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.

By THOMAS THOMSON, M. D.,
REGIUS PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GLASGOW; F. R. S. LONDON AND EDINBURGH; FELLOW OF THE LINNÆAN SOCIETY; OF THE GEOLOGICAL SOCIETY; OF THE CAMBRIAN SOCIETY FOR THE ENCOURAGEMENT OF GEOLOGY, MINERALOGY, AND NATURAL HISTORY; OF THE IMPERIAL MEDICO-CHIRURGICAL AND PHARMACEUTICAL SOCIETIES OF ST. PETERSBURGH; OF THE ROYAL ACADEMY OF SCIENCES OF NAPLES; OF THE MINERALOGICAL SOCIETY OF DRESDEN; OF THE MINING SOCIETY OF FRANKFORT ON THE MAINE; OF THE CÆSARIAN NATURAL HISTORY SOCIETY OF MOSCOW; OF THE LITERARY AND PHILOSOPHICAL, AND NATURAL HISTORY SOCIETIES OF NEW YORK; &C.

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AN ATTEMPT

TO ESTABLISH

THE FIRST PRINCIPLES OF CHEMISTRY

BY EXPERIMENT.

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OF THE ATOMIC WEIGHTS OF URANIUM, ANTIMONY, CHROMIUM, MOLYBDENUM, TUNGSTEN, COLUMBIUM, AND TITANIUM.

THE seven metallic bodies, which I propose to treat of in this chapter, form compounds with oxygen, which possess rather the properties of acids than of bases. The peroxides of three of them, viz. chromium, molybdenum, and tungsten, are well marked acids, for they form neutral salts with the bases, which are (several of them) capable of crystallizing. The peroxides of the other four are not so decidedly acid; but they exhibit a much greater tendency to unite with bases than with acids, and the oxides of tantalum and titanium are found native always united with bases.

SECT. I.

OF THE ATOMIC WEIGHT OF URANIUM.

It is sufficiently known, that uranium was discovered by Klaproth, in a set of experiments which he made on black blende, in 1789; that the properties and some of the compounds of uranium were examined by Bucholz, about the beginning of the present century; and that M. Schönberg made a set of experiments in Berzelius' laboratory in 1813, in order to determine its atomic weight. But by far the most elaborate and instructive investigation of the properties of uranium and its compounds was made by M. Arfwedson, and inserted by him in the Memoirs of the Stockholm Academy of Sciences for 1822. By the kindness of Mr. Heuland of London, whose liberality I have so often experienced, I was supplied with a sufficient stock of pitchblende, to enable me to procure the oxides of this metal in such quantities as put it in my power to repeat such of Arfwedson's experiments as seemed to require examination, and to determine the atomic weight of these compounds, I trust, with considerable accuracy.

Method of obtaining peroxide of uranium.

Pitchblende obviously varies considerably in its composition, consisting, in fact, of a variety of minerals mechanically mixed. Galena and copper pyrites may be occasionally observed interspersed through it. Arfwedson informs us that he found in it arsenic, cobalt, and zinc, in addition to the iron, and copper, and lead which had been noticed by Klaproth. In the specimens of pitchblende which I examined I could find no traces of arsenic, cobalt, or zinc; but copper and iron existed in abundance, and likewise some lead. My method of obtaining the peroxide of uranium was the following: The pitchblende was reduced to powder, and digested in nitric acid till every thing soluble was taken up. The solution was rendered as neutral as possible by evaporation. A current of sulphuretted hydrogen gas was then passed through it till every thing precipitable by that means was thrown down. The precipitate was at first dark brown, and it always retained that colour to the very end; not the least appearance of any thing yellow (to lead to the suspicion of the presence of arsenic) could be detected. The solution, thus freed from copper and lead, was filtered, and, after being heated to drive off the sulphuretted hydrogen, was precipitated by caustic ammonia. The precipitate thus obtained was washed and separated on the filter; and, while still moist, was digested in a pretty strong solution of carbonate of ammonia. A fine lemon yellow solution was obtained; and there remained a red insoluble matter, consisting chiefly of iron, which was not particularly examined. The solution in carbonate of ammonia being set aside for a few days in a close vessel, a considerable number of very fine rich yellow crystals were deposited, consisting of four-sided right prisms, with rectangular bases. This salt was tasteless, and insoluble in water, and proved, on examination, to be a compound of carbonate of ammonia, percarbonate of uranium, and water. It was analyzed in the following manner:

Analysis of ammonio-carbonate of uranium.

1. 49·875 grains of the crystals were put into a small retort, and exposed to a heat not exceeding 400°, on the sand bath. There first came over some moisture, and then carbonate of ammonia sublimed. I did not succeed in weighing the water and the carbonate of ammonia separately, for the carbonate absorbed the whole of the water, and became dry crystals; but the total loss of weight sustained by the salt was 18 grains. The salt, by being thus deprived of its carbonate of ammonia and water, had acquired a most beautiful orange red colour. It still dissolved in acids with effervescence, and therefore contained carbonic acid. When strongly heated by a spirit lamp, some water was disengaged, and some carbonic acid (mixed probably with oxygen gas) and the peroxide of uranium was converted into protoxide. It now consisted of black grains, having considerable lustre. They were easily

reduced to powder, and the powder had a dark green colour. The weight of the protoxide thus obtained was 27 grains; so that the loss of weight was 4·875 grains.

The 18 grains which sublimed first I consider to consist of

3 atoms carbonate of ammonia	14·625
3 atoms water . .	3·375
	18

By dissolving the matter in water, and mixing the solution with muriate of lime, I found by the weight of the precipitate that the carbonate of ammonia was very nearly 14·625 grains. The 4·875 grains, driven off by a red heat, I consider as composed of

1 atom oxygen . .	1
1 atom carbonic acid .	2·75
1 atom water . .	1·125
	4·875

If these suppositions be admitted, the triple salt was a compound of

3 atoms carbonate of ammonia	14·625
1 atom percarbonate of uranium	30·75
4 atoms water . .	4·5
	49·875

From this analysis it is clear that an atom of

Atom of uranium and its oxides.

peroxide of uranium weighs 28, and an atom of protoxide 27; hence the atomic weight of uranium in the metallic state must be 26.

2. It has been long known that uranium combines with two proportions of oxygen, and forms two oxides. Before proceeding farther, it will be proper to give some account of these oxides; because none of the chemical books which I have seen contain any thing on the subject.

Protoxide of uranium.

(1.) Protoxide of uranium, obtained by exposing the percarbonate of uranium and ammonia to a red heat, is composed of small grains, having a black colour, and a good deal of lustre; but when reduced to powder, it has a dark green colour. It is soluble in muriatic and sulphuric acid; but the solution goes on very slowly, except when the oxide is in the state of a hydrate. The solutions are green, and the protoxide is thrown down in the state of a brown coloured hydrate, which dissolves very easily in acids, forming a dark green solution. In nitric acid the protoxide dissolves very readily with the evolution of nitrous gas; and by this solution it is converted into peroxide. The protoxide of uranium is tasteless, and not altered by exposure to the air. It combines readily with the acids; all its salts have a green colour, and none that I have tried is capable of crystallizing.

Peroxide of uranium.

(2.) Peroxide of uranium has, I suppose, a lemon yellow colour,—at least this is the colour by which most of its salts are distinguished. Such is its tendency to combine with other bodies that it seems impossible to obtain it in a separate state. It dissolves with ease in nitric acid, and forms a lemon yellow solution of great intensity, which crystallizes and forms the nitrate of uranium in fine lemon yellow crystals, having the form of right four-sided prisms with square bases. If we throw down the oxide from this salt by caustic ammonia or soda, it retains these alkalies in combination, from which it cannot be freed by washing. If we throw it down by carbonate of ammonia, we obtain a yellow powder, which is most frequently a percarbonate of uranium; but sometimes, a triple salt composed of carbonate of ammonia and percarbonate of uranium. If we throw it down by potash or soda, we obtain a beautiful orange red powder, which is a triple compound of percarbonate of uranium and an alkaline carbonate. Arfwedson has shown, that if we mix together solutions of pernitrate of uranium and any earthy or metallic nitrate, and add caustic ammonia or potash to the solution, the peroxide of uranium precipitates in chemical combination with the earthy or metallic oxide present.

Thus it appears, that peroxide of uranium is capable of uniting both with acids and with bases; so that it performs the double function of an alkali and an acid. None of the simple salts into which it enters as a base crystallizes except the nitrate; but it forms many crystallizable triple salts. I have examined

Persulphate of uranium and potash,
Permuriate of uranium and potash,
Percarbonate of uranium and ammonia,

all of which crystallize very well.

Action of reagents on pernitrate of uranium.

I shall here mention the action of various reagents upon pernitrate of uranium.

1. Prussiate of potash—A dark red brown precipitate, somewhat similar to that of prussiate of copper.
2. Gallic acid or infusion of galls—O, if the salt contain an excess of nitric acid; but if neutral, the precipitate thrown down is very similar to that produced by prussiate of potash.
3. Carbonate of soda—A light yellow precipitate, redissolved by an excess of the carbonate; again precipitated on heating the liquid.
4. Caustic soda—A yellow precipitate, redissolved by an excess of the alkali. [Was this owing to the presence of carbonate of soda? Arfwedson says it is not redissolved by the caustic alkalies.]
5. Caustic ammonia—A fine lemon yellow precipitate, not redissolved by an excess of alkali.
6. Carbonate of ammonia—A yellow precipitate, redissolved by an excess of the carbonate: solution, lemon yellow.
7. Chromate of potash—A fine orange precipitate of great intensity.
8. Phosphate of soda—A yellowish white precipitate.
9. Arseniate of soda—A white precipitate, with a slight yellow tinge.

10. Tungstate of soda—A yellow precipitate.
11. Tartrate of potash—O.
12. Oxalate of potash—O.

Arfwedson says, that peroxide of uranium is slightly soluble in water. Not having been able to procure the oxide in a separate state, I was unable to determine the point; but I found it impossible, by washing, to deprive the percarbonate of uranium of the property of giving a greenish yellow colour to water: hence, I conceive that salt to be slightly soluble in water.

Reduction of uranium.

3. M. Arfwedson passed a current of dry hydrogen gas over hot protoxide of uranium, and by this means reduced it to the metallic state. The metal thus obtained was in crystals, having nearly the form of regular octahedrons: they had a strong metallic lustre and a reddish brown colour. This metal may be exposed to the air in ordinary temperatures without alteration; but when heated, it undergoes a kind of combustion, and is converted into protoxide of uranium. Arfwedson made two experiments to determine how much loss protoxide of uranium sustains when converted in this way into metallic uranium. He found that

1·187	protoxide lost	0·042
1·468	——— —	0·052

According to these experiments, 100 parts of uranium combine, in order to be converted into protoxide, with the following proportion of oxygen :

By first experiment, with	3·66812
By second experiment, with	3·67231
Mean . . .	3·670215

He made two other experiments, the reverse of the preceding. A quantity of metallic uranium was exposed to a red heat in an open vessel : by this means it was converted into protoxide, and the increase of weight was determined. These experiments were as follows :

(1.) 0·636 uranium absorbed, 0·0235 oxygen.
(2.) 1·006 - - 0·0375

According to these experiments, 100 uranium, when converted into protoxide, combines with

By first experiment .	3·69497 oxygen
By second experiment .	3·72763
Mean . . .	3·71130
Mean of first set .	3·670215
Mean of the whole .	3·690757

This last mean, being the result of four careful experiments made in different ways, may be considered to come as near the truth as can be expected by that mode of experimenting. Let us see the atomic weight of uranium which results from this number :—If protoxide of uranium be a compound of 1 atom oxygen and 1 atom uranium, we have

3·690757 : 100 : : 1 : 27·095 = atomic weight of uranium.

This is a little higher than 26—the result which I obtained from the analysis of the triple salt described above. If 26 be the true atomic weight of uranium, as I think it is, then 100 parts of this metal, when converted into protoxide, should combine with 3·8461 parts of oxygen, which is only a little higher than Arfwedson's last result. Indeed, I conceive it to be almost impossible to come to the exact truth by Arfwedson's methods. I have repeated the whole of his experiments with great care; but my results differ fully as much from each other as the difference between 3·73 and 3·84 : and some of my results gave the quantity of oxygen as high as 3·84.

Arfwedson's experiments to determine the atom of peroxide of uranium.

4. M. Arfwedson made a set of experiments likewise, to determine the quantity of oxygen in peroxide of uranium, which I shall state before giving an account of those which I myself made with the same object in view.

(1.) He formed uraniate of lead by mixing together solutions of permuriate of uranium and muriate of lead, and mixing the liquid with caustic ammonia. A yellow precipitate fell, consisting of the two oxides chemically combined.

He found by analysis that this salt was a compound of

Peroxide of uranium	0·9912
Protoxide of lead	1·3088
	2·3000

When 2·3 parts of this salt in an anhydrous state were decomposed by hydrogen gas, the water evolved weighed 0·164, containing 0·14577 oxygen. Now, by this process, both the oxides were reduced to the metallic state: 1·3038 of protoxide of lead contain 0·0935 oxygen, which subtracted from 0·14577 leaves 0·0522 for the quantity of oxygen contained in 0·9912 peroxide of uranium. It is easy from these data to deduce the quantity of oxygen contained in 100 parts of peroxide of uranium:—it is obviously 5·2663 parts. So that peroxide of uranium is composed, according to this experiment, of

Uranium	100
Oxygen	5·559

Another experiment was made with another portion of uraniate of lead composed of

Peroxide of uranium	1·086725
Protoxide of lead	0·173275
	1·260000

The water obtained weighed 0·0785, equivalent to 0·0697 oxygen; of this oxygen 0·012377 belonged to the protoxide of lead, the remainder, amounting to 0·0574, existed in the peroxide of uranium. It follows from these data that the peroxide of uranium is a compound of

Uranium	100
Oxygen	5·5765

The mean of these two results gives us the constituents of the peroxide as follows:

Uranium	100
Oxygen	5·56775

Now, if the atomic weight of uranium be 26, and if the peroxide be a compound of 1 atom metal and 2 atoms oxygen, its constituents would be

Uranium	100
Oxygen	7·6923

The preceding experiments do not correspond with this supposition. They agree more nearly with the notion that the peroxide of uranium contains 1½ atom of oxygen:—for on this supposition, its constituents would be

1 atom uranium	26	or	100
1½ atom oxygen	1·5		5·76923
	27·5		

This somewhat surpasses the result obtained by Arfwedson, but not very much.

(2.) He formed uraniate of barytes by mixing together solutions of permuriate of uranium and muriate of barytes; caustic ammonia being added, the uraniate of barytes precipitated. It was hastily washed on a filter with boiling water, to prevent the precipitation of carbonate of barytes; it was then dried and heated to redness, to render it anhydrous. Two experiments were made with two different preparations of uraniate of barytes. I shall state the results of each.

First. 1·343 of uraniate of barytes gave 0·295 sulphate of barytes, equivalent to 0·195 barytes. The protoxide of uranium obtained from the same salt weighed 1·121; now,

Barytes . .	0·195
Protoxide of uranium	1·121
	1·316

The difference between 1·316 and 1·343 is 0·027, which must be the oxygen driven off when the peroxide of uranium was converted into protoxide. But 1·121 : 0·027 : : 100 : 2·4085. It appears from this experiment that 100 protoxide + 2·4085 oxygen = 102·4085 peroxide.

Second. 1·456 uraniate of barytes gave 0·364 sulphate of barytes, equivalent to 0·2406 barytes, and 1·186 protoxide of uranium. The difference between these weights united, and that of the uraniate is 0·0294, which must be the oxygen driven off when the peroxide of uranium was converted into protoxide. Now, 1·186 : 0·0294 : : 100 : 2·4789. It appears from this experiment that 100 protoxide + 2·4789 = 102·4789 peroxide.

The mean of these two experiments gives us peroxide of uranium composed of

Protoxide of uranium	100
Oxygen . . .	2·4437

Now, if the protoxide of uranium be a compound of 26 uranium + 1 oxygen, it is obvious that 100 parts of it must contain 96·2963 uranium and 3·7037 oxygen; and peroxide of uranium must be a compound of

Uranium	96·2963	or	100
Oxygen	6·1474	-	6·3839
	102·4437		

The proportion of oxygen in the peroxide of uranium, found by the analysis of this salt, exceeds considerably that obtained from the analysis of uraniate of lead. Though it does not amount to two atoms, it exceeds 1½ atom, being very nearly 1⅔ atom.

(3.) M. Arfwedson analyzed the potash sulphate of uranium in the following manner: 2·172 parts of the anhydrous salt were dissolved in water, and precipitated by muriate of barytes. The sulphate of barytes obtained weighed 1·814 parts, equivalent to 0·6149 sulphuric acid. The filtered liquid was mixed with caustic ammonia to get rid of the peroxide of uranium; sulphuric acid was then added, partly to separate any barytes which it might contain, and partly to saturate the potash. The liquid was then evaporated to dryness, and being heated to redness to drive off the ammoniacal salt, there remained 0·533 parts of pure sulphate of potash, equivalent to 0·2907 potash. Thus he obtained the sulphuric acid and the potash in the salt, and he concluded that the deficit of weight was peroxide of uranium. The constituents of the salt then are

Sulphuric acid .	0·6149	or	28·311
Potash . .	0·2907	-	13·384
Peroxide of uranium	1·2664	-	58·305
	2·1720		100

Now, 13·384 potash are saturated by 11·153̇ of sulphuric acid. There remain 17·158 of sulphuric acid, which in the salt must have been united with 58·305 of peroxide of uranium.

M. Arfwedson having obtained this result, calculates the quantity of oxygen in the 58·305 parts of peroxide of uranium from a canon of Berzelius; namely, that 100 parts of sulphuric acid saturate a quantity of basis containing 20 parts of oxygen. From this canon it is obvious, that 17·158 parts of sulphuric acid must saturate a quantity of basis containing 3·4316 oxygen.

This would give us peroxide of uranium composed of

Uranium	54·8734	or	100
Oxygen	3·4316	-	6·254
	58·3050		

But this canon of Berzelius is correct only when the basis is a protoxide, and when the salt is neutral, or a compound of 1 atom sulphuric acid and 1 atom base; for sulphuric acid is capable of combining with bases in various proportions. Sometimes 1 atom of the base unites with 2 atoms of sulphuric acid. Bisulphate of potash is a salt of this kind. In it the potash, combined with a 100 parts of the acid, contains only 10 parts of oxygen instead of 20. Sometimes 1½ atom of sulphuric acid combines with 1 atom of base; such combinations I distinguish by the name of sesquisulphates.—The sesquisulphate of potash (did it exist) would be a compound of such a nature, that the oxygen in the potash, combined with 100 sulphuric acid, would contain only 15 parts of oxygen.

As peroxide of uranium contains certainly more than 1 atom of oxygen, the canon of Berzelius cannot apply to it. As the triple salt, analyzed by Arfwedson, reddens vegetable blues even after having been fused, there is a presumption that it contains more than 1 atom of sulphuric acid united with 1 atom of peroxide of uranium. I shall show immediately that it contains 1½ atom of sulphuric acid united to 1 atom of peroxide of uranium. Let us see, therefore, what the atomic weight of peroxide of uranium will be, if we consider 17·158 as representing 1½ atom of sulphuric acid, and 58·305 as representing 1 atom of peroxide of uranium. It is obvious, that two-thirds of 17·158 or 11·439 must in that case represent 1 atom of sulphuric acid. Now, 11·439 : 58·305 : : 5 : 25·486 = atomic weight of peroxide of uranium. This is somewhat under the truth, as will appear immediately; though it would have been very difficult to have come nearer by Arfwedson's method of analysis; for a portion of the peroxide of uranium precipitates with the sulphate of barytes. This caused him to overrate the quantity of sulphuric acid, and consequently to underrate, by at least as much, the peroxide of uranium in the salt.

5. I shall now relate the experiments which I made on this salt.

Analysis of potash persesquisulphate of uranium by the author.

The peroxide of uranium which I employed to prepare it was in the state of carbonate. It had been thrown down from nitric acid by carbonate of ammonia, and I could not discover any ammonia in it, either by the smell or by any other reagent, when it was digested with caustic potash. Its constituents, by the most careful analysis of it which I could make, appeared to be

1 atom carbonic acid	2·75
1 atom peroxide of uranium	28·00
1 atom water	1·125
	31·875

I took 318·75 grains of this carbonate (equivalent to 10 atoms peroxide of uranium) and poured over it 183·75 grains of sulphuric acid of the specific gravity 1·847 (equivalent to 30 atoms acid) and a considerable quantity of water, and digested the mixture on the sand bath till a complete solution was obtained. I thus employed twice as much acid as the requisite quantity. The reason was, that the solution goes on very slowly unless there be an excess of acid. To this solution I added 110 grains of sulphate of potash (equivalent to 10 atoms of the salt) previously dissolved in water, and evaporated the mixture. The triple sulphate was deposited to the very last from this solution n a state of purity, without any crystals of sulphate of potash ever appearing, showing clearly that in the triple salt there exists just an atom of each basis. When the liquid was reduced to a very small quantity, I was obliged to employ a higher temperature to continue the evaporation. The consequence was, that at last the salt began to acquire a greenish tinge. This effect was doubtless owing to the redundant sulphuric acid present. On account of this change, the 40 or 50 grains of the salt, obtained at the end of the process, were not employed in the experiments to be immediately described.

The salt thus obtained was redissolved, and evaporated a second time. It was obtained partly in the state of small crystalline grains, and partly in hard globular crystals, composed of small needles diverging from a centre; but the form of the crystals was too irregular to be determined. This salt has a most beautiful lemon yellow colour. Its taste is very astringent, like that of all the salts of uranium; but it leaves likewise an impression of bitterness.

(1.) 51 grains of these crystals were exposed to a pretty strong heat (but not quite red heat) in a platinum crucible. The process was stopped when fusion seemed to be beginning—the reason of this was, that in some previous trials I had found that if the salt had been exposed to a strong red heat, and had been completely fused, it was not afterwards altogether soluble in water. The loss of weight by this regulated heat was exactly 4·5 grains, which is equivalent to 4 atoms water; from this experiment it follows, that 51 parts of the triple salt contain 4 atoms of water.

(2.) 51 grains of the crystals of the same salt were dissolved in water, and the solution was mixed with a solution of 33·125 grains of chloride of barium. A double decomposition took place; and after the sulphate of barytes had precipitated, the clear liquid was tested with glauber salt and with muriate of barytes, but did not become in the least muddy by the addition of either, showing that it contained no sensible quantity of barytes or sulphuric acid; but $33{\cdot}125 = 13{\cdot}25 \times 2{\cdot}5$. Consequently, 51 grains of the salt contain 12·5 grains of sulphuric acid, which is equivalent to $2\frac{1}{2}$ atoms of that acid.

(3.) 51 grains of crystallized salt were dissolved in water, and mixed with an excess of ammonia, which precipitated the peroxide of uranium in yellow flocks. The whole was thrown upon a filter, and the peroxide was washed repeatedly with caustic ammonia, till it was judged to be freed completely from all admixture of sulphate of potash. This method was employed, because it was found, that when pure water was used to wash the peroxide of uranium, a portion of it was redissolved. The liquid which passed through the filter was evaporated to dryness in a platinum vessel, and then the whole was heated to redness to expel all the ammoniacal salt: the residual salt was white, with a scarcely perceptible shade of yellow; it weighed 11·2 grains. Being redissolved in water and mixed with ammonia, a few yellow flocks were precipitated, which being collected on a filter and dried, weighed, as nearly as could be determined, exactly 0·2 grain: the salt possessed the character of pure sulphate of potash. Thus it appears, that 51 grains of the crystallized compound salt contain exactly 11 grains of sulphate of potash.

(4.) I did not attempt to determine the weight of the peroxide of uranium. As it was precipitated it contained a quantity of ammonia united to it. By exposure to a heat, very nearly but not quite so high as a red heat, I drove off most of the ammonia, if not the whole of it; by which the peroxide was deprived of its yellow colour, and assumed a fine red with a shade of brown; and 31·8 grains, by this treatment, were reduced to 28 grains. Hence, I consider the yellow precipitate as a compound of

1 atom peroxide of uranium	28
1 atom ammonia . .	2·125
$1\frac{1}{2}$ atom water .	1·6875
	31·8125

The matter driven off consisted partly of ammonia and partly of water; but it would have been difficult to have determined the proportions of each.

(5.) From the above analysis, which was made with the most scrupulous care, it follows, that 51 grains of the crystallized compound salt of uranium contained the following constituents:

4 atoms water . .	4·5
1½ atom sulphuric acid .	7·5
1 atom sulphate of potash	11
	23·0
Deficiency . .	28
	51

This deficiency must consist of peroxide of uranium; consequently, 28 must represent the weight of an atom of peroxide of uranium; and the compound salt must consist of

1 atom sesquisulphate of uranium	1½ atom acid	7·5	35·5
	1 atom oxide	28	
1 atom sulphate of potash . . .			11
4 atoms water			4·5
			51

Analysis of persesquinitrate of uranium.

6. The combination of nitric acid and peroxide of uranium crystallizes very easily in large flat four-sided rectangular prisms. Its colour is a fine lemon yellow—its taste is astringent and acid, and it reddens vegetable blues, even after having been three times dissolved in pure water and crystallized—it is exceedingly soluble both in water and alcohol—it melts in its water of crystallization when exposed to a moderate heat.

(1.) 57·25 grains of the crystals of this salt were gradually heated in a platinum crucible till the whole water and acid were driven off, and till the uranium was reduced to the state of protoxide. It now weighed 27 grains, which, from what has been already stated, is equivalent to 28 grains of peroxide.

(2.) 57·25 grains of the crystals of the same salt were dissolved in water, and the solution being mixed with about 30 grains of carbonate of barytes, was digested in a retort till it had become perfectly colourless : the whole was then thrown on a filter, which retained a yellow powder, consisting of the peroxide of uranium and the barytes, partly combined and partly mixed. The liquid being evaporated to dryness left 24·5 grains of nitrate of barytes, equivalent to 10·023 grains of nitric acid. This is less than 1½ atom of nitric acid by 0·1 grain, or almost exactly one per cent. The reason of this deficiency I found (after some trouble) to be owing to the filter employed containing some sulphate of lime, which decomposed a little of the nitrate of barytes ; for I found distinct traces of lime in the filtered liquid, though neither the carbonate of barytes nor the salt of uranium contained a particle of that earth. It is evident, then, that 57·25 grains of the crystallized nitrate of uranium contain 10·125 grains of nitric acid, equivalent to 1½ atom of acid.

(3.) The remainder wanting to make up the original weight of the crystals, amounting to

19·125 grains, must be the amount of the water of crystallization. It is equivalent to 17 atoms of water.

From the above analysis, which was very carefully conducted, it appears, that the salt is a sesquinitrate composed of

1½ atom nitric acid .	10·125
1 atom peroxide of uranium	28·000
17 atoms water . .	19·125
	57·25

7. When the pernitrate of uranium is exposed to heat, it gives out water and nitric acid, and loses the property of dissolving in water. In this state it is probably a neutral pernitrate; but my analysis of it was not successful.

Analysis of sesquisulphate of uranium.

8. Sesquisulphate of uranium. To form this salt I digested percarbonate of uranium in dilute sulphuric acid for more than a fortnight, till the acid would dissolve no more of the oxide. The yellow solution, thus formed, was evaporated to dryness by a gentle heat: the saline residue was redissolved in water, and the solution evaporated a second time to dryness in a temperature rather above 212°, and kept in that temperature till the yellow residue was reduced to the state of a yellow powder. No appearance of crystals could be perceived during the evaporation; but if a portion of sulphuric acid be added to the liquid,

and we evaporate cautiously to dryness, the dry mass appears a congeries of small and ill-defined prisms.

The dry sulphate of uranium, thus formed, had a fine deep yellow colour and an astringent taste. It strongly reddened vegetable blues. This salt was analyzed in the following manner:

(1.) 36·8 grains of it were dissolved in distilled water: several yellow flocks remained undissolved—these being collected and dried were found to weigh 0·6 grain. Hence, the portion of the salt dissolved was 36·2 grains.

(2.) The aqueous solution was precipitated by ammonia. The yellow precipitate being collected on a filter, and washed with water containing a little ammonia, and then dried, was found to weigh 28·2 grains. This matter being exposed to a strong red heat in a platinum crucible, was reduced to protoxide of uranium, and weighed 24·434 grains; equivalent to 25·339 grains of peroxide of uranium.

(3.) The liquid, thus freed from uranium, was supersaturated by nitric acid and precipitated by muriate of barytes. The sulphate of barytes precipitated, being washed, dried, and heated to redness, weighed 23·67 grains, equivalent to 8·02 grains of sulphuric acid.

(4.) From the preceding experiments it follows that the constituents of the salt are

Sulphuric acid	8·020
Peroxide of uranium	25·339
Water . .	3·746
	36·2

This is equivalent to

Sulphuric acid	8·862
Peroxide of uranium	28·000
Water . .	4·13

8·862 approaches nearest to 1½ atom of sulphuric acid which weigh 7·5; and 4·13 comes nearest to 4·5 which is 4 atoms of water. Hence, it is probable that the salt is a sesquisulphate of uranium mixed with a little bisulphate; and we may infer that the sesquisulphate of uranium, supposing it pure and dried till it falls to powder, is a compound of

1½ atom sulphuric acid	7·5
1 atom peroxide of uranium	28
4 atoms water	4·5
	40

I repeated this analysis several times with sulphate of uranium prepared in different ways, and exposed to as high a temperature as it could bear without acquiring a green tinge. Once I obtained a persesquisulphate of uranium, composed of

$1\frac{1}{2}$ atom sulphuric acid	7·5
1 atom peroxide of uranium	28
	35·5

But in general the sulphuric acid was an intermediate quantity between 7·5 and 8·8; I never came nearer 10 than in the analysis just given.

I conclude from these experiments, that sulphuric acid and peroxide of uranium are capable of uniting in two proportions, forming a bisulphate and a sesquisulphate; and that in general, both of these salts are mixed together.

Analysis of peroxalate of uranium.

9. Peroxalate of uranium. I dissolved 27 grains of the crystals of oxalic acid in water, and digested the solution over 127·5 grains of percarbonate of uranium, till the liquid refused to dissolve any more. The undissolved portion being separated, dried, and weighed, was found to amount to 83·7 grains. Hence, the portion dissolved weighed 43·8 grains.

Twenty-seven grains of crystallized oxalic acid contain 13·5 grains of oxalic acid, equivalent to 3 atoms of that acid. 127·5 grains of percarbonate of uranium contain 84 grains peroxide of uranium, likewise equivalent to 3 atoms. Now, 43·8 is very nearly the third of 127·5; hence, it is obvious, that the solution was a teroxalate of uranium, or a compound of

3 atoms oxalic acid	13·5
1 atom peroxide of uranium	28
	41·5

The solution being evaporated let fall yellow crusts of the oxalate, which had little taste, and were scarcely soluble in cold water. But they dissolved in hot water; the solution had an astringent taste, and reddened vegetable blues.

Analysis of uraniate of potash.

10. Uraniate of potash. Arfwedson having shown that peroxide of uranium possesses the properties of an acid, I wished to see whether I could form a definite compound of this oxide and potash. For this purpose I digested on the sand bath a quantity of percarbonate of uranium in a pretty strong solution of caustic potash; the yellow colour of the powder was speedily changed into a deep orange, bordering on red, and its volume diminished. The caustic potash was poured off after two hours' digestion, and a fresh portion poured on, which was allowed to digest on the powder for twenty-four hours. The uraniate was then collected on a filter, washed, and dried in a low heat. I now examined it in the following manner.

(1.) Nineteen grains of it were dissolved in nitric acid in a balanced glass vessel. There was a slight effervescence, and the loss of weight amounted to 0·3 grain; this loss was occasioned by the escape of some carbonic acid gas.

(2.) The nitric acid solution was evaporated to dryness, to get rid of the excess of acid—the dry mass re-dissolved in water, and precipitated by ammonia. The precipitate, which was orange, being collected on the filter, washed, and dried, weighed 16·5 grains. Being exposed to a red heat, it was reduced to protoxide of uranium, and weighed 14·04 grains; equivalent to 14·54 grains of peroxide of uranium.

(3.) The residual liquid was evaporated to dryness in a platinum cup, and exposed to a heat gradually raised nearly to redness. The nitrate of ammonia was decomposed and driven off, and there remained 2·7 grains of nitrate of potash, equivalent to 1·223 grain of potash.

(4.) Thus the constituents of the salt were

Peroxide of uranium	14·54
Potash . . .	1·223
Carbonic acid . .	0·300
Water . . .	2·937
	19·000

The carbonic acid was no doubt combined with a portion of the peroxide of uranium, showing that the carbonate had not been completely decomposed. If we subtract the portion of percarbonate, amounting to rather less than 6½ grains, we shall find that the uraniate of potash is a compound of

2 atoms peroxide of uranium	56
1 atom potash . . .	6
3 atoms water . . .	3·375
	65·375

The preceding details contain the most satisfactory of the experiments which I made upon this very difficult metal. I consider them myself as proving that the atomic weight of uranium is 26; that its protoxide weighs 27, and contains 1 atom of oxygen; while its peroxide contains 2 atoms of oxygen and weighs 28. But some time after these experiments of mine had been concluded, I had an opportunity of seeing a paper on the Oxide of Uranium and its Compounds, by Professor Berzelius, which that excellent chemist has inserted in the Memoirs of the Stockholm Academy for 1823. Berzelius is of opinion that the oxygen in the protoxide of uranium is to that in the peroxides as 2 : 3. But I have not been able to perceive any thing in his experiments from which this inference can be legitimately drawn. He analyzed three salts of uranium; namely, potash sulphate of uranium, potash muriate of uranium, and oxalate of uranium. I shall here state the results of these analyses.

Experiments of Berzelius on the oxides of uranium.

(1.) The constituents of potash-sulphate of uranium he found as follows:

Sulphuric acid .	26·834
Peroxide of uranium	53·833
Potash . .	15·833
Water . .	3·500
	100·000

The reader will be better able to form an estimate of the constituents of this salt if I state them in atomic proportions:

2½ atoms sulphuric acid	12·5	+	1·2
1 atom peroxide of uranium	28		
1 atom potash . .	6	+	2·308
1 atom water . .	1·125	+	0·699
	47·625		4·207

Or we may state the constituents this way:—

1 atom sulphate of potash .	11
1 atom sesquisulphate of uranium	35·5
1 atom water . . .	1·125
Excess of sulphuric acid .	1·2
——— potash .	2·308
——— water . .	0·699
	51·832

The weight of the integrant particle of the salt is not much higher than I found it, but instead of the 4 atoms of water which I found, there is a surplus of potash and sulphuric acid, and not in such proportions that they saturate each other. It is quite obvious, that this salt as it was examined by Berzelius, was not a pure chemical compound of sulphate of uranium and sulphate of potash, but contained an excess of one of them mechanically mixed: this indeed Berzelius admits. Consequently, no inference can be drawn from the analysis just stated.

(2.) The potash-muriate of uranium was prepared by dissolving muriate of potash in an excess of permuriate of uranium, and allowing the salt to shoot spontaneously into crystals. The crystals were four-sided oblique prisms, or rhomboidal tables. The salt was previously dried in the temperature of 131°. From 1·5 gramme of this salt, he got 1·61 gramme of fused chloride of silver, equivalent to 0·408 muriatic acid. The protoxide of uranium was 0·82, equivalent to 0·85 peroxide of uranium, and the muriate of potash was 0·412 gramme, equivalent to 0·2602 potash. According to this analysis the constituents of the salt are

Muriatic acid .	0·4080	or	26·874
Peroxide of uranium	0·8500	-	55·987
Potash . .	0·2602	-	17·139
	1·5182		100·000

Though Berzelius himself, owing to some inadvertancy, has stated the constituents of this salt to be

Muriatic acid .	0·3075
Peroxide of uranium	0·8346
Potash . .	0·2606
Water . .	0·0973
	1·5000

I examined this salt with a good deal of care, and though, owing to an accident, I cannot state the result of my analysis, yet I satisfied myself that it exactly resembled the potash-sulphate of uranium in its constitution, that is to say, that it was a compound of 1 atom muriate of potash, and 1 atom of sesquimuriate of uranium, and without any sensible portion of water. Now, the preceding analysis of Berzelius comes exceedingly near mine, as will be evident from the following observations. The muriatic acid united to 0·2602 potash, must have been 0·20057; for

6 (the atom of potash) : 4·625 (the atom of muriatic acid) : : 0·2602 : 0·20057.

