxides of copper.

The perchloride is easily obtained by dissolving peroxide of copper in muriatic acid, and concentrating the green coloured solution. Permuriate of copper is formed, and may be obtained in long four-sided rectangular prisms with square bases.   This salt I find, by a careful analysis, is composed of

1 atom muriatic acid   4·625
1 atom oxide of copper   5
2 atoms water   .   2·25

─────

11·875

9

When 11·875 grains of this salt are exposed to a temperature of between 400° and 500°, or indeed to a lower temperature, there is a diminution of weight amounting to exactly 3·375 grains, the green colour disappears, and an orange brown matter remains, weighing exactly 8·5 grains. Now, the 3·375 grains of matter driven off consist of pure water, as may be ascertained by performing the experiment in a retort, to which a receiver is luted. The water will come over into the receiver quite pure, unless too much heat has been applied. In that case some chlorine is apt to pass off, owing I presume to the agency of the common air in the retort.

3·375 grains of water is the equivalent for 3 atoms of that liquid; yet the salt contained only 2 atoms. The other atom of water was formed by the union of the atom of oxygen in the oxide with the atom of hydrogen in the muriatic acid. Thus the salt is changed into chloride of copper, which, as is obvious from the facts just stated, is a compound of

1 atom copper	.	4
1 atom chlorine	.	4·5

$$8·5$$

8. The subchloride of copper was noticed by Boyle; and it has been minutely described by Prout, Chenevix, and Dr. John Davy. I have

Subchloride of copper.

not made any attempts to analyze it, because the previous analysis of Dr. Davy is perfectly accurate. He found it composed of

2 atoms copper	.	8
1 atom chlorine	.	4·5
		——
		12·5

The constituents of the chlorides and sulphuret of copper, compared with those of the oxides, leave no room for doubt that the true atomic weight of this metal is 4.*

---

* It is hardly necessary to remark, that the atom of copper might be represented by 8, as well as by 4. In that case, red oxide of copper would be composed of

1 atom copper	=	8
1 atom oxygen	=	1
		——
		9

and black oxide of

1 atom copper	=	8
2 atoms oxygen	=	2
		——
		10

The chlorides would be :

protochloride	1 atom copper	=	8
	1 atom chlorine	=	4·5
			——
			12·5

perchloride	1 atom copper	=	8
	2 atoms copper	=	9
			——
			17

SECT. VI.

OF THE ATOMIC WEIGHT OF MERCURY.

It has been ascertained by unexceptionable experiments, that mercury combines with two doses of oxygen, and forms two oxides. The protoxide is *black*, and the peroxide *red*. The volatility of mercury and its compounds presents

Oxides of mercury

and the sulphurets :

protosulphuret of   1 atom copper   =   8
                    1 atom sulphur   =   2
                                           10

bisulphuret of   1 atom copper   =   8
                  2 atoms sulphur   =   4
                                           12

persulphuret of   1 atom copper   =   8
                  4 atoms sulphur   =   8
                                           16

This was the idea I originally formed of these compounds, and it seems to be the one generally adopted by chemists. It was the consideration of the salts of copper that induced me to adopt 4 for the atomic weight of copper ; for, if we represent the atom of copper by 8, all the salts of copper, without exception, will be bisalts, or will contain 2 atoms of acid, united to 1 atom of oxide. It was an object of some importance to get rid of this anomaly, which involved the salts of copper in a good deal of confusion. This was accomplished by adopting 4 for the atomic weight of copper, as had been already done by Dr. Wollaston and Dr. Prout.

a formidable obstacle to the rigid determination
of their atomic weights.

1. Fourcroy, long ago, stated, that the pro-
toxide of mercury is a compound of 100 metal
and 4 oxygen ;* but, from the loose way in which
this chemist was accustomed to express himself,
we can consider this determination in no other
light but that of a fortunate conjecture. Mr.
Donovan, from a number of experiments on both
oxides, has concluded that protoxide of mercury
is composed of

Mercury	.	100	or	24·271
Oxygen	.	4·12	-	1*

And peroxide of

Mercury	.	100	or	25·575
Oxygen	.	7·82	-	2

The atomic weight of mercury, deduced from
these two oxides, not being exactly the same, it
is obvious that the experiments from which the
constitution of these oxides has been deduced,
are not quite exact. The mean of both gives us
24·923 for the atomic weight, which differs less
than $\frac{1}{250}$th from 25, the atomic weight of mer-
cury, deduced from the composition of protoxide
of mercury, as stated by Fourcroy.

M. Sefstrom made a set of experiments in Ber-

* Annals of Philosophy, XIV. 244.

zelius' laboratory on the composition of the oxides of mercury, with the results of which only I am acquainted.* He found the constituents of protoxide of mercury

Mercury	.	100	or	25·063
Oxygen	.	3.99	-	1

and those of red oxide

Mercury	.	100	or	25·031
Oxygen	.	7·99	-	2

If we take the mean of these two analyses, which do not exactly agree with each other, though they come much nearer than those of Donovan, we obtain 25·047 for the atomic weight of mercury, which exceeds 25 by less than $\frac{1}{500}$th part.

Now, as the atomic weight of mercury, as deduced from Donovan's experiments, is only a very little less than 25, while the same weight, deduced from the experiments of Sefstrom, is a very little more than 25, the inference from these experiments seems to be, that an atom of mercury weighs exactly 25.

2. The experiments of Donovan and Sefstrom leave no doubt that the oxygen in the peroxide of mercury is just double that in the protoxide. It is, therefore, composed of 1 atom mercury and 2 atoms oxygen; and its atomic weight is

27, if we reckon the atomic weight of mercury 25. The truth of this is sufficiently established by the following experiment.

27 grains of pure peroxide of mercury, prepared on purpose for the experiment, were put into an eight-ounce phial, and as much muriatic acid poured upon it as dissolved it completely. The phial was then placed upon the sand bath (having a charcoal stopper fitted into its mouth), and left till the liquid was evaporated to dryness. The phial was then covered about two-thirds up with sand, and the temperature was gradually raised sufficiently high to sublime the corrosive sublimate, into which the red oxide had been converted, as high as the middle of the phial. The phial, after being allowed to cool gradually, was weighed, and the weight of the corrosive sublimate was exactly 34 grains.

From this experiment it appears, that 27 peroxide of mercury form exactly 34 corrosive sublimate.

To understand this experiment it is necessary to know, that mercury combines with two proportions of chlorine, and forms two chlorides. The protochloride, usually denominated *calomel*, is a compound of 1 atom mercury and 1 atom chlorine ; while the perchloride, or *corrosive sublimate*, is a compound of 1 atom mercury and 2 atoms chlorine.

With the knowledge of these facts, we may

now analyze the conversion of 27 grains of peroxide of mercury into 34 grains of corrosive sublimate.

27 peroxide are composed of

Mercury	.	25
Oxygen	.	2
		27

When muriatic acid is poured upon the 27 peroxide, two atoms of the acid, equivalent to 9·25 grains, unite with the oxide, forming a compound, which will amount to 36·25 grains, and be a compound of

1 atom peroxide	.	27
2 atoms muriatic acid		9·25
		36·25

When the solution is evaporated to dryness, the acid and peroxide mutually act upon each other : the oxygen of the oxide combines with the hydrogen of the acid, constituting 2 atoms of water, which are expelled by the heat ; while the 2 atoms of chlorine combine with the 1 atom of mercury, and form a perchloride. Thus by the heat, the 36·25 of permuriate of mercury is resolved into

Oxygen	2	} constituting two atoms water.
Hydrogen	0·25	
	2·25	

Mercury   25 ⎫
Chlorine   9 ⎬ constituting an atom perchloride.
             ——
             34

It is clear, therefore, that 27 peroxide of mer-
cury could not become 34 corrosive sublimate,
unless the atomic weight of mercury were 25,
and unless peroxide of mercury were composed
of 1 atom mercury and 2 atoms oxygen.

Atom of mercury.

3. The analysis of calomel by Chenevix is so
conclusive, that I did not consider it at first as
worth while to make any researches on the sub-
ject.   But it may be satisfactory to mention the
following experiment, which was made with an-
other object in view.   A quantity of crystallized
protonitrate of mercury, which I knew to contain
precisely 25 grains of mercury, was dissolved in
water, and the solution mixed with a solution of
7·5 grains of decrepitated common salt :—calo-
mel precipitated, which, when collected on a
double filter, washed and dried, weighed 29·5
grains ; and the residual liquid being examined
for mercury and muriatic acid, no traces of either
could be detected.   From this experiment it is
obvious, that calomel is a compound of

Atom of calomel.