Consequently, there remains 0·20743 muriatic acid to saturate 0·85 peroxide of uranium. Now, if muriatic acid be to the oxide in the proportion of 1½ atom to 1 atom, an atom of peroxide of uranium will weigh 28·43; for

0·20743 : 0·85 : : 6·9375 (1½ atom muriatic acid) : 28·43.

I consider the analysis of Berzelius, therefore, to be a corroboration of my previous experiments. The slight excess 0·43 (little more than one per cent.) might be owing to the protoxide of uranium not having been absolutely free from foreign matter; and the slight excess of weight in Berzelius' numbers above the weight of the salt employed, rather confirms this view of the matter. I think it therefore certain, that the true constitution of potash-muriate of uranium is

1 atom sesquimuriate of uranium	34·9375
1 atom muriate of potash .	10·625
	45·5625

But the salt formed by Berzelius contained an excess of muriate of potash amounting nearly to a fourth part.

(3.) Peroxalate of uranium was also analyzed by Berzelius. He does not inform us of the method he employed to prepare it; but from the result of his analysis it is evident that it contained just twice as much peroxide of uranium as my oxalate did. A quantity of this salt previously well dried was subjected to distillation in a small retort. From 2·67 grammes of the salt he obtained 0·353 gramme water, 0·5835 gramme carbonic acid, and 1·7335 gramme uranium in the metallic state, equivalent to 1·8668 peroxide of uranium. Hence, the constituents of this salt must have been

Peroxide of uranium	1·8668
Oxalic acid .	0·4502
Water . .	0·3530
	2·6700

Now, this is equivalent to

		RESULT OF EXPERIMENT.
1½ atom oxalic acid .	6·75	6·75
1 atom peroxide of uranium	28	27·925
2½ atoms water .	2·8125	2·8428
	37·5625	

Thus, the result of this analysis corresponds also exceedingly nearly with mine. The atom of peroxide from this salt falls short of 28 a very little; while the number from the muriate gave a result a little higher than 28.

(4.) Berzelius likewise formed uraniate of barytes by precipitating a solution of pernitrate of uranium with barytes water, and boiling the precipitate in water till all the soluble barytes was removed. 2·128 grammes of this uraniate previously heated to redness gave 0·451 of barytes, and 1·677 of peroxide of uranium. These determinations are merely given by Berzelius, without stating the weight of the sulphate of barytes and protoxide of uranium, from which they were derived. This puts it out of my power to apply any correction to them. According to this statement, uraniate of barytes is composed of

Peroxide of uranium	1·677	or	36·254
Barytes . .	0·451	-	9·75
	2·128		

I suspect that the quantity of peroxide of uranium has been underrated in Berzelius' calculation, and that the uraniate of barytes, when pure, is a sesqui-uraniate composed of

1½ atom peroxide of uranium	42
1 atom barytes . .	9·75

Either this supposition is the true one, or the salt contained a slight excess of barytes, owing to the difficulty of washing it thoroughly: this last is the notion which Berzelius entertains. The composition of the salt may be stated thus:

1½ atom peroxide of uranium	42
1 atom barytes . .	9·75 + 1·546

If this statement be correct, there was an excess of 1·546 barytes, or almost ⅙th of the whole barytes.

Analysis of uranmica.

(5.) Berzelius has likewise given us an analysis of uranmica from Autun, well known for its beautiful yellow colour. He found its constituents as follows:

Phosphoric acid .	14
Peroxide of uranium	56·813
Lime . . .	5·416
Water . . .	14·250
	90·479

Now, if we consider it as composed of

4 atoms phosphoric acid	14
2 atoms peroxide of uranium	56
1½ atom lime . .	5·25
12 atoms water . .	13·5
	88·75

we have almost the identical numbers of Berzelius. We may, therefore, represent the constitution of uranmica in this way:

2 atoms sesquiphosphate of uranium	66·5
1 atom subsesquiphosphate of lime	8·75
12 atoms water . . .	13·5
	88·75

The green uranmica, from Gunnis Lake mine, in Cornwall, had been shown, by Mr. Richard Phillips, to contain phosphoric acid. This induced Berzelius to analyze it, and the result of his experiments agrees very near with the numbers obtained by Phillips. He found its constituents:

Phosphoric acid .	14
Peroxide of uranium .	54·2
Oxide of copper .	7·59
Water . . .	13·54
	89 33

Now, if we consider it as composed of

4 atoms phosphoric acid .	14
2 atoms peroxide of uranium	56
1½ atom oxide of copper	7·5
12 atoms water . .	13·5
	91

we have very nearly the numbers obtained by Berzelius. The greatest deviation is in the peroxide of uranium, which, instead of 56, turns out only 54·2. It is not impossible that it is in the state of protoxide of uranium, instead of peroxide. Meanwhile, it would seem that the difference between the yellow and the green uran-micas consists in this, that the former is a double sesquiphosphate of uranium and lime, and the second of uranium and copper; for the constitution of uranite from Cornwall may be represented thus:

2 atoms sesquiphosphate of uranium	66·5
1 atom subsesquiphosphate of copper	11
12 atoms water	13·5
	91

As the two minerals have the same crystalline shape, and the same constitution nearly, it would appear that lime and oxide of copper are isomorphous bases.

Thus the experiments of Berzelius confirm my own in a very satisfactory manner; and seem to leave no doubt that the atomic weight of uranium and its oxides have been rightly determined.

The tendency which peroxide of uranium has to form sesquisalts is very curious. It would have led me to hesitate about the atomic weight of this metal, had I not likewise met with several neutral compounds of the peroxide of uranium and acids.

SECT. II.

OF THE ATOMIC WEIGHT OF ANTIMONY.

THE laborious experiments of Proust and Berzelius to investigate the oxides of antimony are well known to the chemical world. It is unnecessary to refer to them farther than to say, that they guided me in my researches, and contributed essentially to the accuracy of my results.

Method of obtaining pure antimony.

To obtain pure antimony I dissolved the antimony of commerce in nitro-muriatic acid, and precipitated the peroxide by means of water. This oxide was well washed, dried, mixed with black flux, and exposed to a red heat in a covered crucible. The metallic antimony thus obtained was exceedingly soft, and its specific gravity was only 6·424, at the temperature of 60°. This is somewhat below the specific gravity of this metal usually given by chemists.

1. 5·5 grains of this antimony were put into a platinum crucible, and dissolved by the assistance of heat in nitric acid. The solution was evaporated to dryness, and exposed for some hours to a heat of 500°. A yellow coloured powder was thus obtained, possessing the properties of peroxide of antimony; it weighed 7·5 grains. Four different trials, made in the same way, gave each the same result. Thus it appears that peroxide of antimony is a compound of

Antimony . .	5·5
Oxygen . .	2
	7·5

Atom of antimony and peroxide.

It is evident that 5·5 is the atomic weight of antimony, and that peroxide of antimony is a compound of 1 atom metal and 2 atoms oxygen. Its atomic weight, therefore, is 7·5.

Atom of deutoxide.

2. 7·5 grains of peroxide of antimony were kept for some time in a red heat; the colour changed from yellow to white, and the weight diminished from 7·5 to 7. By this process the peroxide was changed into deutoxide; for the white powder possessed the well known proper-

ties of deutoxide of antimony. The loss of weight sustained in this case was owing to the escape of oxygen; for, if 100 grains of peroxide of antimony be heated to redness in a small green glass retort, connected to a pneumatic trough, the gaseous product evolved, which is oxygen, amounts nearly to 19 cubic inches.

7·5 peroxide being converted into 7 deutoxide, it is plain that deutoxide of antimony is composed of

Antimony . .	5·5
Oxygen . .	1·5
	7

Or, it consists of 1 atom of antimony united to 1½ atom oxygen.

It is this deutoxide that is formed when any of the other oxides of antimony is exposed to a red heat. In this respect antimony and manganese resemble each other; for, whenever any oxide of manganese is exposed to a low red heat, it is always converted into deutoxide of manganese, which, like the deutoxide of antimony, is a compound of 1 atom manganese and 1½ atom oxygen.

Atom of protoxide.

3. It was unnecessary to subject the protoxide of antimony to any analysis; for, if we compare Berzelius' experiments on it with the analysis of the deutoxide and peroxide of antimony in

the preceding paragraphs, it will be obvious that the protoxide must be a compound of

1 atom antimony	.	5·5
1 atom oxygen	.	1
		6·5

and its atomic weight must be 6·5.

Thus it appears, that the atom of antimony weighs 5·5; that the protoxide is a compound of 1 atom metal + 1 atom oxygen, and the peroxide of 1 atom metal + 2 atoms oxygen. The deutoxide may be considered as a compound of 1 integrant particle of protoxide and 1 integrant particle of peroxide. For

	ANTIMONY.		OXYGEN.
1 atom protoxide consists of	5·5	+	1
1 atom peroxide . .	5·5	+	2
	2)11	+	3
	5·5	+	1·5

or we may consider it as a compound of 2 atoms metal and 3 atoms oxygen.

Antimonite of potash.

The only chemical compound of this deutoxide, or antimonious acid as Berzelius calls it, hitherto examined, is antimonite of potash. Berzelius obtained this salt by fusing together deutoxide of antimony and potash, washing off the excess of potash by cold water, dissolving the residual matter in hot water, and evaporating the solution in order to obtain the antimonite which separated in the state of a white powder. According to the analysis of Berzelius, the constituents of the salt are

Deutoxide of antimony	76·6	or	19·641
Potash . . .	23·4	-	6
	100·0		

It is obvious that the salt contained an excess of deutoxide; had it been a binantimonite, it would have been composed of

2 atoms deutoxide of antimony	14	or	70
1 atom potash . . .	6	-	30
	20		100

Chlorides of antimony.

4. There are two chlorides of antimony, though only one of them has hitherto been described; both of them may be easily obtained by dissolving sulphuret of antimony in muriatic acid, and distilling the solution in a retort. There distils off a liquid having a straw yellow colour, containing both muriatic acid and antimony. The liquid in the retort, which was at first of rather a deep yellow, becomes gradually lighter, and at last quite colourless and transparent. When the concentration has been carried a certain length, the fire must be withdrawn, and the apparatus left untouched for twenty-four hours.

A number of beautiful white scales, with a silky lustre, gradually make their appearance at the bottom of the liquid in the retort. These scales may be taken out and dried upon blotting paper: they do not deliquesce, and as far as I have observed, undergo no alteration whatever by exposure to the air. They may be dissolved, at least partially, in water without undergoing decomposition; by digesting them with a solution of carbonate of soda, I decomposed them; and by collecting the oxide of antimony, and determining the quantity of chlorine by means of nitrate of silver, I found that these scales constitute a dichloride of antimony composed of

1 atom chlorine	4·5
2 atoms antimony	11
	15·5

If the muriatic solution of antimony, thus deprived of the dichloride, be still farther concentrated, till liquid no longer passes into the receiver, the whole matter in the retort concretes on cooling into a solid mass, having a silky lustre, and the property of deliquescing very rapidly when exposed to the air. I have obtained it crystallized in octahedrons, usually having two of the opposite faces of the pyramids a good deal larger than the other two. Frequently, the octahedron does not terminate in a pointed summit, but forms a ridge; this is the substance formerly called butter of antimony, and usually obtained by distilling a mixture of two parts corrosive sublimate and one part antimony. Its constituents are

1 atom chlorine	4·5
1 atom antimony	5·5
	10

as was shown long ago by Dr. John Davy.

Kermes mineral.

5. The dark red substance long celebrated under the name of *kermes mineral*, and constituting an excellent medicinal preparation, though but little used in this country, was suspected by Proust to be a compound of sulphuretted hydrogen gas and protoxide of antimony. Dr. John Davy demonstrated the truth of this opinion by showing that, when heated, it is converted into common sulphuret of antimony and water. When I published a similar set of experiments, about four years ago, I did not recollect at the time that I had been anticipated by Dr. Davy. It is obvious from the experiment just stated, that kermes mineral is a compound of 1 atom sulphuretted hydrogen and 1 atom protoxide of antimony. For sulphuretted hydrogen is a compound of

	ATOM.		ATOM.
	1 sulphur	+	1 hydrogen
Protoxide of antimony of	1 antimony	+	1 oxygen

The atom of sulphur combining with the atom of antimony forms an integrant particle of sulphuret of antimony; while the atom of hydrogen uniting with the atom of oxygen, forms an integrant particle of water.

Sulphuret of antimony.

6. That sulphuret of antimony is composed of one atom of each of its constituents, is obvious from the following experiment: *5·5* grains of pure antimony in powder were fused with a quantity of flowers of sulphur in a covered crucible, the temperature of which was gradually raised till the excess of sulphur was driven off. The weight of the sulphuret formed was 7·5 grains; consequently, the antimony had combined with 2 grains of sulphur. Now, *5·5* represents the weight of an atom of antimony, and 2 the weight of an atom of sulphur.

SECT. III.

OF THE ATOMIC WEIGHT OF CHROMIUM.

Oxides of chromium.

Chromium is a white coloured brittle metal, which is not affected by the magnet, and which combines with three proportions of oxygen, and forms three oxides. The protoxide has a fine green colour, the deutoxide is brown, and the peroxide, commonly called *chromic acid*, has a very deep yellowish red, or extremely dark orange colour. It is very soluble in water, and possesses the characters of a strong acid.

Chromates.

1. The salts formed by the union of chromic acid and bases are called *chromates*. They have a *yellow* or a *red* colour; the chromates being commonly yellow, and the bichromates red. The bichromate of potash, being now used by the calico printers, is manufactured in Glasgow in very large quantities; it is a salt of a fine orange red colour, having a bitter and metallic taste, and is much less soluble in water than the chromate of potash.* It contains no water of crystallization, and as it bears a red heat without decomposition, it may be easily freed from all the water mechanically lodged between the plates of the crystals. It has been demonstrated, that in the bichromate of potash the quantity of acid is just twice as much as in the chromate. The bichromate reddens vegetable blues; but the chromate is neutral, and, consequently, a compound of one atom chromic acid and one atom potash. Of course, the bichromate is a compound of two atoms chromic acid and one atom potash. Either of these salts may be employed to determine the atomic weight of chromic acid; but the bichromate is much more easily procured in a state of purity, and therefore deserves the preference.

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* For an account of the chromate and bichromate of potash, the reader is referred to the Annals of Philosophy, XVI. 321.

2. Nineteen grains of anhydrous bichromate of potash were dissolved in distilled water, and in another portion of distilled water there was formed a solution of 41·5 grains of dry nitrate of lead. These two solutions being mixed together a double decomposition took place; chromate of lead was formed, and speedily fell to the bottom of the vessel, leaving a transparent colourless liquid which was not affected by sulphate of soda nor by nitrate of lead, and consequently, contained no sensible quantity either of lead or chromic acid. Thus it appears, that the oxide of lead in 41·5 grains of dry nitrate of lead just saturates the chromic acid in 19 grains of dry bichromate of potash; but the oxide of lead in 41·5 grains of nitrate is 14 × 2 = 28 grains, which is the equivalent for two atoms. Consequently, 19 grains of bichromate of potash contain a quantity of chromic acid just equivalent to 2 atoms.

Analysis of chromate and bichromate of potash.

If, instead of 19 grains of bichromate, we take 12·5 grains of anhydrous chromate of potash, and 20·75 grains of dry nitrate of lead, the result will be just the same; namely, the whole chromic acid of the chromate will be precipitated in combination with the whole oxide of lead in the nitrate. Consequently, 12·5 grains of dry chromate of potash contain just the equivalent of one atom of chromic acid.

The quantity of potash in 19 grains of bichromate and 12·5 grains of chromate of potash is just the same. The only difference between the two salts is, that the former contains two atoms of chromic acid while the latter contains only one. It is evident from this, that the difference between 19 and 12·5, which amounts to 6·5, must represent the weight of an atom of chromic acid.

Atom of chromic acid.

Chromate of potash is composed of

1 atom chromic acid = 6·5
1 atom potash = 6
12·5

Bichromate of potash consists of

2 atoms chromic acid = 13
1 atom potash = 6
19

3. Now, as there are three oxides of chromium, the probability is, that the atomic weight of chromium is 3·5, and that the three oxides are composed as follows:

	CHROMIUM.		OXYGEN.	ATOMIC WEIGHT.
Protoxide of	1 atom	+	1 atom	4·5
Deutoxide	1 atom	+	2 atoms	5·5
Chromic acid	1 atom	+	3 atoms	6·5

The protoxide combines readily with the different acids; but I have not been able to obtain any of the salts which it forms in the state of crystals, and consequently, susceptible of exact analysis. The muriate is a beautiful green solution, which may be evaporated to dryness without losing its colour. The sulphate is a dirty pale green powder, not soluble in water. Neither nitric, phosphoric, or acetic acids gave better results.

Atom of protoxide.

To determine the nature of protoxide of chromium I dissolved a quantity of chromate of potash in water, and added tartaric acid to the solution. An effervescence took place, and the solution assumed a fine green colour, because the chromic acid was converted into protoxide of chromium. Ammonia being poured into the green coloured liquid, the protoxide of chromium was precipitated. It was collected on a filter, well washed with water, and dried in the open air. In this state it constituted a fine green powder, exceedingly light, tasteless, and dissolving with facility in acids. I could detect no ammonia, nor tartaric acid, nor potash, in this powder; but found it a combination of water and protoxide of chromium. 33·75 grains of this hydrate were gradually heated to redness in a green glass retort. Water was driven off to the amount of 29·25 grains, and there remained a fine green powder, weighing 4·5 grains, and still in the state of protoxide of chromium; but it dissolves in acids with great difficulty, or not at all in several; because it is now anhy-

26 hydrate of protoxide.

drous. The reader will observe, that 29·25 represents 26 atoms of water. Hence, if protoxide of chromium weighs 4·5, the hydrate of it is a componnd of

1 atom protoxide of chromium	4.5
26 atoms water . . .	29·25
	33·75

This hydrate appears perfectly dry; yet it contains only $\frac{2}{15}$ths of its weight of solid matter, while $\frac{13}{15}$ths consist of pure water. I am not aware of any metallic hydrate that contains so great a proportion of water, or so many atoms of water as this one does.

Muriate of chromium.

337½ grains of this hydrate (containing 45 grains of protoxide of chromium) were dissolved in muriatic acid, and the solution cautiously evaporated in as low a temperature as possible till the muriatic solution was reduced to the state of a powder, apparently dry. It weighed 192·5 grains. From this experiment it is obvious, that the atomic weight of protoxide of chromium is 4·5; for the salt was neutral. Hence, every atom of the oxide must have combined with an atom of muriatic acid. The quantity being 45, equivalent to 10 atoms, must have united to 46·25 (equivalent to 10 atoms) of muriatic acid. The remaining 101·25, wanting to complete the sum, must be water, and it is equivalent to 90 atoms.

Thus, we see that the constituents of this muriate are

1 atom muriatic acid .	4·625
1 atom protoxide of chromium	4·500
9 atoms water . .	10·125
	19·25

for this is just the weight of salt formed from 4·5 of protoxide of chromium.

Chloride of chromium.

These 192·5 grains of muriate of chromium were exposed in a close vessel to a heat raised very slowly nearly to redness. It had not undergone fusion, and was still a powder having an olive green colour. It weighed 82 grains. Had it been reduced to a pure anhydrous chloride of chromium, the weight would have been 80 grains; for it consisted (abstracting the water) of

Muriatic acid	46·25
Protoxide of chromium	45
	91·25

When converted into chloride it would lose 10 atoms of water, or 11·25. Now, 91·25 − 11·25 = 80. In the preceding experiment the muriate had not been completely, though very nearly, reduced to a chloride. When I subjected the muriate of chromium to a strong red heat, the loss of weight was always too great, owing to the escape of chlorine; but these experiments, though not absolutely exact, are sufficient approximations to satisfy us that the atomic weight of chromium is 3·5, and that of the protoxide 4·5; and consequently, that it contains only 1 atom of oxygen combined with an atom of chromium.

Atom of chromium and protoxide.

Deutoxide, or chromous acid.

The brown oxide, as usually prepared, neither combines with acids nor bases: yet it may be made to combine with alkalies, and to form with them a soluble compound. This was ascertained in the following way:—on a quantity of chromate of soda in crystals I poured some alcohol, and digested the mixture: the yellow colour disappeared and the salt became green, owing to the conversion of the chromic acid into protoxide of chromium. This green matter was evaporated to dryness, and digested repeatedly in nitric acid—it assumed the colour of deutoxide of chromium. The whole was then evaporated to dryness to get rid of the nitric acid, and the residual brown matter was dissolved in water: I obtained a dark brown opaque liquid, which I concentrated as much as possible, and then set aside in order to obtain crystals; but none would form. The salt in this opaque liquid was obviously a combination of deutoxide of chromium and soda. It might, therefore, be called chromite of soda: probably the other chromites might be obtained by a similar process.

Bichromite of iron.

When a solution of chromate of potash is poured into a fresh solution of protosulphate of iron, there is deposited a dark brown powder, exceedingly similar, in its appearance, to the mineral usually distinguished by the name of *chromate of iron.* In this precipitate, the iron is in the state of peroxide; it immediately robs the chromic acid of a portion of its oxygen, and converts it into deutoxide. The mineral has not yet been analyzed with the requisite care; but from the analysis of Klaproth, it seems probable that it is composed of

2 atoms deutoxide of chromium	9
1 atom peroxide of iron .	5
	14

I am disposed, therefore, to consider it as a bichromite of iron,—the chromate of iron, probably, does not exist.

Similar phenomena take place when chromate of potash is dropped into protosulphate of manganese. Probably the black precipitate, which I have not examined, is a chromite of manganese.

SECT. IV.

OF THE ATOMIC WEIGHT OF MOLYBDENUM.

Bucholz first showed that molybdenum combines with three proportions of oxygen. The *protoxide* has a brown colour; the *deutoxide*, or *molybdous acid*, has a purple colour when anhydrous, but a beautiful indigo blue when mixed with water. The *peroxide*, or *molybdic acid*, is white, or when hot, yellow.

Atom of molybdenum and molybdic acid.

1. Bucholz found that 100 parts of molybdenum, when converted into molybdic acid, unite with 49 or 50 parts of oxygen. Now, if this acid be a compound of 1 atom metal + 3 atoms oxygen, (as is likely, from the existence of three oxides of molybdenum) it will follow, that the atomic weight of molybdenum is 6, and that of molybdic acid 9. For 50 : 100 : : 3 : 6.

Analysis of molybdate of potash.

To verify this estimate, I exposed a quantity of molybdate of potash to such a temperature as I knew, from previous trials, was sufficient to drive off all the water of crystallization. Fifteen grains of this anhydrous salt were dissolved in water, and mixed with a solution of 20·75 grains of anhydrous nitrate of lead: a double decomposition took place; and molybdate of lead precipitated in the state of a white powder. The supernatant liquid was colourless, and was neither affected by sulphate of soda nor by nitrate of lead; showing that it contained no sensible quantity either of lead or of molybdic acid.

We see from this experiment, that 15 grains of anhydrous molybdate of potash contain just the quantity of molybdic acid necessary to saturate the protoxide of lead in 20·75 grains of nitrate of lead. But 20·75 grains of nitrate of lead contains 14 grains of protoxide of lead, which is equivalent to an atom: 15 grains of anhydrous molybdate of potash, therefore, contains a quantity of molybdic acid equivalent to an atom. It must be in combination with an atom of potash. But as an atom of potash weighs 6, and the salt 15, it is plain that the weight of the atom of molybdic acid must be 9; and the anhydrous salt consists of

1 atom molybdic acid .	9
1 atom potash . .	6
	15

The molybdate of lead being collected and dried, weighed 23 grains. Now, it contained 14 grains of protoxide of lead; consequently, its constituents are

1 atom molybdic acid .	= 9
1 atom protoxide of lead	= 14
	23

2. Molybdate of potash crystallizes in small four-sided right prisms, terminated by rhombic bases. Its colour is white, with considerable lustre; it is opaque, and has a taste that puts one in mind of that of a weak solution of potash;

it renders cudbear paper violet, however carefully washed and crystallized. When exposed to the air it slowly deliquesces; this circumstance prevented me from being able to determine its water of crystallization. The salt dissolves readily in water, and the solution is transparent and colourless.

Action of reagents on

The characters of molybdic acid being rather imperfectly described in chemical books, I shall here state the effects of the different reagents upon a solution of this salt.

1. Prussiate of potash—Produces no change.
2. Gallic acid—Strikes a fine orange red, but occasions no precipitate.
3. Tincture of galls—Gives the same colour, and throws down a bulky orange red coagulum.
4. A piece of tin, with a drop of muriatic acid—Strikes a deep blue, and a dark blue precipitate falls.
5. Sulphuric acid—Throws down a chalk white precipitate, redissolved in an excess of acid. When this solution is evaporated nearly to dryness, it is colourless while hot; but on cooling, assumes a very beautiful blue colour, which continues, though the solution be diluted with water.
6. Nitric acid—A white precipitate, redissolved by an excess of acid. The solution being evaporated to dryness leaves a yellow crust, which becomes white on adding water.
7. Muriatic acid—The same. The solution being evaporated becomes green, and of a fine blue colour on adding water.
8. Phosphoric acid }—A white precipitate redissolved by
9. Arsenic acid } an excess of acid.

10. Chromic acid—A white flocky precipitate.
11. Acetic acid
12. Oxalic acid —No effect.
13. Tartaric acid
14. Muriate of lime—O.
15. Muriate of magnesia—O.
16. Muriate of barytes—A copious white precipitate in powder.
17. Muriate of strontian—A copious white precipitate in small flocks.
18. Alum—Numerous white flocks.
19. Sulphate of glucina—Ditto.
20. Nitrate of zirconia—Milk white flocks.
21. Nitrate of lead—A copious white flocky precipitate.
22. Nitrate of silver—Abundance of white flocks.
23. Nitrate of mercury—Abundance of yellowish white flocks.
24. Protosulphate of iron—Abundance of reddish brown flocks.
25. Sulphate of copper—Abundance of greenish white flocks.
26. Sulphate of zinc—A copious white precipitate in powder.
27. Muriate of tin—A bulky dark buff precipitate in flocks.
28. Protomuriate of cerium—Numerous white flocks.
29. Sulphate of nickel—Milk white flocks.
30. Nitrate of cobalt—O.
31. Soda-muriate of rhodium—O.
32. Muriate of platinum—A yellow precipitate, having the appearance of triple muriate of platinum and potash.
33. Aqueous solution of oxide of osmium—O.
34. Protosulphate of manganese—A copious white flocky precipitate.

From the preceding table it is obvious, 1.

That molybdic acid is disengaged from potash by sulphuric, nitric, muriatic, phosphoric, arsenic, and chromic acids; but not by acetic, oxalic, or tartaric acids. 2. That molybdates of potash, soda, ammonia, lime, magnesia, cobalt, and rhodium are soluble in water. 3. That the molybdates of all the other bases mentioned in the table are insoluble in water, or nearly so.

Atom of molybdous acid.

3. Bucholz formed molybdous acid by triturating in a mortar a mixture of 1 part metallic molybdenum and 2 parts molybdic acid, with a certain quantity of hot water, till the mixture assumed a deep blue colour. I find that it is easily formed by heating together a mixture of molybdic and muriatic acids, and continuing the heat till the whole muriatic acid is driven off. The molybdous acid formed in this way has a dark purple colour, but becomes of a fine indigo blue when water is poured on it. This acid effervesces with nitric acid, and is converted into molybdic acid. From Bucholz's process for obtaining this acid, it is obvious that it is a compound of 1 atom molybdenum and 2 atoms oxygen; consequently, its atomic weight must be 8.

Protoxide of molybdenum.

4. No accurate experiments have been made on the protoxide of molybdenum. My stock of molybdenum was too small to enable me to enter upon the investigation; but, since the atomic weight of molybdenum is known, and since it

has been shown that molybdous acid is a compound of 1 atom molybdenum and 2 atoms oxygen, and molybdic acid of 1 atom molybdenum and 3 atoms oxygen,—there is no reasonable ground of doubt that the protoxide is a compound of 1 atom molybdenum and 1 atom oxygen. Thus the atomic weight and composition of molybdenum and its oxides is

	MOLYBDEN.		OXYGEN.	ATOMIC WEIGHTS.
Molybdenum	.	.	.	6
Protoxide of	1 atom	+	1 atom	7
Molybdous acid	1 -	+	2 -	8
Molybdic acid	1 -	+	3 -	9

Sulphuret of molybdenum.

5. Sulphuret of molybdenum exists native, and is the mineral substance well known under the name of *molybdena*. It has a bluish colour, and the metallic lustre; is soft and sectile, and composed of thin leaves. It may be formed artificially, by heating together 1 part of molybdic acid and 5 parts of sulphur. Bucholz analyzed this sulphuret with sufficient accuracy, and showed that it was a compound of

Molybdenum	.	3	or	6
Sulphur	. .	2	-	4
				10

It is, therefore, a bisulphuret, or a compound of 1 atom molybdenum, with 2 atoms sulphur.

SECT. V.

OF THE ATOMIC WEIGHT OF TUNGSTEN.

THE only chemist who has hitherto attempted to determine the atomic weight of tungsten and its compounds is Berzelius.* He has shown that this metal combines with two proportions of oxygen, and forms two oxides. The *protoxide* has a flea brown colour, and, when heated, burns like tinder, and is converted into tungstic acid. The *peroxide*, or tungstic acid, has a *yellow* colour, when obtained from wolfram by the usual process. When strongly heated, it becomes *green*; and, if we prepare it by heating tungstate of ammonia in close vessels, its colour is *blue*. Berzelius has shown that tungstic acid, of all these three colours, is the same in its composition. He formed protoxide of tungsten by putting tungstic acid into a glass tube, heating it to redness, and passing a current of hydrogen gas through the red hot acid, till it ceased to produce any farther change.

Experiments of Berzelius on the atoms of tungsten and its oxides.

100 parts of this protoxide, when converted into tungstic acid, became 107 parts. From this experiment of Berzelius it is obvious that tungstic acid is a compound of

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* Annals of Philosophy, III. 244.

Protoxide of tungsten	100
Oxygen . .	7
	107

Berzelius endeavoured to determine the quantity of oxygen in tungstic acid by a very ingenious experiment, but rather of too complicated a nature to be capable of perfect accuracy. He formed a sulphuret of tungsten, by heating 1 part of tungstic acid and 3 parts of cinnabar in a Hessian crucible. The mixture was covered with charcoal powder; and the crucible, with a flat lid on it, was exposed for half an hour to the greatest heat which he could raise in a wind furnace. The sulphuret thus obtained was a greyish black powder, which, when rubbed against a polished surface, acquired the metallic lustre, and resembled sulphuret of copper, but was rather more blue.

100 parts of this sulphuret were digested in nitromuriatic acid, till the sulphur was acidified. The sulphuric acid was thrown down by muriate of barytes; and the sulphate of barytes formed weighed 182 parts, equivalent to 24·678 parts of sulphur. Hence the sulphuret of tungsten is a compound of

Tungsten .	75·322
Sulphur .	24·678
	100·000

100 parts of the same sulphuret of tungsten, heated in a platinum cup till it disengaged no more sulphurous acid, left a brown powder, weighing 93·5. This powder, being exposed to a strong heat, became dark green, without any alteration of its weight; hence Berzelius considered it as tungstic acid.

From this experiment it follows, that tungstic acid is composed of

Tungsten	75·322	or	80·558
Oxygen	18·178	-	19·442
	93·500		100·000

But 107 tungstic acid contains 100 protoxide of tungsten and 7 oxygen; or, its constituents may be stated thus:

Tungsten	.	86·197
Oxygen	.	20·803
		107·000

If from the 20·803 we subtract 7, there will remain 13·803 for the oxygen in 100 parts of protoxide of tungsten.

From this it appears, that the composition of the oxides of tungsten is as follows:

Protoxide	86·197	tungsten	+	13·808
Tungstic acid	86·197	-	+	20·803

But 13·803 : 20·803 : : 2 : 3 very nearly. Thus it appears, that the oxygen in the protoxide is to that in the peroxide as 2 to 3; so that, if the protoxide be a compound of 1 atom tungsten and 1 atom oxygen, the peroxide must be a compound of 1 atom tungsten and 1½ atom oxygen. Thus we see that the oxides of tungsten in this respect resemble the oxides of iron, nickel, cobalt, and cerium.

Tungstate of ammonia.

I shall now state the experiments which I made, in order to ascertain the atomic weight of tungstic acid.

1. I first prepared a considerable quantity of tungstate of ammonia from wolfram, by heating wolfram in powder alternately in muriatic acid and ammonia, till the mineral was decomposed. The ammoniacal solutions, when properly concentrated, deposited the tungstate of ammonia in small brilliant crystals.

Of this tungstate I obtained two different varieties. The first was crystallized in four-sided rectangular prisms with rhombic bases. When put into the mouth this salt appeared at first tasteless, but in a short time it left a bitter impression on the palate, which was succeeded by a certain degree of sweetness mixed with a disagreeable metallic taste. This salt was so very sparingly soluble in water, that the solution did not answer well for determining the effect of reagents upon tungstic acid salts.

But in some of my other processes, I got a tungstate of ammonia which crystallized in silky plates. Its taste was much stronger, though similar, and it was much more soluble in water. I employed this last salt to determine the action of reagents on its solution. I shall state the results which I obtained, conceiving them calculated to throw considerable light on the affinities and compounds of tungstic acid.

Action of reagents on

1. Prussiate of potash—No effect at first; but after a little time a white precipitate falls.
2. Gallic acid } —O.
3. Tincture of galls } —O.
4. Sulphuric acid—A white precipitate in flocks.
5. Nitric acid—Ditto.
6. Muriatic acid—Ditto; soluble in an excess of acid.
7. Phosphoric acid—O.
8. Arsenic acid—O.
9. Acetic acid—O.
10. Oxalic acid—O.
11. Tartaric acid—O.
12. Chromic acid—O.
13. Muriate of barytes—A white precipitate in flocks.
14. Muriate of strontian—Ditto.
15. Muriate of lime } — { A white precipitate, which disappears on agitation.
16. Nitrate of lime } — { A white precipitate, which disappears on agitation.
17. Muriate of magnesia—O.
18. Alum—A white precipitate in powder.
19. A fragment of tin with a drop of muriatic acid—White flocks first separate, which gradually acquire a blue tinge, and a deep blue colour surrounds the tin globule.
20. Protosulphate of iron—A yellowish white precipitate in powder.

21. Persulphate of iron with excess of acid—Ditto; redissolved on agitation.
22. Sulphate of nickel—O.
23. Nitrate of cobalt—A light pink precipitate.
24. Sulphate of manganese—A copious white precipitate in powder.
25. Sulphate of zinc—A white precipitate, redissolved by agitation.
26. Nitrate of lead—A white flocky precipitate.
27. Muriate of tin—A copious white flocky precipitate.
28. Sulphate of copper—A white precipitate in powder.
29. Nitrate of mercury—Copious milk white flocks.
30. Nitrate of silver—A copious white flocky precipitate.
31. Muriate of platinum—O.
32. Muriate of palladium—O.
33. Soda-muriate of rhodium—O.

From the preceding table it appears that sulphuric, nitric, and muriatic acids have a stronger affinity for ammonia than tungstic acid; but phosphoric, arsenic, chromic, and the vegetable acids are incapable of disengaging that acid from ammonia.

The tungstates of barytes, strontian, lime, alumina, iron, cobalt, manganese, zinc, lead, tin, mercury, copper, and silver are insoluble, or nearly so. But tungstates of magnesia, nickel, platinum, palladium, and rhodium are probably soluble in water.

After some attempts to analyze the tungstate of ammonia, I was induced to abandon that salt as not likely to yield satisfactory results, and to have recourse to tungstate of soda.

Analysis of tungstate of soda.

2. Tungstate of soda, formed by boiling together a solution of carbonate of soda and tungstic acid, till the liquid refused to take up any more of the acid, was set aside after being concentrated as far as possible, so as to retain the liquid state. In about a week it shot into fine crystals of tungstate of soda; these crystals were white and semitransparent. The first time I obtained them in pretty regular short six-sided prisms; but the second time I repeated the process, the salt shot into flat rhombic prisms. The lustre of these crystals is silky; however carefully washed, they give a violet colour to cudbear paper, and restore the blue colour of litmus paper reddened by acetic acid. Yet the solution, from which they had crystallized, had been boiled for nearly a fortnight with a considerable excess of hydrated tungstic acid. The taste of this salt is at first sweet, but it speedily becomes an intense and pure bitter, almost exactly similar to the taste of quassia.

3. After a considerable number of trials, which it is needless to detail, I found that when 29·5 grains of these crystals are dissolved in water, and mixed with a solution of 20·75 grains of dry nitrate of lead, a double decomposition takes place; tungstate of lead precipitates in a white powder, and the residual liquid is neither affected by sulphate of soda nor by nitrate of lead; showing, that it contains no sensible quantity

either of oxide of lead or of tungstic acid. The tungstate of lead that had been precipitated, being collected, washed, dried, and exposed to a red heat, was found to weigh 32·75 grains; but it contained just the quantity of protoxide of lead in 20·75 grains of nitrate: which has been shown before to amount to 14 grains. Hence, it follows, that tungstate of lead is composed of

Tungstic acid	18·75
Protoxide of lead	14
	32·75

Atom of tungstic acid.

14 being the equivalent for an atom of protoxide of lead, and the salt being neutral, 18·75 must represent the atomic weight of tungstic acid.

4. 29·5 grains of crystallized tungstate of soda being heated on the sand bath, gave out a quantity of water, and fell into a white powder. This white powder being heated to redness, melted, and formed a kind of enamel, which it was very difficult afterwards to separate from the inside of the platinum crucible, to which it had attached itself. The loss of weight amounted to 6·75 grains. Now, 6·75 is the equivalent for 6 atoms of water.

Thus, we learn that 29·5 grains of crystallized tungstate of soda contain 18·75 of tungstic acid, and 6·75 of water. The remaining 4 grains must be soda, and the constitution of the salt may be stated as follows:

1 atom tungstic acid .	18·75
1 atom soda . .	4
6 atoms water . .	6·75
	29·50

The salt, while on the sand bath, lost 5·86 grains of weight, so that the quantity which remained was less than an atom.

5. From Berzelius' experiments, related at the beginning of this section, there is reason to conclude, that tungstic acid contains 3 atoms of oxygen, and brown oxide of tungsten 2 atoms; consequently, the atomic weight of tungsten must be 15·75, and that of brown oxide 17·75.

Atom of tungsten and oxide of tungsten.

6. From my experiments on the tungstate of ammonia, compared with the analysis of it by Berzelius, I have little doubt that its constituents are

2 atoms tungstic acid .	37·5
1 atom ammonia	2·125
2 atoms water . .	2·25
	41·875

The quantity of the most soluble tungstate of ammonia in my possession was too small to admit of an accurate analysis, but it certainly contained a smaller proportion of acid than the least soluble tungstate. Probably, therefore, it is a compound of 1 atom acid and 1 atom ammonia; but this must be left for future investigation.

7. Berzelius precipitated nitrate of lead by means of bitungstate of ammonia, and obtained a tungstate of lead composed of

Tungstic acid . .	34·866
Protoxide of lead . .	14
	48·866

It was obviously a bitungstate, and quite different from that which I obtained from tungstate of soda by means of nitrate of lead.

It is evident from this, that it would be hazardous to attempt the analysis of tungstates by means of nitrate of lead: the precipitate might be either a tungstate or bitungstate of lead; and most frequently it would be a mixture of both.

SECT. VI.

OF THE ATOMIC WEIGHT OF COLUMBIUM.

This metal was discovered in 1801, by Mr. Hatchett, in a black mineral in the British Museum, which had been sent by Dr. Winthorp to Sir Hans Sloane, from Massachussets in North America. Mr. Hatchett found the constituents of this mineral to be about

Columbic acid . .	77·5
Protoxide of iron . .	18·9*
	96·4

He gave the metal the name of columbium, from Columbia, the poetical name for America; because the ore which contained it came from that quarter of the world.

Discovery of tantalum.

About two years after Mr. Hatchett's paper was published, there appeared in the Memoirs of the Academy of Sciences at Stockholm, the analysis of two minerals by M. Ekeberg, to which that gentleman had given the names of *tantalite*, and *yttrotantalite*. The former of these minerals was from Finland, the latter from the quarry of Ytterby in Roslagen, Sweden. In both of these minerals Ekeberg discovered the oxide of a peculiar metal, to which he gave the name of *tantalum*, because it was nearly insoluble in the mineral acids. In 1809, Dr. Wollaston demonstrated that the columbium of Hatchett and the tantalum of Ekeberg were one and the same metal. Berzelius, alleging that the oxide examined by Hatchett was merely a mixture of columbic and tungstic acids, has thought proper to ascribe the discovery of this metal to Ekeberg, and on that account has adopted the name tantalum assigned it by Ekeberg.

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* Mr. Hatchett obtained 21 grains of peroxide of iron. But we know from a subsequent analysis of Berzelius, that the iron in the ore is in the state of protoxide.

The evidence which Berzelius has advanced in support of this opinion is the statement by Hatchett, that when his powder was fused with phosphate of ammonia before the blow pipe in a platinum spoon, the globule, when cold, had a deep blue colour, with a tinge of purple. Now, it is well known that tungstic acid produces this effect when fused with phosphate of soda; whereas, columbic acid melts with that salt into a white transparent globule. Berzelius found tungstic acid in some specimens of *columbite*, which he examined, from the neighbourhood of Fahlun, and he was informed that Ekeberg had examined the columbic acid of Hatchett, and had found it a mixture of the oxides of columbium and tungsten.

With respect to Mr. Hatchett's experiment, it will be impossible to account for it, unless we suppose that some tungstate of potash, which he was obviously using, as appears from his paper, had accidentally got into the platinum spoon and produced the blue colour of the bead. That the specimen in the British Museum, examined by Mr. Hatchett, contained no tungsten is next to certain, because Dr. Wollaston did not find any in it; and though he made a trial on purpose at my request, when Professor Berzelius informed me of his opinion, he was still unsuccessful. I conceive, therefore, that it is but an act of justice to Mr. Hatchett to retain the name *columbium*, which he originally imposed.

Both Hatchett and Ekeberg had tried unsuccessfully to reduce the oxide of columbium to the metallic state. But Berzelius, Gahn, and Eggertz, were more successful in the year 1815; and Berzelius, in the fourth volume of the Afhandlingar, published a detailed account of the properties of this metal, and the result of a set of experiments to determine the proportion of oxygen with which it unites in order to be converted into the white oxide, to which Hatchett gave the name of columbic acid.

After these introductory remarks, I shall proceed to relate the experiments which I have made in order to determine the atomic weight of columbic acid.

Preparation of columbic acid.

1. 162 grains of oxide of columbium, which I had procured from the Finland mineral called tantalite, was fused in a platinum crucible with six times its weight of anhydrous carbonate of soda: water was poured upon the fused mass to soften it, and the crucible having been inadvertently left on the sand bath till the water was driven off, I found the whole matter converted into large, white, opaque prismatic crystals. The quantity of salt and oxide having been too great for the size of my crucible, I had been obliged to divide it into two portions. After the first portion had been washed out of the crucible, I repeated the fusion with the second portion · the fused mass was digested with water, and the

water driven off as at first. The result was precisely the same. I have been induced to give an account of the appearance of these crystals as a curious fact. I did not examine them, but dissolved the whole in water, expecting that it would be in my power to form them at pleasure; but none of my subsequent attempts to obtain similar crystals was crowned with success.

The aqueous solution of the fused mass contained all the alkali, and the greatest part of the oxide of columbium, but not the whole. To separate this undissolved portion, which amounted only to a few grains, the liquid was passed through the filter. The liquid was now decomposed by sulphuric acid, in order to obtain columbic acid in the state of a hydrate. This hydrate was collected on the filter, and, being well washed with water, was allowed to dry in the open air.

2. Hydrated columbic acid thus obtained was a white tasteless powder. When placed upon litmus paper, it gave it a lively red colour; and yet I could not detect in it the presence of any acid. This property had been observed by Hatchett, and induced him to consider the oxide as an acid. It was soluble in sulphuric and muriatic acids; but I could not succeed in saturating these acids with it, nor indeed in perceptibly diminishing their acid properties;—and though it dissolved in the vegetable acids, as Dr. Wol-

laston had discovered, no definite compound or crystallizable salt seemed to be formed. Neither could I succeed in saturating an alkali with it, by boiling it in an alkaline ley, although I continued the process for several weeks.

The alkaline ley employed was a weak solution of caustic soda. The solution was at length decanted off, and, being concentrated on the sand bath, was set aside for 24 hours. Next morning a number of crystals were deposited; they were white, had a most beautiful silky lustre, and the form of scales similar to boracic acid. Mr. Hatchett had formed similar crystals, with potash and columbic acid; but neither Dr. Wollaston nor Professor Berzelius obtained any crystallizable salt in their experiments.

I found, likewise, that I could obtain similar crystals, by concentrating the solution formed by digesting water on a mixture of 1 part columbic acid and 6 parts anhydrous carbonate of soda, fused in a platinum crucible.

Columbate of soda.

3. Columbate of soda, as these crystals may be called, had an alkaline taste, and rendered cudbear paper purple; but the salt contained no excess of soda: for neither the taste nor the power of acting on cudbear paper was altered by digesting the salt in alcohol. When water was poured on these crystals, they assumed at first the appearance of beautiful silky flocks, but gradually dissolved. It will be worth while to

state the effect of reagents upon rather a dilute solution of this salt in water. The reader may compare these effects with the corresponding experiments by Hatchett.*

Action of reagents on

1. Prussiate of potash—No change.
2. Gallic acid—The liquid assumed a fine orange, inclining to red, but no precipitate fell.
3. Tincture of nut galls—The same.
4. Sulphuric acid }
5. Nitric acid } —A milk white precipitate in flocks.
6. Muriatic acid }
7. Phosphoric acid }
8. Chromic acid } —Milk white flocks.
9. Acetic acid }
10. Arsenic acid—○.
11. Oxalic acid—○.
12. Tartaric acid—○.
13. Oxalate of Ammonia—○.
14. Tartrate of potash—○.
15. Nitrate of lead—A copious milk white precipitate in flocks, not redissolved by nitric acid.
16. Sulphate of copper—A milk white precipitate.
17. Nitrate of silver—A copious milk white precipitate.
18. Sulphate of zinc—A milk white precipitate.
19. Sulphate of manganese—The same.
20. Nitrate of mercury—The same.

Analysis of

4. My next object was to analyze this columbate of soda, in order to determine the atomic weight of columbic acid.

(1.) When 34·25 grains of these crystals were heated on the sand bath, they lost their silky

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* Phil. Trans. for 1802.

lustre, and assumed the appearance of an opaque white matter like chalk; but at this temperature the whole water of crystallization was not driven off; the salt was, therefore, exposed to a red heat. The loss of weight was 11·25 grains. Now, 11·25 is equivalent to 10 atoms of water.

(2.) The salt, thus rendered anhydrous, was digested for a long time in water acidulated with muriatic acid. The whole was then thrown on a filter; and the columbic acid, after being well washed, dried, and heated to redness, weighed 19 grains.

(3.) The muriatic liquid was saturated with carbonate of ammonia, gradually evaporated to dryness in a platinum crucible, and the dry mass which remained exposed to a heat sufficient to expel the sal-ammoniac which constituted the principal part of it. There remained a quantity of common salt, which weighed almost exactly 7·5 grains. This is equivalent to 4 grains of soda.

From this analysis it appears, that the crystals of columbate of soda are composed as follows:

Columbic acid .	19
Soda . .	4
Water . .	11·25
	34·25

4 is equivalent to an atom of soda, and 11·25 to 10 atoms of water. As the salt renders cudbear

paper purple, it is clear that it can contain only 1 atom of columbic acid at the very utmost; consequently, 19 must represent the atomic weight of columbic acid.

Atom of columbic acid.

Hydrate of columbic acid.

5. I found the hydrate of columbic acid formed, by drying the precipitated acid in the open air, a compound of

1 atom columbic acid	19
7 atoms water	7·875
	26·875

Berzelius seems to have obtained a hydrate, containing a much smaller proportion of water. Probably it had been dried in a much higher temperature than mine.

Berzelius' experiments on the metal.

6. Berzelius could form only one oxide of columbium, namely, columbic acid. He informs us, that, when 100 parts of columbic acid were reduced to the metallic state, the metallic tantulum formed weighed 94·8. Now, if the quantity of metal had been 94·737, instead of 94·8, it would have exactly corresponded with the atomic weight of columbic acid as above determined; for,

5·263 (the oxygen in the acid) : 94·737 (the quantity of base in it) : : 1 : 18.

Thus it appears, that Berzelius' analysis of the columbic acid, and my determination of its atomic weight, correspond exceedingly well.

There is no reason, therefore, to doubt that the atomic weight of columbium is 18; and that columbic acid is a compound of 1 atom columbium and 1 atom oxygen.

SECT. VII.

OF THE ATOMIC WEIGHT OF TITANIUM.

Discovery of metallic titanium.

TITANIUM, in the metallic state, was discovered by Dr. Wollaston, in 1822, in the slag at the bottom of the iron smelting furnace at Merthyr Tydvil, in South Wales; and he determined and described its properties with his usual sagacity and precision.* It has the form of small smooth cubes, having a red colour, exceedingly similar to that of copper. The cubes are hard enough to scratch rock crystal, and cannot be fused by the highest temperature which can be raised by the blow pipe. Its specific gravity, as determined by Dr. Wollaston, is 5·3. It is brittle—conducts electricity. From the situation in which it occurs, we may infer that it does not combine with iron, and Dr. Wollaston tried in vain to unite it with lead, tin, silver, and copper.

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* Phil. Trans. 1823, p. 17.

These cubes of metallic titanium are not absolutely free from iron. They are not sensibly attracted by the magnet; but Dr. Wollaston found that, when suspended by a fine thread, a magnet drew it about 20 degrees from the perpendicular. He succeeded in detecting the presence of iron in it, and calculated the amount of that metal at $\frac{1}{250}$th part of the weight of the titanium.* From an experiment which I shall state below I am disposed to conclude, that the proportions of iron present in these cubes of titanium is still greater than this.

When metallic titanium is heated in the open air its surface is oxydized, assuming a blue or rather purple colour. The process goes on better in melted nitre, and if we add some borax to dissolve the oxide as it forms, the oxydation is still farther accelerated. I found also, that when metallic titanium in powder was fused in a platinum crucible with carbonate of soda, it was converted into protoxide.

Oxides of titanium.

1. Titanium appears capable of combining with two doses of oxygen, and of forming two oxides. The protoxide is *blue*, and has been found native in slender elongated octahedrons, which have been distinguished by the name of *anatase*. It has a specific gravity of 3·857, according to Hauy. The peroxide, when pure, is

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* Phil. Trans. 1823. p. 200.

snow white. It possesses the properties of a weak acid, and has in consequence been called *titanic acid* by M. H. Rose, to whom we owe by far the best set of experiments hitherto made on it.[*] Titanic acid occurs native in the form of long prisms, or needles having usually a reddish colour, and therefore called *red schorl.* It is never quite pure, being always combined with peroxide of iron; though hitherto no good method has been discovered of separating peroxide of iron from titanic acid, and determining the quantity of each. Titanic acid occurs, likewise, united to a considerable proportion of peroxide of iron in black grains like gunpowder, and distinguished by the names of menaccanite, nigrine, and iserine, according to the size of the grains.

2. M. H. Rose is the first chemist who obtained titanic acid in a state of purity. It will be proper, therefore, to state his mode of proceeding before attempting to investigate the atomic weight of this substance. He employed *rutile* or red schorl for this purpose. The mineral was reduced to a fine powder, and fused with thrice its weight of carbonate of potash. The mass was softened with water, and the compound of titanic acid, peroxide of iron, and potash was dissolved in muriatic acid, and mixed

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[*] Kong. Vetensk. Acad. Hand. 1821. p. 231.

with an excess of ammonia. Flocks fell down, which consisted of titanic acid and peroxide of iron, still in combination with each other. These flocks were washed, and put into a flask while still moist, and hydrosulphuret of ammonia poured over them. In this situation the mixture was left for some time. The iron was gradually converted into a sulphuret, while the titanium still continued in the state of titanic acid. The hydrosulphuret of ammonia being washed off, and the residuum digested in muriatic acid, the iron was dissolved, and the titanic acid left behind in a state of purity.

Properties of titanic acid.

Titanic acid, thus obtained, has a fine white colour. When heated to redness it becomes yellow, but when cold the original white colour again appears. After exposure to a red heat, it is insoluble in acids; but when precipitated from muriatic acid by heat it continues slightly soluble in that acid. When precipitated titanic acid is digested in water, that liquid passes milky through the thickest paper, and the acid cannot be collected on the filter; but this property is destroyed by an acid, or an alkali, or even a neutral salt. When titanic acid is fused with potash, and dissolved in muriatic acid, and the solution evaporated, the titanic acid often gelatinizes, but the jelly is never so stiff as that of silica. When titanic acid, precipitated by heat, is dried by a gentle heat, the surface is covered by a brownish shining crust. This crust becomes white when heated to redness, but still appears as if the whole were coated with varnish. When titanic acid is precipitated by ammonia, and the dried bulky precipitate is heated to redness, we obtain a mass cohering together, having a brownish colour, an adamantine lustre, and a good deal of resemblance to the native oxide of titanium, called *rutile.* When titanic acid heated to redness is laid upon litmus paper and moistened with water, the liquid becomes red, but the paper retains its blue colour. Titanic acid forms insoluble compounds with the alkalies; it combines with some acids, but does not neutralize them. As an acid, it is nearly as feeble as silica; hence the difficulty of determining its atomic weight. Such are the properties of titanic acid determined by M. Rose.

3. I shall now state the experiments which have been made to determine the atomic weight of titanic acid.

Bisulphuret of titanium

(1.) Rose prepared a sulphuret of titanium in the following way: Titanic acid was made into a paste with water, dried, and heated to redness. By this contrivance it formed a cohering mass, which was put into a porcelain tube; a small retort, containing bisulphuret of carbon, was luted to one extremity of this tube, and a glass tube to the other extremity. The porcelain tube was heated to redness, and then the bisulphuret passed very slowly through it. The heat of the furnace was found sufficient to produce this effect, though the retort was at some distance from it; the process lasted six hours. When it was terminated, the glass tube was sealed hermetically, that the sulphuret of titanium might cool, while surrounded with the vapour of bisulphuret of carbon.

Sulphuret of titanium thus formed has a dark green colour. When rubbed against a hard body, it assumes the metallic lustre:—the streak is brass yellow. When heated in an open vessel, it burns with a blue flame, giving out the fumes of sulphur, and leaves titanic acid. When heated with nitric acid, nitrous gas is given out, and titanic acid is formed, while sulphur separates.

Analyzed.

1·017 gramme of sulphuret of titanium, when burned on a platinum plate, left 0·757 of titanic acid. Hence, 1·000 would have left 0·7443 titanic acid.

0·19 of sulphuret of titanium, were digested for eight days in nitro-muriatic acid, till the sulphur was acidified. The titanic acid was then precipitated by ammonia, and the sulphuric acid by means of muriate of barytes. The sulphate of barytes obtained weighed 0·679. Hence, 1·000 sulphuret of titanium would have given 3·5737 of sulphate of barytes, equivalent to 0·48457 sulphur.

If we subtract the 0·48457 sulphur from 1·000, the original weight of the sulphuret of titanium, we obtain 0·51543 for the titanium in the compound. Hence, its constituents must be

Titanium	51·543	or	4·2547
Sulphur	48·457	-	4
	100·000		

4 representing the weight of two atoms of sulphur, it follows from this experiment that the compound is a bisulphuret, and that an atom of titanium weighs 4·2547.

But the titanic acid from 1·000 of sulphuret of titanium was 0·7443; which, as appears from the preceding calculations, contained 0·51543 of titanium. Hence, titanic acid must be a compound of

Titanium	0·5154	or	4·5035
Oxygen	0·2289	-	2
	0·7443		

2 representing the weight of two atoms of oxygen, 4·5035 must represent the weight of an atom of titanium.

Thus, from the analysis of bisulphuret of titanium by Rose, we have obtained two different atomic weights of titanium, namely 4·25 and 4·5. I am disposed to consider the weight derived from the sulphur found by experiment, to be nearest the truth, as it is not absolutely certain that the whole titanium was converted into titanic acid by the combustion. A little of it may have continued in the metallic state, or have been only converted into protoxide of titanium.

This experiment certainly gives us a near approximation to the atomic weight of titanium, though the want of exact agreement between the parts of it shows us that it is not quite accurate.

Acidification of titanium.

(2.) It occurred to me that I might probably come tolerably near the truth by acidifying metallic titanium by means of a mixture of potash and nitre, and determining the increase of weight. I took a quantity of metallic titanium, which I had procured from the slag of the furnace at Merthyr Tydvil, and mixing it with potash and nitre, exposed it to a red heat in a platinum crucible. The titanium was acidified, but the nitre and potash had acted on the crucible, blackened its interior surface, and oxydized 11 grains of the platinum which were mixed with the titanic acid. I attempted to separate this oxide of platinum from the titanic acid; but the result was not quite satisfactory. I therefore repeated the experiment in a small green glass retort. 4 grains of metallic titanium, 37·05 grains of nitre, and 5·88 grains of caustic potash, were mixed together, and kept for half an hour in a dull red heat in a green glass retort, the weight of which had been previously determined.

The whole was then washed out of the glass with distilled water, and dissolved in muriatic acid, leaving 2·63 grains of metallic titanium behind; so that 1·37 grain of the titanium had been converted into titanic acid. This titanic acid was obtained partly by boiling the muriatic solution, and partly by mixing the residual liquid with ammonia, evaporating to dryness, and redissolving. The whole titanic acid, after being heated to redness, weighed 2·185 grains; it was white, but had a shade of brown, indicating the presence of peroxide of iron, which however I did not succeed in separating by means of muriatic acid. The retort, in which the titanium had been heated, had lost 0·1 grain of its weight; deducting this for silica, the true weight of the titanic acid was 2·085. And as the weight of the titanium from which it had been formed was 1·37, it is evident that titanic acid is a compound of

Titanium	1·37	or	3·8322
Oxygen	0·715	-	2
	2·085		

The result of this experiment gives us 3·8322 for the atomic weight of titanium. Though it was repeated again, the result did not differ materially from what has been stated. It is extremely difficult to obtain titanic acid perfectly free from all traces of potash when prepared in the way just stated. Hence, its weight may have exceeded the truth a little ; had the potash in it amounted to 0·035 grain, the atomic weight of titanium would have come out exactly 4. I am disposed to consider the mean of the weight derived from the sulphuret, and from the acid obtained from metallic titanium, as coming very near the truth. Now, this mean is 4·0434; which comes so near 4, that we may without hesitation pitch upon that number as the true atomic weight of titanium. The atomic weight of titanic acid is 6, and that of protoxide of titanium undoubtedly 5.

Ratio between the atoms of carbonic acid and titanic acid.

(3.) M. H. Rose employed another method to determine the saturating power of titanic acid. He mixed determinate weights of it with anhydrous carbonate of soda, and exposing the mixture to a red heat, ascertained how much carbonic acid gas was driven off precisely in the way described in a preceding part of this work, when I tried by a similar process to determine the atomic weight of silica. The following table exhibits the results of Rose's experiments.

Experiments.	Titanic acid used. GRAMMES.	Carbonate of Soda used.	Carbonic acid expelled.	Atomic weight of titanic acid.
1	0·544	2·595	0·252	5·913
2	0·624	3·684	0·318	5·396
3	9·469	2·453	0·234	5·512
4	0·3055	4·255	0·1475	5·696
5	0·498	4·112	0·2300	5·954

It is obvious that the titanic acid occupied the place of the carbonic acid expelled; hence, if we suppose that the whole titanic acid combined with the soda, we can easily from these experiments determine the atomic weight of titanic acid. For as the carbonic acid expelled is to the titanic acid employed, so is 2·75 (the atom of carbonic acid) to the atom of titanic acid. In this way, the numbers in the last column of this table were calculated. The results obtained from these experiments, do not agree with each other. The smallest atomic weight of the acid derived from them is 5·396, and the greatest 5·954. It is obvious that in experiments of this nature, where we have no certain criterion to determine whether the whole titanic acid has combined with the soda, the highest result must come nearest the truth. Consequently, 5·954 is the most accurate atomic weight of titanic acid derived from these experiments. Now, this number differs less than one per cent. from 6, the atomic weight of this acid, which I consider as the most probable deduction from other experiments: it is therefore a confirmation of that deduction, and, together with my own experiment, shows that the atomic weight of this acid cannot be so high as 6·25.

Analysis of tert. titaniate of soda.

(4.) M. Rose formed combinations of titanic acid with the two fixed alkalies, potash and soda. His method was, to fuse a determinate weight of titanic acid with carbonate of soda or carbonate of potash; to dissolve the fused mass in water, and pass the whole through a filter. The compound of titanic acid and the alkali remained on the filter; it was washed and dried in the open air. Being heated to redness to drive off the water, the loss of weight was noted, and the excess of the weight of the anhydrous salt above that of the titanic acid was considered as the alkali.

The mean of two experiments conducted in this way gives the constituents of titaniate of soda as follows:

Titanic acid	75·10	or	19·737
Soda .	15·22	-	4
Water .	9·68	-	2·544
	100·00		

It would seem from this to be a compound of 3 atoms titanic acid, 1 atom soda, and 2 atoms water. If we consider the atomic weight of titanic acid to be 6, then the true constitution of the salt will be

3 atoms titanic acid .	18
1 atom soda .	4
2 atoms water . .	2·25
	24·25

But the atomic weight of titanic acid will be (if we suppose the experiments of Rose perfectly exact) $\frac{19\cdot737}{3} = 6\cdot579$, a quantity which certainly exceeds the truth somewhat.

Of quinte titaniate of potash.

The constituents of titaniate of potash, determined in the same way, from a mean of two experiments, are

Titanic acid	82·33	or	27·955
Potash .	17·67	-	6
	100·00		

Hence it would seem to be a compound of 5 atoms of titanic acid and 1 atom of potash. Now, $\frac{27\cdot955}{5} = 5\cdot591$, which constitutes the weight of an atom of titanic acid, according to these experiments. Thus we have two atomic weights of titanic acid:

1. From titaniate of soda	6·579
2. —— ——— potash	5·591
	2) 12·170
Mean . . .	6·085

a number which does not exceed 6 by much more than 1 per cent.

Combination of titanic acid and sulphuric acid,

(5.) Rose found that titanic acid is likewise capable of combining with acids. Let us see what deductions can be drawn from these compounds.

Titaniate of potash was dissolved in muriatic acid, and sulphuric acid poured into the solution. A combination of titanic acid and sulphuric acid precipitated. It was washed, dried, dissolved in muriatic acid, and analyzed by throwing down the titanic acid by ammonia, and the sulphuric acid by muriate of barytes. The constituents were

Sulphuric acid	7·78	or	5
Titanic acid	76·83	-	49·377
Water .	15·39	-	9·890
	100·00		

It was probably a compound of

1 atom sulphuric acid	.	5
8 atoms titanic acid	.	48
9 atoms water	. .	10·125
		63·125

If we take Rose's analysis as perfectly exact, then the atomic weight of titanic acid will be $\frac{49\cdot377}{8} = 6\cdot172$.

and oxalic acid.

By a similar process he obtained a combination of titanic acid and oxalic acid, a white compound, composed (from a mean of two analyses) of

Oxalic acid	10·405	or	4·5
Titanic acid	74·095	-	32·045
Water .	15·500	-	6·703
	100·000		

It is probably a compound of

1 atom oxalic acid	4·5
5 atoms titanic acid	30
6 atoms water	6·75
	41·25

If we calculate from Rose's analysis, the atomic weight of titanic acid will be $\frac{32 \cdot 045}{5} = 6 \cdot 409$.

Different atomic weights of titanic acid.

Thus no fewer than eight values have been obtained for the atomic weight of titanic acid.

1. From the analysis of the sulphuret	6·250
2. From titanic acid from a given weight of sulphuret	6·500
3. From the acidification of titanium	5·832
4. From the decomposition of carbonate of soda	5·954
5. From the titaniate of soda	6·579
6. From titaniate of potash	5·591
7. From the compound of titanic and sulphuric acids	6·171
8. From ditto of titanic and oxalic acids	6·409

The mean of all these values gives us 6·161 for the atomic weight; and if we were to reject the second value, which seems least likely to be correct, the weight would be 6·112. Now, from the law which has been so amply confirmed in the preceding chapters of this work, it follows, that the true weight must be either 6 or 6·25; and, as 6·112 is nearest the former of these numbers, 6, in all probability, is the true atomic weight of titanic acid.

Analysis of menaccanite.

4. But it was the composition of menaccanite which induced me to fix upon 6 as the true atomic weight of titanic acid. We have four different analyses of menaccanite by Gregor, Klaproth, Lampadius, and Chenevix; but, as the ore, in the state in which it occurred in the valley of Menaccan, is a mixture of menaccanite and small grains of octahedral iron ore, and as none of these gentlemen seems to have taken the trouble to separate the true menaccanite from the iron ore, no dependence can be put upon the results which they obtained. The specimen of menaccanite analyzed in my laboratory had been given me by Mr. Gregor himself, to whom we owe the first knowledge of the substance. He had collected it himself; and he assured me that it was a portion of the very quantity which he had himself subjected to analysis. The largest particles of the ore were picked out, and great care was taken to reject every particle which was in the slightest degree obedient to the magnet.

The ore was reduced to a very fine powder, and was digested in a platinum matrass, with muriatic acid, till all action was at an end. The titanic acid remained, and was collected on a filter, and washed with water acidulated with muriatic acid. It was then dried, ignited, and weighed.

The filtered liquid had a greenish yellow colour. When heated with nitric acid it became brown, showing the evolution of nitrous gas, and at last, when the gas had escaped, it became yellow. The peroxide of iron was precipitated with ammonia, ignited, and weighed. Its colour indicating the presence of manganese, it was dissolved in muriatic acid (with the exception of a few flocks of titanic acid), evaporated to dryness, and redissolved in water acidulated by muriatic acid. The peroxide of iron was precipitated by benzoate of soda. The filtered liquid was mixed with carbonate of soda, and boiled for some time: a brownish precipitate fell, which possessed the characters of oxide of manganese. There could be no doubt from the appearances that both the iron and manganese exist in menaccanite in the state of protoxide. The result of the analysis was as follows:

Titanic acid .	57·682	or	6·134
Protoxide of iron	40·108	-	4·5
Protoxide of manganese	2·210		
	100·000		

The two protoxides, having the same atomic weight, may be included together. By this analysis, the atomic weight of titanic acid was 6·134. Now, it was certain that it had not been quite freed from iron; for its colour was grey, and not snow white. And Rose has shown that titanic acid cannot be completely freed from iron by acids. Now, 6·134 is very near 6·164, the weight deduced from a mean of all the other experiments related in this section; but we are certain that 6·134 is a little too high. Consequently, the true atomic weight of titanic acid must be 6, and not 6·25, or any intermediate number.

True atomic weight of titanic acid.

It is obvious that menaccanite is a simple titaniate of iron, or a compound of 1 atom titanic acid and 1 atom protoxide of iron. Hence the true constitution of the ore is

1 atom titanic acid	6·0	or	57·143
1 atom protoxide of iron	4·5	-	42·857
	10·5		100

Nigrine.

If any confidence can be put in the analysis of Klaproth, nigrine is a compound of 4 atoms titanic acid and 1 atom protoxide of iron; or, numerically,

4 atoms titanic acid	24
1 atom protoxide of iron	4·5
	28·5

I do not notice the manganese, because its atomic weight agrees with that of iron.

Iserine.

Iserine is probably identical in its composition with menaccane;—but no analysis of it hitherto made can be depended on; for it is much mixed with foreign bodies, and, on account of the small size of the grains, these cannot be separated completely from the true iserine.

Sphene.

The only remaining known ore of titanium (except the oxides) is *sphene*, which Rose has recently analyzed anew, and found to consist of an integrant particle of trisilicate of lime, united to an integrant particle of trititaniate of lime. Hence it consists of

1 atom trisilicate of lime	9·5
1 atom trititaniate of lime	21·5
	31

Or, its constituents may be stated in this way:

3 atoms silica	6	or	19·355
3 atoms titanic acid	18	-	58·064
2 atoms lime .	7	-	22·581
	31		100

This differs very considerably from the analysis of Klaproth; but that chemist was not in possession of a good method of separating titanic acid from silica.

CHAP. XIV.

OF THE ATOMIC WEIGHTS OF THE COMBUSTIBLE ACIDS.

The acids formed in organized vegetable bodies, or by the action of nitric acid on organized bodies, contain (with a very few exceptions) both carbon and hydrogen, united to oxygen in various proportions. When these acids are combined with a base, and distilled in a retort, they all give out combustible gases; most of them form oils, and several of them leave behind them a quantity of charcoal. All of them, therefore, when decomposed by heat, resolve themselves partly into combustible products, while this is not the case with any of the acids composed of a single base united to oxygen, or chlorine, or iodine. This difference has induced me to distinguish the acids with compound bases by the name of *combustible acids.*

About thirty combustible acids have been described by chemists, and distinguished by particular names; but by far the greater number of these bodies are of rare occurrence, and consequently, in a theoretical point of view, of very inferior importance. There are six of them which are very much employed in chemical analyses, and with which, therefore, every chemist ought to be familiarly acquainted; and there are some others which, though scarcely ever employed in chemical investigations, yet have acquired considerable importance in consequence of their connection with the physiology of vegetables, or animals. I shall, therefore, in this chapter treat of the atomic weights of nine different combustible acids.

SECT. I.

OF THE ATOMIC WEIGHT OF OXALIC ACID.

Crystalline shape of oxalic acid.

This is, upon the whole, the most important of all the combustible acids as far as chemical analysis is concerned. It is usually crystallized, and the apparent figure is a flat four-sided prism terminated by a bihedral summit; but Mr. Brooke informs us that the primary form is an oblique rhombic prism. The rhombic base, to the unexperienced eye, passes for one of the sides of the flat prism; and as the crystal is usually attached by one of its sides, two of the lateral faces appear to the eye as the dihedral summit. Two of the opposite lateral edges are usually deeply truncated, which makes the prism six-sided instead of four-sided.* These crystals

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* Annals of Philosophy, (second series) VI. 119.

being always in the same state, it is of importance to know with precision the weight of them capable of neutralizing an atom of each of the bases. The following experiments were made to determine this point.

Composition of the crystals.

1. Nine grains of crystals of oxalic acid were dissolved in distilled water, neutralized by ammonia, and evaporated to dryness by a very gentle heat, in order to get rid of all excess of ammonia. The oxalate of ammonia, thus formed, was redissolved in water.

6·25 grains of pure calcareous spar were dissolved in very dilute muriatic acid; the solution was slowly evaporated to dryness, twice successively, in order to drive off any excess of acid which might have been present; and the muriate of lime, thus rendered neutral, was redissolved in water.