                1 atom mercury   .   25
                1 atom chlorine   .   4·5
                                         ——
                                         29·5

Analysis of cinnabar.

4. A careful analysis of cinnabar gave evi-

dence equally satisfactory, that the atomic weight of mercury is 25. It will be proper to premise, in the first place, that the cinnabar which I employed was not quite free from traces of silica and peroxide of iron : but I made allowance for these bodies, and have left them out of the results to avoid complicated statements as much as possible.

Nitric acid has not the property of decomposing cinnabar, but nitromuriatic acid dissolves it with rapidity, when assisted by heat. 29 grains of cinnabar in powder were put into a retort, along with a sufficient quantity of nitromuriatic acid : the retort being placed on the sand bath, a pretty strong effervescence began, and the cinnabar disappeared in a few minutes, with the exception of a yellow matter, which was separated. This yellow matter was soft and ductile. When first collected, it weighed 3·46 grains ; but being left a few days exposed to the air it became hard and brittle, and the weight was reduced to 3·2 grains. It was pure sulphur, burning all away with a blue flame without leaving any residue.

The nitromuriatic solution was supersaturated with carbonate of soda without the appearance of any precipitate. It was, therefore, evaporated nearly to dryness, redissolved in water, and mixed with a solution of caustic soda : the mercury precipitated in the state of brownish red flocks,

and being carefully collected and weighed,
amounted to 27 grains very nearly.

The liquid, thus freed from mercury, was neu-
tralized by nitric acid, and being mixed with ni-
trate of barytes, a precipitate of sulphate of
barytes fell, which, after being washed, dried,
and heated to redness, weighed 6 grains, equiva-
lent to 0·81 grains of sulphur.   Thus, we have
obtained from 29 grains of cinnabar

Peroxide of mercury	27
Sulphur	4·01
	31·01

This exceeds the quantity analyzed by 2 grains.
The reason is, that in the cinnabar the mercury
is in the metallic state, while in the analysis it
was obtained in the state of peroxide : but 27
peroxide are equivalent to 25 in the metallic
state.   Hence, cinnabar is a compound of

Mercury	25
Sulphur	4·01
	29·01

The 0·01 grain of excess is, doubtless, owing to
an error in the analysis ; which, with all my care,
I was not able to avoid.   But I consider the
analysis as proving that cinnabar is a compound
of

1 atom mercury	25
2 atoms sulphur	4
	—
	29

showing that 25 is the atomic weight of mercury.

The experiments related in this section, constitute the best of a very great number which I have made upon this difficult metal. They leave no doubt on my mind that the atomic weights of mercury and its compounds are as follows:

<div style="float: right">Atomic weights of compounds of mercury.</div>

ATOMIC WEIGHT.

Mercury	25		
		MERCURY.	OXYGEN.
Protoxide	26	1	+ 1 atom
Peroxide	27	1 atom	+ 2
			CHLORINE.
Protochloride	29·5	1	+ 1
Perchloride	34	1	+ 2
			IODINE.
Protiodide	40·5	1	+ 1
Periodide	56	1	+ 2

At the same time, it is proper to state, that I have made no attempts to analyze the iodides of this metal.

SECT. VII.

OF THE ATOMIC WEIGHT OF SILVER.

I HAVE already stated an experiment in page 105 of this work, from which the atomic weight of

16

silver may be deduced. It was there mentioned,
that when solutions of 21·5 grains of nitrate of
silver and 7·5 grains of decrepitated common
salt are mixed together, a curdy precipitate falls,
and the residual liquid is neither affected by ni-
trate of silver nor common salt. It is evident
from this experiment, that the silver in 21·5
grains of nitrate of silver, and the chlorine in 7·5
grains of chloride of sodium, just saturate each
other.

Now, 7·5 grains of chloride of sodium con-
tain exactly 4·5 grains of chlorine. And, if
21·5 grains of nitrate of silver be cautiously
heated to redness, the salt will be decomposed,
the acid driven off, and the oxide reduced; the
weight of silver remaining will be exactly (or at
least very nearly) 13·75 grains. It is obvious
from this, that the chloride of silver, formed by
the mutual decomposition of 21·5 nitrate of sil-
ver and 7·5 chloride of sodium, must consist
of

Silver	.	.	.	13·75
Chlorine	.	.	.	4·5
				18·25

Accordingly, when the precipitate is collected
without loss, and after being well washed and
dried is exposed to a heat sufficiently high to fuse
it, the weight is exactly 18·25 grains.

Now, as 4·5 is the weight of an atom of chlo-
rine, and as the chloride is neutral, it is obvious
that 13·75 must represent the weight of an atom Atom of
of silver. silver.

We have various analyses of the chloride of
silver by preceding chemists; some of which it
will be worth our while to state.

According to Dr. Marcet,* it is composed of

<div style="text-align:center">

Chlorine   4·5
Silver   13·844

</div>

According to M. Gay-Lussac,* its constituents
are

<div style="text-align:center">

Chlorine   4·5
Silver   13·683

</div>

According to Berzelius,† it consists of

<div style="text-align:center">

Chlorine   4·5
Silver   13·758

</div>

This determination of Berzelius differs from
mine by only $\frac{1}{1719}$th part, a quantity so small, Difficulties
that in almost every case of chemical analysis it lysis.
may be neglected. I am almost ashamed to
acknowledge the great number of times that I
repeated this experiment before I could obtain
what I considered as perfect accuracy. I began
by employing the lunar caustic of commerce;

---

* Annals of Philosophy, XII. 347.   † Afhandlingar, III. 192.

but was constantly foiled. I then prepared ni-
trate of silver in platinum vessels, and found that
it was anhydrous, and that 21·5 grains of it were
just precipitated by 7·5 grains of chloride of so-
dium; but the weight of chloride obtained did
not tally with the calculated weight. After
many trials to discover the cause of the discor-
dancy (for the chloride was always slightly de-
ficient) I began to suspect that the distilled
water which I employed might perhaps contain
some ammonia, sufficient to dissolve a small
portion of the chloride, and thus to occasion a
deficiency, which became perceptible in conse-
quence of the great quantity of that liquid with
which it had been washed. This induced me
to acidulate the water with a few drops of nitric
acid in my next experiment. By this addition I
found that the chloride of silver (as far as I
could weigh it) amounted to just 18·25. The
slight excess of chloride in the experiment of
Berzelius, and the still greater excess in that of
Marcet, the former amounting to 0·008 grain,
and the latter to 0·094 grain, I ascribe to a
minute portion of some muriate in the filter em-
ployed by these chemists. This could have no
effect in my trials; because I employed just the
quantity of nitrate of silver that was decomposed
by 7·5 grains of common salt. Hence, my chlo-
ride was always deficient; and I had more than
once given up the experiment as desperate be-

fore I thought of acidulating the water with nitric acid.

2. The preceding experiment gives us not only the atomic weight of silver, but enables us likewise to determine the atomic weight of oxide of silver; for it is obvious from it, that nitrate of silver is anhydrous, and that 21·5 grains of it contain exactly 13·75 grains of silver. Now, as the salt is neutral, and as 13·75 is equivalent to an atom of silver, it is obvious, that the 21·5 of the salt must contain an atom of nitric acid; and that the difference between 21·5 and 20·5, (viz. 13·75 + 6·75) must be the quantity of oxygen with which the silver is united. Hence, nitrate of silver is composed of

$$
\begin{array}{l}
\text{1 atom oxide of silver} \left\{ \begin{array}{ll} \text{of 1 atom silver} & 13\text{·}75 \\ \text{1 atom oxygen} & 1 \end{array} \right\} 14\text{·}75 \\
\text{1 atom nitric acid} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad 6\text{·}75 \\
\hline
\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad 21\text{·}5
\end{array}
$$

It is obvious, that the oxide of silver is a compound of 1 atom silver + 1 atom oxygen, and that its atomic weight is 14·75.

Atom of oxide of silver.

3. When oxide of silver is dissolved in ammonia, and the solution left exposed to the air, a brilliant black pellicle collects on the surface. This pellicle was first examined by Mr. Faraday, from whose experiments it appears, that it contains two thirds of the oxygen in the common oxide of silver. My experiments on this pellicle,

Suboxide of silver.

which were made soon after Mr. Faraday had published his observations, were upon too small a scale. My object was merely to verify Mr. Faraday's statement; but as far as I went I obtained just the same results as had been stated by that chemist. This oxide then, which may be called a suboxide, would seem to be a compound of

$$
\begin{array}{ll}
1\tfrac{1}{2} \text{ atom silver} & = 20\cdot625 \\
1 \text{ atom oxygen} & = 1 \\
\hline
& 21\cdot625
\end{array}
$$

This suboxide does not appear to form distinct salts with acids.