These two solutions being mixed together, a double decomposition took place, and the insoluble oxalate of lime gradually precipitated to the bottom, leaving a clear and transparent liquor, containing in solution the muriate of ammonia formed by the mutual decomposition of the two salts. This liquid, being tested by oxalate of ammonia and by muriate of lime, was not affected by either of these reagents, showing that it contained no sensible quantity either of lime or of oxalic acid.—From this experiment it is evident, that the oxalic acid in 9 grains of the crystals just saturates all the lime in 6·25 grains of calcareous spar; but it has been already shown that the quantity of lime in 6·25 grains of the carbonate is 3·5 grains, which is equivalent to the atom of lime. As the oxalate of lime formed is quite neutral, the oxalic acid united to the lime must be equivalent to an atom of that acid. Thus it appears, that 9 of the crystallized acid is the equivalent for an atom of the acid.

2. The oxalate of lime, formed in the preceding experiment, was collected on a double filter, and after being well washed with distilled water, was dried in a temperature between 90° and 100°; its weight was 10·25 grains. Being kept for some hours in the temperature of 560°, its weight was reduced to 8 grains, and it still possessed all the characters of oxalate of lime. Now, 3·5 grains of the salt were lime; hence, the weight of the oxalic acid necessary to saturate an atom of lime is $8 - 3{\cdot}5 = 4{\cdot}5$. And, since the salt is neutral, 4·5 must be the weight of an atom of oxalic acid.

Atomic weight of the acid.

3. The 4·5 grains constituted the quantity of real oxalic acid in 9 grains of the crystals. The rest of the weight must consist of water. Consequently, oxalic acid crystals are composed of

Oxalic acid .	4·5	= 1 atom
Water . .	4·5	= 4 atoms
	9	

Thus, the crystals contain just half their weight of water, as was pointed out long ago by Vauquelin.*

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* Understanding that a chemical friend, of whose accuracy and information I entertain a very high opinion, had stated, that the uniform result of his experiments was, that the crystals of oxalic acid contain only 3 atoms of water instead of 4, and that they are composed of

1 atom anhydrous acid . .	4·5
3 atoms water . . .	3·375
	7·875

I was induced to repeat the experiments in the text with every possible attention to accuracy, and to extend them a good deal farther. It may be proper to state here the result of these new experiments.

1. 18 (= 9 × 2) grains of the crystals of oxalic acid were dissolved in water, supersaturated with ammonia, the solution evaporated to dryness in a gentle heat, and the oxalate of ammonia left redissolved in water. 13·5 grains of very pure calcareous spar were dissolved in nitric acid, the solution evaporated to dryness, and the residual salt being heated sufficiently to drive off any excess of acid which it contained, was redissolved in water. These two solutions were mixed together, and after the oxalate of lime had subsided, the clear liquid was tested with muriate of lime and oxalate of ammonia, but was not affected by either, showing that it contained neither lime nor oxalic acid.—This experiment agrees with the one stated in the text; the only difference being the substitution of nitric acid for muriatic acid to dissolve the lime. It shows, that the oxalic acid in 9 grains of the crystals just saturates 3·5 grains of lime, which is equivalent to an atom.

2. The preceding experiment was repeated, with this difference, that, instead of 9 grains of oxalic acid I substituted 8·875 grains of the crystals of oxalate of ammonia:—the result was the same as before—the residual liquid was neither affected by oxalate of ammonia nor muriate of lime. This experiment shows, that 8·875 grains of oxalate of ammonia and 9 grains of oxalic acid crystals, contain the same weight of real oxalic acid.

Oxalate of lime.

4. The oxalate of lime dried at 95° lost 2·25 grains of its weight when kept in the temperature of 560°; and, as the salt continued still neutral, this loss must have been owing to the

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3. 9 grains of oxalic acid crystals were dissolved in water, and 6·75 grains of anhydrous carbonate of soda were thrown into the solution : an effervescence took place, and the carbonate gradually diminished in bulk; but the liquid soon became muddy, and the whole carbonate never disappeared though the effervescence completely stopped. I, therefore, evaporated the liquid to dryness in a gentle heat, and pouring water upon the dry salt, digested it for a considerable time on the sand bath. At first the liquid reddened vegetable blues strongly; but the property became gradually weaker and weaker, and after 48 hours' digestion I found the liquid perfectly neutral. From this experiment it appears, that 9 grains of oxalic acid crystals just saturate 4 grains of soda, which is the quantity of that alkali contained in 6·75 grains of anhydrous carbonate.

4. I mixed together solutions of oxalic acid crystals and anhydrous carbonate of potash, in the proportion of 9 grains of the former to 8·75 grains of the latter. This solution, by evaporation, yielded crystals of oxalate of ammonia to the very last drop;—these crystals were neutral, and had the shape and properties of oxalate of potash.

5. 9 grains of the crystals of oxalic acid were dissolved in water, saturated with ammonia, and the solution heated till every trace of ammonia in excess had disappeared. 23·625 grains of crystals of acetate of lead were then dissolved in water with the assistance of heat, and the two solutions were mixed together: the oxalate of lead, which was formed, subsided to the bottom very fast, in consequence of its great weight, and left the supernatant liquid quite transparent and colourless. This liquid was tested with muriate of lime and sulphate of soda, but was not in the least altered by either; showing that it contained no sensible quantity either of oxalic acid or oxide of lead. Now, 23·625 grains of acetate of lead contain just 14 grains of oxide of lead, which is equivalent to an atom. From this experiment, like the former, it follows, that 9 grains of oxalic acid crystals contain just the equivalent for an atom of anhydrous acid.

6. The preceding experiment was repeated, with this difference, that 8·875 grains of crystallized oxalate of ammonia were substituted for the 9 grains of oxalic acid crystals:—the result was the same—the residual liquid contained no oxalic acid or oxide of lead. This is the counterpart of the second experiment, and shows, as it did, that 9 grains of oxalic acid and

escape of water. Now, 2·25 is equivalent to 2 atoms water. It is obvious from this, that oxalate of lime dried in the temperature of 95° is composed of

1 atom oxalic acid . .	4·5
1 atom lime . .	3·5
2 atoms water . .	2·25
	10·25

Composition of oxalic acid

5. Such are the atomic weights of oxalic acid and its crystals. Various attempts have been made to determine the constituents of this acid. The first set of experiments on the subject was made by myself, in 1806, and published in the Philosophical Transactions for 1807. I decomposed oxalate of lime by heat, collected and analyzed the products, and concluded that the constituents of oxalic acid were

Oxygen . . .	64
Carbon . . .	32
Hydrogen . . .	4
	100

8·875 grains of oxalate of ammonia contain the same quantity of oxalic acid.

These experiments leave not the smallest doubt on my mind, that 9 grains of oxalic acid crystals represent the equivalent for an atom of oxalic acid. Now, as it is universally admitted that the atomic weight of oxalic acid is 4·5, there cannot be a doubt that one half of the crystals consist of water, or at least of something which does not enter into combination with bases.

The next set of experiments on the subject was made by M. M. Gay-Lussac and Thenard. They made up oxalate of lime, dried at the temperature of 212°, into balls with chlorate of potash: these balls were heated to combustion, in a tube, and the gaseous products collected and analyzed. They deduced from these experiments the constituents of oxalic acid as follows:

Oxygen . . .	70·689
Carbon . . .	26·566
Hydrogen . . .	2·745
	100·000*

The data employed in these calculations might be rectified a little, were it not that the salt which they employed still contained a quantity of water of crystallization, which vitiates all the conclusions of these very ingenious experimenters.

Berzelius repeated the experiments of these chemists with his usual precision, and was at very great pains to render his oxalate of lime anhydrous. He obtained from 100 parts of oxalic acid

Oxygen . . .	66·534
Carbon . . .	33·222
Hydrogen . . .	0·244
	100·000

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* Recherches Physico-Chemique, II. 299.

Thus, the quantity of hydrogen found by every succeeding experimenter was less than that found by his predecessor. The reason was, that he was at more pains to free the salt operated upon from moisture.

We have no certainty that Berzelius' salt was perfectly anhydrous—it might, and probably did, retain a little water. It occurred to me, that the question of the existence of hydrogen in oxalic acid would be best determined by employing the crystals, which are now known to contain exactly half their weight of water. Nine grains of the crystals were triturated with 200 grains of peroxide of copper, and exposed to a low red heat in a copper tube: to the mouth of this tube was ground a glass tube, filled with fused chloride of calcium, in very small fragments; the extremity of this tube was plunged into the mercurial trough, and the gaseous products were collected in graduated glass jars. By this process, which was originally suggested by Gay-Lussac, the whole of the acid was resolved into carbonic acid gas and water—the water was absorbed by the chloride of calcium, while the carbonic acid gas was collected over mercury. Making allowance for the small quantity of hygrometrical water which peroxide of copper always contains, as was shown by Berzelius, Saussure, and Mr. Walter Crum, the weight of the water retained by the chloride was very nearly 4·5 grains, or just half the weight of

Determined.

the crystals.* The carbonic acid gas evolved amounted to 11·8 cubic inches. Now, the weight of this volume of that gas is 5½ grains; and as carbonic acid is a compound of 2 oxygen + 0·75 carbon, it is evident that 5½ grains contain just 1·5 grain of carbon. From this experiment it appears, that 9 grains of oxalic acid crystals contain

Water . . .	4·5
Carbon . . .	1·5
	6·0

The remaining 3 grains wanting to complete the weight is oxygen, which existed in the acid; but the 4·5 grains of water must be considered as water of crystallization, as it can be driven off from oxalate of lime without destroying the acid. The true constituents of oxalic acid, therefore, are

Carbon . . .	1·5
Oxygen . . .	3
	4·5

But 1·5 is equivalent to 2 atoms of carbon, and 3 is equivalent to 3 atoms oxygen; consequently,

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* In some of my experiments I obtained as much as 6·5 grains of water; but I give the average in the text. It is more difficult to determine the water with rigid accuracy than the carbonic acid gas; but I have been led to fix upon 4 atoms, chiefly by the experiments detailed in a preceding part of this section.

this acid, when anhydrous, must be considered as a compound of

2 atoms carbon	. .	1·5
3 atoms oxygen	. .	3·0
		4·5

This constitution exactly agrees with the atomic weight of oxalic acid as deduced from the experiments related in the former part of this section. We see that the weight of the oxygen is just double that of the carbon. This agrees with the result of my original experiments—it agrees too, almost exactly, with the proportions of oxygen and carbon given by Berzelius from his own analysis.

It is obvious enough, that if an integrant particle of carbonic acid and an integrant particle of carbonic oxide were to unite together, the compound would be the same, as far as its constituents are concerned, as oxalic acid. For

	OXYGEN.		CARBON.
Carbonic acid is composed of	2	+	0·75
Carbonic oxide . .	1	+	0·75
Total . . .	3	+	1·50

which constitute the very constituents of oxalic acid.

There is a curious experiment of Doboreiner, which deserves to be mentioned, because it corroborates the preceding statements; and seems to prove, that oxalic acid cannot exist in an insulated state except in combination with water. 5 grains of oxalic acid dried, but still containing a quantity of water, were mixed with 200 grains of fuming sulphuric acid, in an apparatus for receiving gases over mercury: the oxalic acid gradually and totally disappeared, and produced 9·4 cubic inches of gas; the sulphuric acid became less fuming; the gas, washed with ammonia, lost half its volume, which was consequently carbonic acid gas; the residual 4·7 cubic inches were carbonic oxide, for the gas burned with a blue flame, required for complete combustion half its volume of oxygen gas, and formed its own volume of carbonic acid gas. Thus, by the action of sulphuric acid, the water was separated from the acid, and the anhydrous acid was resolved into equal volumes of carbonic acid and carbonic oxide.*

Were the hydrogen detected by Berzelius to be reckoned a constituent of the acid, then the acid would be composed of

Oxygen	3
Carbon	1·5
Hydrogen	0·011
	4·511

Now, 0·011 is only $\frac{1}{10}$th of an atom of hydrogen,

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* Annals of Philosophy (second series) III. 315.

a quantity too small to enter as a constituent into the acid. Berzelius himself considers this acid as composed of

18 atoms oxygen = 18
12 atoms carbon = 9
1 atom hydrogen = 0·125
27·125

This would raise the atomic weight of the acid to 27·125, a quantity which, by Berzelius' own acknowledgment, is 6 times greater than the truth. In reality his analysis of the acid would give its constitution as follows:

33 atoms oxygen = 33
22 atoms carbon = 16·5
1 atom hydrogen = 0·125
49·625

And the atomic weight would be 11 times greater than the truth.*

SECT. II.

OF THE ATOMIC WEIGHT OF TARTARIC ACID.

This acid, which is obtained by the decomposition of cream of tartar, forms large but irregular

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* Berzelius has lately satisfied himself that oxalic acid contains no hydrogen. See Ann. de Chim. et de Phys. XVIII. 155.

crystals, which are not altered by exposure to the air. Tartaric acid is much more easily decomposed by heat than oxalic acid; hence, it is apt to acquire a brown tinge, unless great care be taken to crystallize it in rather a low temperature. It is manufactured in the neighbourhood of London, and sold for the use of the calico printers in the state of most beautiful crystals.

1. In the experiments which I formerly published to determine the atomic weight of tartaric acid,* I employed crystals of tartaric acid. These were dissolved in water, and saturated with ammonia, and the atomic weight of the acid was determined by the quantity of nitrate of lead, or carbonate of lime necessary to throw down the whole of the acid; but happening soon after to examine somewhat particularly a quantity of very fine tartaric acid in uncommonly large crystals, prepared I believe by Mr. Luke Howard in the neighbourhood of London, I was struck with an appearance, on breaking one of the crystals, that led me to suspect that water might be mechanically lodged between the plates. The possibility of this having been the case with the crystals which I had employed in my experiments (though much smaller, and carefully pressed between folds of blotting paper) rendered it proper to repeat the whole in

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* Annals of Philosophy, (second series) II. 138.

a way not liable to any such suspicions. I shall now relate the results of my new experiments on this subject.

Analysis of tartrate of potash.

2. Tartrate of potash is a salt which crystallizes in large transparent four-sided right prisms with rectangular bases. They contain two atoms of water of crystallization, but are easily rendered anhydrous by heat. A quantity of these crystals was left upon the sand bath for twenty-four hours in a covered glass capsule in a heat amounting for several hours to about 240°; 14·25 grains of the salt, thus rendered anhydrous, were dissolved in distilled water; 20·75 grains of dry nitrate of lead were dissolved in another portion of distilled water, and the two liquids were mixed together: a double decomposition took place, and the tartrate of lead precipitated with such rapidity that in about an hour it left the mother water quite transparent and colourless. This mother water was tested with nitrate of lead and tartrate of potash, without being in the least affected by either. Hence, it contained no sensible quantity either of tartaric acid or of lead. The whole of these two bodies was contained in the precipitate which had fallen.

From this experiment we see that 14·25 grains of anhydrous tartrate of potash contain just the quantity of acid necessary to saturate 14 grains of protoxide of lead, which are contained in the 20·75 grains of nitrate of lead. The tartrate of lead was collected on a double filter, washed, and dried in the temperature of about 150°. It weighed exactly 22·25 grains. Now, it contained 14 grains of protoxide of lead; hence, it was composed of

Protoxide of lead	14
Tartaric acid	8·25
	22·25

Atom of tartaric acid.

This tartrate being neutral, and 14 being the weight of an atom of protoxide of lead, it is evident that 8·25 must be the weight of an atom of tartaric acid. We see from this that anhydrous tartrate of potash is composed of

1 atom tartaric acid	8·25
1 atom potash	6
	14·25

For 14·25 grains of it, the quantity employed in the experiment, contained just 8·25 grains of acid.

3. In the experiments described in the Annals of Philosophy, (second series, II. 139.) 9·5 grains of crystallized tartaric acid were saturated with ammonia, and the solution, after being rendered neutral, was mixed with a neutral solution of 6·25 grains of calcareous spar in muriatic acid; and the whole being evaporated to dryness, a quantity of tartrate of lime was obtained which

weighed (dried at 100°) 12·3 grains. In this experiment there was a small excess of tartaric acid, amounting only to 0·125 grain, and it appears from the result, that this small quantity did not form a sensible precipitate when evaporated to dryness with muriate of lime. The method, therefore, was not delicate enough to decide the atomic weight of tartaric acid; but it is obvious, that the tartrate of lime would consist of 3·5 grains of lime united to 8·25 grains of tartaric acid, and that the excess of the weight above 11·75 must have been water. But this excess is almost exactly half an atom of water; for half an atom of water is 0·5625, and 11·75 + 0·5625 = 12·3125. Now, this differs from 12·3 grains by so small a fraction of a grain, that the whole difference may be safely ascribed to an error in weighing. It appears from this, that when tartrate of lime is dried in a temperature of 100° it retains just half an atom of water.

4. From the preceding experiments, which were several times repeated, it is obvious, that the true atomic weight of tartaric acid is 8·25, and not 8·375, as I formerly stated, misled by some water mechanically lodged between the plates of the crystals. Hence, the crystals must in reality be composed of

Composition of the crystals.

1 atom tartaric acid	8·25
1 atom water	1·125
	9·375

or the weight of an integrant particle of these crystals is 9·375 and not 9·5 as I formerly stated.

Constituents of tartaric acid.

5. When the tartrates are subjected to destructive distillation, they yield a quantity of empyreumatic oil, showing clearly that hydrogen enters as a constituent into the acid. The quantity of carburetted hydrogen and carbonic acid gases evolved, leaves no doubt that carbon and oxygen constitute the other two. Berzelius endeavoured to determine the proportion of these constituents by burning a mixture of tartrate of lead and chlorate of potash in a glass tube, and collecting the products in the manner described in the last section, when treating of the decomposition of oxalic acid. The products obtained were

Hydrogen	3·807
Carbon	35·980
Oxygen	60·213
	100·000 *

Now, if we consider it as a compound of

2 atoms hydrogen	=	0·25	or	3·030
4 atoms carbon	=	3	-	36·364
5 atoms oxygen	=	5	-	60·606
		8·25		100

we find its constituents just give the true ato-

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* Annals of Philosophy, V. 95.

mic weight of the acid, while the composition per cent. agrees very nearly with the results of Berzelius. The agreement would be still nearer were we to correct the data by which Berzelius calculated the constituents: for the true weight of the hydrogen which he obtained was not 3·807, but 3·641 per cent. A very slight trace of water derived from some unknown source would easily account for the slight surplus of hydrogen.

6. As the quantity of water in crystals of tartaric acid is accurately known, it occurred to me that a more accurate idea might be formed of the constituents of this acid, by analyzing the crystals, than by any tartrate whatever. Accordingly, a quantity of the acid was reduced to a fine powder, and being placed between the folds of a quantity of blotting paper, was subjected to a considerable pressure for twenty-four hours, in order to get rid of the hygrometrical water. 9·375 grains of this powder were triturated with 200 grains of peroxide of copper, and the mixture being put into a copper tube, was exposed to a red heat, under similar circumstances with the oxalic acid, the analysis of which was related in the preceding section. The weight of the water obtained was almost exactly 3·375 grains,* while the volume of carbonic acid was just

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* In some of my experiments the quantity of water extricated was 4·85 grains; but I give in the text the average of a number of trials.

double that procured from 9 grains of crystallized oxalic acid.

Now, the 9·375 grains analyzed contained 1·125 grain of water. The residual 2·25 grains of water indicate 0·25 of hydrogen. The quantity of carbonic acid evolved showed that the carbon in 9·375 of tartaric acid crystals is just double that in 9 grains of oxalic acid crystals. But we have seen in the last section, that the carbon in 9 grains of the crystals of the latter acid is 1·5 grain: consequently, 9·375 grains of crystallized tartaric acid contain 3 grains of carbon. The 5 grains wanting to make up the weight must be oxygen. Thus it appears, that the constituents of 9·375 grains of crystallized tartaric acid are as follows:

1 atom water	=	1·125
2 atoms hydrogen	=	0·25
4 atoms carbon	=	3
5 atoms oxygen	=	5
		9·375

Some years ago, Dr. Prout gave me the result of a set of experiments which he had made, to determine the composition of tartaric acid in crystals. The table which he gave me was as follows:

3 atoms hydrogen	0·375
4 atoms carbon	3
6 atoms oxygen	6
	9·375

This result agrees exactly with the preceding one of my own. Had I been aware of Dr. Prout's result when I published my first experiments on the atomic weight of tartaric acid, it would have induced me to have paused before I stated the integrant particle of these crystals to weigh 9·5. But I had forgotten the statement of Dr. Prout, till I accidentally met with it after all my experiments on this acid were finished. I mention it now, as affording a strong corroboration of the accuracy of the atomic weight of this acid as now determined: for my opinion of Dr. Prout's precision is so high, that I am disposed to place much value upon all his investigations; for I have had an opportunity of judging of the uncommon care with which all his experiments are performed.

SECT. III.

OF THE ATOMIC WEIGHT OF CITRIC ACID.

Though the taste of citric acid in crystals is as intensely acid as that of tartaric or even oxalic acid, yet it acts with less energy upon other bodies, and does not so easily decompose other salts as these two acids do. Thus, when we mix oxalate or tartrate of ammonia with a solution of muriate of lime, oxalate or tartrate of lime immediately precipitates. But citrate of ammonia produces no such effect; yet citrate of lime is insoluble in water, as well as the other two calcareous salts. Citrate of ammonia does not occasion a precipitate in nitrate of lead, although citrate of lead is quite insoluble in water. But oxalate and tartrate of ammonia precipitate lead with great energy. This acid is seldom employed by chemists as a reagent, and of course, is of inferior importance in a chemical point of view. But it exists so abundantly in the vegetable kingdom, constituting a portion of so many fruits, that a knowledge of its nature and constitution, constitutes an interesting problem in vegetable physiology. In my experiments to determine the atomic weight of this acid, I was directed by those which Berzelius had published in 1815.*

Atomic weight of citric acid.

1. 9·5 grains of the crystals of citric acid were dissolved in water, saturated with ammonia, and the solution deprived of all excess of ammonia by evaporation. 20·75 grains of dry nitrate of lead were dissolved in another portion of distilled water, and the two solutions were mixed together. No precipitate appearing, and no indication of a double decomposition taking place, the liquid was slowly evaporated to dryness. Water being digested upon the dry resi-

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* Annals of Philosophy, V. 93.

due, nitrate of ammonia was dissolved, while an insoluble citrate of lead remained behind. The aqueous solution, even when very much concentrated, was not affected by sulphate of soda, showing that it contained no lead. A portion of it being mixed with some liquid nitrate of lead, and the mixture being evaporated gently to dryness, and the residue being digested in water, a complete solution took place without the appearance of any citrate of lead whatever. This shows that the liquid contained no sensible quantity of citric acid.

From the preceding experiment it follows, that 9·5 grains of citric acid crystals contain a quantity of citric acid just capable of saturating all the protoxide of lead in 20·75 grains of nitrate of lead, which amount to exactly 14 grains. The citrate of lead was carefully collected upon a double filter, well washed, and dried, first in the open air, and then in a temperature not exceeding 150°—its weight was 21·25 grains. Now, of this weight, 14 grains were protoxide of lead; the remainder must be citric acid. Thus citrate of lead, dried in 150°, is a compound of

Citric acid . .	7·25
Protoxide of lead .	14
	21·25

This citrate being neutral, and 14 being the atomic weight of protoxide of lead, it is clear that 7·25 is the atomic weight of citric acid.

Composition of the crystals.

2. But the weight of the crystallized citric acid employed was 9·5 grains. The excess of weight of these crystals above 7·25 must be owing to combined water. This excess is 2·25, which is equivalent to the weight of 2 atoms of water. Hence it follows, that crystallized citric acid is a compound of

1 atom real acid	.	7·25
2 atoms water	.	2·25
		9·5

3. I find, when 9·5 grains of crystallized citric acid are exposed to a heat rather below 212°, they lose very nearly 0·73 grain of their weight, and fall down in the state of a powder. Now, 0·73 is ⅓d of 2·25; so that, by the application of heat, these crystals give out just the third of their water,—and no more can be driven off without, at the same time, decomposing the acid; for its colour is rendered brown, and a peculiar odour becomes sensible.

Constituents of citric acid.

4. Berzelius decomposed citric acid by mixing 1 part of citrate of lead with chlorate of potash, burning the mixture in a glass tube, and collecting the products. He deduced from this analysis that the constituents of citric acid per cent. are

Hydrogen	. .	3·800
Carbon	. .	41·369
Oxygen	. .	54·831
		100

Now, if we suppose the constituents to be

2 atoms hydrogen	= 0·25	or	3·448
4 atoms carbon	= 3	-	41·379
4 atoms oxygen	= 4	-	55·173
	7·25		100·000

the weight of the atom of the acid will be 7·25, as indicated by the preceding experiments; while the constituents per cent. agree very nearly indeed with those given by Berzelius from his experiments.

5. It occurred to me that, as the quantity of water in the crystals of citric acid had been accurately determined, the analysis of a given weight of these crystals would give the most satisfactory evidence of the true constituents of this acid. 9·5 grains of the crystals, in the state of a fine powder, were well triturated with 200 grains of peroxide of copper, and exposed to a red heat in a copper tube, with all the necessary precautions to collect the whole of the products. The weight of the water retained by the chloride of calcium approached nearly to 4·5 grains;*

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* The average of my own experiments gave the amount of water from 9·5 grains of citric acid crystals only 4·15 grains. It was a comparison of my experiments with those of Berzelius that induced me to state 4·5 grains as the amount of the water.

and the very same volume of carbonic acid gas came over as when 9·375 grains of tartaric acid crystals were decomposed in the same manner. 4·5 water indicate 4 atoms of that liquid; but the crystals contain 2 atoms of water;—consequently, the other 2 atoms were formed by the decomposition of the acid, and they indicate 2 atoms of hydrogen. The carbon, being the same as in tartaric acid, amounts to 4 atoms, the weight of which is 3. The weight necessary to make up the whole 9·5 of citric acid decomposed must be oxygen. Thus it appears, from the preceding analysis, that 9·5 of citric acid crystals are composed of

2 atoms water .	2·25
2 atoms hydrogen .	0·25
4 atoms carbon .	3·00
4 atoms oxygen .	4·00
	9·5

Thus, both the atomic weight and the constituents of the acid are confirmed by this analysis.

SECT. IV.

OF THE ATOMIC WEIGHT OF ACETIC ACID.

The determination of the atomic weight of this acid is attended with peculiar difficulties, because it forms no insoluble salts. On this account, we cannot have recourse to the method of double decomposition, which has answered so well in many of the investigations communicated in the preceding pages of this work. Before proceeding farther, I must express my obligations to two of my friends, both of them chemical manufacturers in Glasgow, I mean Mr. Charles M'Intosh and Mr. Ramsay; the former of whom furnished me with liquid acetic acid in a state of perfect purity, while the latter gave me a pure hydrated acetic acid, in the state of crystals. Had it not been for the purity of the acids thus furnished me, I should have been under the necessity of relinquishing this acid in despair.

Analysis of acetate of soda by Berzelius.

1. Berzelius analyzed several of the acetates with his accustomed care and accuracy, and was at great pains to obtain them quite free from water; but, unfortunately, there is no criterion by which we can determine whether we have rendered a salt perfectly anhydrous or not, unless it be a substance capable of bearing a red heat, which is far from being the case with any of the acetates. It is the freeing these salts from water which constitutes the great difficulty in analyzing them; but Berzelius' experiments are made with such scrupulous attention to accuracy, that they deserve peculiar notice. They will certainly furnish us with pretty near

approximations. He found the constituents of acetate of soda as follows:

Acetic acid . .	36·995	or	6·448
Soda .	22·895	-	4
Water . .	40·11	-	7·007
	100 00*		

Now, this salt is perfectly neutral; hence it must consist of an atom of acetic acid and an atom of soda united together, with a certain number of atoms of water of crystallization. The numbers in the second column exhibit the atomic weights calculated from the analysis: 4 is the atomic weight of soda, and 7·007 approaches nearly to 6·75, which is the weight of 6 atoms of water; 6·448 is the weight of an atom of acetic acid according to this analysis. We may conclude, then, that crystallized acetate of soda is a compound of

1 atom acetic acid,
1 atom soda,
6 atoms water.

And the atomic weight of acetic acid, deduced from Berzelius' analysis of this salt, is 6·448.

As we have hitherto found that the atomic weights of all the acids and bases are multiples

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* Ann. de Chim. LXXXII. 113. Correcting his estimate of soda.

of 0·25, it is exceedingly probable that the atomic weight of acetic acid is either 6·25 or 6·5, as Berzelius' number lies between these. That I might be able to determine which of these two numbers was the real atomic weight of acetic acid, I dissolved 6·75 grains of anhydrous carbonate of soda in distilled water, saturated the solution with very pure acetic acid, and evaporated the solution to dryness, by means of a gentle but long continued heat. The dry salt thus obtained, which was in an eight ounce phial, was kept for four hours upon the sand bath, in a heat which was as nearly as possible 550°. I was obliged to repeat this experiment a great many times, before I made myself acquainted with the limit of the temperature which the salt is capable of bearing without decomposition. The heat must be sufficient to keep the salt in a state of fusion, otherwise the whole water is not driven off—if it be as high as 600° decomposition takes place. While the salt is in fusion it has a darkish colour, but it becomes beautifully white as soon as it congeals, if none of the acid has been destroyed. In two successive experiments, which were quite successful, the weight of the salt was 10·25 grains: now, 6·75 grains of anhydrous carbonate of soda contain just 4 grains of soda; consequently, anhydrous acetate of soda is composed of **By the author.**

Soda	4
Acetic acid . . .	6·25
	10·25

The salt, after this treatment, was still neutral. We see, therefore, that the true atomic weight of acetic acid is 6·25; and the true constituents of crystallized acetate of soda must be

1 atom acetic acid	6·25	or per cent.		36·764
1 atom soda .	4	-	-	23·529
6 atoms water	6·75	-	-	39·706
	17			

And these numbers approach so near those of Berzelius, that they may be said to confirm one another.

Analysis of acetate of lead.

2. Acetate of lead is a neutral salt, which can be easily procured in beautiful crystals, and in a state of the greatest purity. Hence, an accurate analysis of it will furnish us with very good data for determining the atomic weight of acetic acid.

Berzelius published an analysis of this salt a good many years ago, which approaches very near the truth, though not sufficiently so to give the correct atomic weight of acetic acid.

(1.) I followed his method of freeing the salt of water, by placing it over a flat glass vessel containing concentrated sulphuric acid in the vacuum of an air-pump: 23·625 grains of the crystals when thus treated, lost almost exactly 3·375 grains of water—which is equivalent to 3 atoms of that liquid.

(2.) It will be shown in a subsequent chapter of this work, that crystallized oxalate of ammonia is composed of

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

8·875 grains of crystallized oxalate of ammonia were dissolved in a minimum of distilled water; in another portion of the same liquid, I dissolved 23·625 grains of beautiful semitransparent crystals of acetate of lead: the two solutions being mixed, a double decomposition took place, and oxalate of lead precipitated to the bottom in a very fine powder, leaving the supernatant liquid quite transparent and colourless. This liquid being tested by sulphate of soda and muriate of lime, was not in the least affected by either of these reagents; showing that it contained no sensible quantity either of oxide of lead or of oxalic acid. From this experiment it is evident, that the oxalic acid in 8·875 grains of oxalate of ammonia just saturates the oxide of lead in 23·625 grains of acetate of lead. The oxalate of lead, which had precipitated, was carefully collected on a double filter, and being washed and dried in a temperature not quite so high as 212°, weighed as nearly as possible 18·5 grains. Now, 4·5 of this weight were oxalic acid; consequently, the protoxide of lead in 23·625 grains of acetate of lead is precisely 14 grains. The portion of the salt wanting to make up the total weight of 23·625, is obviously acetic acid. Thus it appears, from the preceding analysis, that acetate of lead is composed of

Acetic acid . .	6·25
Protoxide of lead .	14·00
Water . . .	3·375
	23·625

The salt being neutral, and 14 being equivalent to the weight of an atom of protoxide of lead, and 3·375 to that of 3 atoms of water, it is obvious that 6·25 must represent the atomic weight of acetic acid.

Acetate of lime.

3. I made some experiments upon the acetate of lime; but found that it cannot be rendered anhydrous without exposing it to a temperature so high that the acid is partially driven off or decomposed. At the temperature of 450°, the salt retains about the third of an atom of water. Berzelius kept the salt for some time in the highest temperature which it could bear: it appears from the result of his analysis, that when

thus treated, it still retains nearly the eighth of an atom of water.*

Analysis of acetic acid.

4. Berzelius analyzed acetic acid by burning a mixture of chloride of potash and anhydrous acetate of lead in a glass tube, and collecting the products. The water formed, and carbonic acid gas collected, together with the known weight of acid in 1·06 of acetate of lead employed, give us the constituents of the acid. The acid in 1·06 of dry acetate of lead is 0·332; he obtained 0·18 of water, indicating 0·02 hydrogen; and 0·574 carbonic acid, indicating 0·15654 of carbon. Thus the constituents of the acid were

Hydrogen	0·02	or per cent.	6·0240
Carbon	0·15654	- -	47·1506
Oxygen	0·15546	- -	46·8254
	0·33200		100·0000

Now, if we consider the constituents of this acid to be

2 atoms hydrogen	0·25	or	4
4 atoms carbon .	3	-	48
3 atoms oxygen .	3	-	48
	6·25		100

we have the atomic weight as determined in the preceding part of this section; while the constituents per cent. deviate very little from those of

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* Annals of Philosophy, V. 174.

Berzelius. It is obvious from the analysis of Berzelius, that the weights of the carbon and oxygen in the acid are the same; consequently, there must be 4 atoms of the former for 3 of the latter. The hydrogen found by Berzelius would indicate 3 atoms of hydrogen instead of 2. This was, no doubt, owing to the introduction of a very small quantity of water from some unknown source—an accident against which it is extremely difficult to provide.

I have not repeated the analysis of acetic acid, considering the result obtained by Berzelius as sufficient (together with the knowledge of the atomic weight) to determine the composition of this acid. The most accurate method of proceeding would be to employ the crystals of acetate of lead, without depriving them of their water of crystallization. This water has been shown to amount to 3 atoms, and it must be allowed for in the calculation; the quantity of salt which should be employed is 23·625 grains, which is equivalent to an integrant particle.

Crystals of acetic acid

5. It has been long known that, when dry acetate of soda and sulphuric acid are mixed in the requisite proportions, and distilled in a retort, an acetic acid comes over so strong that it crystallizes when cooled down to a low temperature, and remains in crystals as long as the thermometer is lower than 50°. If we have a considerable quantity of the acid in this concentrat-

ed state, we have it in our power, by pouring the liquid portion off the crystals, to obtain them in a state of great purity, and quite dry. It is in this way that crystallized acetic acid is prepared by Mr. Ramsay of Glasgow. By drying these crystals on blotting paper, at a low temperature, I freed them completely from all adhering liquid, and made them as dry as the crystals of tartaric acid.

Putting a quantity of these dry crystals into a phial, I melted them by leaving them for 24 hours in a warm room. The liquid thus obtained did not crystallize, though kept for a long time in a temperature as low as 40° ; but if we raise it to the temperature of 45°, and throw into it a single crystal of acetic acid, a number of crystalline spiculæ dart out with rapidity all over the liquid, and the temperature rises from 45° to 51°. By degrees, after this commencement of crystallization, the whole liquid assumes the solid form, although the temperature be not lower than 45°.

These crystals, while in a liquid state, and at the temperature of 60°, have a specific gravity of 1·06296.

Contain one atom of water.