'Sulphuret of silver.

4. The sulphuret of silver furnishes an additional evidence that the atomic weight of this metal is 13·75. This sulphuret, which is a black looking compound, possessed of some ductility, and quite sectile, may be formed by stratifying silver and sulphur in a covered crucible, and heating the mixture till the excess of sulphur is driven off. Berzelius made two experiments in this way.* In the first, 2·605 parts of silver became 2·993 parts of sulphuret. Here we have the sulphuret composed of

$$
\begin{array}{llll}
\text{Silver} & 2\cdot605 & \text{or} & 13\cdot75 \\
\text{Sulphur} & 0\cdot388 & - & 2\cdot048
\end{array}
$$

In the second, 10 parts of silver became 11·49

* Ann. de Chim. LXXIX. 131.

parts of sulphuret. This sulphuret was com-
posed of

| Silver | 10 | or | 13·75 |
| Sulphur | 1·49 | - | 2·0487 |

These experiments very nearly agree with each
other; yet I am satisfied that the quantity of
sulphur is somewhat overrated; it is difficult to
say from what cause.

Vauquelin,* who formed the sulphuret of sil-
ver in the same way, found it composed of

| Silver | 100 | or | 13·75 |
| Sulphur | 14·59 | - | 2·0061 |

In this experiment, the excess of sulphur is only
the eighth part of what existed in the sulphuret
prepared by Berzelius.

Klaproth analyzed the native sulphuret of sil-
ver in the year 1793, at a time when minute ac-
curacy in chemical analyses was not attempted.
From 100 grains of the sulphuret, he obtained
112 grains of chloride of silver, equivalent to
84·383 grains of silver, and likewise 1½ grain of
sulphate of silver, equivalent to 1·044 grain of
silver.† From this analysis, it follows, that sul-
phuret of silver is composed of

| Silver | 85·427 | or | 13·75 |
| Sulphur | 14·573 | - | 2·3459 |

100·000

* Ann. de Mus. d'Hist. Nat. XVII. 16.   † Beitrage, I. 162.

E e 2

This result does not approach the truth so near-
ly by a great deal, as the synthetical experiments
of Berzelius and Vauquelin.

In repeating these experiments, I found it
much more difficult than I expected to procure
absolutely pure silver. I found that silver
which I had reduced from well washed chloride
was not absolutely free from copper. The me-
thod which I ultimately adopted was to keep
crystallized nitrate of silver in a state of fusion
for some time. It was then dissolved in water,
and precipitated by common salt. The precipi-
tate was digested for some time in water acidu-
lated with nitric acid. It was then thrown on
a filter, and well washed with distilled water.
Silver reduced from this chloride, and heated
with sulphur, gave a sulphuret exceedingly near
the theoretic proportions. As far as I could
estimate the weight of sulphuret from 13·75
grains of silver, it amounted to 15·75 grains;
certainly the weight was not so much as 15·76
grains. There can, therefore, be no doubt that
sulphuret of silver is composed of

$$
\begin{array}{lll}
1 \text{ atom silver} & = & 13\cdot75 \\
1 \text{ atom sulphur} & = & 2 \\
\hline
& & 15\cdot75
\end{array}
$$

Sulphate of
silver.

5. I analyzed likewise the sulphate of silver,
which corresponds in its constituents with the

atomic weight of oxide of silver already deduced from the nitrate. Sulphate of silver is anhydrous, and its constituents are

Sulphuric acid	5
Oxide of silver	14·75
	19·75

Thus it appears certain that the atomic weight of silver, of its oxide, and its chloride, have been rightly stated. I have not examined the iodide, but see no reason to doubt that it is a compound of

1 atom iodine	15·5
1 atom silver	13·75
	29·25

CHAP. XII.

OF THE ATOMIC WEIGHTS OF GOLD, PLA-
TINUM, PALLADIUM, RHODIUM, AND IRI-
DIUM.

THESE five metals possess many peculiar charac-
ters. Their oxides are easily reduced to the me-
tallic state by exposure to a red heat ; they have
little tendency to combine with acids and form
salts : the consequence is, that we know very
few saline compounds into which these oxides
enter, with the exception of certain triple com-
pounds, by means of which chiefly I have been
enabled to determine the atomic weights of these
metals, I trust with tolerable precision.

SECT. I.

OF THE ATOMIC WEIGHT OF GOLD.

IT has been long known to all the world, that
gold dissolves with facility in aqua regia ; that
the solution has a yellow colour, an astringent
and very acrid taste ; and that when sufficiently
concentrated, it forms beautiful prismatic crys-

tals, which, however, are so very deliquescent, that I found it impossible to analyze them with even an approach to accuracy.

Analysis of triple chloride of gold and sodium. But there is a triple salt of gold, which owes its formation to M. Chretien's attempt to introduce gold, or rather to revive the use of gold in medicine. Finding the muriate of gold too deliquescent for his purpose, he added a quantity of common salt to the muriatic solution, and then evaporated to dryness : the mass thus obtained did not deliquesce. Messrs. Figuier and Berard, on examining the mixture, detected the triple salt of gold to which I allude, described its properties, and even subjected it to analysis.[*] But as the results of their experiments do not furnish a very near approximation to the truth, I think it best to proceed at once to the experiments which I made on the subject, with a view of discovering the atomic weight of gold.

Preparation. 1. I employed in my experiments a very pure muriatic acid which I had myself prepared, and which was a compound of 40 parts real muriatic acid and 60 parts of water. I found that in order to dissolve 300 grains of gold, it was necessary to employ more than 277·5 grains of this acid. Now, the atomic weight of muriatic acid is 4·625 ; and 277·5 grains of the acid employed consisted of

           Real acid   111
           Water   166·5
                        ——————
                          277·5

But 111 grains of muriatic acid are equivalent
to 24 atoms : for 4·625 × 24 = 111. It will
appear from the facts about to be stated in this
section, that the atomic weight of gold is 25 :
and 300 = 25 × 12. So that 300 grains are
equivalent to 12 atoms of gold.

From this it appears, that in order to obtain a
solution of 12 atoms of gold, we must employ
at least 24 atoms of muriatic acid. Hence, from
this preliminary experiment, I considered it as
probable, that muriate of gold is a compound
containing 2 atoms muriatic acid for every atom
of gold.

2. To the solution of 300 grains of gold in
nitric muriatic acid, previously made as neutral
as possible, 90 grains of pure decrepitated com-
mon salt were added, previously dissolved in
water. On evaporating this solution, it crystal-
lized readily, and I obtained fine crystals of the
triple salt of gold to the very last drop. Not a
single crystal of common salt separated ; nor had
even the last portions of the salt the least ten-
dency to deliquesce. From this experiment,
which was several times repeated, it is obvious,
that the triple salt is a compound of 90 grains
of common salt, and the quantity of muriate

of gold which 300 grains of gold are capable of forming.

But an integrant particle of chloride of sodium weighs 7·5 : and 7·5 × 12 = 90.   From this it is evident, that 90 grains of decrepitated common salt are equivalent to 12 atoms of chloride of sodium ; and it has been stated that 300 grains of gold are equivalent to 12 atoms of that metal :—from this experiment it follows, that the triple salt contains just as many atoms of common salt as it does of gold.

3. The triple salt of gold crystallizes in long four-sided prisms.   It has a beautiful orange colour, and is not in the least altered by exposure to the air ; the description of its properties by Figuier is in general exact.

Analysis.   I shall pass over a great many unsuccessful experiments which I made to determine the proportions of its constituents, and satisfy myself with describing the process, which was finally successful.   Into a very small green glass retort, the weight of which had been previously ascertained and marked on it with a diamond, I put 50·5 grains of the crystallized triple salt, quite dry, but still retaining the whole water of crystallization ; the retort was placed on a choffer, and kept for two hours completely red hot, while its beak was plunged into a bason, over which was suspended an inverted glass jar filled with a solution of 55 grains of nitrate of silver

in distilled water. The salt melted and boiled, and was gradually deprived of its water; as soon as it became dry, chlorine gas was given out very rapidly at first, but more and more slowly, as the heating continued. This gas was absorbed by the nitrate of silver solution, and occasioned a precipitate of chloride of silver.

This experiment is attended by two difficulties, which it cost me some practice to obviate. The first is, the tendency which the liquid has to make its way into the red hot retort, in consequence of the absorption of the chlorine gas. This difficulty was obviated by having a contrivance for letting common air into the retort when the absorption began to threaten the destruction of the retort. The other difficulty is, the application of the requisite degree of heat to reduce the gold completely to the metallic state. Quite different from muriate of gold, this triple salt bears an incipient red heat with impunity, and it was not till after two or three failures that I became aware of the necessity of raising the fire as high as the glass would bear without melting, which was a distinct red heat, and keeping it up at least a couple of hours.

Three different successful experiments were made, with three different objects in view. In the first, I determined the weight of gold contained in 50·5 grains of the triple salt; in the second, the whole of the chlorine was combined

with silver, and the chloride of silver collected, washed, dried, fused, and weighed ; in the third, I endeavoured to approximate as nearly as possible to the quantity of water of crystallization, by distilling it over into a small receiver.   Perfect accuracy in this last experiment was not attempted, but merely such an approximation as enabled me to judge how far the quantity of water deduced from the other two experiments would be borne out by the analysis.   I shall state at once the general result which was obtained.

The loss of weight which the salt sustained was 18 grains ; one-half of this was chlorine, determined from the chloride of silver formed. This chloride, in two different experiments, weighed 36 grains, indicating 8·87 grains of chlorine.   The small portion of chlorine gas remaining in the retort was estimated to weigh 0·13 grain ; these two quantities together making 9 grains—the other 9 grains of loss were water.   Of this I actually obtained 7 grains by the process above described ; and by passing a current of air through the retort, and this through a solution of nitrate of silver, I satisfied myself that the weight of the residual chlorine gas did not exceed 0·13 grain.   There can be no doubt, therefore, that the whole 9 grains were pure water.   There remained in the retort 25 grains of gold.   We see from paragraph 2d, that the

true quantity of chloride of sodium was 7·5 grains ; in general, the quantity actually obtained did not exceed 7·4 grains. Probably the 0·1 grain missing made its escape along with the water, owing to the rapidity with which the heat was raised, or to some other circumstance which I was not able to appreciate. I attempted to find it in the water ; but the evidences were not sufficiently unequivocal to enable me to speak positively on the subject.

From the preceding analysis it appears, that 50·5 grains of the triple salt of gold are composed of

Gold	. .	25
Chloride of sodium		7·5
Chlorine	. .	9
Water	. .	9
		50·5

Now, it is obvious that 7·5 is an integrant particle of common salt, 9 two atoms of chlorine, and 9 eight integrant particles of water. As the salt is neutral, and as all the other constituents enter into it in atomic proportions, gold must do so too ; consequently, the atomic weight of gold is 25. It is obvious, therefore, that the constituents of the salt are as follows :

Atom of gold.

1 atom bichloride of gold	= 34
1 atom chloride of sodium	= 7·5
8 atoms water . .	= 9
	50·5 *

Whether the gold and the sodium exist in this salt in the metallic state, or in the state of ox-

* M. Figuier has more recently published the result of a new analysis of this salt, which approaches exceedingly near what I have given in the text. Probably the small differences are owing to the different data from mine, according to which his calculations were made. He found the constituents as follows:

Bichloride of gold .	34·99
Chloride of sodium .	7·13
Water . . .	8·38
	50·50 †

Chloride of potassium likewise forms a triple salt, with the solution of gold. It crystallizes in prisms, is not altered by exposure to the atmosphere, and has a striking resemblance to the salt described in the text. It has been analyzed by M. Javal, who found the constituents to be

Chloride of gold .	68·64
Chloride of potassium .	24·26
Water . . .	7·10
	100·00

Probably it consists of

1 atom bichloride of gold .	34
1 atom chloride of potassium	9·5
4 atoms water . . .	4·5
	48

Javal's analysis does not agree very well with the preceding supposition. His quantity of chloride of potassium indicates very nearly 2 atoms. I have not myself made any experiments on this triple salt. See for Javal's Paper, Ann. de Chim. et de Phys. XVII. 337.

† Ann. de Chim. et de Phys. XIX. 177.

ides, we have not data to determine, unless the presence of water of crystallization in the salt may be considered as a proof of the truth of the latter supposition. If these metals be in the state of oxides, then it follows, that the peroxide of gold, which the salt must contain, is a compound, not of 3 atoms oxygen and 1 atom gold, as Berzelius supposes, but of 2 atoms oxygen and 1 atom gold ; for upon no other supposition can the products of the analysis be accounted for. No muriatic acid, but only chlorine, was disengaged from the salt. If the metals be oxydized, then the salt is composed of

2 atoms muriatic acid	= 9·25	⎫ 36·25
1 atom peroxide of gold	= 27·00	⎭
1 atom muriatic acid	= 4·625	⎫ 8·625
1 atom soda	= 4·000	⎭
5 atoms water		5·625

50·5

The great difficulty attending the decomposition Seems a chloride. of this salt by heat rather leads to the supposition, paradoxical as it may appear, that the gold in it is in the state of a bichloride. If that supposition be admitted as the most probable, then Berzelius' deduction, that peroxide of gold contains 3 atoms of oxygen, still retains its plausibility.

If we adopt Berzelius' experiments on the Oxides of gold.

9

oxides of gold, (and they have been confirmed by Javal,) then the atomic weight of the protoxide of gold will be 26, and of the peroxide 28.

Tritosul-
phuret of
gold.

4. Sulphuret of gold, formed by pouring hydrosulphuret of potash into the muriate of gold, was analyzed by Oberkampf. He found it composed of

| Gold | . | 100 | 25 |
| Sulphur | . | 24·39 | 6·09 |

This approaches very nearly to 1 atom gold and 3 atoms sulphur. Doubtless the proportion of sulphur in this compound is overrated; for the sulphuret of gold cannot be dried by heat without being decomposed.* This analysis, therefore, serves to corroborate the atomic weight of gold as just determined.

Peroxide of
gold.

5. Berzelius' analysis of the peroxide of gold is likewise very satisfactory. He deduced, from the quantity of mercury necessary to reduce a given weight of peroxide of gold, that it is a compound of

| Gold | . | 100 | or | 25 |
| Oxygen | . | 12·077 | - | 3·019 |

Had the quantity of oxygen been 12 grains, instead of 12·077, the coincidence would have been complete; but, considering the nature of

* Ann. de Chim. LXXX. 141.

the experiment from which Berzelius deduced the proportion of oxygen in the peroxide, I rather think it surprizing that the coincidence is so great as it is. Javal actually analyzed the peroxide of gold, by heating it in a glass tube, and collecting the oxygen gas. He estimates the composition at gold 100, oxygen 11·909; but his estimate was founded on the specific gravity of oxygen gas as determined by Berzelius and Dulong, which I have shown in a former chapter to be too low. When we correct his estimate, the proportion of oxygen united to 100 gold turns out to be 12·0008,—a number which I am persuaded is almost exact.*

SECT. II.

OF THE ATOMIC WEIGHT OF PLATINUM.

PLATINUM dissolves, as every body knows, in strong nitromuriatic acid with effervescence. The solution has a dark brown colour, and is very astringent and corrosive. When concentrated by evaporation it does not crystallize, but forms a dark coloured dirty looking matter, not easily

---

* 1 have some suspicion that the true atomic weight of gold may ultimately turn out only 12·5 instead of 25. If that be the case, the triple salt analyzed in this section would be a compound of 2 atoms chloride of gold and 1 atom chloride of sodium. We have not data, at present, to determine this point with certainty.

analyzed with accuracy. From the nitromuri-
atic solution of platinum it is easy to form tri-
ple salts by adding solutions of muriate of potash,
muriate of soda, or muriate of ammonia. The
triple salts with muriates of potash and ammonia
are insoluble powders of a fine yellow colour:
the triple salt with muriate of soda is soluble,
and crystallizes in beautiful rhombic prisms.
These salts furnish a method for determining the
atomic weight of platinum, to which I had re-
course, after a few unsuccessful trials with muri-
ate of platinum.

Analysis of
bichloride
of platinum
and potas-
sium.

1. Triple muriate of platinum and potash is
an insoluble yellow tasteless powder, and when
properly dried contains no water of crystalliza-
tion. After a number of preliminary trials to
enable me to judge how I ought to proceed, and
which it is unnecessary to detail, I analyzed the
salt in the following manner :

30·5 grains of it were put into a platinum
crucible, and subjected to a heat which was
slowly and cautiously raised till the crucible be-
came red hot : by this process the platinum was
reduced to the metallic state, and the loss of
weight sustained amounted to 9 grains,—it was
owing to the escape of chlorine in the form of
gas. If the salt has been overheated, (which
happened in some of my first trials) the loss of
weight will exceed 9 grains ; but when this hap-
pens, the weight of the chloride of potassium

remaining mixed with the platinum will be found just as much less than 9·5 grains, as that of the loss exceeds 9 grains. This gives us the cause of the excessive loss ;—it is owing to the volatilization of a portion of that salt.