6. I dissolved 22·125 grains of these crystals in water, and added to the solution 26·25 grains of anhydrous carbonate of potash, obtained by exposing bicarbonate of potash to a red heat. This addition just neutralized the acid, for the

mixture produced no change upon the colour of litmus or cudbear paper. If we divide each of the substances employed by 3, the consequences which I mean to draw from the experiment will be plainer.

$$\frac{22{\cdot}125}{3} = 7{\cdot}375\text{; and}$$

$$\frac{26{\cdot}25}{3} = 8{\cdot}75$$

We may say, then, that 7·375 grains of crystals of acetic acid were just neutralized by 8·75 grains of anhydrous carbonate of potash; but 8·75 grains of this carbonate contain just 6 grains of potash, which is equivalent to an atom. Consequently, 7·375 grains of the crystals of acetic acid must contain just 6·25 grains of real acetic acid; for that is the quantity requisite to saturate 6 grains of potash. The remainder of the weight of the acid is obviously water, and it amounts to 1·125, which is equivalent to an atom of water. Thus it appears that the crystals of acetic acid are composed of

1 atom real acid .	6·25
1 atom water .	1·125
	7·375

They do not contain 2 atoms of water, as I formerly supposed, misled by the statements of Mollerat, which I find to be inaccurate.

7. By dissolving given weights of these crystals in water, and taking the specific gravity of the solutions at 60°, I was enabled to form the following table, exhibiting the specific gravity of various atomic compounds of this acid and water:

Table exhibiting the specific gravity of acetic acid of different strengths.

ACID.		WATER.		SP. GR. AT 60°.
1 atom	+	1 atom	.	1·06296
1 -	+	2 -	.	1·07060
1 -	+	3 -	.	1·07084
1 -	+	4 -	.	1·07132
1 -	+	5 -	.	1·06820
1 -	+	6 -	.	1·06708
1 -	+	7 -	.	1·06349
1 -	+	8 -	.	1·05974
1 -	+	9 -	.	1·05794
1 -	+	10 -	.	1·05439

We see from this table that the specific gravity of the liquid is a maximum, when it consists of 1 atom acid united to 4 atoms water; or, when it is composed of

Acid	. 6·25	or	100	or	58·1395
Water	. 4·5	-	72	-	41·8605
					100

We see, too, that the specific gravity of acid, containing only 1 atom water, is nearly the same with that containing 7 atoms water; or the two following compounds

1.	Acid	6·25	or	100	or	84·7457
	Water	1·125	-	18	-	15·2543
2.	Acid	6·25	or	100	or	44·2477
	Water	7·875	-	126	-	55·7523

have nearly the same specific gravity. It is obvious from this, that the specific gravity of an acetic acid does not assist us in determining its strength, or the true quantity of acid which it contains.*

SECT. V.

OF THE ATOMIC WEIGHT OF SUCCINIC ACID.

THIS acid, as it is at first obtained by the distillation of amber, has a yellow colour, and an empyreumatic smell, both of which are removed by digesting it in nitric acid, which decomposes the oily matter with which it was contaminated. When thus purified, its colour is very white, and it crystallizes in four-sided prisms. I do not find it to contain any water of crystallization. The crystals consist entirely of anhydrous acid.

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* In the two last editions of my System of Chemistry (Vol. II. p. 141.) I inserted a table, exhibiting the specific gravity of acetic acid of various strength, deduced from the experiments of Mollerat. That table is quite erroneous, as may be seen by comparing it with the one now given.

Atomic weight of succinic acid.

1. To determine the atomic weight of this acid, 6·25 grains of the crystals were dissolved in water, and neutralized by ammonia. 17·375 grains of the crystals of protosulphate of iron were dissolved in water, and the iron peroxidized by digesting the solution, mixed with a little nitric acid. The brown coloured liquid thus obtained was rendered as neutral as possible by ammonia. These two solutions being mixed together, a double decomposition took place, and succinate of iron precipitated in abundance. The whole being thrown upon a double filter, the succinate of iron was retained, and the liquid which passed through was transparent and colourless. This liquid was not rendered blue by prussiate of potash—showing that it contained no sensible quantity of iron. Neither was it precipitated or altered by ammonia, or by persulphate of iron; the last of which salts would have occasioned a precipitate, if it had contained any succinic acid.

From this experiment it appears, that 6·25 grains of succinic acid just saturate all the peroxide of iron from 17·375 grains of protosulphate of iron. Now, it was shown in a former section of this work, that 17·375 grains of protosulphate of iron contain just 4·5 grains of protoxide, which is equivalent to 5 grains of peroxide of iron.

Succinate of iron.

The succinate of iron, precipitated in the preceding experiment, being well washed, and dried in the temperature of 212°, weighed 11·25 grains; and it was obviously composed of

Succinic acid	6·25	or	$0{\cdot}55\dot{5}$
Peroxide of iron	5	-	$0{\cdot}44\dot{4}$
			1·000

The salt being neutral, and five being the atomic weight of peroxide of iron, 6·25 must be the atomic weight of succinic acid.

Thus it appears, that acetic and succinic acid have the same atomic weights; yet scarcely any two acids differ more from each other in their properties. Acetic acid is so soluble in water that it is difficult to obtain it in the state of crystals, and these crystals cannot exist, unless they contain an atom of water united to an atom of acid; but succinic acid requires nearly 100 times its weight of water to dissolve it, and its crystals contain no water whatever. There is some analogy, however, in the way in which the two acids combine with bases. Thus, acetic acid unites with 1 atom and with 2 atoms of protoxide of lead, and so does succinic acid. Probably many other similar analogies would be discovered if the succinates were better known than they are at present.

Composition of succinic acid.

2. I have not made any experiments upon the constituents of this acid, because I considered

the analysis of Berzelius as sufficiently decisive. He mixed 1·294 of anhydrous succinate of lead with chlorate of potash, and burned it in a glass tube, collecting the product. The water formed was 0·1536, and the carbonic acid 0·7.

Now, 1·294 succinate of lead contain 0·40215 of succinic acid; 0·1536 water contain 0·01706 hydrogen, and 0·7 carbonic acid contain 0·19091 carbon. What is wanting besides these constituents to make up the weight of the succinic acid is oxygen. Thus, the constituents of succinic acid are

Hydrogen	0·01706	or	0·2651
Carbon	0·19091	-	2·9670
Oxygen	0·19418	-	3·0179
	0·40215		6·2500*

The second column in which the constituents are reduced to what they would be, if 6·25 or an atom of succinic acid had been decomposed, approach so nearly to

2 atoms hydrogen	0·25
4 atoms carbon	3
3 atoms oxygen	3
	6·25

that we cannot hesitate to admit that these represent the atomic constituents of succinic acid.

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* Annals of Philosophy, V. 99.

Thus it appears, not only that the atomic weight of succinic acid is the same with that of acetic acid, but that both acids are composed of the very same atomic constituents. This is a decisive proof that these vegetable acids are not formed immediately by the combination of all their atomic constituents together; but that they consist of certain binary or ternary combinations combined together. For example, we might suppose one of these acids formed by the union of

	OXYGEN.		CARBON.		HYDROGEN.
1 atom carbonic acid . =	2	+	1	+	0
1 atom carbonic oxide . =	1	+	1	+	0
2 toms olefiant gas . =	0	+	2	+	2
	3	+	4	+	2

and the other of

1 atom oxalic acid . =	3	+	2	+	0
2 atoms olefiant gas . =	0	+	2	+	2
	3	+	4	+	2

for such combinations would give the atomic proportions, and yet they might constitute compounds possessed of very different properties. These constituents are not given from any idea that they constitute the true secondary elements of the acids in question, but only to help to enable the reader to conceive how two acids may have the same elements, and yet possess very different properties; but this difficult subject stands in need of farther investigation.

3. Succinic acid furnishes a very easy method of separating iron from other bodies with which it is mixed in acid solutions, and determining its quantity—a method proposed many years ago by M. Gehlen. The method is this: Peroxidize the iron in the solution by digesting it with some nitric acid. Then make the solution as neutral as possible by means of ammonia. Succinate of ammonia will now precipitate the iron in red coloured flocks. Separate the precipitate upon a double filter, wash it well, and dry it in the temperature of 212°; $\frac{4}{9}$ths of the weight of this precipitate is peroxide of iron, and the remaining $\frac{5}{9}$ths are succinic acid.

SECT. VI.

OF THE ATOMIC WEIGHT OF BENZOIC ACID.

THIS acid, like the preceding, is obtained by sublimation, and its crystals, like those of succinic acid, are free from water. There is therefore little difficulty in determining its atomic weight.

Atomic weight of benzoic acid.

1. Fifteen grains of the crystals were dissolved in distilled water by means of ammonia, and the solution was concentrated on the sand bath till

all excess of ammonia was driven off. 17·375 grains of crystallized protosulphate of iron were dissolved in water, the oxide was peroxidized, and the solution rendered neutral precisely in the manner described in the last section. These two solutions being mixed, a double decomposition took place, and benzoate of iron immediately precipitated in buff coloured flocks. This precipitate was separated by means of a double filter. The liquid which passed through was transparent and colourless, and was not in the least altered by prussiate of potash, nor was any precipitate occasioned by the addition of persulphate of iron, showing that it contained no sensible quantity of iron, or of benzoic acid.

From this experiment we learn that 15 grains of benzoic acid just neutralize 5 grains of peroxide of iron. And as 5 represents the atomic weight of peroxide of iron, 15 must be the atomic weight of benzoic acid.

Benzoate of iron.

2. The benzoate of iron formed in the preceding experiment being dried in the temperature of 212°, weighed exactly 20 grains. It was therefore anhydrous, and consisted of

1 atom benzoic acid	15
1 atom peroxide of iron	5
	20

Hence, the fourth part of this precipitate is peroxide of iron and the other three-fourths benzoic acid. Benzoate of soda or ammonia was proposed by Hizinger as an excellent reagent for separating iron from other bodies; and I find it to answer just as well as succinate of soda. The method of proceeding with both salts is precisely the same.

Composition of benzoic acid.

3. Benzoic acid, like acetic and succinic acids, combines with protoxide of lead in two proportions, forming a salt composed of 1 atom acid and 1 atom protoxide, and another composed of 1 atom acid and 3 atoms protoxide. Berzelius found that when a mixture of benzoate of lead and chlorate of potash was burned in the way formerly described in glass tubes, a portion of the acid was apt to sublime without decomposition. This did not happen so readily when the sub-benzoate of lead was employed. The analysis of a quantity of sub-benzoate containing 0·317 of benzoic acid gave 0·1414 water, equivalent to 0·01571 hydrogen; and 0·8645 carbonic acid, equivalent to 0·23577 carbon. Consequently, the constituents of benzoic acid are

Hydrogen	0·01571	or	0·75
Carbon	0·23577	-	11·15
Oxygen	0·06552	-	3·10
	0·31700		15·00*

The second column, which exhibits the propor-

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* Annals of Philosophy, V. 181.

tions of the constituents, answering to the atomic weight 15 of the acid approaches so very nearly to

6 atoms hydrogen	0·75
15 atoms carbon	11·25
3 atoms oxygen	3
	15

that we can have no hesitation in admitting that these represent the true atomic constituents of the acid. It is therefore a very complicated body, as it contains no fewer than 24 atoms. Like all other very complex bodies its affinities are very weak.

SECT. VII.

OF THE ATOMIC WEIGHT OF SACLACTIC ACID.

Purification of saclactic acid.

I HAVE prepared this acid both from sugar of milk and from gum. The acid obtained from gum is always contaminated with saccolate of lime; the best way of freeing it from which is to dissolve it in water. The saccolate of lime remains behind, and may be separated by the filter. Then by evaporating the aqueous solution to dryness by a gentle heat, we recover the saclactic acid in a state of purity. But great care must be taken not to expose the evaporating liquid to too high a temperature; for the saclactic acid is very easily rendered brown, indicating the looseness with which its elements are combined. The saclactic acid from sugar of milk is quite pure as at first prepared.

Saclactic acid has a fine white colour when dried in a temperature sufficiently low. Its taste is only slightly acidulous, but it acts powerfully on vegetable blues, reddening them with considerable energy. It is but little soluble in water, though boiling water dissolves a greater portion than cold water; and if a saturated solution of this acid in boiling water be set aside, the greatest part of the acid is deposited as the water cools in the state of small crystals.

Saclactate of soda analyzed.

1. To determine the atomic weight of this acid, I employed saclactate of soda;—a salt which I formed by saturating sesquicarbonate of soda with saclactic acid. The acid dissolved in the liquid with effervescence, and I continued to add new portions of the acid till the effervescence was at an end. The liquid was then passed through a filter, to separate a portion of undissolved acid. Being left for twenty-four hours, it had deposited an additional portion of saclactic acid, yet it still reddened vegetable blues. Being gently evaporated to dryness, it deposited the saclactate of soda in white semitransparent crystals, consisting of four-sided rectangular prisms with square bases. The taste of this salt

is slightly saline, and somewhat similar to that of phosphate of soda. It is not very soluble in water, and is very easily rendered brown, unless great care be taken in regulating the heat to which it is exposed.

22·625 grains of these crystals were dissolved in water, and the liquid mixed with a solution of 20·75 grains of nitrate of lead. A double decomposition took place immediately, and saclactate of lead was precipitated in abundance. The clear supernatant liquid was tested by sulphate of soda and nitrate of lead, but was not in the least affected by either; showing, that it contained no sensible quantity of lead or of saclactic acid.

The saclactate of lead being collected on a double filter, washed and dried in a temperature not exceeding 212°, weighed 27 grains. Now, it contained all the protoxide of lead existing in 20·75 grains of nitrate of lead, amounting to 14 grains. It was therefore composed of

Protoxide of lead	14
Saclactic acid	13
	27

From this experiment it follows that 22·625 grains of crystallized saclactate of soda contain 13 grains of saclactic acid. As these 13 grains just saturated 14 grains of protoxide of lead, which is the equivalent for an atom, it is obvious that in the saclactate of soda they must have been in combination with an atom of soda, the equivalent for which is 4 grains. The remaining 5·625 grains, still remaining to make up the weight of the salt, must have been water; and this weight is equivalent to 5 atoms water. Thus it appears, that saclactate of soda is composed as follows:

1 atom saclactic acid	13
1 atom soda	4
5 atoms water	5·625
	22·625

Atom of saclactic acid.

It is obvious that 13 represents the atomic weight of this acid.

Constituents of saclactic acid.

2. Berzelius analyzed saclactic acid by the same process as the other vegetable acids. 1 part of saclactate of lead, equivalent to 0·4814 of saclactic acid, when burned with chlorate of potash, gave out 0·21 water, equivalent to 0·0233 hydrogen; and 0·594 carbonic acid, equivalent to 0·1620 carbon.* From this it follows, that the constituents of saclactic acid are

Hydrogen . .	0·0233	or	0·6292
Carbon . .	0·1620	-	4·3747
Oxygen . .	0·2961	-	7·9961
	0·4814		13·0000

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* Annals of Philosophy, V. 180.

The second column, exhibiting the proportion of the constituents in 13 of the acid, which is the atomic weight, approaches nearest to

4 atoms hydrogen . .	0·5
6 atoms carbon . .	4·5
8 atoms oxygen . .	8·0
	13·0

The greatest deviation is in the hydrogen, which is about $\frac{1}{6}$th part too high, while the carbon is rather more than $\frac{1}{45}$th part too low. The proportion of oxygen is almost exact.

Berzelius analyzed, likewise, 0·333 parts of saclactic acid in the same way. He obtained 0·149 of water, equivalent to 0·01655 hydrogen; and 0·393 carbonic acid, equivalent to 0·10718 carbon.* Hence, the constituents of the acid, according to this analysis, are

Hydrogen . .	0·01655	or	0·64
Carbon . .	0·10718	-	4·18
Oxygen . .	0·20960	-	8·18
	0·33333		13·00

We perceive, from the second column exhibiting the proportion of the constituents in 13 parts, or an atom of the acid, that the proportion, both of hydrogen and oxygen, is greater in this analysis than in the preceding. No doubt, the reason

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* Annals of Philosophy, V. 180.

was that the saclactic acid contained a greater proportion of adhering water than the saclactate of lead; though even the saclactate of lead was, probably, not absolutely free from water—unless, indeed, the small excess of water in that analysis was derived from some other accidental source—as the moisture of the air when the ingredients happened to be mixed together. Upon the whole, these analyses of Berzelius come wonderfully near the truth, and do much honour both to the sagacity and skill of this most indefatigable chemist.

SECT. VIII.

OF THE ATOMIC WEIGHT OF FORMIC ACID.

Though formic acid was discovered by Margraff, and several of its properties pointed out, it is only of late years that very correct notions respecting it have been attained. Fourcroy and Vauquelin endeavoured to prove, in 1802, that it was merely a mixture of acetic and malic acids; but this opinion was refuted, and the peculiar nature of formic acid established by Suersen, and Gehlen. Dobereiner has lately pointed out some properties by which this acid may be readily distinguished from every other.

Properties of formic acid.

1. Formic acid, as far as is known at present, cannot be obtained in the state of crystals, but

only in solution in water. It is as volatile as acetic acid, and has a smell somewhat similar to that of that acid. It was this similarity of smell, and the property which it has of forming soluble salts with most of the bases, that led Fourcroy and Vauquelin to the opinion that it was identical with acetic acid.

Dobereiner has ascertained, that when formic acid is mixed with concentrated sulphuric acid, it undergoes decomposition at the ordinary temperature of the atmosphere—being converted into water, which combines with the sulphuric acid, and into carbonic oxide, which makes its escape in the form of gas. When it is mixed with nitrate of silver or nitrate of mercury, and a gentle heat applied, the formic acid is equally decomposed; carbonic acid is disengaged, and the oxides are reduced to the metallic state. These curious phenomena are easily observed, and they are sufficient to enable us to distinguish this acid from every other.*

Analysis of formic acid.

2. Berzelius was the first chemist who attempted to determine the composition of formic acid. He found† that anhydrous formate of lead is a compound of

Formic acid .	100	or	4·696
Protoxide of lead	298·1	-	14

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[*] Gilbert's Annalen der Physick, LXXI. 107.

[†] Annals of Philosophy, IX. 107

According to this analysis the atomic weight of formic acid is 4·696. Now, the nearest multiple of 0·125 to this is 4·625. Hence, the probability is, that this number represents the true atomic weight. Berzelius analyzed the acid by burning a certain proportion of formate of lead and chlorate of potash in a glass tube, precisely in the way formerly described. He found the constituents, by this process, to be

Hydrogen .	2·84	or	0·13135
Carbon .	32·40	-	1·49850
Oxygen .	64·76	-	2·99515
	100·00		4·62500

The second column, showing the weight of each constituent in 4·625, or an atom of the acid, approaches so nearly to

1 atom hydrogen .	0·125
2 atoms carbon .	1·5
3 atoms oxygen .	3
	4·625

that we can have little reason to hesitate about adopting these as the true atomic constituents of the acid. The only difference between its atomic constitution and that of oxalic acid, is, that formic acid contains an atom of hydrogen which is wanting in oxalic acid. But the loose manner in which the constituents of this acid are held together, compared to the stability of oxalic acid, renders it probable, that the secondary constituents of the two acids are very different.

3. Dr. Gobel has given us another analysis of this acid, by means of peroxide of copper. He analyzed formate of lead, and found it a compound of

Formic acid . .	4·5693
Protoxide of lead .	14·0744
Water . . .	1·1063
	19·75*

Doubtless the true numbers are

1 atom formic acid .	4·625
1 atom protoxide of lead	14·000
1 atom water . .	1·125
	19·75

He analyzed 10 grains of the formate of lead by heating it with peroxide of copper in a glass tube. His description of the result of the analysis is not very clear, and it seems to contain some arithmetical slips. When these are corrected (supposing the formate of lead used anhydrous) the constituents obtained were the following:

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* Annals of Philosophy, (second series) III. 463.

Hydrogen	.	0·0698	or	0·129
Carbon	.	0·7970	-	1·485
Oxygen	.	1·6164	-	3·011
		2·4832		4·625

In this analysis the hydrogen and oxygen are exceedingly near the truth. There is a slight deficit in the carbon, which, however, amounts only to 1 per cent.

4. The experiments of Dobereiner tend strongly to confirm the constitution of formic acid as determined by the preceding experiments. He found that, when concentrated sulphuric acid was mixed with formic acid, carbonic oxide gas was extricated; while the acid became weaker, from an addition of water. Now, it is obvious that, if formic acid be a compound of 1 atom hydrogen, 2 atoms carbon, and 3 atoms oxygen, it may be resolved into water and carbonic oxide; for,

	HYDROGEN.	OXYGEN.	CARBON.
1 atom water consists of	1 atom	+ 1 atom	+ 0 atom
2 atoms carbonic oxide of	0 -	+ 2 -	+ 2 -
	1	+ 3	+ 2

So that 4·625 grains of formic acid may be decomposed into 1·125 grain of water, and 3·5 grains of carbonic oxide, equivalent to 11·8 cubic inches of carbonic oxide gas.

5. Dobereiner has made another curious dis-

covery, which has put it in my power to obtain formic acid, and to ascertain its properties. He found that, when tartaric acid, or bitartrate of potash, is mixed with black oxide of manganese and water, and a gentle heat applied, an effervescence takes place, and carbonic acid gas is evolved, while a colourless acid liquid passes over into the receiver, which is formic acid. When sulphuric acid is added, the whole of the tartaric acid is decomposed, and a greater quantity of formic acid is obtained. During the process, the tritoxide of manganese is converted into protoxide, which combines with the sulphuric acid; or, if that acid be not present, with the tartaric and formic acids. The best proportions he finds to be

Formation of this acid from tartaric.

1 part of crystallized tartaric acid,
$2\frac{1}{2}$ parts tritoxide of manganese,
$2\frac{1}{2}$ parts of sulphuric acid, which should be diluted with twice or thrice its weight of water.*

If we compare the constituents of tartaric and formic acids, we will be enabled to see what takes place in this case.

	HYDROGEN.		CARBON.		OXYGEN.
Tartaric acid	2	+	4	+	4
Formic acid	1	+	2	+	3
	—		—		—
Difference	1	+	2	+	1

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* Gilbert's Annalen, LXXI, 108.

This difference is reducible to an atom of water and two atoms of carbon. The sulphuric acid seems to remove the atom of water, which destroys the equilibrium of the constituents of the acid. The two surplus atoms of carbon are converted into carbonic acid, by uniting with the oxygen of the tritoxide of manganese.

If we suppose all the substances employed in this experiment pure, it is evident that the atomic quantities requisite for the decomposition of the tartaric acid, and formation of formic acid, must be

1 atom tartaric acid . .	9·375
2 atoms tritoxide of manganese	11
2 atoms sulphuric acid .	12·25

Or, 24·75 of bitartrate of potash might be substituted with equal advantage, instead of the 9·375 of tartaric acid.

SECT. IX.

OF THE ATOMIC WEIGHT OF URIC ACID.

This acid was detected by Scheele, and some of its most characteristic properties determined. It was afterwards examined more in detail by Dr. Henry of Manchester, who made it the subject of his inaugural dissertation. Since that time, some important additions have been made to our knowledge of its properties and constitution by Dr. Prout.

The uric acid which I made use of in the following experiments was obtained from the excrements of the boa constrictor. This serpent voided its excrements about once in the month: the matter was white and solid, and in appearance very similar to the album Græcum voided by dogs. A slight examination of it satisfied me that it consisted almost entirely of uric acid. It was digested in caustic potash ley, by which the greatest part of it (indeed almost the whole) was dissolved. The solution was drawn off clear from the undissolved sediment, and mixed with a sufficient quantity of very pure acetic acid, to saturate the whole of the potash. A copious white precipitate fell, which was collected on the filter, and thoroughly washed by the affusion of a great quantity of water. It was then dried in a gentle heat, and considered as pure uric acid.

Properties of uric acid.

1. Uric acid thus prepared was sometimes in the state of an impalpable powder—sometimes in small four-sided prisms, having a good deal of lustre. I was not able to procure these crystals at pleasure; but succeeded most frequently when the precipitate was separated by the filter from the supernatant liquid, immediately after

being thrown down. When I allowed the precipitated acid to remain in the mother liquor for 24 hours, I never got it in any other state than an impalpable powder.

Uric acid is tasteless, very white, very light, and quite insoluble in water and alcohol.

In concentrated sulphuric acid it speedily assumes the form of a jelly; and, upon applying a very gentle heat, a complete solution is obtained, without in the least affecting the colour or transparency of the acid. In nitric acid, even though dilute, it dissolves with effervescence. The solution is nearly colourless, and when it is evaporated to dryness, it leaves a sediment having a beautiful pink colour; and if water be poured over it, a most lovely pink coloured solution is obtained—which, however, cannot be preserved for any length of time without entirely losing its colour. In muriatic acid it dissolves only in small proportion, the undissolved part assuming a fine white colour. If uric acid be precipitated with a tinge of buff or yellow, which sometimes happens, the easiest way of restoring the whiteness is to digest it in pure muriatic acid. When the muriatic acid is evaporated, it leaves a slight sediment upon the bottom of the vessel, which has a yellowish brown colour, and which is not altered by pouring water over it.

2. Uric acid may be united with the different bases by boiling it in water, holding the wished-

for base in solution. The urates of potash, soda, lime, barytes, and strontian, formed in this way, almost exactly resemble the uric acid itself in appearance. Dr. Prout has shown that urate of ammonia is the most soluble of all the urates. This salt reddens vegetable blues like uric acid itself; and 1 grain of it is soluble in 480 grains of cold water.

3. 11·25 grains of uric acid were exposed for 24 hours to a heat of about 400°, upon a sand bath: the acid was placed upon a watch glass, over which another watch glass was inverted, partly to prevent any accidental impurity, and partly to prevent any of the acid from being dissipated or sublimed without my knowledge. Some water was seen to attach itself to the upper glass, but in less than an hour all appearance of moisture had vanished, and no farther sensible alteration took place. The crystals, thus treated, being weighed, were found to have lost 2·25 grains of their weight,—the colour was rather darker than before this treatment, but no other alteration could be perceived in the appearance of the crystals. When treated with nitric acid, they exhibited the very same phenomena as uric acid which had not been exposed to heat. From this experiment it appears, that crystallized uric acid is composed of

Real acid . . .	9
Water . . .	2·25
	11·25

As 2·25 represents 2 atoms of water, the probable inference from this experiment is, that the atomic weight of uric acid is 9, and that the crystals constitute a hydrate composed of

2 atoms water . .	2·25
1 atom uric acid . .	9
	11·25

Analysis of urate of soda.

4. 18 grains of crystallized carbonate of soda were dissolved in distilled water, and to the solution 11·25 grains of crystallized uric acid were added. This mixture being digested for some hours on the sand bath, the whole uric acid disappeared, and a complete colourless solution was obtained; which, however, still rendered cudbear paper violet. The solution being set aside, a bulky and beautifully white precipitate of urate of soda fell: this precipitate being separated on a double filter, well washed and dried in the open air, was found to weigh 8·56 grains; and, when exposed to a heat of between 300° and 400°, it lost very nearly 1·125 grains,—the residual liquid was supersaturated with muriatic acid and evaporated to dryness—the residual matter, which was white, with a shade of brown, weighed 6·94 grains. It was heated to redness, lixiviated

with distilled water, and the water evaporated to dryness in a glass capsule; the common salt which remained behind weighed 2·94 grains, equivalent to 1·568 grains of soda.

In order to understand the preceding experiment, it is necessary to know that the crystals of carbonate of soda are composed of

1 atom carbonic acid .	2·75
1 atom soda . .	4
10 atoms water . .	11·25
	18

So that 18 grains of this salt are equivalent to 4 grains of soda. Let us now analyze the preceding experiment.

(1.) We see from it that uric acid (contrary to the present opinion of chemists) is capable, in time, of driving off the whole of the carbonic acid from carbonate of soda, and taking the place of that acid. No effervescence took place when the muriatic acid was poured into the residual liquid from which the urate of soda had precipitated—a proof that the whole soda had united to the uric acid. It appears from this, that urate of soda, while in solution, has the property of giving a violet colour to cudbear paper, so that the acid does not destroy the alkaline qualities of the soda.

(2.) The urate of soda which remained in solution must have consisted of

Uric acid . . .	4
Soda . . .	1·568
	5·568

For, if we subtract the weight of the common salt (2·94 grains) from that of the residual matter, (6·94 grains) there remain 4, which must be uric acid; and 2·94 grains of common salt are equivalent to 1·568 grains of soda.

(3.) The 8·56 grains of urate of soda obtained by precipitation, obviously contained 2·432 grains of soda. When heated, this salt lost 0·656 grain of its weight, which was water, for it condensed on the glass placed over the evaporating capsule. Hence, it is obvious that the urate of soda was composed of

Uric acid . . .	5·472
Soda . . .	2·432
Water . . .	0·656
	8·560

Let us reduce this to what the weight of each ingredient would be if the soda had amounted to 4 grains, which is equivalent to an atom of that alkali, and we have the constitution of urate of soda as follows:

Uric acid . . .	9
Soda . . .	4
Water . . .	1·079

9 must denote the atomic weight of uric acid—1·079 is a very little less than an atom of water. There can be no doubt, from this analysis, that the true composition of urate of soda, supposing it to retain all its water of crystallization, is as follows:

1 atom uric acid . .	9
1 atom soda . .	4
1 atom water . .	1·125
	14·125

Composition of uric acid.

5. Dr. Prout made a very careful analysis of uric acid, by exposing the acid in the state of hydrate to heat, mixed with the requisite quantity of peroxide of copper. He found the constituents as follows:

2 atoms hydrogen . .	= 0·25
6 atoms carbon . .	= 4·5
2 atoms azote . .	= 3·5
3 atoms oxygen . .	= 3·0
	11·25

The weight of the hydrate, according to this analysis, is 11·25—just what I found it to be in the preceding experiments. But we have seen that this hydrate contains 2 atoms water, and that the true atomic weight of the anhydrous acid is 9. To obtain the true constitution of the anhydrous acid, we must take away from the preceding constituents 2 atoms hydrogen and 2 atoms oxygen; this will give us the component parts of uric acid as follows:

6 atoms carbon . . = 4·5
2 atoms azote . . = 3·5
1 atom oxygen . . = 1·0
—
9

Thus, uric acid, when anhydrous, contrary to the opinions hitherto entertained by chemists, contains no hydrogen, and instead of a quaternary is only a ternary compound, like the vegetable acids. It contains a much smaller proportion of oxygen than any of the vegetable acids.

CHAP. XV.

OF THE ATOMIC WEIGHT OF FLUORIC ACID AND ITS COMPOUNDS.

The investigation of the atomic weight of fluoric acid is attended with particular difficulties, owing to the great tendency which it has to combine with silica. The fluor spar employed for procuring it is seldom quite free from silica; but the specimens selected, in order to procure the acid for investigation, must be quite pure. The spar must be reduced to powder, mixed with sulphuric acid, and heated in metallic vessels, and the fluoric acid must be received in a metallic vessel; for if the acid come in contact with glass it is instantly converted into fluosilicic acid. I employed a leaden alembic and receiver for preparing the acid; but I find that it cannot be kept in a leaden vessel for any length of time, for the lead is soon corroded, and an insoluble fluate of lead formed. Vessels of silver answer very well for keeping it, provided the stopper be air tight; for it is so volatile as not to be easily confined. I put a vessel containing it upon a shelf in a press, where I keep my collection of acids in glass phials; on opening the press door some days after, I was surprised to observe all the phials quite opaque, and white on the outside, as if they had been coated over with silica. The fluoric acid had made its escape, and had corroded the whole of the surface of every one of the phials.

SECT. I.

OF THE ATOMIC WEIGHT OF FLUORIC ACID.

The properties of pure fluoric acid have been detailed with great accuracy by Gay-Lussac and Thenard, and by Sir H. Davy. I have nothing to add to the statements of these eminent chemists, except to say that I found them all quite exact so far as I repeated them.

1. The only person who has attempted to determine the atomic weight of fluoric acid, so far as I know, is Berzelius. And it will be worth while, before I detail the experiments which I have myself made, to state those of this most laborious and accurate experimenter. He endeavoured to determine the atomic weight of this acid by analyzing fluate of silver, fluate of barytes, and fluate of lime, each in as pure a state as he could prepare them.

Berzelius' experiments to determine the atom of fluoric acid.

(1.) 4·936 parts of fused fluate of silver left, when dissolved in water, 0·185 of metallic silver —so that the quantity of fluate of silver actually dissolved was 4·751 parts. This solution being precipitated by sal-ammoniac, furnished 5·349 parts of fused chloride of silver, which is equivalent to 4·32316 parts of oxide of silver. Consequently, if the fluate of silver was anhydrous, and composed of fluoric acid and oxide of silver, its constituents must be

Fluoric acid	0·42784	or	1·45965
Oxide of silver	4·32316	-	14·75
	4·75100 *		

(2.) Six parts of fluate of barytes, when decomposed by sulphuric acid, yielded 7·968 parts of sulphate of barytes, equivalent to 5·267 parts of sulphate of barytes. Hence, fluate of barytes is composed of

Fluoric acid	0·733	or	1·35693
Barytes	5·267	-	9·75
	6·000 †		

(3.) Ten parts of very pure transparent fluate of lime from Derbyshire, when decomposed by sulphuric acid, furnished 17·368 parts of sulphate of lime, equivalent to 7·15153 parts of lime. Hence, fluate of lime is composed of

Fluoric acid	2·84847	or	1·39446
Lime	7·15153	-	3·5
	10·00000		

(4.) Sir H. Davy had made a previous analysis of fluor spar which deserves to be stated. He found its constituents

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* Annals of Philosophy, XV. 279.

† Ibid.

Fluoric acid	27·859	or	1·3514
Lime	72·141	-	3·5
	100·000		

The second column of figures exhibits the atomic weight of fluoric acid, according to these experiments. The reader will perceive that the analysis cannot be perfectly accurate, because a different atomic weight is obtained from every salt examined.

From fluate of silver it is . . .	1·45965
From Berzelius' analysis of fluor spar it is	1·39446
From fluate of barytes it is . . .	1·35693
From Davy's analysis of fluor spar it is	1·3514

The highest atomic weight is 1·45965 and the lowest 1·3514.

Experiments of the author.

2. I prepared some very pure fluate of soda by the following process: Two ounces of carbonate of ammonia were dissolved in water, and a current of fluosilicic acid gas was passed through the liquid till the ammonia was saturated. The solution was then filtered into a silver bason, and carbonate of soda added by small quantities at a time, till the ammonia was almost all driven off, and fluate of soda formed. The whole was then evaporated to dryness in a silver bason, and the dry salt redissolved in water and filtered again, to get rid of a little silica which it still contained. The clear liquid was

evaporated in a silver crucible till the fluate of soda crystallized. It formed transparent crusts very like ice, having a saline but not a strong taste; it was heated in a silver crucible till its water of crystallization was expelled. In this state it formed opaque white crusts, which became again transparent when put into water. The salt had been prepared with so much care, that there was no reason to doubt of its purity. In order to be sure that it was quite anhydrous, the crucible containing it was raised to a low red heat before every experiment.

(1.) *5·25* grains of this salt (which was neutral) were dissolved in a little water in a platinum crucible.

Into another platinum crucible were put *6·25* grains of pure calcareous spar, (equivalent to *3·5* grains of lime,) which were dissolved in dilute muriatic acid; the solution evaporated to dryness, and the salt which was left was dissolved in water.

These two liquids being mixed together, a double decomposition took place, fluate of lime being deposited, and muriate of soda remaining in solution. The crucible containing the whole contents was put on the sand bath, and the whole liquid evaporated to dryness by means of a very gentle but long continued heat. A little hot distilled water was then poured on the dry saline mass, and allowed to remain digesting on it in a very moderate heat for twenty-four hours. A little of the water was then drawn off, and tested with oxalate of ammonia and muriate of lime. It did not become in the least muddy or even opalescent, showing that it contained no sensible quantity either of lime or fluoric acid.