. The matter remaining in the crucible, when the heat had been properly applied, weighed 21·5 grains : water was poured upon it repeatedly, and digested on it for some time, to dissolve off all the chloride of potassium. The platinum being then dried, was weighed, and its weight was found to amount to exactly 12 grains ; consequently, the weight of the chloride of potassium was 9·5 grains. From this analysis it appears, that the triple salt is composed of

Platinum	. . .	12
Chlorine	. . .	9
Chloride of potassium	.	9·5
		30·5

But the salt is neutral—9 indicates the weight of 2 atoms of chlorine, and 9·5 of an integrant particle of chloride of potassium : 12, therefore, must either be the weight of an atom of platinum, or at least, a multiple of it. From experiments to be stated immediately, it will be seen, that 12 represents the atomic weight of platinum. In the salt we find 1 atom of platinum combined with 2 atoms of chlorine, constituting a bichlo-

ride.   The constituents of the triple salt are ob-
viously

$$1 \text{ atom bichloride of platinum} = 21$$
$$1 \text{ atom chloride of potassium} = 9 \cdot 5$$
$$\overline{}$$
$$30 \cdot 5$$

And the atomic weight of an integrant particle
of the salt is 30·5.

Berzelius has published an analysis of this
powder, which differs but little from mine.   He
found the constituents

Platinum	.	40	or 12·2
Chlorine	. .	29·2	- 8·906
Chloride of potassium		30·8	- 9·394
		100	30·5

The atomic weight of the salt is the same as
that deduced from my own experiments.   Not
having seen the particulars of Berzelius' expe-
riments, but merely the result, I cannot judge of
the cause of the slight discrepancies between the
proportions of the ingredient, when his analysis
is compared with mine :—they are probably, in
a great measure, owing to the difference of the
data, which he employs for his calculations.
But, notwithstanding these slight differences, the
analysis of Berzelius is a most important corro-
boration of the very near approach to accuracy
which I have attained in mine.

6

2. The triple muriate of platinum and soda has not hitherto been described in any chemical book which I have seen—though it must have often been prepared by practical chemists. It may be worth while, therefore, to mention its most striking properties before proceeding to its analysis.

Its colour is a fine orange red—it crystallizes in flat, and very oblique four-sided prisms—its taste is cooling, bitter, and disagreeable—it has no smell—its specific gravity is 1·980—at the temperature of 62°·5, 100 parts of water dissolve 107·2 parts of the crystals of this salt—it is soluble, likewise, in alcohol. I analyzed it in the following manner :

37·5 grains of the crystals being cautiously heated on the sand bath for about an hour, were found to sustain a loss of weight amounting, at an average, to 9 grains. Sometimes, when the heat happened to be too low, the loss of weight was less than 9 grains ; and at other times when it was too high, it exceeded that amount. The salt, thus deprived of its water of crystallization, was heated to redness in a platinum crucible, and the heat was continued till the platinum in the salt was reduced to the metallic state : the additional loss of weight sustained was 9 grains—this loss was owing to the disengagement of chlorine. The matter remaining in the crucible was digested in distilled water till every thing soluble

was taken up. The platinum now remaining in a state of purity, after being dried, weighed 12 grains ; consequently, the weight of the chloride of sodium removed by the distilled water was just 7·5 grains. From this analysis it follows, that the triple muriate of platinum and soda is composed as follows :

Platinum	12
Chlorine	9
Chloride of sodium	7·5
Water	9
	37·5

In one portion of this salt which I examined, the water, instead of 9 grains, amounted only to 8·31 grains, which would indicate only $7\frac{1}{2}$ atoms of water instead of 8 atoms. The cause of this difference I am unable to explain :—perhaps the salt had been accidentally deprived of a portion of its water.

The constituents of this salt give us 12 for the atomic weight of platinum, precisely like that of the preceding salt. We may either consider it as composed of

1 atom bichloride of platinum	= 21
1 atom chloride of sodium	= 7·5
8 atoms water	= 9
	37·5

Or, its constituents in the crystallized state may
be

    1 atom bipermuriate of platinum   = 23·25
    1 atom muriate of soda   .   .   = 8·625
    5 atoms water   .   .   .   .   = 5·625
                                          ————
                                           37·5

The constituents, which ever supposition we
adopt, are the same ; the only difference consists
in the way in which they are arranged.   If the
salt be a permuriate, 3 atoms of the water must go
to convert the platinum and sodium into oxides,
and the 3 atoms of chlorine into muriatic acid.

3. Ammonio-muriate of platinum is formed by *Analysis of*
mixing sal-ammoniac with a concentrated solu- *ammonio-*
muriate of
tion of muriate of platinum.   This salt is soluble *platinum.*
in water, though very slightly, and it crystallizes
in small grains seemingly octohedrons.   Its co-
lour is a rich yellow, and it contains no water,
but is composed of

    2 atoms chlorine   9 ⎞
    1 atom platinum   12 ⎠   21
    1 atom sal-ammoniac   .   .   . 6·75
                                        ————
                                         27·75

The preceding analyses are sufficient to show
that 12 either denotes the atomic weight of pla-
tinum, or that it is a multiple of that weight.
Some other compound of platinum is still want-

ing to enable us to decide which of these two suppositions is the true. After some unsuccessful attempts, I at last found that the sulphate of platinum put it in my power to solve the problem.

4. I formed a quantity of sulphate of platinum by the process pointed out by Mr. Edmund Davy.

Analysis of
sulphate of
platinum. 19 grains of this dry sulphate were put into a small green glass retort, and exposed to a red heat till the platinum was reduced to the metallic state ; it weighed exactly 12 grains. This experiment was repeated several times, in order to collect the oxygen gas evolved by the reduction of the platinum, and to determine the quantity of sulphuric acid separated ; for both these products could not be conveniently collected at the same time. The oxygen gas evolved was rather less than three cubic inches, and amounted, therefore, very nearly to 2 grains. The sulphuric acid was a very little less than 5 grains ; the reason was, that a little sulphurous acid was disengaged, which I found it difficult to obtain without some loss. From these experiments it is obvious enough, that the constituents of sulphate of platinum are

Platinum	12
Oxygen	2
Sulphuric acid	5
	19

Now the salt was neutral, and 5 being equiva-

lent to an atom of sulphuric acid, it follows that 12 must denote an atom of platinum : 2 being Atom of platinum. equivalent to 2 atoms of oxygen, it is obvious that the oxide of platinum in the sulphate, which is the peroxide, is a compound of 1 atom platinum and 2 atoms oxygen. Consequently, its Atom of peroxide. atomic weight is 14.

The knowledge of the atomic weight of platinum deduced from this salt, enables us to decide, that the triple chlorides of platinum and potash, and platinum and soda, contain 1 atom of platinum united to 2 atoms of chlorine.

Mr. Edmund Davy made an analysis of the sulphate of platinum, a good many years ago, and his results, though not quite accurate, constitute near approximations to the truth. It was his analysis that pointed out to me the mode which I had to follow. My method being nearly the same with his, I considered it unnecessary to describe it minutely. Mr. E. Davy's results are as follows :*

Platinum	12·4697
Oxygen	1·5352
Sulphuric acid	4·9951
	19·0000

The weight of an integrant particle of the salt deduced from this analysis is the same as from my own, namely 19. The proportion of sulphuric

* Phil. Mag. XL. 354.

acid is very nearly correct ; but the platinum is too much, while the oxygen is as much too little, as if the metal had not been completely reduced to the metallic state.

5. I tried to prepare a quantity of peroxide of platinum by the process pointed out by Berzelius. Finding it to contain both muriatic acid and an alkali, I reduced it to a fine powder, and boiled it for a week in a flask kept nearly full of distilled water. After this treatment, the proportion of salt which it contained was so exceedingly small, that I am disposed to consider the characters which my powder possessed, as very nearly those of pure peroxide of platinum. Its colour was a brownish black ; it was tasteless, insoluble in nitric, sulphuric, oxalic, and acetic acids ; but it dissolved, though slowly, and not without considerable boiling, in muriatic and phosphoric acids. I made no attempt to analyze it, both because it was not absolutely pure, and because I was not sure whether it was perfectly anhydrous.