The fluate of lime, formed in this experiment, was carefully collected on a double filter, washed and dried, first in the open air, and then heated to redness. Its weight certainly did not differ by $\frac{1}{100}$th of a grain from 4·75 grains.

From this experiment, which was repeated four or five times before I succeeded in removing all ambiguity from the phenomena, it is evident that 5·25 grains of anhydrous fluate of soda contain just the quantity of acid necessary to saturate 3·5 grains of lime; and that the fluate thus formed weighs 4·75 grains. Hence, it must consist of

Composition of fluate of lime.

Fluoric acid	1·25
Lime	3·5
	4·75

3·5 being the atomic weight of lime, and the salt being neutral, it is obvious that 1·25 must denote the weight of an atom of fluoric acid. It is obvious, likewise, that the anhydrous fluate of soda was composed of

Atom of fluoric acid.

Fluoric acid	1·25
Soda	4
	5·25

for it was neutral, and contained (as we have seen) 1·25 of fluoric acid, which, being equivalent to an atom, required for saturation 4, or an atom of soda.

(2.) 5·25 grains of anhydrous fluate of soda, and 13·25 grains of chloride of barium were dissolved in separate portions of water, the liquids were mixed together, and evaporated to dryness in a platinum crucible by means of a very gentle heat. Distilled water was poured upon the residue, and digested on it for twenty-four hours. A little of it was then drawn off, and tested with sulphate of soda and muriate of barytes; but it was not in the least affected by either of these reagents, showing that it contained no sensible quantity either of barytes or of fluoric acid.

Fluate of barytes.

The fluate of barytes formed in this experiment, being collected on a double filter, washed, dried, and heated to redness, weighed almost exactly 11 grains.

This experiment agrees with the preceding, and serves to confirm it. We see that anhydrous fluate of barytes is composed of

Fluoric acid	1·25
Barytes	9·75
	11

and that 1·25 grains of fluoric acid just saturate 9·75 grains of barytes. This experiment, like the preceding, was made four or five times before I thought of evaporating the whole liquid to dryness. I found traces both of fluoric acid and of barytes in the liquid, whatever proportion of the two salts I mixed; it was the same thing with the fluate of lime. To expel these two salts completely, we must evaporate the liquids containing them to dryness. Then they become insoluble, and we can easily determine by means of a little water whether any of the fluate of soda, and of the muriate of lime, or muriate of barytes originally employed, still exist in the dry salt formed.

Fluate of lead.

(3.) I tried whether solutions of 5·25 grains of fluate of soda, and 20·75 grains of nitrate of lead would completely decompose each other, but the experiments, though frequently repeated, led to no satisfactory results; for I could detect both fluoric acid and oxide of lead in the residual liquid, whether I employed the salts in these proportions, or increased or diminished the quantity of fluate of soda. I was not at that time aware of the effect produced by evaporating the mixture to dryness, and after I became aware of it, my stock of fluate of soda was too far exhausted to allow me to resume my experiments with nitrate of lead, without the risk of not leaving enough to determine the atomic weight of fluoric acid exactly, by means of muriate of lime and muriate of barytes, which I considered as of most importance.

(4.) These experiments show decidedly that the atomic weight of fluoric acid is 1·25. It is obvious, therefore, that the true constituents of fluate of barytes are

Fluoric acid	0·6818
Barytes	5·3182
	6·0000

instead of

Fluoric acid	0·733
Barytes	5·267
	6·000

the proportions found by Berzelius, owing probably to a little silica existing in his fluate of barytes.

It is equally obvious, that the true composition of fluate of lime is

Fluoric acid	26·3158
Lime	73·6842
	100·0000

which approaches nearest to the analysis of Sir H. Davy. I made some experiments with fluor spar in the same way as Berzelius; but they did not agree with each other so closely as to induce me to put much confidence in their accuracy. Indeed, unless we were assured before hand of the perfect purity of the fluor spar employed, the analysis of it could not lead to any useful result.

SECT. II.

OF THE ATOMIC WEIGHT OF FLUOSILICIC ACID.

WHEN sulphuric acid is poured upon the powder of fluor spar in a glass retort, or upon a mixture of pounded glass and fluor spar, and heat applied, it is well known that a gas is extricated, which was long distinguished by the name of fluoric acid; but the presence of silica, which had been recognised in it from the first, has induced modern chemists to give it the name of fluosilicic acid. For by far the most accurate set of experiments on this gas we are indebted to Dr. Davy.*

Specific gravity.

The specific gravity of this gas, as determined by Dr. Davy, is 3·5735. I found the specific gravity 3·58313; but the specimen examined contained a very small proportion of common air. The quantity of this mixture being ascertained and deducted, I found that the real specific gravity was 3·6; for reasons which will appear immediately, I consider the true specific gravity of this gas to be 3·611̇, that of air being reckoned unity. Consequently, 100 cubic inches

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* Phil. Trans. 1812. p. 352.

of it at the temperature of 60°, and when the barometer stands at 30 inches, weigh 110·1385 grains.

When this gas is placed in contact with liquid ammonia it is rapidly absorbed, while the silica which it contains is deposited in a gelatinous state. Dr. Davy found that 40 cubic inches of the gas, when thus treated, deposited 27·2 grains of silica. Upon repeating the experiment, I obtained 27·1 grains of silica; but having procured an apparatus by which I could measure the volume of the gas to within $\frac{1}{1000}$th of a cubic inch, the weight of the silica obtained from 40 cubic inches of the gas was 27·14 grains, or more nearly 27·145 grains.* Now, the weight of 40 cubic inches of this gas is 44·0554 grains. Consequently, it appears from this experiment, that fluosilicic acid is a compound of

Composition of fluosilicic acid.

Fluoric acid	16·9104	or	1·25
Silica	27·1450	-	2·006
	44·0554		

1·25 is the atomic weight of fluoric acid, and

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* This experiment is of very difficult execution, and cost me much labour and time before I was able to execute it with the requisite precision. The silica is very bulky and light, and is apt to be dissolved by the water employed to wash it. In consequence of this, I obtained always too little silica at first, till I discovered the source of the diminution. I have omitted all the unsuccessful experiments. Those given in the text I consider as very near the truth.

2·006 approaches so nearly to 2, the atomic weight of silica, that we can have no hesitation in considering fluosilicic acid as a compound of 1 atom fluoric acid and 1 atom silica; hence, its atomic weight is 3·25.

It was shown in the seventh chapter of this work, that if we multiply the atomic weight of a gaseous body by $1{\cdot}111\dot{1}$ (the specific gravity of oxygen gas) or $0{\cdot}555\dot{5}$, (half the specific gravity of oxygen gas) or by $0{\cdot}277\dot{7}$ (¼th of that specific gravity) we obtain the specific gravity of the gaseous body so multiplied. Now, $3{\cdot}25 \times 1{\cdot}111\dot{1} = 3{\cdot}611\dot{1}$. This number approaches so nearly the specific gravity of fluosilicic acid determined experimentally, as to leave no doubt that it represents the true specific gravity of this gas.

The specific gravity of fluosilicic acid gas, then, is $3{\cdot}611\dot{1}$, and its atomic weight 3·25, and it is a compound of 1 atom fluoric acid and 1 atom silica.

As this gas is decomposed when it comes in contact with water, there are very few of its saline combinations which we have it in our power to form; for the dry bases, as far as my trials went, did not exhibit any disposition to absorb it. When one volume of fluosilicic acid gas is mixed with two volumes of ammoniacal gas, they condense each other into a white solid salt, which is obviously a fluosilicate of ammonia.

This salt is a white powder, which has a saline taste, pretty similar to that of sal-ammoniac. When laid dry upon litmus paper it does not produce any alteration, but when a drop of water is added, the litmus paper becomes red. Fluosilicate of ammonia dissolves in water; but flocks of silica are at the same time disengaged, and the solution reddens vegetable blues. Hence, it is obvious, that water has the property of destroying this salt by decomposing its acid.

From the account given of fluosilicic acid in the preceding part of this section, it is obvious, that it resembles oxygen gas in the number of atoms contained in a given volume of the gas; but oxygen gas contains four times as many atoms in a given volume, as ammoniacal gas does. It follows from this, that the fluosilicate of ammonia, formed by mixing the two gases, is a compound of 2 atoms fluosilicic acid, and 1 atom of ammonia; or it is a bifluosilicate of ammonia. Hence, its composition and atomic weight must be as follows:

2 atoms of fluosilicic acid	6·5
1 atom ammonia	2·125
	8·625

It is obviously anhydrous.—I did not find that one volume of fluosilicic gas was capable of condensing four volumes of ammoniacal gas. I succeeded once in obtaining a complete condensation by mixing three volumes of the acid gas with four volumes of the alkaline gas; but a repetition of the experiment did not succeed.

SECT. III.

OF THE ATOMIC WEIGHT OF FLUOBORIC ACID.

Messrs. Gay-Lussac and Thenard discovered another compound gas, one of the ingredients of which is fluoric acid, and the other boracic acid. It has been generally distinguished by the name of *fluoboric acid*. They procured it by exposing a mixture of fluor spar and anhydrous boracic acid to a strong heat. The gas came over in abundance, and was collected over mercury. Dr. Davy, to whom we are indebted for an excellent set of experiments on this gas, procured it by mixing together one part of anhydrous boracic acid and two parts of fluor spar in a retort, and pouring twelve parts of sulphuric acid on the powder. When the heat of a lamp is applied, the gas comes over, and it must be received over mercury. I prepared the gas by Dr. Davy's method, not having been provided with an apparatus similar to that employed by the French chemists; but I found the process very tedious, and the quantity of gas obtained but small.

Specific gravity.

The specific gravity of this gas was found by Dr. Davy to be 2·3709. I took its specific gravity two different times with great care, and obtained 2·3984. This, as will appear immediately, exceeds the theoretical specific gravity by a quantity rather too great to be ascribed to error in experimenting. I was long unable to account for this difference; I could perceive no mistake in the process, and a repetition of it gave me almost exactly the same result. I found that the gas contained a slight mixture of fluosilicic acid gas. The volume of this being determined, and allowed for, reduced the specific gravity of fluoboric acid gas to 2·38833, which is still above the theoretical gravity. At last I discovered that this gas carries along with it a little sulphuric acid, which, of course, increases its gravity somewhat. According to the most accurate experiments which I could make, 100 cubic inches of the fluoboric acid gas which I examined, contained about 0·8 grain of sulphuric acid. Now, if from 72·844 grains, which I found to be the weight of 100 cubic inches of this gas, we subtract 0·8, there will remain 72·044 grains for the true weight of fluoboric acid gas. This will make its specific gravity 2·3622. Now, we shall see immediately, that the theoretical specific gravity, which undoubtedly must be exact, is $2{\cdot}361\dot{1}$—a number which comes within $\frac{1}{2000}$th part of the actual result of experiment —a difference considerably within the unavoidable errors of experiment.

Fluoborate of ammonia.

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

$$(1.)\quad \left.\begin{array}{l}\text{1 volume fluoboric gas}\\ \text{1 volume ammoniacal gas}\end{array}\right\}\text{forming a solid salt.}$$

$$(2.)\quad \left.\begin{array}{l}\text{1 volume fluoboric gas}\\ \text{2 volumes ammoniacal gas}\end{array}\right\}\text{forming a liquid.}$$

$$(3.)\quad \left.\begin{array}{l}\text{1 volume fluoboric gas}\\ \text{3 volumes ammoniacal gas}\end{array}\right\}\text{forming a liquid.}$$

Upon repeating these experiments I obtained the very same results.

From what was said in the seventh chapter of this treatise, it will be evident to the reader, that ammoniacal gas is twice as bulky with relation to its atomic weight as any of the other gases, with the exception of the four contained in the same table with it. Consequently, if we consider a volume of fluoboric acid gas to represent an atom, it is clear that an atom of ammonia must be represented by two volumes of that gas. It is, therefore, the second of the compounds of the two gases, consisting of 1 volume fluoboric gas, and 2 volumes ammoniacal gas, that represents the neutral compound of 1 atom of each constituent.

Now,

1 volume fluoboric gas weighs	2·3611	or	4·25
2 volumes ammoniacal .	1·1805	-	2·125

2·125 represents the weight of an atom of ammonia, and 4·25 must represent the weight of an atom of fluoboric acid. Now, an atom of boracic acid being 3, and an atom of fluoric acid 1·25, it is evident that fluoboric acid is a compound of 1 atom of boracic acid and 1 atom of fluoric acid united together. For

Atom of fluoboric acid.

3 × 1·25 = 4·25 = the atomic weight of fluoboric acid.

The solid salt, composed of 1 volume fluoboric acid and 1 volume ammoniacal gas, is obviously a bifluoborate of ammonia, composed of

2 atoms fluoboric acid	8·5
1 atom ammonia .	2·125
	10·625

So that an integrant particle of it is represented by the number 10·625.

The third saline compound, consisting of 1 volume of fluoboric gas and 3 volumes of ammoniacal gas, is obviously a subsesquifluoborate, composed of

1 atom fluoboric acid	4·25
$1\frac{1}{2}$ atom ammonia	3·1875
	7·4375

So that an integrant particle of it weighs 7·4375.

The property which the neutral fluoborate of ammonia has to lose half of its ammonia when exposed to the air, and of being converted into a bisalt, is analogous to what happens to other ammoniacal salts. Thus when neutral carbonate of ammonia is exposed to the air in powder, one-half of the ammonia flies off, and a bicarbonate of ammonia remains.

It was shown in the seventh chapter of this treatise, that we obtain the specific gravity of most gases if we multiply their atomic weight by $0{\cdot}555\dot{5}$ (= half the specific gravity of oxygen gas). This law holds in the present case. For

$$4{\cdot}25 \times 0{\cdot}555\dot{5} = 2{\cdot}361\dot{1},$$

a number which only differs by $\frac{1}{2000}$th part from the specific gravity obtained by experiment. This coincidence is too near to leave any doubt that $2{\cdot}361\dot{1}$ is the true specific gravity of fluoboric acid gas.

In this chapter I have taken no notice of the hypothesis originally started by M. Ampere, and so ably supported by Sir H. Davy, that fluoric acid is a compound of equal volumes of hydrogen gas and an unknown supporter of combustion, to which Davy has given the name of *fluorine.* All the facts stated above may be explained just as well by this hypothesis as by the common one. An atom of fluorine will weigh 2·25, and fluoric acid will be a compound of

Fluorine.

1 atom fluorine	2·250
1 atom hydrogen	0·125
	2·375

Fluosilicic acid will be a compound of

1 atom fluorine	2·25
1 atom silicon	1
	3·25

And fluoboric acid will be composed of

1 atom fluorine	2·25
2 atoms boron	2
	4·25

Fluor spar will be a compound of

1 atom fluorine	2·25
1 atom calcium	2·5
	4·75

And in the same easy way may all the other combinations given in this chapter be represented according to Davy's theory. At the same time, this mode of representing these combinations does not give us any superior advantages in accounting for the phenomena. And as no satisfactory evidence of the existence of fluorine had been adduced, I think it safer in the present state of the subject, to abide by the old opinion, without pretending even to conjecture which of the two opinions will be ultimately established. Whoever can succeed in extracting from fluoric acid either a new combustible body, or a new supporter, will settle the point. But the difficulty of experimenting upon fluoric acid is so great, in consequence of the property which it has of decomposing glass vessels, that I was heartily tired of it by the time that I had made out its atomic weight and that of its two compounds, which was the object that I had in view.

CHAP. XVI.

OF THE SULPHURETS.

In the preceding chapters, the composition of several of the metallic sulphurets has been noticed, but it may be acceptable to the reader to take a general view of this important class of bodies. This will be the subject of the present chapter.

Sulphurets of potassium,

1. Sulphuret of potassium. Gay-Lussac first showed that when sulphur and potash are heated together, a portion of the sulphur is acidified at the expense of the oxygen of the potash, and that the compound formed is a mixture of sulphate of potash and sulphuret of potassium.* This view of the matter was further confirmed by Vauquelin.† But for by far the most important set of experiments on the subject, we are indebted to Berzelius, whose paper on the Alkaline Sulphurets, published in 1821,‡ threw a new and unexpected light over this department of chemistry.

Berzelius put a quantity of sulphate of potash into a glass tube, and after having heated it to

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* Ann. de Chim. LXXVIII. 86. † Ann. de Chim. et de Phys. VI. 5.
‡ Kong. Vetensk. Acad. Hand. 1821. p. 80.

redness, he passed a current of hydrogen gas over it as long as water continued to be formed. By this process, both the acid and base were deprived of their oxygen, and there remained a sulphuret of potassium composed of

1 atom sulphur	2
1 atom potassium	5
	7

It had a deep red colour, fused at a temperature below redness, and dissolved in water forming a coloured solution.

By substituting sulphuretted hydrogen gas instead of hydrogen, and repeating the process in the same way, he obtained a compound of

Potassium	5
Sulphur	7·21

5 is an atom of potassium, and 7·21 is somewhat less than 4 atoms of sulphur.

When the experiment was repeated, substituting bisulphuret of carbon, the sulphuret was composed of

Potassium	5
Sulphur	8·42

These compounds are not quite definite.

By fusing carbonate of potash and sulphur together in various proportions, Berzelius obtained several other compounds of potassium and sulphur. The five following sulphurets of potassium seem to be established by these experiments.

	POTASSIUM.		SULPHUR.
1. Sulphuret of potassium	1 atom	+	1 atom
2. Bisulphuret . .	1 atom	+	2 atoms
3. Trisulphuret . .	1 atom	+	3 atoms
4. Quadrosulphuret .	1 atom	+	4 atoms
5. Quintosulphuret .	1 atom	+	5 atoms

Berzelius is also of opinion that there exist two others composed of

	POTASSIUM.		SULPHUR.
1.	1 atom	+	$3\frac{1}{2}$ atoms
2.	1 atom	+	$4\frac{1}{2}$ atoms

But though he formed substances containing the ingredients nearly in these proportions, it is more likely that they were mixtures. For we do not in other cases find sulphur entering into combination in such extraordinary proportions.

2. Sulphurets of sodium.
3. Sulphurets of lithium. } Though these sulphurets have not been particularly examined, we may conclude, from analogy, that they are similar to those of potassium. The protosulphuret of sodium was made by Berthier, and found very similar to the protosulphuret of potassium.*

4. Sulphuret of calcium was formed by Berzelius, by passing a current of sulphuretted hy- Calcium,

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* Ann. de Chim. et de Phys. XXII. 225.

drogen gas over red hot lime: water was formed, and the reduced calcium united with the sulphur of the gas. The sulphuret, thus obtained, was composed of

Calcium . . .	2·5
Sulphur . . .	1·988

Hence, it is obviously a protosulphuret composed of

1 atom calcium . .	2·5
1 atom sulphur . .	2
	4·5

Berthier formed it by heating anhydrous sulphate of lime in a charcoal crucible: the sulphuret of calcium obtained was white, dissolved completely in water, and was not altered by roasting. Its constituents were

Calcium . . .	2·5
Sulphur . . .	1·91

It was, therefore, a protosulphuret of calcium, like that obtained by Berzelius.

Barium, 5. Sulphuret of barium was formed by Berthier from sulphate of barytes, precisely in the same way as he had obtained sulphuret of calcium. This sulphuret is white, with grey spots slightly cohering, capable of being kneaded between the fingers, and in crystalline grains. It dissolved completely in water, and the solution was colourless. Muriatic acid disengaged sulphuretted hydrogen from the solution. The sulphuret of barium is not altered by roasting, but when detonated with nitre it is converted into sulphate of barytes.* Hence, it is obviously a protosulphuret of barium composed of

1 atom barium	8·75
1 atom sulphur	2
	10·75

In Berthier's process there was a slight loss of the sulphur. Hence, he obtained a compound of

Barium	8·75
Sulphur	1·95

Strontium,

6. Sulphuret of strontium. This sulphuret was obtained by Berthier in a similar way; its properties agree nearly with those of sulphuret of calcium. It was a protosulphuret composed of

1 atom strontium	5·5
1 atom sulphur	2
	7·5

In Berthier's process a little of the sulphur had escaped, for he obtained a compound of

Strontium	5·5
Sulphur	1·95

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* Ann. de Chim. et de Phys. XXII. 232.

7. Sulphuret of magnesium is not so easily obtained as the sulphurets of the preceding metals. When sulphate of magnesia is heated in charcoal almost the whole acid is dissipated, and nothing remains but magnesia mixed with a small quantity of sulphuret of magnesium. But sulphuret of magnesium may be obtained in combination with sulphuret of potassium, by heating a mixture of sulphates of potash and magnesia in charcoal: Berthier has shown that it is a protosulphuret of magnesium which is thus obtained. It is a compound of

1 atom magnesium . .	1·5
1 atom sulphur . .	2
	3·5

There was an excess of sulphur in the sulphuret formed by Berthier, amounting to rather less than ¼th of an atom.

8. No attempts have been hitherto made to form the sulphurets of aluminum, glucinum, yttrium, or zirconium. It is by no means unlikely that some of the processes tried by Berzelius would succeed in forming these sulphurets also.

Iron, 9. Sulphuret of iron. Iron and sulphur combine in three proportions.

(1.) The protosulphuret may be formed by heating a mixture of iron filings and sulphur in a close crucible, and continuing the heat till the excess of sulphur is driven off. It has a pale yellow colour, and I have sometimes obtained it in small crystals—it is attracted by the magnet. This sulphuret may be obtained, likewise, by mixing a solution of protosulphate of iron with hydrosulphuret of potash : a black precipitate falls, which is a protosulphuret of iron. Its constituents are

1 atom iron	3·5
1 atom sulphur	2
	5·5

(2.) The sesquisulphuret of iron is obtained when a solution of neutral persulphate of iron is precipitated by hydrosulphuret of potash,—it is necessary to drop the iron solution into the hydrosulphuret: if we reverse the process, the powder which falls is a protosulphuret of iron. The sesquisulphuret of iron is a black powder, which has not been much examined. Its constituents are

1 atom iron	3·5
$1\frac{1}{2}$ atom sulphur	3
	6·5

(3.) Persulphuret of iron is found native, and is known by the name of iron pyrites. It is a brass yellow substance, having the metallic lustre, and usually crystallized in cubes, either smooth or striated—it is not the least attracted by the magnet. This sulphuret may be obtained also artificially, by mixing intimately together 2 parts of protosulphuret of iron and 1 part of sulphur, and heating it in a temperature which must never be elevated to redness. When persulphuret of iron is heated to redness in close vessels, one half of the sulphur is sublimed and protosulphuret of iron remains. It is a compound of

1 atom iron . . .	3·5
2 atoms sulphur . .	4
	7·5

Berthier has shown, that protosulphuret of iron is formed when protosulphate of iron is heated in a charcoal crucible.

When magnetic pyrites is dissolved in an acid some sulphur precipitates: hence, it obviously contains either a slight excess of sulphur, or a slight mixture of cubic pyrites; for protosulphuret of iron dissolves in acids without any deposite of sulphur.

Nickel,

10. Sulphuret of nickel. It may be formed by fusing a mixture of oxide of nickel and sulphur in close vessels, and continuing the heat till the excess of sulphur is driven off. This sulphuret occurs in the mineral kingdom, and was formerly distinguished by the name of *Haarkies (hair pyrites)*. When a current of

sulphuretted hydrogen gas is passed through a neutral solution of nickel in an acid, the sulphuret of nickel also precipitates; but the precipitation is prevented by adding an excess of acid to the solution. The colour of the sulphuret is yellowish grey; it has the metallic lustre, and is not brittle; it is not attracted by the magnet. Its constituents are

1 atom nickel . .	3·25
1 atom sulphur . .	2
	5·25

Cobalt,

11. Sulphuret of cobalt. This sulphuret may be formed either by heating metallic cobalt or its oxide with sulphur in close vessels. It precipitates when sulphuretted hydrogen gas is passed through a solution of cobalt, provided there be no excess of acid, which prevents the precipitate from appearing. This sulphuret has a greyish yellow colour, a metallic lustre, and appears crystallized; it melts in a red heat. Its constituents are

1 atom cobalt . .	3·25
1 atom sulphur . .	2
	5·25

Manganese,

12. Sulphuret of manganese. This sulphuret is easily obtained by heating the protosulphate of manganese in a charcoal crucible. Prepared in this way, it has an iron grey colour, a semime-

tallic lustre, and a crystalline appearance. Its avidity for oxygen is so great that when put into nitric acid it decomposes both the acid and the liquid. When protacetate of manganese is precipitated by an alkaline hydrosulphuret, or by a current of sulphuretted hydrogen gas, a yellowish precipitate falls, which becomes red when collected on the filter, and at last white; when heated, it gives out water and becomes green. It is uncertain, at present, whether this precipitate be a hydrosulphuret of manganese, or a hydrated sulphuret; but what remains after the powder is exposed to heat is a sulphuret of manganese.

Sulphuret of manganese is found native at Nagyag, in Transylvania, and has been described by the German mineralogists under the name of *Manganblende*. It was considered, from the analyses of Klaproth and Vauquelin, as a compound of protoxide of manganese and sulphur; but modern chemists have ascertained that it is in reality a sulphuret of manganese. It has a steel grey colour, and occurs crystallized in oblique four-sided prisms; the fracture is foliated, and the specific gravity 3·950. The constituents of sulphuret of manganese are

1 atom manganese .	3·5
1 atom sulphur . .	2
	5·5

for it dissolves in acids without the deposition of any sulphur.

13. Sulphuret of cerium. This sulphuret is still unknown. When a solution of cerium is precipitated by a hydrosulphuret, the precipitate is in the state of an oxide, and the sulphuretted hydrogen gas escapes. When sulphur is heated with peroxide of cerium, protosulphate of cerium is formed, and perhaps some sulphuret. The mass has a green colour. Cerium,

14. Sulphuret of zinc. When a solution of sulphate of zinc is precipitated by hydrosulphuret of potash, the precipitate is white; but when heated, it becomes light yellow. In this state it is a sulphuret of zinc, similar in its composition to yellow blende. Berthier has shown that this sulphuret is formed likewise when sulphate of zinc is heated in a charcoal crucible. He found that charcoal, in a high temperature, has the property of decomposing blende—bisulphuret of carbon is formed, and zinc sublimes. Sulphuret of zinc dissolves in acids, without depositing any sulphur. It is, therefore, a compound of Zinc,

1 atom zinc . .	4·25
1 atom sulphur .	2
	6·25

15. Sulphuret of cadmium. This sulphuret is formed when cadmium and sulphur are heated Cadmium,

together, or when a salt of cadmium is precipitated by sulphuretted hydrogen—the sulphuret has a fine yellow colour. In a white heat it melts, and crystallizes in cooling; and the crystals are a fine lemon yellow. It dissolves in muriatic acid, without depositing any sulphur, but with the evolution of sulphuretted hydrogen gas. Hence, its constituents are

1 atom cadmium	.	7
1 atom sulphur	.	2
		9

Tin, 16. Sulphuret of tin. Three sulphurets of tin are known.

(1.) Protosulphuret of tin is obtained when sulphur and tin are heated together in a close vessel. To saturate the tin with sulphur, the process should be repeated a second time, mixing the sulphuret intimately with a new portion of sulphur, and exposing the mixture to a full red heat, to drive off all excess. The sulphuret thus formed has the metallic lustre, a bluish grey colour, and fibrous and crystalline appearance. It dissolves in concentrated muriatic acid, without depositing any sulphur; and the gas extricated is totally absorbed by caustic potash. Hence the constituents of this sulphuret are

1 atom tin . .	7·25
1 atom sulphur .	2
	9·25

(2.) If protosulphuret of tin be reduced to a fine powder, triturated with the third of its weight of sulphur, and the mixture be distilled in a heat raised very nearly to redness, till no more sulphur passes off, the sulphuret increases in weight about ten and a half per cent., or, more exactly, 9·25 of protosulphuret became 10·25. It is obvious from this, that a sesquisulphuret of tin has been formed, composed of

1 atom tin . .	7·25
1½ atom sulphur .	3
	10·25

This sulphuret has a yellowish colour, the metallic lustre, and takes a fine polish when rubbed upon a hard body.

(3.) Persulphuret of tin may be obtained by precipitating permuriate of tin by means of sulphuretted hydrogen. The well known substance called Mosaic gold, which is in beautiful yellow scales, and which is prepared in the dry way, by a process pointed out by Mr. Woulfe, is a persulphuret of tin. Its constituents are

1 atom tin . .	7·25
2 atoms sulphur .	4
	11·25

Lead, 17. Sulphuret of lead. There are two sulphurets of lead, both of which I have met with native.

(1.) Protosulphuret of lead is common galena, a well known ore of lead. It has a bluish white colour, the metallic lustre, is crystallized in cubes, very heavy, and very brittle; it melts easily when heated, but does not part with any of its sulphur. Its constituents are

1 atom lead . .	13
1 atom sulphur .	2
	15

(2.) About 20 years ago, I got a specimen of galena from Sir John Sinclair, which had the property of burning with a blue flame when held to the flame of a candle. When distilled, it gave out a quantity of sulphur. I did not subject it to analysis; but, from these properties, it was obviously either a sesquisulphuret or bisulphuret of lead.

(3.) Berthier has shown that, when sulphate of lead is exposed to a strong heat in a charcoal crucible, it is converted into a disulphuret of lead, composed of

2 atoms lead . .	26
1 atom sulphur .	2
	28

Copper,

18. Sulphuret of copper. I have already shown in a former chapter of this work, that there are three sulphurets of copper:

(1.) Disulphuret, composed of

2 atoms copper . .	8
1 atom sulphur . .	2
	10

This sulphuret is obtained when sulphate of copper is heated in a charcoal crucible, as Berthier has shown. During the process, one-half of the sulphur in the salt makes its escape. It is obtained likewise when sulphur and copper are heated together: the combination is accompanied by combustion. This sulphuret has a bluish black colour, and occurs native, being the glance copper ore of mineralogists.

(2.) Sulphuret of copper has not yet been formed artificially; but it exists in copper pyrites, which H. Rose has shown to be a compound of

1 atom sulphuret of copper	6
1 atom sulphuret of iron	5·5
	11·5*

This sulphuret is a compound of

1 atom copper . .	4
1 atom sulphur . .	2
	6

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[*] Ann. de Chim. et de Phys. XXV. 197.

(3.) Bisulphuret of copper. It is formed when any of the salts of copper are precipitated by a current of sulphuretted hydrogen gas. The precipitate is at first brown, but becomes black when dried. Its constituents are

1 atom copper	4
2 atoms sulphur	4
	8

Bismuth, 19. Sulphuret of bismuth. This compound is easily formed by melting bismuth and sulphur together in a close vessel. It exists native, and is known by the name of bismuth glance. It has a light lead grey colour, and the metallic lustre. It occurs in small prismatic striated crystals, so minute that their form has not been recognised. It is much more difficult of fusion than bismuth. Its constituents are

1 atom bismuth .	9
1 atom sulphur .	2
	11

20. Sulphuret of mercury. Two sulphurets of mercury are known. The protosulphuret is formed when a current of sulphuretted hydrogen gas is passed through a solution of protonitrate of mercury; or still better, when the protonitrate of mercury is mixed with a solution of hy-

drosulphuret of potash. The precipitate is a black powder, similar in appearance to protoxide of mercury, but composed of

1 atom mercury	25
1 atom sulphur	2
	27

The persulphuret of mercury is obtained when a solution of corrosive sublimate is decomposed by a current of sulphuretted hydrogen gas. The precipitate is black, and bulky; but when sublimed, it assumes a deep red colour, and becomes the pigment well known by the name of cinnabar. It assumes a scarlet colour when reduced to powder; and the colour becomes the lighter the finer the powder is. The constituents of cinnabar are

1 atom mercury	25
2 atoms sulphur	4
	29

Silver,

21. Sulphuret of silver. This compound is easily formed by heating sulphur and silver together. It has a lead grey colour, the metallic lustre, possesses malleability and sectility, and is much more easily fused than pure silver; it occurs native, and crystallized. The primary form of the crystals is probably the cube. Its constituents are

1 atom silver .	13·75
1 atom sulphur .	2
	15·75

Gold. 22. Sulphuret of gold. Oberkampf made us first acquainted with the sulphuret of gold. He obtained it by precipitating nitro-muriate of gold with sulphuretted hydrogen gas. From his experiments it appears to be a trisulphuret, composed of

1 atom gold . .	25
3 atoms sulphur .	6
	31

But the experiments of Oberkampf were repeated unsuccessfully by Javal and Berzelius. Berzelius found that the sulphur was acidified at the expense of the oxygen in the oxide of gold existing in the solution.

Platinum. 23. Sulphuret of platinum. There are two sulphurets of platinum. When ammonio-muriate of platinum is mixed intimately with sulphur, and the mixture heated in close vessels till the sal-ammoniac flies off and the excess of sulphur, a bisulphuret of platinum is formed. It is grey coloured, and assumes the metallic lustre when rubbed against a hard body. Its constituents are

1 atom platinum	.	12
2 atoms sulphur	.	4
		16

When the bisulphuret of platinum is exposed to a higher temperature, one-half of the sulphur is driven off, and a sulphuret of platinum remains, composed of

1 atom platinum	.	12
1 atom sulphur	.	2
		14

The external appearance of the two sulphurets of platinum is nearly the same.

Rhodium,

24. Sulphuret of rhodium. When the triple salt of rhodium is mixed with a solution of hydrosulphuret of potash, no precipitate appears at first; but, if the liquid be heated, a dark brown powder falls, which becomes black when dried. From the experiments of Berzelius it would appear, that this sulphuret is composed of

1 atom rhodium	.	5·5
1 atom sulphur	.	2
		7·5

Dr. Wollaston found that rhodium and sulphur unite together when heated. The sulphuret thus formed is bluish grey, and has the metallic lustre; and may be deprived of its sulphur by being kept red hot in the open air. From an experiment of Vauquelin, there is reason to consider this as a similar sulphuret with the preceding. He found it a compound of 4 parts rhodium and 1 sulphur. Now, this is nearly 1 atom of rhodium + $\frac{3}{4}$ atom of sulphur.

Palladium, 25. Sulphuret of palladium. This sulphuret is easily formed by heating together palladium and sulphur, or by passing a current of sulphuretted hydrogen gas through a solution of palladium. The sulphuret is greyish white, possesses the metallic lustre, and is a compound of

1 atom palladium .	7
1 atom sulphuret .	2
	9

Uranium, 26. Sulphuret of uranium. I have made no experiments on this sulphuret. It was obtained by Rose, by passing a current of bisulphuret of carbon, in the state of vapour, over protoxide of uranium, heated to redness in a porcelain tube. It was black, and when rubbed by a hard body it assumed the metallic lustre. It has not been analyzed; but is probably a compound of

1 atom uranium .	26
1 atom sulphur .	2
	28

27. Sulphuret of antimony. This sulphuret is easily formed by heating antimony and sulphur mixed together in a close vessel; but it exists native in abundance, being the common ore of antimony. It has the metallic lustre, a leaden grey colour, and is crystallized. The primary form of the crystals is a right rhombic prism, with angles of 88° 30′, and 91° 30′. Its constituents are **Antimony,**

1 atom antimony .	5·5
1 atom sulphur .	2
	7·5

28. Sulphuret of chromium. I have made no experiments on this sulphuret. Berzelius states, in his Lärbok i Kemien,* that it may be formed by passing a current of the vapour of bisulphuret of carbon over protoxide of chromium, raised to a white heat in a porcelain tube. Its colour is light grey, without any metallic lustre; and when pounded in a mortar, it gives a black powder. When treated with nitric acid, it may be converted into neutral sulphate of chromium. Hence its constituents are **Chromium,**

1 atom chromium .	3·5
1 atom sulphur .	2
	5·5

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* II. p. 165.

Molybdenum,

29. Sulphuret of molybdenum. This sulphuret exists native, and is known by the name of molybdena. It has a leaden colour, and is composed of laminæ, which are soft and flexible; and occasionally occur crystallized, in six-sided prisms. It is a bisulphuret, and composed of

1 atom molybdenum	6
2 atoms sulphur	4
	10

Tungsten,

30. Sulphuret of tungsten. I have made no experiments on this compound. Berzelius informs us, that tungsten combines with sulphur in two proportions. He formed one of these compounds by mixing cinnabar and tungstic acid intimately together in a crucible, covering the mixture with charcoal powder and a lid, and then keeping the whole in a white heat for half an hour. The sulphuret is a black powder, which assumes the metallic lustre when rubbed against a hard body. Berzelius says it contains 25 per cent. or ¼th of its weight of sulphur. Hence it was a bisulphuret, composed of

1 atom tungsten	15·75
2 atoms sulphur	4
	19·75

When tungstic acid is dissolved in hydrosulphuret of potash, and precipitated by an acid, a sulphuret is obtained, containing a greater proportion of sulphur. It has a dark yellow colour, and is slightly soluble in water. When heated, it gives out a little water, and its excess of sulphur, and becomes bisulphuret of tungsten.*

Columbium,

31. Sulphuret of columbium. Rose obtained this compound by passing a current of the vapour of bisulphuret of carbon over the oxide of columbium, heated to whiteness in a porcelain tube. It has a dark grey colour, and assumes the metallic lustre when rubbed against a hard body. From Rose's experiments it is obviously a compound of

1 atom columbium .	18
1 atom sulphur .	2
	20

Titanium,

32. Sulphuret of titanium. I have already, in a preceding chapter of this work, given an account of M. H. Rose's experiments on the sulphuret of titanium ; and given my reasons for considering it as a compound of

1 atom titanium .	4
1 atom sulphur .	2
	6

Tellurium,

33. Sulphuret of tellurium. According to

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* Lärbok i Kemien, II. 179.

Klaproth, there are two sulphurets of tellurium. The protosulphuret is steel grey, and has the metallic lustre. When this sulphuret is fused with an additional quantity of sulphur, a leaden coloured sulphuret is formed, having a crystalline texture, and containing a maximum of sulphur.

Arsenic, 34. Sulphuret of arsenic. There are two sulphurets of arsenic which have been long known, and both of which occur in the mineral kingdom.

(1.) Protosulphuret of arsenic (realgar) is formed when sulphur and metallic arsenic are heated together in close vessels, and the heat continued till the excess of sulphur is driven off. It is transparent, has a ruby red colour, and is a compound of

1 atom arsenic	4·75
1 atom sulphur	2
	6·75

(2.) Sesquisulphuret of arsenic (orpiment) is obtained when a solution of arsenic in muriatic acid is precipitated by sulphuretted hydrogen : a yellow powder falls, which is a compound of

1 atom arsenic	4·75
$1\frac{1}{2}$ atom sulphur	3
	7·75

CHAP. XVII.

OF THE MURIATES AND CHLORIDES.

The knowledge of the composition of muriatic acid and the theory of chlorides, for which we are indebted to Sir H. Davy, constitutes, in my opinion, one of the greatest improvements of modern chemistry. It was only advanced by its great discoverer in general terms; and though Dr. John Davy afterwards published a most admirable paper on the chlorides, containing a very great number of experiments, the exactness of which I am enabled to testify from having repeated almost the whole of them; something seems still wanting to enable the chemist to see the connection between the muriate and chloride of the same base. I conceive, therefore, that the facts which I have determined experimentally upon this subject will be acceptable to chemists in general, and of considerable service in the analytical branch of the science.

Action of muriatic acid on metals.

1. A few only of the alkalifiable combustibles are acted upon rapidly by muriatic acid. It dissolves iron, zinc, tin, and antimony with considerable facility. During the solution of these metals, exactly the volume of hydrogen gas is

evolved which ought to have been combined with the oxygen, requisite to convert them into protoxides, supposing that this oxygen had been in the state of water. The reader will recollect that the atomic weights of these bodies are as follows:

Iron .	3·5
Zinc .	4·25
Tin .	7·25
Antimony	5·5

Now, 3·5 grains of iron, 4·25 grains of zinc, 7·25 grains of tin, and 5·5 grains of antimony, supposing these metals pure, give out, when dissolved in muriatic acid, exactly the same volume of hydrogen gas; namely, about 5·9 cubic inches or $\frac{1}{8}$ of a grain. There seems no doubt from this, that these metals during their solution combine with oxygen, and that they derive this oxygen from water, which is decomposed precisely as when iron or zinc is dissolved in sulphuric acid, the oxygen uniting to the metal, and the hydrogen flying off.

It would indeed be equally possible to account for the evolution of the hydrogen gas by conceiving the chlorine of the muriatic acid to combine with the metal, while its other ingredient, the hydrogen, escapes under the form of gas; for the volume of hydrogen evolved on either suppositions, would be precisely the same; but what makes the notion, that the hydrogen comes from water decomposed, preferable to the other is, that these metals cannot be thrown down from the muriatic solution in any other state than that of oxides.

Copper dissolves, likewise, in muriatic acid; but very slowly, and without any sensible effervescence. The solution is brown and opaque, and the copper is at least chiefly in the state of suboxide. I suppose the theory of this solution the same as of the others, and that the want of visible effervescence is to be ascribed to the slowness of the process; for more than a week elapses before a few grains of copper can be dissolved in this acid.

Difference between muriates and chlorides.

2. Most of the alkaline bases combine with muriatic acid very readily, and without any apparent alteration either in the acid or base. I suppose that all these combinations (or almost all of them) while in solution, are in the state of muriates, or that they are compounds of muriatic acid, and the base unaltered. Whether they continue muriates after they are separated in crystals or in powder, depends upon circumstances, and can only be known by an examination of every particular compound. I shall, therefore, take a review of all these compounds which I have examined, and point out their various states as far as I have been able to determine them.

1. Muriate of ammonia. This salt I find, when obtained in the usual way by sublimation, is anhydrous, and is a compound of

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

The water found in this salt by Dr. Murray was no doubt accidental. It has an affinity for water, and even deliquesces if kept in a damp place; but the quantity of water found not amounting to an atom, it is obvious that it cannot be considered as a chemical constituent of the salt.

Chlorides of potassium and sodium.

2. Muriate of potash and muriate of soda exist only in solution—when separated by evaporation in the state of crystals, they are no longer muriates but chlorides; for 9·776 grains of the crystals, usually called muriate of potash, when exposed to a red heat lose 0·276 grain of water, and leave 9·5 grains of the fused salt; and when these 9·5 grains of salt are dissolved in water, and thrown down by nitrate of silver, the chloride of silver after fusion weighs just 18·25 grains, equivalent to 4·5 grains of chlorine. It is obvious then, that the crystals must be composed of

1 atom chlorine	4·5
1 atom potassium	5
	9·5

The water, amounting to rather less than ¼th of an atom, can only be mechanically interposed between the plates of the crystals, and not in chemical combination.

Similar experiments were made with common salt with exactly the same result.

Hence, the crystals of both these salts are chlorides of potassium and sodium, with a little water lodged mechanically between their plates. No crystallized muriate of potash or soda exists.

Muriate

3. Muriate of barytes. This salt usually crystallizes in tables consisting of very short four-sided prisms with square bases. It is not altered by exposure to the air, and is composed of

1 atom muriatic acid	4·625
1 atom barytes	9·750
1 atom water	1·125
	15·5

and chloride of barytes.

When 15·5 of this salt are heated to redness in a platinum crucible, the loss of weight amounts to 2·25, equivalent to two atoms of water, and chloride of barium remains weighing 13·25, and composed of

1 atom chlorine	4·5
1 atom barium	8·75
	13·25

We may either consider the crystals as composed of 1 atom chloride of barium and 2 atoms water, or of 1 atom of anhydrous muriate of barytes and 1 atom water. From the phenomena which take place when barytes is dissolved in muriatic acid, I adopt the second hypothesis as the simplest; indeed, whenever a salt belonging to this genus contains water of crystallization, I conceive it to be simplest, and therefore best to consider it as a muriate. A red heat, if it can resist such a temperature, not only drives off all the water of crystallization, but causes the hydrogen of the acid to unite with the oxygen of the base, and to fly off likewise in the state of water, leaving the salt in the state of a chloride. For it is worthy of remark, that whenever the base is a deutoxide, the salt contains two atoms of muriatic acid or is a bimuriate.

Muriate

4. Muriate of strontian. This salt crystallizes in very long white needles, which when viewed by the microscope have the form of hexagonal prisms. It is more soluble in water than muriate of barytes, and likewise soluble in alcohol, which muriate of barytes is not. Its constituents are

1 atom muriatic acid	4·625
1 atom strontian	6·5
8 atoms water	9
	20·125

When 20·125 of it are heated, they lose 10·125 of their weight, which is equivalent to 9 atoms water, and there remain 10 of chloride of strontium, composed of

and chloride of strontium.

1 atom chlorine	4·5
1 atom strontium	5·5
	10

Muriate of lime

5. Muriate of lime. This salt is easily formed by saturating muriatic acid with lime. It is so soluble and deliquescent as not to be easily crystallized. Yet I have frequently obtained it in regular transparent crystals—and they may be obtained at any time by putting a strong solution of it under the exhausted receiver of an air pump, along with sulphuric acid to absorb the vapour as it flies off. These crystals are four-sided or six-sided prisms, striated longitudinally, and bearing a considerable resemblance to the crystals of sulphate of soda. The constituents of these crystals are the following:

1 atom muriatic acid	4·625
1 atom lime	3·5
6 atoms water	6·75
	14·875

When these crystals are exposed to a red heat, not only the water, but a portion of the acid is apt to make its escape. However, I have repeatedly succeeded in rendering the crystals anhydrous without destroying their subsequent solubility in water, and consequently, without any loss of acid. In such cases, 14·875 lost 7·875, which is equivalent to 7 atoms water. The 7 of chloride of calcium remaining are composed of

and chloride.

1 atom chlorine	4·5
1 atom calcium	2·5
	7

Muriate of magnesia

6. Muriate of magnesia. This salt is easily obtained by saturating muriatic acid with magnesia. The solution is colourless, has a hot, biting taste, and is not easily crystallized. However, I have obtained it from a manufacturer of Epsom salt in pretty large four-sided prisms, apparently with square bases, but too irregular to admit of measurement. These crystals deliquesce when exposed to the air; they are composed of

1 atom muriatic acid	4·625
1 atom magnesia	2·500
5 atoms water	5·625
	12·75

When exposed to heat in a close vessel, they not only lose their water but a portion also of their acid. However, a considerable portion remains undecomposed, and converted into chloride of magnesium. If we make allowance for the decomposed portion, then 12·75 parts of this salt in crystals lose 6·75 parts, which is equivalent to 6 atoms of water, and there remain 6 parts of chloride of magnesium, composed of

and chloride.

1 atom chlorine	4·5
1 atom magnesium	1·5
	6

When this chloride is thrown into water, a hissing noise takes place as when a red hot iron is plunged into water; a great deal of heat is evolved, and the whole is gradually dissolved, leaving behind always a portion of pure magnesia, which I subtracted in the preceding statements.

Muriate of alumina.

7. Muriate of alumina. This salt is easily obtained by saturating muriatic acid with hydrate of alumina. It is a beautiful white matter, without any appearance of a crystalline texture. Its constituents are

1 atom muriatic acid	4·625
1 atom alumina	2·250
3 atoms water	3·375
	10·25

This salt cannot be converted into a chloride of aluminum by heat; when we make the experiment, not only the water, but the whole of the acid is driven off, leaving the alumina behind in a state of purity. Chloride of aluminum is still unknown.

Bucholz, in his Beitrage, (III. 111.) gives us an analysis of this salt. He states its constituents as follows :

Muriatic acid	29·8
Alumina	30·0
Water	40·2
	100·0

Dimuriate.

I have never obtained any salt whose constituents approached those given by Bucholz. His salt seems to have been a dimuriate composed of

1 atom muriatic acid	4·625	or	29·13
2 atoms alumina	4·5	-	28·35
6 atoms water	6·75	-	42·52
	15·875		100·00

For, considering the imperfection of the data which Bucholz employed, the deviations in his analysis, from these numbers, are not greater than might have been expected. What renders the existence of this dimuriate more probable, is, that alumina has the property of uniting in the same way with some other acids.

Muriate of iron

8. Protomuriate of iron. This salt is easily formed by dissolving pure iron filings in muriatic acid in a retort, and setting aside the solution : the salt crystallizes spontaneously, and the super-

natant liquid prevents the absorption of oxygen by it. Protomuriate of iron has a light green colour, exactly similar to that of protosulphate of iron; its taste is sweetish and astringent; it has the form of rhombic plates, which do not deviate far from a right angle, but I was not able to measure them. They are soluble both in water and alcohol. I never could succeed in preserving the solution for any time without alteration, but have kept the dry crystals for a considerable time in a well stopped phial without their undergoing any alteration. The constituents of this salt are as follows:

1 atom muriatic acid .	4·625
1 atom protoxide of iron	4·500
3 atoms water .	3·375
	12·5

When 12·5 parts of this muriate are heated sufficiently without the contact of air, the loss of weight is 4·5 parts, equivalent to 4 atoms of water, and there remain behind 8 parts of chloride of iron, composed of

and chloride.

1 atom chlorine . .	4·5
1 atom iron . .	3·5
	8

The chloride, thus formed, has a grey colour, a good deal of lustre, and a lamellar texture. I have never succeeded in converting the whole of any portion of protomuriate of iron into chloride: on dissolving the chloride in water there always remains more or less of oxide, so that a portion of the muriatic acid is disengaged by the heat; but in the above statement this decomposition was allowed for—the portion decomposed being abstracted from the original weight of salt employed.

Muriate of manganese

9. Protomuriate of manganese. This salt is easily formed by dissolving carbonate of manganese in muriatic acid. It is not easily crystallized: however, by very careful concentration of the solution I have obtained very short six-sided prisms, two opposite faces of which were much larger than the other four. The taste of this salt, like that of the other salts of manganese, has some resemblance to that of sulphate of soda; it is very soluble both in alcohol and water, and is an exceedingly deliquescent salt. Its constituents, when dried by pressure between folds of blotting paper, are as follows:

1 atom muriatic acid .	4·625
1 atom protoxide of manganese	4·5
4 atoms water . .	4·5
	13·625

When 13·625 parts of it are heated just to redness, they lose 5·625 parts of their weight, equivalent to 5 atoms water, and the remaining 8 parts consist of chloride of manganese. This chloride has a red colour and a lamellar texture, and is a beautiful looking substance when first formed. Its constituents are obviously

and chloride.

1 atom chlorine . .	4·5
1 atom manganese . .	3·5
	8

The protomuriate of manganese is apt to be partly decomposed when heated; but in the above statement the portion of the salt thus decomposed is supposed to be withdrawn.

Green muriate of copper

10. Green muriate of copper. This muriate is easily obtained by dissolving the black oxide of copper in muriatic acid, and concentrating the solution. It forms long crystals, consisting of four-sided rectangular prisms of a fine grass green colour. Its taste is exceedingly disagreeable, and when exposed to the air it soon deliquesces. Its constituents are as follows:

1 atom muriatic acid	4·625
1 atom black oxide of copper	5·000
2 atoms water . .	2·250
	11·875

When 11·875 parts of this salt are exposed to a heat of about 400° they lose 3·375 of their weight, equivalent to three atoms water, and a yellowish brown matter remains, weighing 8·5 parts, which is a chloride of copper. It is composed of

and chloride.

1 atom chlorine	. .	4·5
1 atom copper	. .	4
		8·5

This chloride dissolves readily in water, and may be again obtained in the state of muriate of copper.

Dimuriate

11. White muriate of copper. If we mix together copper in the state of fine powder in which it is obtained by precipitating it from its solutions by a plate of zinc, and black oxide of copper also in a fine powder, in the proportion of 4 parts of the former to 5 of the latter; put the mixture into a phial, and pour on it a quantity of concentrated muriatic acid; an intense action takes place at once, great heat is evolved, and a dark coloured opaque solution is formed in a few minutes. If the phial be well corked and placed in an inverted position, a great number of very small crystals are speedily deposited in the form of white grains; but in a more dilute solution I have obtained pretty large white octahedral crystals. These crystals consist of suboxide of copper united to muriatic acid; they contain water of crystallization, but I have not ascer-

tained how much. When heated to redness in a close vessel, they are converted into a dichloride of copper, composed of

1 atom chlorine . .	4·5
2 atoms copper . .	8
	12·5

and dichloride.

In general, there is a slight excess of copper, because a portion of the chlorine is driven off during the process. By Berzelius' analysis, the constituents were

Chlorine . .	4·5
Copper . .	8·316 *

Here the excess of copper was about $\frac{1}{27}$th part or nearly $\frac{1}{12}$th of an atom. I have formed this chloride with a still smaller excess of copper than Berzelius did; but I never was able to get it absolutely free from all excess of copper, owing to the cause just specified.

Muriate of nickel

12. Muriate of nickel. This salt has a fine grass green colour, and crystallizes readily enough; but so irregularly, that I have not been able to determine the shape of the crystals, though they are prismatic, and I believe composed of four-sided prisms. They deliquesce when exposed to the air; when heated, they readily lose their water, and are converted into chloride

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

of nickel. The crystals, carefully dried on blotting paper, are composed of

1 atom muriatic acid .	4·625
1 atom protoxide of nickel	4·25
5 atoms water . .	5·625
	14·5

When 14·5 grains of these crystals are heated cautiously in a retort, they lose 6·75 grains of water (equivalent to 6 atoms), and assume a golden colour. In this state they constitute a chloride of nickel, composed of

and chloride.

1 atom chlorine .	4·5
1 atom nickel .	3·25
	7·75

When this chloride is exposed to the air, it absorbs moisture, and is gradually restored to its original state of muriate of nickel.

Muriate of cobalt

13. Muriate of cobalt. This salt is easily obtained by saturating muriatic acid with carbonate of cobalt, and concentrating the solution sufficiently. When set aside, it deposites beautiful garnet red crystals (probably rhombs, but the shape could not be well made out), which deliquesce when exposed to the air. When these crystals are heated, they melt in their water of crystallization; and, giving out water, the liquid assumes a fine deep blue colour. If we continue

the heat in a close vessel, the whole water is driven off, and a smalt blue coloured chloride of cobalt remains in a hard mass, which readily dissolves in water, forming a red coloured solution. When the solution of muriate of cobalt is dilute, it has a red colour; but when very much concentrated by evaporation, the colour becomes blue—or green, if iron or nickel be present in the liquid. This change of colour takes place more readily if an excess of acid be present in the liquid. The crystallized muriate of cobalt is composed of

Chloride.

1 atom muriatic acid .	4·625
1 atom protoxide of cobalt	4·250
4 atoms water - .	4·500
	13·375

When 13·375 grains of these crystals are heated, they give out 5·625 grains of water, equivalent to 5 atoms; and there remain 7·75 grains of blue coloured chloride of cobalt.

Muriate of zinc,

14. Muriate of zinc. Muriatic acid dissolves zinc with facility; but the solution cannot be made to crystallize. When kept for some time on the sand bath till it ceased to lose weight, it concreted, on cooling, into a white opaque matter, having a very strong and disagreeable taste, and speedily deliquescing, when exposed to the air. It was analyzed by dissolving a given

weight in water, and precipitating the oxide of zinc by an alkali, and the muriatic acid by nitrate of silver. Its constituents are

1 atom muriatic acid	4·625
1 atom oxide of zinc	5·25
	9·875

Chloride.

If 9·875 of this muriate be very cautiously heated in a glass tube, it may be made to give out 1·125 of water, equivalent to an atom. Of course, it has become a chloride of zinc, composed of

1 atom chlorine .	4·5
1 atom zinc . .	4·25
	8·75

This is the only muriate which I have met with, except sal-ammoniac, containing no water of crystallization. When chloride of zinc is heated to redness, it fuses into a transparent liquid. In a red heat it may be sublimed in the open air, giving out a peculiar and not unpleasant odour.

Muriate of cadmium,

15. Muriate of cadmium. A strong solution of muriate of cadmium, committed to spontaneous evaporation, is gradually converted into a mass of short, satiny crystals, somewhat resembling asbestus. 25·29 grains of this salt, decomposed by carbonate of soda, gave 14·59 grains

of ignited oxide. Hence the constituents of the salt are

1 atom muriatic acid .	4·625
1 atom oxide of cadmium	8
1 atom water . .	1·125
	13·75

When 13·75 grains of the crystals are heated in the sand bath, they give out 2·25 grains of water, equivalent to 2 atoms, and become 11·5 grains of chloride of cadmium, obviously composed of

Chloride.

1 atom chlorine .	4·5
1 atom cadmium .	7
	11·5

Bimuriate of tin.

16. Bimuriate of tin. When tin is dissolved in muriatic acid, and the solution sufficiently concentrated, crystals are deposited, usually in the form of plates. They are white and brilliant, have a disagreeable taste, and are soluble in water. The constituents of these crystals I find to be

2 atoms muriatic acid .	9·25
1 atom peroxide of tin .	9·25
3 atoms water . .	3·375
	21·875

I have not attempted to convert these crystals into bichloride of tin. There exists also a protomuriate of tin; but it is not easily got in a state fit for analysis.

Chloride of lead.

17. The muriate of lead does not exist. When acetate or nitrate of lead is mixed with a solution of common salt, and the liquid concentrated somewhat, and then set aside, long white needle formed crystals are deposited. These crystals have a silky lustre. When examined before the microscope, they appear to be flat four-sided prisms, terminated by oblique summits. They have very little taste; and are very sparingly soluble in cold water, though boiling water dissolves a considerable quantity of them. When these crystals were exposed to the greatest heat that I could raise in my sand bath, they lost no weight. When heated to redness in an open vessel, they sublime almost entirely; but, in a close vessel, they may be heated to redness, fused, and converted into *plumbum corneum*, without any loss of weight. This plumbum corneum is a chloride of lead, composed of

1 atom chlorine . .	4·5
1 atom lead . .	13
	17·5

Chlorides of mercury.

18. Neither of the oxides of mercury is capable of uniting with muriatic acid; for both calomel and corrosive sublimate are chlorides. It is needless to enter into any details respect-

ing these well known substances. Their constituents, as determined by numerous experiments, are as follows:

(1.) Calomel or protochloride of mercury,

1 atom chlorine	4·5
1 atom mercury	25
	29·5

(2.) Corrosive sublimate or perchloride of mercury,

2 atoms chlorine	9
1 atom mercury	25
	34

Chenevix's analysis of calomel is very near the truth, but his analysis of corrosive sublimate is not quite so accurate—that of Zaboada is the best which I have seen.

Chloride of silver.

19. Neither does the oxide of silver combine with muriatic acid. The precipitate from nitrate of silver by common salt, when well washed and dried in the open air, loses, when fused, about 2 per cent. of water. Now, this small fractional part of an atom of water can only have been mechanically attached to the precipitate. This precipitate is a chloride of silver, composed of

1 atom chlorine	4·5
1 atom silver	13·75
	18·25

as I have satisfied myself by the most careful experiments.

No general principles respecting the constitution of muriates can be deduced from the salts belonging to that genus whose constitution is known; but it may be worth while to state the facts in a few simple propositions.

Conclusions.

(1.) There are five bases which do not seem capable of combining with muriatic acid except in solution. These are

1 Potash,
2 Soda,
3 Lead.
4 Mercury,
5 Silver.

The combinations which they form, when in the state of crystals or precipitates, are chlorides.

(2.) All the muriates contain water of crystallization, except sal-ammoniac and muriate of zinc.

(3.) Muriates exist, containing

1 atom water.	Muriates of barytes, cadmium.
2 atoms water.	Muriate of copper.
3 atoms water.	Muriate of alumina, protomuriate of iron, bimuriate of tin.
4 atoms water.	Muriate of manganese, cobalt.
5 atoms water.	Muriates of magnesia, nickel.
6 atoms water.	Muriate of lime.
8 atoms water.	Muriate of strontian.

The great variation in the quantity of water in these salts is astonishing.

Water of crystallization per cent.

The muriate of barytes contains the smallest proportion of water; it amounts only to 7·258 per cent. The muriate of lime contains the greatest quantity; it amounts to 45·378 per cent. As it may be useful in some cases to know the quantity of water contained in 100 parts of these salts, I shall set it down in the following table:

Muriate of barytes	7·258
- - cadmium	8·182
- - tin	15·424
- - copper	18·947
- - iron	27
- - alumina	30
- - manganese	33·027
- - cobalt	33·644
- - nickel	38·793
- - magnesia	44·117
- - strontian	44·720
- - lime	45 378

CHAP. XVIII.

OF THE COMPOSITION OF THE SALTS.

It was an opinion advanced long ago by Wentzel, that it was only necessary to determine what we at present call the atomic weight of the acids and bases, which constitute the salts, in order to be able to draw up tables exhibiting the constituents of all of them, without being at the trouble to subject them to a chemical analysis. Berzelius has followed up this idea; and after determining the atomic weights of the acids and bases by a very careful analysis of a certain number of salts, he drew up a complete set of tables, exhibiting the proportion of acid and base contained in all the known salts. But such tables, even supposing the atomic weights on which they are founded to be perfectly exact, can be of little utility to chemists; for they contain no new information whatever. They merely state the known ratio between the acid and base in numbers different from those attached to these bodies, and representing their atomic weights. Now, when we have occasion to use these ratios for calculating the result of a chemical experiment, it is in general much easier

Berzelius' tables of salts.

to have recourse to the atomic weights themselves than to the proportions of the constituents contained in 100 parts of the salt. To give an example:

Atom of sulphuric acid	5
Atom of protoxide of lead	14
Of sulphate of lead	19

Now, the constituents of sulphate of lead per cent. are

Sulphuric acid	26·3158
Protoxide of lead	73·6842
	100·0000

Suppose I have 86 grains of sulphate of lead, and that I wish to know how much sulphuric acid it contains: it is easier to use the proportion

19 : 5 : : 86 : 22·63 = oxide of lead required,

than the proportion

100 : 26·3158 : : 86 : 22·63 = oxide of lead.

or if the second process be sometimes as short as the former, the former has the advantage of always giving a precise result, whereas the latter in general is only an approximation. This has induced me for sometime to abandon the old mode of stating the constituents of salts in the proportions contained in 100 parts of the salt, and to substitute the atomic weight of each constituent. This conveys a more precise idea of the constitution of the salt, and gives us at the same time the atomic weight of an integrant particle of it. This method will come to be adopted likewise in the analysis of minerals, as soon as we have acquired more definite ideas respecting the chemical constitution of these complex bodies—a kind of knowledge into which great progress of late years has been made by Berzelius and his pupils, and capable even at present of a satisfactory developement with regard to many minerals.

Utility of such tables.

The great use of a table of the composition of the salts is to give us an exact knowledge of the weight of each constituent contained in a given weight of the salt. For example, carbonate of soda is a compound of

1 atom carbonic acid	2·75
1 atom soda	4
10 atoms water	11·25
	18

I am in the habit of keeping carbonate of soda in my laboratory in two states; namely, in crystals and anhydrous. If I want exactly 4 grains of soda for any particular purpose, I have only to employ 18 grains of the crystallized carbonate, or 6¾ grains of the anhydrous carbonate; in either case I am sure of having exactly the quantity of soda required: whereas, if I were obliged to employ caustic soda, it would not be so easy to determine how much of it contained the exact quantity of soda required. But it is obvious, that no table exhibiting the composition of the salts can furnish us with any information which will be useful in this point of view, unless it tells us whether the salts are anhydrous; and, if they contain water, how many atoms of that liquid enter into the integrant particle of the salt. No general laws respecting the water of crystallization being known, it is still necessary to subject every salt to a rigid analysis in order to determine whether any water be present in it, and how much.

I have made a very considerable number of analyses with this object in view, and I shall state the results of them in this chapter. Now, salts are of two different kinds—some are composed of an acid and a base simply united together, with or without water: these may be called simple salts. Others are formed by the union of two simple salts together, and this either with or without an alteration in the atomic quantity of water present. These salts are usually called *triple salts;* but the term *double salts,* applied to them by Berzelius, is much more appropriate. These double salts are exceedingly numerous, though only a few of them have been noticed in chemical books. It will be convenient to consider the simple salts in the first place, because a knowledge of them is necessary in order to understand the constitution of the double salts.

SECT. I.

OF THE SIMPLE SALTS.

M. Gayton-Morveau, to whom the science of chemistry is indebted for the present nomenclature of the salts, divided them into as many genera as there were acids, and gave each genus a name derived from that of the acid belonging to it. Bergman, who had contrived a Latin nomenclature for the salts some years before the appearance of Morveau's nomenclature, on the other hand, divided them into as many genera as there were bases, and derived the generic names from that of the base. In this plan he was followed by Dr. Black. Both of these methods of arranging the salts have their advantages and disadvantages. In reality, which ever mode we adopt, we clap under the same genus, salts possessing very different and almost opposite properties. At present I shall follow Bergman's method, because I have arranged the salts according to it in my System of Chemistry. In general I shall merely give the constituents of each salt without making any observations on its properties, except when they may be necessary, when speaking of salts not previously accurately described in chemical books.

1. SALTS OF AMMONIA.

1. Sulphate of ammonia. Its constituents are

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

Mode of analysis.

The specimen analyzed was in large and beautiful crystals prepared expressly for the purpose. My method was this: 8·25 grains were dissolved in water, and the liquid mixed with a solution of 13·25 grains of chloride of barium. After the sulphate of barytes had precipitated, the residual liquid was examined for barytes and sulphuric acid, but found to contain no traces of either; hence, 8·25 grains of the salt contain 5 grains of sulphuric acid. The remaining 3·25 grains constitute the ammonia and water. The salt was neutral; consequently, 2·125 of ammonia must have been present to saturate the 5 of sulphuric acid. The remaining 1·125 was obviously water. I mention these particulars because Berzelius, in the tables of the constituents of salts which he published, has stated that the sulphate of ammonia contains 23·91 per cent. of water, (the result of his analysis was 23·3.*) Now it is obvious, that the salt which I analyzed contained per cent.

Sulphuric acid	60·606
Ammonia	25·757
Water	13·636
	99·999

Berzelius' salt, therefore, must have contained two atoms of water. The salt which I analyzed was composed of regular rectangular plates with bevilled edges, and from some observations on the crystals, I am induced to consider their primary form as a four-sided rectangular prism with square bases. It would seem from Berzelius' analysis, that there is another sulphate of ammonia, containing twice as much water as the salt which I analyzed. It is the only form of the sulphate of ammonia with which I am acquainted. I wish Berzelius had mentioned the shape of the crystals which he examined.

Mode of analysis.

2. Nitrate of ammonia. To ascertain the composition of this salt I put a quantity of it into a small retort, from the beak of which a bent tube passed to the top of a graduated glass jar filled with mercury, and standing on the mercurial trough, the apparatus was precisely similar to the one described in chapter sixth, sect. 1st, p.

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* Afhandlingar, V. 148.

140, by means of which I determined the volume of carbonic acid gas disengaged from a given weight of calcareous spar. A spirit lamp was applied to the bottom of the retort, by which the salt was melted and decomposed into protoxide of azote and water. The volume of deutoxide of azote evolved was measured; the undecomposed salt was washed out of the retort, and evaporated in the very same temperature ás the original salt had been till it ceased to lose weight—it was then weighed. By this means I ascertained the exact quantity of salt decomposed. The reader is probably aware, that when nitrate of ammonia is heated it is completely decomposed into protoxide of azote and water, as was shown many years ago by Sir H. Davy. It is easy to see that this must be the case.

	OXYGEN.	AZOTE.	HYDROGEN.
Nitric acid composed of	5 atoms	+ 1 atom	+ 0 atom
Ammonia . .	0	+ 1	+ 3
Total	5	+ 2	+ 3

Now,

3 atoms water consist of	3	+ 0	+ 3
2 atoms protoxide of azote	2	+ 2	+ 0
Total	5	+ 2	+ 3

So that an integrant particle of nitrate of ammonia (supposing it anhydrous) is decomposed by heat into 3 atoms water and 2 atoms protoxide of azote.

3 atoms water weigh	3·375
2 atoms protoxide of azote	5·5
	8·875

8·875 parts of nitrate of ammonia (if anhydrous) would give out, when decomposed, 5·5 parts of protoxide.

The volume of protoxide of azote obtained, enabled me to determine the weight of anhydrous nitrate of ammonia decomposed; and the difference between this weight, and that of the salt decomposed in my experiment, gave me the water of crystallization which my salt contained. The constituents of nitrate of ammonia obtained in this way are as follows:

1 atom nitric acid	6·75
1 atom ammonia	2·125
1 atom water	1·125
	10·000

This is just the quantity of water found by Berzelius in his analysis of this salt.*

Davy analyzed this salt in three states: namely, in prismatic crystals, in a fibrous state, and compact. The result is as follows:

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* Ann. de Chim. LXXX. 180.

	PRISMATIC.	FIBROUS.	COMPACT.
Nitric acid	69·5	72·5	74·5
Ammonia	18·4	19·3	19·8
Water	12·1	8·2	5·7
	100·0	100	100

The first salt contained obviously 1 atom of water; it was in the same state as the salt which I analyzed. The second contained nearly three fourths of an atom, and the third very nearly half an atom. These experiments were made before chemists were in possession of the requisite data for accurate analysis. But I mention them because they show that this salt may exist with different proportions of water of crystallization.

Carbonate, 3. Carbonate of ammonia. This salt is anhydrous; its constituents are

1 atom carbonic acid	2·75
1 atom ammonia	2·125
	4·875

It may be easily formed by mixing together 1 volume of carbonic acid gas and 2 volumes of ammoniacal gas, both as dry as possible. These two gases immediately condense into a white powder, which is obviously a compound of 1 atom carbonic acid and 1 atom of ammonia, and which does not contain any water. But I have never met with this salt in commerce; the freshest carbonated ammonia which I have been able to procure containing 1½ atom of carbonic acid to the atom of ammonia, and constituting, therefore, the salt which I am just going to notice.

Sesquicarbonate,

4. Sesquicarbonate of ammonia. This is the name which ought to be given to the carbonate of ammonia of the shops. It is usually in the state of hard white cakes, having a strong ammoniacal odour, and instantly giving a purple colour to cudbear paper. I have frequently examined this salt at different times and in different places, to ascertain whether there was any difference in its composition. It is only a sesquicarbonate when newly prepared; by keeping, it gradually loses a portion of its ammonia, and I have obtained it in a great variety of states between a sesquicarbonate and bicarbonate; but never constituting a true bicarbonate. I analyzed this salt in the following manner:

7·375 grains of it were dissolved in water, and mixed with a solution of 9 grains of oxalic acid crystals. The mixture, when recent, produced no change on cudbear paper, and therefore contained no free ammonia. It reddened litmus paper; but the blue colour was speedily restored when the paper was left exposed to the air: hence, it was owing to the carbonic acid disengaged from the ammonia by the oxalic acid. Now, 9 grains of oxalic acid crystals contain 4·5 grains of true acid, which require for saturation 2·125 grains of ammonia. This, consequently, is the weight of ammonia in 7·375 grains of sesquicarbonate.

7·375 grains of sesquicarbonate of ammonia were dropped into sulphuric acid, and the carbonic acid gas disengaged was driven through lime water. The weight of the carbonate of lime precipitated was 9·375 grains, equivalent to 4·125 grains of carbonic acid. Hence, the constituents of the salt are

$1\frac{1}{2}$ atom carbonic acid	4·125
1 atom ammonia	2·125
1 atom water . .	1·125
	7·375

This salt may be obtained anhydrous by mixing together 3 volumes of carbonic acid gas and 4 volumes of ammoniacal gas.

Bicarbonate, 5. Bicarbonate of ammonia. This salt may be obtained by reducing the sesquicarbonate to powder, and exposing it to the open air for some time in a dry place. It gives out a portion of its ammonia, and at the same time loses its smell. Its constituents, determined in the same way as those of the preceding salt, are

2 atoms carbonic acid	5·5
1 atom ammonia .	2·125
1 atom water . .	1·125
	8·75

It may be obtained anhydrous by mixing equal volumes of carbonic acid and ammoniacal gases.