6. Conceiving that the amalgam of platinum was likely to throw some light on its atomic weight, I made a quantity of it by triturating platinum powder and mercury in a mortar ; beginning with a few grains of each, and adding additional portions of both metals as the amalgamation proceeded. The fluid amalgam thus formed was put into a leathern bag, and subjected to strong pressure in

order to squeeze out all the uncombined mercury. I obtained a solid brittle amalgam, having the colour of mercury, a granular texture, and a brittle consistency. 61 grains of this amalgam were exposed to a heat at first moderate, but gradually raised as much as possible in a wind furnace, and kept up for half an hour. The loss of weight sustained was 24·9 grains, and there remained 36·1 grains of platinum apparently pure. Now, 24·9 is very nearly 25, which denotes the atomic weight of mercury ; and 36·1 is also exceedingly near 36 = 3 atoms of platinum. It is obvious from this, that the amalgam was a compound of

$$
\begin{array}{ll}
3 \text{ atoms platinum} & 36 \\
1 \text{ atom mercury} & 25 \\
\hline
& 61
\end{array}
$$

Conceiving that by allowing the fluid amalgam of platinum to crystallize, I should probably obtain a compound of the two metals in a different proportion, I placed a quantity of the fluid amalgam on an inclined plane, and when it had become solid by the running off of the superfluous mercury, I analyzed it in the way just described, and found its constituents to be

$$
\begin{array}{ll}
\text{Platinum} & 12 \\
\text{Mercury} & 35\cdot3
\end{array}
$$

It is obvious that the crystals had retained a portion of the mercury mechanically lodged between their particles. In fact, these crystals resembled crystals of a salt taken out of the mother liquor before being dried; yet I think it not unlikely from this experiment, that the crystals of amalgam of mercury, if they could be obtained in a state of purity, would consist of

1 atom platinum	12	
1 atom mercury	25	
	37	

7. From the preceding experiments there seems no doubt that the atom of platinum weighs 12; and that it forms two oxides, only one of which, the peroxide, has been yet obtained in a separate state. The atomic weight of the peroxide is 14. The protoxide must be a compound of 1 atom platinum and 1 atom oxygen, and its atomic weight must be 13.

SECT. III.

OF THE ATOMIC WEIGHT OF RHODIUM.

THE soda-muriate of rhodium, a triple salt discovered by Dr. Wollaston, and with a quantity of which he was so obliging as to supply me a

good many years ago, enabled me to determine the atomic weight of rhodium and its oxides, with considerable precision. This salt forms rhomboidal crystals of an intensely deep red colour, and not altered by exposure to the air. It is insoluble in alcohol, but sufficiently so in water. Carbonate of ammonia produces no effect upon the solution of this salt; but caustic ammonia, as well as the caustic fixed alkalies precipitate the peroxide of rhodium in yellow coloured flocks. An excess of the fixed alkalies redissolves the whole of the precipitate. Though ammonia does not act so powerfully as a solvent, yet it is not without its effect; for the whole oxide of rhodium is never obtained if an excess of ammonia be added to the solution.

1. A hundred grains of crystals of soda muriate of rhodium were dissolved in water, and the peroxide was precipitated by ammonia, taking care not to add that alkali in excess. The oxide of rhodium, when collected, washed, and dried, was found to weigh 26·07 grains. Analysis of soda-muriate of rhodium.

Into a solution of another 100 grains of the same salt a polished plate of zinc was put, and left in the solution till the whole of the rhodium which it contained had been precipitated in the metallic state. To prevent the rhodium from adhering to the zinc, which would have made it difficult to weigh it correctly, the liquor had been acidulated with some muriatic acid. The

weight of the metallic rhodium obtained in this experiment was 19·1 grains.

From this preliminary experiment it appears, that 26·07 grains of yellow oxide of rhodium contain 19·1 grains of metallic rhodium, and consequently, 6·97 grains of oxygen : therefore, yellow oxide of rhodium is a compound of

$$\begin{array}{lccc} \text{Rhodium} & 19\cdot1 & \text{or} & 5\cdot486 \\ \text{Oxygen} & 6\cdot97 & - & 2 \end{array}$$

I was induced to infer from this experiment, that the atomic weight of rhodium is 5·5 ; and that the yellow oxide is a compound of 1 atom of rhodium, and 2 atoms of oxygen ; and consequently weighs 7·5.

2. 28·625 grains of the crystals of soda-muriate of rhodium were put into a small green glass retort, and exposed to a heat which was gradually raised to an incipient redness, and kept up a considerable time in order to dissipate completely the aqueous vapours which are disengaged from the salt by the heat. This experiment cannot be made in a metallic vessel without disengaging some muriatic acid, and reducing a portion of the rhodium to the metallic state; but I have kept the salt in a low red heat for upwards of an hour in a green glass retort, and found it still perfectly soluble in water with the usual dark red colour, and consequently, still retaining the whole of its acid. The loss of

weight in this experiment was 9 grains; which is, therefore, the water of crystallization in 28·625 grains of soda-muriate of rhodium.

3. 28·625 grains of soda-muriate of rhodium were dissolved in water, and precipitated by ammonia added very cautiously, and all excess avoided. The yellow oxide obtained weighed 7·5 grains.—This step of the analysis cost me a great deal of trouble, and was repeated about ten times before I succeeded in separating the whole of the oxide, and collecting it without loss.

4. The residual liquid, from which the oxide of rhodium had been thrown down, was evaporated with great caution to dryness, and the residual salt weighed. The weight did not exactly agree in the different trials; doubtless, because I applied the heat so cautiously that the whole aqueous portion was not driven off; but the average weight of this saline residual was 14·5 grains. It was a mixture of common salt and sal-ammoniac. Being exposed to a heat sufficient to drive off the sal-ammoniac, the residual common salt weighed 7·5 grains. Consequently, the loss of weight was 7 grains; but the weight of an integrant particle of sal-ammoniac is 6·75 grains; for it is composed of

1 atom muriatic acid	4·625
1 atom ammonia	2.125
	6·75

9

It is obvious that the 0·25 grain of loss, over and above this integrant particle of sal-ammoniac, must have been water. Now, the 4·625 grains of muriatic acid, in the 6·75 grains of sal-ammoniac volatilized, must have existed in the 28·625 grains of the soda-muriate of rhodium, and must have been in combination with the oxide of rhodium.

From the preceding analysis it appears, that soda-muriate of rhodium is a compound of

Yellow oxide of rhodium	7·5
Muriatic acid . .	4·625
Common salt . .	7·5
Water . . .	9·0
	28·625

Atom of peroxide of rhodium.   Now, this salt is perfectly neutral: 9 represents eight atoms of water ; 7·5 is an integrant particle of chloride of sodium ; and 4·625 an integrant particle of muriatic acid. 7·5 therefore, must represent the weight of an integrant particle of yellow oxide of rhodium. The constituents of the soda-muriate of rhodium may therefore be represented as follows :

1 atom permuriate of rhodium	12·125
1 atom muriate of soda .	8·625
7 atoms water . .	7·875
	28·625

For one of the atoms of water separated by heat,

was in all probability formed by the change of the integrant particle of muriate of soda into chloride of sodium.

5. The preceding analysis, when compared with the preliminary experiment, leaves no doubt that the weight of an atom of rhodium is 5·5, and that the yellow oxide is a compound of 1 atom rhodium and 2 atoms oxygen.

Atom of rhodium.

This oxide of rhodium is described by Berzelius as *brown*; but when obtained by precipitation from the soda-muriate of rhodium, it is always *yellow*. When exposed to heat it becomes slowly *brown*, and at last *black*. During this change of colour, I could detect no escape of moisture, to induce me to suppose that the yellow coloured powder is a hydrate, and the brown the anhydrous oxide. Whether the brown oxide be the same, or different from the yellow, I have not ascertained; most probably it is a mixture of the yellow and the black oxides. The black oxide is undoubtedly the protoxide of rhodium, and a compound of 1 atom rhodium and 1 atom oxygen; so that its atomic weight is 6·5.

Oxides of rhodium.

If the brown powder should appear, upon farther examination, to be a peculiar oxide, it is obvious that it must be a compound of 1 atom rhodium and 1½ atom oxygen; and that its atomic weight must be 7. I did not succeed in my attempts to dissolve it in acids; but this insolu-

bility may have been owing to the heat to which
it had been exposed.

SECT. IV.

OF THE ATOMIC WEIGHT OF PALLADIUM.

My stock of palladium was so small, that I was
under the necessity of making my experiments
upon a very minute scale. This precluded the
possibility of attaining the mathematical accu-
racy necessary for determining the atomic weight
with certainty ; but as my experiments, so far as
they go, confirm those already made by Berze-
lius on this metal, I flatter myself that the num-
ber which I have deduced from them is a very
near approximation to the truth. From the great
scarcity of this metal at present, it is unlikely
that quantities sufficiently large to decide the
point with certainty, will speedily be at the dis-
posal of any chemist.

1. Palladium, as is known, dissolves in all the
acids ; but by far the best solvent of it is nitro-
muriatic acid : the solution has a very deep red
Properties colour. When we evaporate the solution to
of muriate
of palladi- dryness, and re-dissolve the residual salt in wa-
um. ter, the colour of the liquid is a reddish brown ;
its taste is intensely astringent, without any ac-
companying flavour of a disagreeable nature.

This solution is precipitated by potash in *dark red* flocks; by ammonia in *buff coloured* flocks. The precipitate by potash readily dissolves in nitric acid; but the ammoniacal precipitate does not dissolve in that acid till the action of the acid is assisted by heat. Gallic acid gives the liquid a *greenish brown* colour, but occasions no immediate precipitate; prussiate of potash throws down *reddish brown* flocks, but the solution is not rendered colourless.

Muriate of palladium has a reddish brown colour. It does not crystallize; its taste is intensely astringent. When the dry salt is exposed to the air, it becomes moist on the surface, but does not flow into a liquid. This salt dissolves readily in water.

2. I dissolved 7 grains of palladium in muriatic acid (assisted by a little nitric acid). To the solution I added a quantity of carbonate of potash, which I knew to contain exactly 6 grains of potash. This solution being evaporated, yielded crystals of triple muriate of palladium and potash to the very last drop. This experiment shows, that in the triple salt the palladium bears to the potash the ratio of 7 to 6. *Potash muriate of palladium.*

3. Berzelius has given us the result of two experiments which he made with palladium. He oxydized 100 parts of palladium, by heating them in a platinum crucible, with some potash and nitre; the oxide weighed 114·209 parts. *Oxide of palladium.*

G g 2

As palladium forms only one oxide, we may consider it as a compound of 1 atom metal and 1 atom oxygen. Now,

14·209 (the oxygen which united with the metal) : 100 (the weight of metal) : : 1 (atomic weight of oxygen) : 7·038 = atomic weight of palladium.

He informs us likewise, that 100 parts of palladium, when converted into sulphuret, combine with 28·15 parts of sulphur. If we consider the sulphuret thus formed as a compound of 1 atom metal and 1 atom sulphur, we obtain 7·104 for the atomic weight of palladium ; for

28·15 : 100 : : 2 (atom of sulphuret) : 7·104. *

These two separate estimates of the atomic weight of palladium approach so nearly to 7, that I was led from them to consider 7 as the true atomic weight of this metal. It was this that induced me to make choice of 7 grains of palladium, and to add to the muriatic solution 6 grains of potash, both of these quantities being equivalent to the atomic weight of these bodies. The result of the experiment shows that the opinion was correct, or very nearly so, and authorizes us to make choice of 7 as the true atomic weight of palladium. It would have been desirable to have made the experiment upon a larger scale—to have employed, for example,

* Essai sur la Theorie des Proportions Chimiques, p. 137.

70 grains of palladium and 60 grains of potash. Such quantities would have shown more decisively whether there was an excess of either of the ingredients ; but, unfortunately, my stock of palladium was inadequate to any such experiment.

4. The triple muriate of palladium and potash crystallized in very small needles, of a most beautiful brown colour. Dr. Wollaston describes them as four-sided prisms ; and says, that when viewed transversely, they are of a bright green ; but when seen in the direction of their axes, they are dark red. In my crystals, from their extreme minuteness, it was impossible to observe these appearances. Was the brown colour owing to a mixture of the two colours described by Wollaston?

It has an intensely astringent taste, accompanied with a perceptible sweetness. It is insoluble in alcohol, but pretty soluble in water ; and the solution has a dark red colour, like that of muriate of palladium. It contains very little water ; for 10 grains of it, when kept 24 hours upon the sand bath, in a temperature of nearly 600°, lost only 0·12 grain of weight. When heated to redness the salt melted, and I kept 10 grains in a state of fusion for half an hour ; the loss of weight was 0·8 grain. When exposed to the intense heat of a wind furnace, the palladium is reduced to the metallic state ; but the tem-

perature requisite for this reduction is so nigh, that the greatest part of the muriate of potash is volatilized. The weight of palladium obtained from 10 grains of the triple salt was 3·08 grains.

Now, it was shown by a preliminary experiment, that the potash in this salt bears to the palladium the ratio of 6 to 7; consequently, 10 grains of the salt must contain 2·64 grains of potash.

The palladium in the salt is doubtless in the state of oxide. If the atomic weight of palladium be 7, and that of oxide of palladium 8, then (since 7 : 8 : : 3·08 : 3·52,) 3·52 grains must be the weight of oxide of palladium in 10 grains of the triple salt.

Both of these bases in the triple salt are combined with muriatic acid. Now, the atomic weight of muriatic acid being 4·625, it is evident that 8 grains of oxide of palladium will be just saturated by 4·625 grains of muriatic acid; and 3·52 grains of oxide will require for saturation 2·035 grains of muriatic acid.

And, since 6 potash require 4·625 of muriatic acid, 2·64 grains of potash must require for saturation 1·526 grain of muriatic acid.

From this it appears, that 2·035 grains of muriatic acid are in combination with the oxide of palladium, and 1·526 grain with the potash.

These calculations enable us to state the con-

stituents of the triple muriate of palladium as
follows :

Oxide of palladium 3·52 ⎫
Muriatic acid   2·035 ⎬ 5·555 muriate of palladium.

Potash   .   2·64 ⎫
Muriatic acid   1·526 ⎬ 4·166 muriate of potash.

Water   .   .   .   0·279

———

10·000

This estimate would give us the constitution of
the salt in atomic numbers as follows :

1 atom muriate of palladium   =   12·625
1 atom muriate of potash   =   10·625
⅗ths of an atom water   .   =   0·675

———

23·925

Had the quantity of water amounted to 1 atom
instead of ⅗ths of an atom, the analysis would
have been more satisfactory.

The reader will observe that with respect to
palladium, I was obliged to rest satisfied with
the preliminary experiments which I made on
the other metals, before attempting the analysis
from which the atomic weights are deduced.
These preliminary trials I have thought it need-
less to state in the other sections ; but my stock
of palladium having been exhausted by them, I
was under the necessity of drawing my conclu-
sions respecting this metal from them entirely.
The above analysis, (if analysis it can be called)

was thrice repeated with very nearly the same result.

5. I made three attempts to ascertain the atomic weight of palladium, by forming a chloride. My method was to dissolve 7 grains of palladium in muriatic acid, to evaporate the solution to dryness, and to expose the muriate to heat in a covered platinum crucible.

The first trial gave		11·910	grains of chloride
The second	.	12·133	
The third	:	12·231	
Mean	. .	12·091	

These weights are too high, if 7 be the atomic weight of palladium; for if we subtract 7 from 12·091, the remainder is 5·091, which somewhat exceeds the weight of an atom of chlorine. Perhaps the salt was not exposed to a heat sufficiently high to decompose the muriate completely. The experiment is scarcely susceptible of accuracy; because at the heat necessary to decompose the muriates, a portion of the chlorine is apt to escape.

The preceding experiments, imperfect as they are, lead to the conclusion, that the atomic weight of palladium is 7, and that of its oxide 8. These numbers are certainly very near the truth.

SECT. V.

OF THE ATOMIC WEIGHT OF IRIDIUM.

I PREPARED a quantity of muriate of iridium from the black matter which remains when crude platina is dissolved in nitro-muriatic acid. The process which I followed was nearly that pointed out by Vauquelin in his paper on osmium and iridium. This black matter was found to contain a very considerable proportion of iron and some titanium ; the quantity of iridium which it yielded was much less than I had anticipated.

1. Muriate of iridium crystallizes in tetrahedrons; it has a great deal of lustre, and a brown colour so deep that the salt appears black. Its taste is intensely bitter and astringent; its solution in water has a red colour, so deep that the liquid continues opaque even after it has been a good deal diluted with water. When so much diluted as to be transparent, the colour appears yellow.

The aqueous solution of muriate of iridium is rendered colourless by the addition of a few drops of any of the following bodies :

Gallic acid,
Prussiate of potash,

9

> Ammonia.
> Potash,
> Soda,
> Lime Water,
> Barytes water,
> Sulphuretted hydrogen,
> Protosulphate of iron,
> Sulphate of zinc.

Zinc or tin, when left in the liquid, renders it colourless in twenty-four hours.

The following bodies produce no alteration in the colour and transparency of this liquid.

> Blue vitriol,
> Persulphate of iron,
> Muriate of manganese,
> Nitric acid,
> Oxalic, tartaric, citric, acetic acids,
> Sulphuric, nitric, muriatic acids.

When nitrate of mercury is dropped into the solution of muriate of iridium, an abundant precipitate of orange flocks falls down, and the liquid becomes colourless. Muriate of tin produces a slight yellow precipitate, and renders the liquid colourless.

Such are the effects of reagents upon this singular substance. It is not precipitated either by alkalies or by acids—so that no good method of analyzing it readily presents itself. Yet, upon making the trial, I found the analysis of it both easy and satisfactory.

2. A hundred grains of the crystals were put into a small green glass retort, and kept red hot for two hours by means of a charcoal fire. The crystals did not alter their appearance in the least; yet they emitted a perceptible smell of chlorine, and the salt sustained a loss of weight amounting to 2·625 grains. The crystals thus treated were completely soluble in water; they were therefore in a state of a pure anhydrous chloride of iridium.

3. 82·5 grains of this chloride dried in a red heat were put into a platinum crucible, and exposed to the strongest heat which I could raise in a wind furnace. When the crucible was cold, I found that the chloride had been decomposed, and that there remained 37·5 grains of metallic iridium. The loss of weight sustained was therefore 45 grains, and this loss was obviously occasioned by the dissipation of the chlorine.

This experiment will be more easily under stood if we divide the quantity of chloride employed by ten. 8·25 grains of chloride of iridium, when decomposed by heat, lose 4·5 grains of chlorine, and the remaining 3·75 grains consist of metallic iridium. Thus we see that the chloride is composed of

Iridium	.	.	.	3·75
Chlorine	.	.	.	4·5
				8.25

Now, as 4·5 is equivalent to an atom of chlorine, 3·75 must represent the atomic weight of iridium.

I repeated this experiment twice, employing each time 8·25 grains of chloride of iridium; because my stock of salt had been too much exhausted by the preceding trials to allow me to employ a greater quantity. These two experiments did not quite agree with each other; the first leaving a greater quantity of iridium than 3·75 grains, and the second a smaller quantity: the mean of the two made the quantity of iridium amount to 3·88 grains. This approaches as near to 3·75, the atomic weight deduced from the first experiment, as could be expected, when we take into view the very small scale on which the experiments were made. For when we employ in our trials very small quantities of matter, exact results are not to be looked for; because the unavoidable inaccuracies arising from weighing, or from want of absolute correctness in the weights which we employ, bear too great a proportion to the whole quantity used. But the first experiment, which was made with great care upon a quantity sufficiently great for accuracy, gives us, I conceive, the true atomic weight of iridium.

I believe the crystals usually called muriate of iridium should be called chloride of iridium; for the loss of weight being only 2·625 per cent.,

does not amount to quite so much as the fifth of an atom of water. This explains the reason why the iridium is not precipitated by alkalies, as is usually the case with metallic oxides.

When the solution of this salt in water is made without heat, it has a fine green colour ; but if we boil the green liquid, it gradually loses its original colour and becomes red. This change of colour has been generally ascribed to the addition of oxygen to the oxide of iridium. It has been concluded from it that there are two oxides of iridium,—the protoxide is *green* and the peroxide *red*. Whether this explanation be the true one I have not been able to determine, as all my attempts to obtain the oxides of iridium in a separate state have ended in disappointment. If there be two oxides of iridium, the protoxide is doubtless composed of 1 atom iridium and 1 atom oxygen, and its atomic weight must be 4·75. Peroxide of iridium must be a compound of 1 atom iridium and 2 atoms oxygen, and its atomic weight must be 5·75.

Oxides of iridium.

SECT. VI.

OF THE ATOMIC WEIGHT OF OSMIUM.

I AM still unacquainted with the atomic weight of osmium—the quantity of that anomalous sub-

stance at my disposal being too small to enable me to prosecute the subject to any extent.

1. I mixed together equal weights of zinc filings and osmium, and putting the mixture into a glass tube bent like a retort, I poured on it a quantity of dilute sulphuric acid, to see whether the hydrogen gas evolved contained any osmium in solution : but I could obtain no evidence that it contained any. The gas had no sensible smell nor taste ; it was not absorbed by water, and did not produce any sensible effect upon the solutions of lead. It burned just like common hydrogen gas, and required, as usual, half its volume of oxygen gas for complete combustion.

The sulphuric acid solution of the zinc was black and opaque, and contained, obviously, a portion of the osmium in a state of solution. But upon attempting to obtain this triple solution in a dry state, the colour gradually became lighter as the evaporation advanced, and when the whole had been reduced to dryness, all traces of the presence of osmium had vanished.

Osmium, in the metallic state, was digested in caustic soda ley :—a yellow coloured liquid was obtained, but the greatest part of the osmium remained undissolved.
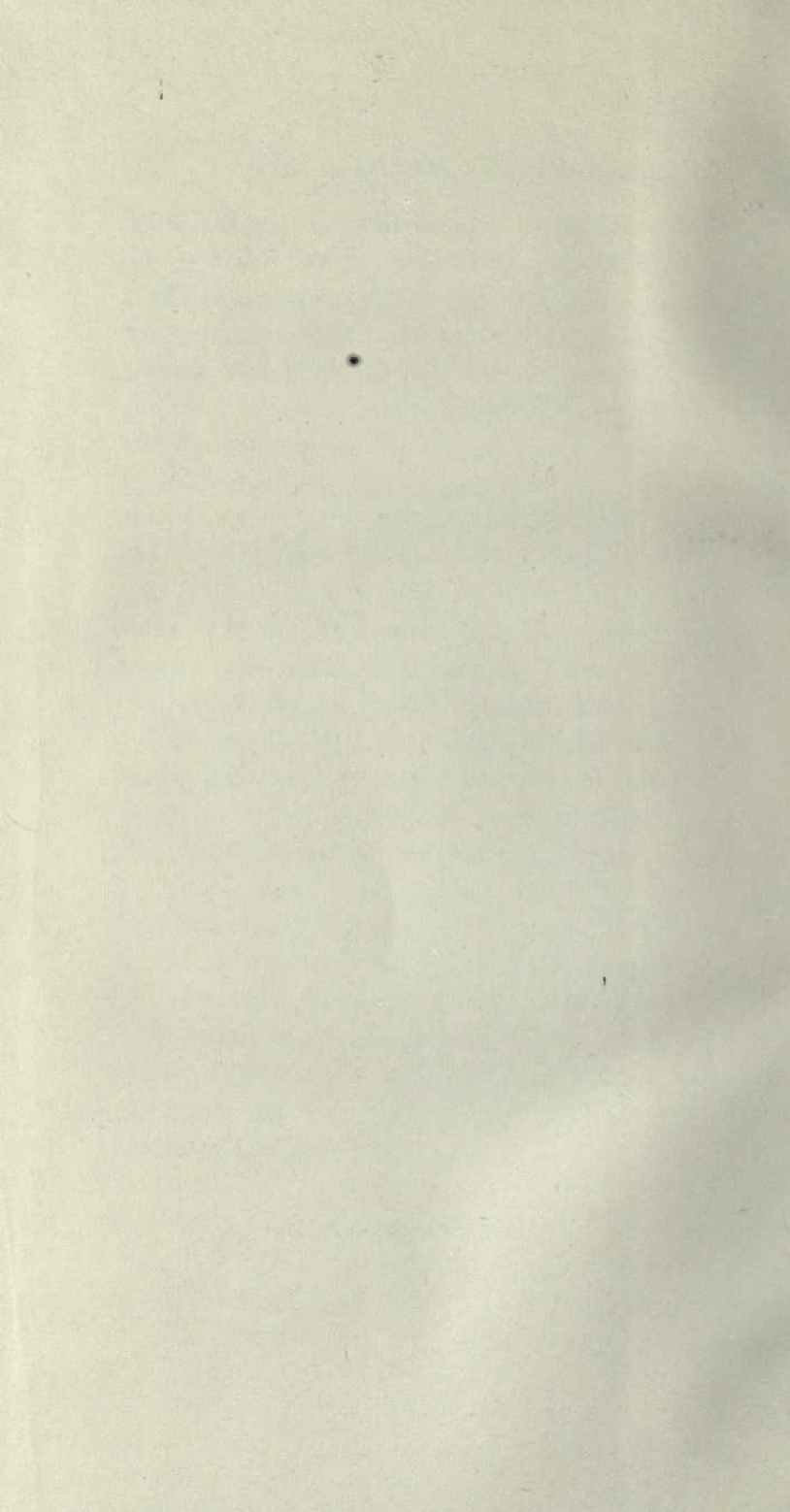
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