Borate,

6. Borate of ammonia. The constituents of this salt seem to me to be as follows:

1 atom boracic acid	3
1 atom ammonia .	2·125
2 atoms water . .	2·25
	7·375

I merely satisfied myself that the acid existing in the salt is not more than 1 atom. I then ascertained the weight of the acid, and inferred the other constituents from the deficiency of weight. The above analysis approaches to that of Berzelius.*

Phosphate,

7. Phosphate of ammonia crystallizes in rhomboids, and is much less transparent than biphosphate. The constituents of this salt are as follows:

1 atom phosphoric acid	3·5
1 atom ammonia .	2·125
2 atoms water . .	2·250
	7·875

7·875 grains of phosphate of ammonia in crystals were dissolved in water, and mixed with a solution of 20·75 grains of nitrate of lead. After the precipitation of the phosphate of lead, the

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* See Annals of Philosophy, III. 57.

residual liquid was not rendered muddy by phosphate of ammonia or nitrate of lead. But a little of the phosphate of lead remains in solution, unless the liquid be evaporated to dryness, and the residue dissolved in water. The consequence of this is, that sulphate of soda renders the residual liquid slightly opalescent.

Biphosphate,

8. The biphosphate of ammonia is composed of

2 atoms phosphoric acid	7
1 atom ammonia . .	2·125
	9·125

9·125 grains of biphosphate of ammonia in crystals were just decomposed by 41·5 grains of nitrate of lead. Hence, the crystallized salt contains no water. This salt forms very beautiful transparent four-sided right prisms with square bases. Taste acid,—reddens vegetable blues.

Arseniate,

9. Arseniate of ammonia crystallizes without any great difficulty; though it has a considerable tendency to pass into binarseniate. Its crystals are regular octahedrons often with an intervening prism between the pyramids. It is anhydrous, and is composed of

1 atom arsenic acid	7·75
1 atom ammonia	2·125
	9·875

For 9·875 grains are just decomposed by 20·75 grains of nitrate of lead.

10. Binarseniate of ammonia. This salt was obtained by dissolving crystallized arseniate of ammonia and dry arsenic acid in water, each in the atomic proportions. The solution being sufficiently concentrated and set aside, large crystals of binarseniate of ammonia were deposited. They were opaque white irregular rhomboids; the taste of the crystals was saline, astringent, and acid, and they strongly reddened vegetable blues. Binarseniate,

19·875 grains of this salt were dissolved in water, and mixed with a solution of 41·5 grains of nitrate of lead. After the arseniate of lead had precipitated, the residual liquid was neither affected by glauber salt nor nitrate of lead. Hence, we see that 19·875 of this salt contain just 2 atoms of arsenic acid. The constituents of the salt consequently are

2 atoms arsenic acid	15·5
1 atom ammonia	2·125
2 atoms water	2·25
	19·875

11. Chromate of ammonia. This salt is not easily obtained in a state of purity, from the great tendency which it has to part with half of its ammonia during its concentration. It may, however, be procured in a solid state by the following process: supersaturate chromic acid with ammonia, and place the solution (which should Chromate,

be concentrated) under the exhausted receiver of an air pump, standing over a vessel filled with concentrated sulphuric acid. The water and excess of ammonia gradually evaporate, and leave the chromate of ammonia behind in a dry state. It has a fine yellow colour, and is in crystalline scales, which are not altered by exposure to the air. Its taste is hot and saline, and it is exceedingly soluble in water; it produces no alteration on cudbear paper, but very slightly reddens litmus paper. Solutions of 8·625 grains of this salt and 20·75 grains of nitrate of lead being mixed together, chromate of lead precipitated, and the supernatant liquid was transparent and colourless, and contained no traces of chromic acid or of lead. Hence, the salt is anhydrous and composed of

1 atom chromic acid	6·5
1 atom ammonia	2·125
	8·625

Bichromate,

12. Bichromate of ammonia. This salt is obtained when we concentrate the solution of chromate of ammonia on the sand bath. One half of the ammonia flies off, and the bichromate gradually precipitates in the form of beautiful red crystalline scales, which are not altered by exposure to the air. The taste of this salt is hot, and bitter, and very disagreeable; it reddens

vegetable blues, and is very soluble in water. When heated it melts and loses its water and ammonia; a dark green matter remains, which speedily becomes solid, exhibiting the rudiments of crystallization on the surface. This matter is brittle, has a cooling and sharp taste, and partly dissolves in water, forming a deep yellow solution, and partly remains in the state of a deep green insoluble matter. It is obvious, that by the heat the chromic acid had been partly converted into protoxide of chromium; so that the dark green matter left was a kind of chromate of chromium.

17·375 grains of this salt were just deprived of the whole of their chromic acid by 41·5 grains of nitrate of lead. Hence, the constituents of the salt are

2 atoms chromic acid	13
1 atom ammonia . .	2·125
2 atoms water . .	2·25
	17·375

13. Bitungstate of ammonia. I have already given an account of this salt in a preceding chapter of this work. Its constituents I believe to be

Bitungstate,

2 atoms tungstic acid	37·5
1 atom ammonia .	2·125
2 atoms water . .	2·25
	41·875

I have not analyzed the other species of this salt, which is perhaps a tungstate—not having obtained it in sufficient quantity.

Acetate,

14. Acetate of ammonia. Taste hot and aromatic—crystals transparent four-sided oblique prisms, terminated by a rhomb. Faces apparently striated—very deliquescent, so that they cannot be measured. Analyzed by digesting a solution of 40 grains of the crystals with 40 grains of pure carbonate of lime in fine powder; 15·5 grains of the carbonate of lime had been dissolved, indicating 15·5 grains of acetic acid. Hence, the constituents of the salt are

1 atom acetic acid	6·25
1 atom ammonia	2·125
7 atoms water	7·875
	16·25

This salt was crystallized by placing a concentrated solution of it under the exhausted receiver of an air pump over sulphuric acid. Mr. Rootsey of Bristol crystallized it in that way about eight years ago.

Benzoate,

15. Benzoate of ammonia. This salt forms beautiful crystals, having a silky lustre. I find, that when kept in a carelessly stopped vessel they gradually lose half of their ammonia, and are converted into bibenzoate; but I have not ascertained the water of crystallization of this

last salt. The benzoate is very sparingly soluble in water. Its constituents are

1 atom benzoic acid	15
1 atom ammonia	2·125
1 atom water .	1·125
	18·25

Succinate,

16. Succinate of ammonia. From an analysis of this salt which I made several years ago, I am disposed to consider it as composed of

1 atom succinic acid	6·25
1 atom ammonia .	2·125
2 atoms water .	2·25
	10·625

Oxalate,

17. Oxalate of ammonia. This salt, being of considerable service in chemical analyses, was examined by me with great care, and its constituents found to be

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

Binoxalate,

18. Binoxalate of ammonia. This salt is easily obtained by adding to a solution of oxalate of ammonia crystals of oxalic acid, in the proportion of 8·875 of the former to 9 of the latter. When the solution is concentrated it yields

beautiful crystals of binoxalate of ammonia: these crystals are partly octahedrons, partly four-sided flat prisms, apparently rectangular, having two opposite lateral edges usually truncated. Taste acid,—reddens vegetable blues, and is not altered by exposure to the air. When 20·125 grains of these crystals are dissolved in water and mixed with a neutral solution of 12·5 grains of carbonate of lime in muriatic acid, the residual liquid, after the precipitation of the oxalate of lime, is neither affected by oxalate of ammonia nor muriate of lime. Hence, the constituents of the salt are

2 atoms oxalic acid	9
1 atom ammonia .	2·125
8 atoms water .	9
	20·125

Tartrate.

19. Tartrate of ammonia. The constituents of this salt are

1 atom tartaric acid	8·25
1 atom ammonia .	2·125
	10·375

For 10·375 grains of it and 20·75 grains of nitrate of lead exactly decompose each other.

If the preceding list of ammoniacal salts be sufficiently extensive to entitle us to draw any deductions, we may conclude, that about ¼th of the ammoniacal salts are destitute of water of crystallization, and that the hydrous salts usually contain only 1 or 2 atoms, and very rarely more than 2 atoms of water in an integrant particle of the salt. Acetate of ammonia, alone, was found to contain 7 atoms, and binoxalate of ammonia 8 atoms.

2. SALTS OF POTASH.

Sulphate,

1. Sulphate of potash. This well known salt contains no water, but is composed of

1 atom sulphuric acid	5
1 atom potash . .	6
	11

Bisulphate,

2. Bisulphate of potash. This salt, which has been long well known, may be easily obtained by dissolving sulphate of potash in dilute sulphuric acid, and evaporating the solution. It crystallizes in thin rhomboids: the plane angles of the larger faces are 97° 20′ and 82° 40′; and the inclinations of the faces to each other are 107° 15′ and 72° 45′. Its taste is acid and bitter, and it is not altered by exposure to the air. A pretty strong heat is necessary to drive off the excess of acid and reduce the salt to the state of simple sulphate of potash. The proportion of the acid and potash to each other, in this salt, has been

long known;—the following experiment shows us, likewise, the proportion of water:—18·25 grains of it being dissolved in water and mixed with a solution of 26·5 grains of chloride of barium, a double decomposition took place, and after the sulphate of barytes had precipitated the residual liquid was neither affected by sulphate of soda nor muriate of barytes. Hence, the constituents are

2 atoms sulphuric acid	10
1 atom potash . .	6
2 atoms water . .	2·25
	18·25

Nitrate,

3. Nitrate of potash. This salt is seldom free from a little water lodged mechanically between the plates of the crystals, which is easily driven off by drying the salt on the sand bath. Its constituents are

1 atom nitric acid .	6·75
1 atom potash .	6
	12·75

Carbonate,

4. Carbonate of potash. This salt is, in general, stated in chemical books to be incapable of crystallizing: however, I have obtained it in pretty regular prismatic crystals by evaporating its solution in a gentle heat. These crystals are composed of

1 atom carbonic acid	2·75
1 atom potash .	6
2 atoms water .	2·25
	11

The water was determined by heating 11 grains of the crystals to redness : the loss of weight was 2·25 grains.

Sesquicarbonate,

5. Sesquicarbonate of potash. In a solution of impure carbonate of potash, with which carbonate of ammonia had been mixed and ammonia disengaged, large crystals formed : they were irregular six-sided plates, and seemed composed of a congeries of small crystals, whose form could not be determined. They were translucent, had an alkaline taste, and rendered cudbear paper violet. When analyzed they proved a compound of

$1\frac{1}{2}$ atom carbonic acid	4·125
1 atom potash .	6
6 atoms water .	6·75
	16·875

These crystals were first observed by Dr. Nimmo of Glasgow, a very ingenious chemical friend of mine, who was so good as to bring them to my laboratory, where their composition was determined.

Bicarbonate,

6. Bicarbonate of potash. The constituents of this well known salt are as follows :

2 atoms carbonic acid	5·5
1 atom potash	6
1 atom water	1·125
	12·625

The crystallized bicarbonate of commerce always contains a little more than an atom of water. This surplus varies in quantity, and is, I suppose, lodged mechanically between the plates of the crystals. The greatest quantity of water which I have met with in this salt is 1½ atom, and the least about 1¼ atom. This uncertainty in the aqueous portion of this salt renders it difficult to employ it in chemical analyses, where an exact quantity of potash is wanted for any particular purpose. But, if we expose the salt to a red heat we convert it into an anhydrous carbonate, composed of

1 atom carbonic acid	2·75
1 atom potash	6
	8·75

So that 8·75 grains of it contain just 6 grains of potash—in this way I use it.

Phosphate, 7. Phosphate of potash. This salt is not very easily obtained in a state of purity; however, by neutralizing a solution of carbonate of potash with phosphoric acid, concentrating the solution, and setting it aside for some days, a neutral phosphate of potash may be obtained in regular crystals. The taste of this salt is saline and not strong; its crystals are octahedrons, having, most commonly, a short rectangular prism interposed between the two pyramids. It produces no alteration on vegetable blues, and its constituents are

1 atom phosphoric acid	3·5
1 atom potash .	6
1 atom water .	1·125
	10·625

In general, the crystals contain rather more than 1 atom of water. Indeed, in a very careful analysis I obtained exactly 1·68 grain of water from 11·18 grains of the crystals; this is precisely 1½ atom water. I am rather inclined to consider the half atom as chemically combined with the salt likewise; because the crystals may be kept for any length of time in a temperature above 500° without losing any weight. When phosphate of potash is fused it assumes a yellow colour, but becomes again white on cooling.

8. Binarseniate of potash. This salt crystallizes in four-sided prisms, with square bases; but the primary form, according to Mitcherlich, is an octahedron, with a square base. Its constituents are **Binarseniate,**

2 atoms arsenic acid	15·5
1 atom potash .	6
1 atom water .	1·125
	22·625

But there is almost always a little surplus water (amounting to about half an atom) lodged mechanically between the plates of the crystals.

Chromate,

9. Chromate of potash. This beautiful salt contains no water of crystallization. Its constituents are

1 atom chromic acid	6·5
1 atom potash .	6
	12·5

Bichromate,

10. Bichromate of potash. Neither does this salt, the most splendid and one of the most useful of the whole tribe of salts, contain any water of crystallization. Its constituents are

2 atoms chromic acid	13
1 atom potash .	6
	19

Acetate,

11. Acetate of potash. This salt is so deliquescent that it is not easy to analyze it by the usual methods; but the following experiment comes sufficiently near to leave no doubt about the quantity of water which it contains when in crystals: 29·5 grains of protohydrate of acetic

acid, equivalent to 25 grains of the pure acid, were saturated with bicarbonate of potash. The quantity necessary for the purpose was 52·74 grains, which I knew, by a previous analysis, to contain exactly 24 grains of potash. Thus I obtained a solution of acetate of potash in water; and I knew the exact weight of the acetic acid, and of the potash constituting the salt. The solution was placed in a small wedgewood dish under the exhausted receiver of an air pump, a few inches above a glass tray, containing concentrated sulphuric acid. In a few days the whole water had evaporated, and left the dry salt, partly in a state of crystals, and partly in that of a dry white crust, which had probably lost a little of its water of crystallization. Its weight was 57·26 grains; and it was obviously composed of

Acetic acid .	25
Potash . .	24
Water . .	8·26
	57·26

If we divide each of these numbers by 4, we shall obtain the atomic weights of the constituents as follows:

Acetic acid	6·25	or	1 atom,
Potash .	6	-	1 atom,
Water .	2·06	-	2 atoms.

There is a slight deficiency in the water, which

I ascribe to the portion of the salt, which had been reduced to a white crust.

Binacetate, 12. Binacetate of potash. This salt was obtained by dissolving carbonate of potash in acetic acid, in the proportion of one integrant particle of the former to two integrant particles of the latter, and concentrating the solution over sulphuric acid, under the exhausted receiver of an air pump. The binacetate crystallized to the very last drop in large transparent flat plates, so irregular, that their form could not be determined, though they were probably four-sided prisms. These crystals had a sour taste, reddened vegetable blues, and deliquesced rapidly when exposed to the air.

25·25 grains of these crystals, when cautiously heated on the sand bath, lost 6·75 grains of their weight, consisting of pure water; and when heated to redness in a platinum crucible, left 8·75 grains of carbonate of potash, equivalent to 6 grains of potash. Hence, the constituents of the salt are

2 atoms acetic acid	12·5
1 atom potash .	6
6 atoms water .	6·75
	25·25

Benzoate, 13. Benzoate of potash. This salt was obtained by digesting benzoic acid and carbonate of potash (in the proportion of 15 parts acid and 8·75 carbonate of potash) in water, and concentrating the solution. The crystals obtained were large, transparent flat four-sided rectangular right prisms, terminated by rectangular bases; the lustre silky; the crystals not altered by exposure to the air; taste, a peculiar and not unpleasant sweet. 24·5 grains of these crystals, when burnt in an open crucible, left very nearly 8·75 grains of carbonate of potash. Hence, the constituents of the salt are

1 atom benzoic acid	15
1 atom potash .	6
3 atoms water .	3·375
	24·375

14. Oxalate of potash. This well known salt, which crystallizes in four-sided oblique prisms, is composed of

Oxalate,

1 atom oxalic acid	4·5
1 atom potash .	6
1 atom water .	1·125
	11·625

15. Binoxalate of potash. This salt crystallizes in rhombs, only slightly oblique, and therefore approaching the form of cubes. Its constituents are

Binoxalate,

2 atoms oxalic acid	9
1 atom potash .	6
2 atoms water .	2·25
	17·25

Quadroxalate,

16. Quadroxalate of potash. This salt, for the first knowledge of which we are indebted to Dr. Wollaston, crystallizes in octahedrons, the apexes of which are generally deeply truncated. It is composed of the following constituents:

4 atoms oxalic acid	18
1 atom potash .	6
7 atoms water .	7·875
	31·875

Teroxalate,

I once obtained another oxalate of potash, consisting of long prisms, which effloresced when exposed to the air. I found the constituents of this salt in its effloresced state

3 atoms oxalic acid*	13·5
1 atom potash .	6
6 atoms water .	6·75
	26 25

But, as this analysis was only made once, and upon a small scale, I lay no great stress upon it. I mention the circumstance to put others on their guard respecting the existence of a fourth

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* The analysis gave $3\frac{1}{7}$th atoms.

oxalate of potash, if they should happen to meet with these efflorescing crystals in any of their experiments.

Tartrate.

17. Tartrate of potash. This salt may be obtained in large four-sided prisms, with bases, which are rhombs, with angles of about 93° and 87°. I have obtained it in very large crystals, not less than an inch in diameter.

To determine the quantity of potash which it contains, I exposed 16·5 grains of it to a heat gradually raised to redness, and kept up the red heat in an open platinum crucible till the tartaric acid was completely destroyed. Water was poured into the crucible, and 9 grains of crystals of oxalic acid being added, the crucible was covered with a piece of glass. After the effervescence was at an end, the solution was gently evaporated to dryness, and the dry salt redissolved in water. This solution was perfectly neutral, for it neither altered the colour of litmus nor cudbear paper; but 9 grains of crystals of oxalic acid contain just 4·5 grains of true acid, equivalent to an atom. Hence, 16·5 grains of tartrate of potash contain just 6 grains of potash, equivalent to an atom. This potash must be combined with an atom of tartaric acid, equivalent to 8·25 grains. The remaining 2·25 grains, necessary to make up the weight of tartrate of potash employed, must be water, and is obviously equivalent to 2 atoms. Thus we see that the crystals of this salt are composed of

1 atom tartaric acid	8·25
1 atom potash .	6
2 atoms water .	2·25
	16·5

The crystals used in the preceding experiment were large and transparent, and had been prepared with great care. I have had in my possession crystals of this salt in needles, which seemed to contain no water of crystallization; for, 14·25 grains of them, being dissolved in water, and mixed with a solution of 20·75 grains of nitrate of lead; the liquid, being examined after the deposition of the tartrate of lead, was found to contain no sensible quantity of tartaric acid, or of oxide of lead, by the tests of tartrate of potash and nitrate of lead.

Bitartrate, 18. Bitartrate of potash. This salt is seldom or never quite free from tartrate of lime. 24·75 grains of it were exposed to a red heat in a platinum crucible; and the residue, being dissolved in water, and mixed with 9 grains of crystallized oxalic acid, was found to be quite neutral. Hence, it is obvious that the constituents of this salt are

2 atoms tartaric acid	16·5
1 atom potash .	6
2 atoms water .	2·25
	24·75

If the salts of potash exhibited above be sufficiently numerous to entitle us to draw any conclusions, we may infer that these salts are either anhydrous, or contain 1, or at most 2 atoms of water. Quadroxalate of potash and sesquicarbonate constitute the only deviations from this law; and from their singular nature, we had reason to look for some peculiarity in their constitution.

3. SALTS OF SODA.

Sulphate,

1. Sulphate of soda. This well known salt crystallizes commonly in flat four-sided prisms, the faces of which are channelled longitudinally. It effloresces very speedily when exposed to the air; and loses all its water of crystallization in 24 hours, when confined in the exhausted receiver of an air pump, with sulphuric acid. Its constituents are

1 atom sulphuric acid	5
1 atom soda .	4
10 atoms water . .	11·25
	20·25

There is usually a minute quantity of water lodged mechanically between the plates of the crystals. This, in an integrant particle of the salt, may amount at a maximum to 0·03 parts, which constitutes about $\frac{1}{376}$th part of the whole water in the salt. It amounts to only $\frac{1}{37\cdot5}$th of an atom, showing clearly that it is not chemically combined with the salt.

Nitrate,

2. Nitrate of soda. This salt, which crystallizes in rhombs, resembles nitrate of potash in the absence of water of crystallization, and the presence of a small quantity of that liquid lodged mechanically between the plates of the crystals. Its constituents are

1 atom nitric acid	.	6·75
1 atom soda	.	4
		10·75

Carbonate,

3. Carbonate of soda. This salt is familiarly known in this country, being manufactured to a considerable extent. It may be met with in commerce in beautiful crystals, seven or eight inches long; but I have never got it in a state of complete purity. It usually contains about 2 per cent. of sulphate of soda; and it is exceedingly difficult to get rid of this impurity. After 12 careful crystallizations of it in my laboratory, we still could detect the presence of sulphuric acid in the crystals, though in too minute quantity to appreciate its weight. The constituents of this salt, when crystallized in octahedrons, with a rhombic base, the apices of which are always deeply truncated, are as follows:

1 atom carbonic acid	2·75
1 atom soda	4
10 atoms water	11·25
	18

When the salt is crystallized in hot water, the shape of the crystals is different; and the quantity of water of crystallization is less.

Sesquicarbonate,

4. Sesquicarbonate of soda. This salt is found native in Barbary, where it is known by the name of trona. It constitutes hard masses, which do not deliquesce in the air; and is said to be employed in the north of Africa, where rain seldom falls, for building the walls of houses. It is manufactured in London, for the use of the soda-water makers; and is sold in the state of a white powder. I have tried to crystallize it, without success. Its constituents are as follows:

$1\frac{1}{2}$ atom carbonic acid	4·125
1 atom soda	4
2 atoms water	2·25
	10·375

This constitution was first pointed out by Mr. Phillips.

Bicarbonate,

5. Bicarbonate of soda. This salt was made and analyzed many years ago by Rose, and afterwards by Berthollet. I tried to form it in a Nooth's apparatus—the crystallization of the salt

speedily plugged up the tubes, and prevented the process from succeeding. I then suspended a concentrated solution of carbonate of soda in a distiller's fermenting tun, till the bicarbonate was deposited in crystals. This process is easy, because the bicarbonate of soda is much less soluble in water than the carbonate. The colour of this salt is white, and the crystals are semi-transparent, and not altered by exposure to the air. They have the shape of four-sided rectangular prisms, terminated by an oblique rectangular base; but were not susceptible of accurate measurement. The taste is alkaline, but exceedingly weak, even when compared with the taste of carbonate of soda. This salt gives a purple colour to cudbear paper, in the same manner as common carbonate of soda. At the temperature of 64°, 100 parts of water dissolve 9·33 parts of this salt. The solution cannot be heated, far less concentrated, without driving off a portion of the acid, and converting the salt first into sesquicarbonate, and finally into common carbonate of soda.

When 10·625 grains of this salt in crystals are fused in a platinum crucible, they lose 3·875 grains of their weight, and leave a residue of anhydrous carbonate of soda, weighing 6·75 grains. 106·25 grains of the crystals dissolved in dilute sulphuric acid with a very violent effervescence; and the loss of weight, owing to the escape of carbonic acid gas, amounted to 59 grains. This loss is rather too high. The reason was, that the effervescence was so violent, that a little of the liquid was dissipated in drops before I was able to prevent it; but the following experiment, in conjunction with the two preceding ones, leaves no doubt respecting its constituents: 10·625 grains of the crystals were put into a glass jar, water was poured over them, and 9 grains of crystals of oxalic acid added to the liquid. After the effervescence was at an end, the liquid was heated to drive off the whole of the carbonic acid gas. It was then examined, and found perfectly neutral; for it did not in the least alter the colour of cudbear or litmus paper.

From this last experiment we see that 10·625 grains of the crystals contain 4 grains of soda. From the first experiment it appears that, after fusion, these 4 grains of soda still retained 2·75 grains (equivalent to 1 atom) of carbonic acid. Now, $2{\cdot}75 \times 2 = 5{\cdot}5$; and, by the second experiment, the carbonic acid in 10·625 grains of the crystals was 5·9 grains. This exceeds 5·5 a little, for the reason already specified. Thus the constituents of the salt are

2 atoms carbonic acid	5·5
1 atom soda . .	4
1 atom water . .	1·125
	10·625

Borax, 6. Borax. This well known salt has been long in the hands of chemists, and subjected to many analytical experiments; but our processes for separating the boracic acid from the soda are so imperfect, that it was not till after perusing Mr. Arfwedson's new process for analyzing the borates, that I was able to perform a satisfactory analysis. I have shown in a preceding part of this work, that borax is, in reality, a biborate of soda, composed of

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

Phosphate, 7. Phosphate of soda. This salt, which is the best known of all the phosphates, is much more soluble in hot than in cold water; and, therefore, is easily obtained in regular crystals. The primary form of the crystal is an oblique prism with a rhombic base. The inclinations of the faces of the prism to each other are, according to Mitcherlich's measurement, 67° 50′, and 112° 10′. It effloresces very speedily when exposed to the air; and, on that account, the water of crystallization is not easily determined. The taste of this salt is saline, and not strong. It melts readily when heated; and even the anhydrous salt easily fuses in a red heat.

I made use of this salt, which is perfectly neutral, to determine the atomic weight of phosphoric acid. After analyzing it in the way described in a preceding part of this work, I formed it by dissolving in water 35 grains of pure phosphoric acid, and adding to the solution 180 grains of crystallized carbonate of soda. The solution, after this addition, was perfectly neutral, and yielded phosphate of soda to the very last drop. Now, 35 grains of phosphoric acid represent 10 atoms, and 180 grains of crystallized carbonate of soda contain 40 grains of soda, equivalent to 10 atoms. This experiment proves decisively, that the atom of phosphoric acid weighs 3·5, and that phosphate of soda is composed of an atom of acid united to an atom of base. The water of crystallization was determined by exposing the salt to a red heat. I have already stated, that when the salt is quite free from efflorescence the water amounts to 12 atoms, for 21 grains of the salt lose 13·5 grains of water. But I have frequently found the water less than this, obviously from an incipient efflorescence. In some of my earlier experiments it amounted only to 11 atoms; but in my later experiments in which I was at the requisite pains to prevent efflorescence, the water was always 12 atoms. The constituents of the salt are

1 atom phosphoric acid	3·5
1 atom soda .	4
12 atoms water .	13·5
	21·0

Biphosphate,

8. Biphosphate of soda. I formed this salt by mixing together solutions of 210 grains of phosphate of soda and 78·75 grains of phosphate of ammonia. The solution was evaporated to dryness, and the dry mass exposed to a red heat to drive off the whole of the ammonia. By this process it is obvious, that the salt contained just 2 atoms of phosphoric acid united to 1 atom of soda. The salt is very difficult to crystallize; it usually concretes into a thick mass when evaporated; it is only by spontaneous evaporation that crystals can be got, and the quantity must be considerable otherwise no crystals can be procured. I did not succeed in procuring crystals in the vacuum of the air pump.

This salt has an acid and saline taste, reddens vegetable blues, and is usually crystallized in four-sided prisms terminated by four-sided pyramids. The inclinations of the faces of the prisms are to each other, according to Mitcherlich's measurement, 78° 30′ and 101° 30′. He considers the primary form to be a rectangular octahedron.

From the method of forming this salt, it is obvious that its constituents are 2 atoms of acid and 1 atom of base. 135·5 parts of the salt, when heated to redness, lose, according to Mitcherlich, 35·5 parts of water; this is equivalent to 3½ atoms. Hence, the constituents of the salt are

2 atoms phosphoric acid	7
1 atom soda . .	4
3½ atoms water .	3·9375
	14·9375

It remains to be seen whether the half atom of water be not mechanically lodged between the plates of the crystals.

Arseniate.

9. Arseniate of soda. This salt is obtained with great ease in large crystals; because it is much more soluble in hot than in cold water. Mitcherlich has shown that the crystals have the same form as those of phosphate of soda: when exposed to the air the salt speedily effervesces on the surfaces, but does not fall to powder; when heated it undergoes the watery fusion. 100 parts of water at 47° dissolve 22·268 parts of this salt.

I obtained this salt by mixing solutions of 7·75 parts of arsenic acid and 18 of crystallized carbonate of soda. The salt formed was neutral, and the liquid yielded crystals to the very last drop. 20·75 grains of the crystals, when heated, lose 9 grains of water, equivalent to 8 atoms. Hence, the constituents of the salt are obviously

1 atom arsenic acid	7·75
1 atom soda .	4
8 atoms water .	9
	20·75

Binarseniate,

10. Binarseniate of soda. I formed this salt by adding to a solution of 20·75 parts of arseniate of soda, 7·75 parts of arsenic acid. The solution does not crystallize readily; but by perseverance I obtained crystals of the bisalt to the very last drop.

This salt, as Mitcherlich has shown, has the same form with biphosphate of soda. The crystals redden vegetable blues, and do not undergo any visible change from several weeks' exposure to the air; they are exceedingly soluble in water; when heated, they do not, like arseniate of soda, undergo the watery fusion. 25·125 grains of these crystals were exposed to a heat slowly raised to redness: the salt fused into a white enamel, and lost 5·625 grains of its weight. It is obvious from this, and from the method of preparing it, that the constituents of the salt are

2 atoms arsenic acid	15·5
1 atom soda . .	4
5 atoms water . .	5·625
	25·125*

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* The analysis of the arseniate of soda, which I published some years ago in the Annals of Philosophy, Vol. XV. p. 82, is very incorrect. I

11. Chromate of soda. This is a beautiful transparent yellow salt, one of the finest of the chromates. Its crystals are four-sided transparent prisms, with square bases—sometimes octahedrons, usually elongated. It does not seem to undergo any alteration by exposure to the air, but melts when exposed to a very moderate heat. Its constituents are as follows: Chromate,

1 atom chromic acid	6·5
1 atom soda	4
12 atoms water	13·5
	24

12. The bichromate is a very dark red salt with a shade of brown; it crystallizes in large irregular plates, seemingly rhombic. I have not yet succeeded in getting it quite free from chromate, for the solubility of both salts is nearly the same. Bichromate,

13. Tungstate of soda. I have obtained this salt both in six-sided prisms, apparently regular, and in four-sided oblique prisms. Its taste is intensely bitter. Its constituents are as follows: Tungstate,

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was not aware at the time, that neither the quantity of arsenic acid nor phosphoric acid can be accurately determined by precipitation. The method of determining these salts, which I have given in the text, was by synthesis—a method susceptible of the most perfect accuracy, if the requisite care be taken to employ the constituents in a state of purity.

1 atom tungstic acid	18·75
1 atom soda	4
6 atoms water	6·75
	29·5

Columbate, 14. Columbate of soda. The appearance and properties of this salt have been described in Vol. II. p. 78. of this work. Its constituents are as follows:

1 atom columbic acid	19
1 atom soda .	4
10 atoms water .	11·25
	34·25

Acetate, 15. Acetate of soda. This salt is the best known of all the alkaline acetates. It is not altered by exposure to the air, and is capable of bearing a higher temperature without decomposition than any of the other acetates which I have examined. The constituents of this salt are as follows:

1 atom acetic acid	6·25
1 atom soda	4
6 atoms water	6·75
	17

Succinate, 16. Succinate of soda. This salt crystallizes in four-sided prisms, and its constituents are as follows:

1 atom succinic acid	6·25
1 atom soda	4
6 atoms water	6·75
	17

so that it resembles the acetate of soda exactly in its constitution.

Oxalate,

17. Oxalate of soda. I have never been able to obtain this salt in regular crystals. It usually forms white opaque crusts; once I got it in small round globules rather beautiful, and probably composed of small prisms diverging from a centre; it contains no water of crystallization; but the integrant particle of the salt, dried in the open air, usually contains about $\frac{1}{4}$th of an atom of water, lodged mechanically between the fibres of the mass. Its constituents (when this water is driven off by a moderate heat) are

1 atom oxalic acid	4·5
1 atom soda	4
	8·5

Binoxalate,

18. Binoxalate of soda. This salt is easily formed by digesting a solution of 9 parts of oxalic acid crystals on 9·5 parts of oxalate of soda. A complete solution takes place, and when the solution is concentrated it readily deposites fine crystals of binoxalate of soda, which have the form of flat rectangular prisms, the larger faces of which consist of rhomboids with angles of

nearly 120° and 60°—not altered by exposure to the air—taste very sour, and it reddens vegetable blues powerfully. At the temperature of 46°, 100 parts of water dissolve 1·88 of these crystals. At the temperature of 83°, the quantity of crystals dissolved by 100 water is 3·49—specific gravity of the crystals 1·980. 16·375 grains of these crystals, heated on the sand bath, lost 3·375 grains of weight; hence, the constituents are

2 atoms oxalic acid	9
1 atom soda	4
3 atoms water	3·375
	16·375

Tartrate,

19. Tartrate of soda. This salt crystallizes in fine needles having considerable lustre. Its constituents are

1 atom tartaric acid	8·25
1 atom soda	4
2 atoms water	2·25
	14·5

To a solution of this salt in water, we added the requisite quantity of tartaric acid to convert the whole into a bitartrate, in order to verify Thenard's statement, that there exists a bitartrate of soda nearly as insoluble as bitartrate of potash;*

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* Ann. de Chim. XXVIII. 12.

but we could not succeed in obtaining any such salt.

20. Saclactate of soda. This salt has been noticed in a preceding chapter. Its constituents are Saclactate.

1 atom saclactic acid	13
1 atom soda	4
5 atoms water	5·625
	22·625

21. Urate of soda. This salt was formed by digesting together uric acid, and a solution of the carbonate of soda in the requisite proportions. The whole acid dissolved in the hot liquid, but afterwards precipitated when the solution was set aside; it was dried in the open air. This salt is a white tasteless powder, not sensibly soluble in water. Its constituents are Urate.

1 atom uric acid	9
1 atom soda	4
1 atom water	1·125
	14·125

The salts of soda, in general, present a striking contrast to those of potash: only two of them are anhydrous—the nitrate and oxalate; the urate contains only 1 atom of water, and the sesquicarbonate and tartrate only 2; all the rest contain 5, 6, 8, 10, or 12 atoms of water.

No other genus of salts, except those of soda, contains 12 atoms of water.

4. SALTS OF BARYTES.

Sulphate,

1. Sulphate of barytes. This well known salt contains no water of crystallization; though the native crystals decrepitate, and probably, therefore, contain a little water mechanically lodged between their plates. I find that precipitated sulphate of barytes, if it be well washed, and thoroughly dried by exposure to the air for a sufficient time, retains about 3 per cent. of water, which is easily driven off by exposing the powder to a red heat in a platinum crucible. This amounts to rather more than the third of an atom of water which is only mechanically lodged in the pores of the powder, and not chemically combined with it. The constituents of the salt are

1 atom sulphuric acid	5
1 atom barytes	9·75
	14·75

Nitrate,

2. Nitrate of barytes. This salt usually crystallizes in octahedrons; it is not altered by exposure to the air; it is apt to be contaminated with muriate of barytes, and then contains

water; but the pure nitrate of barytes is anhydrous, being composed of

1 atom nitric acid	6·75
1 atom barytes	9·75
	16·5

From the analyses of this salt by Kirwan, and Fourcroy, and Vauquelin, and also from the method which Dr. Forchhammer took to obtain manganesic acid—namely, heating black oxide of manganese and nitrate of barytes, (the success of which, he says, depends upon not driving off the water of crystallization of the salt)—there is reason to suspect that nitrate of barytes sometimes contains water of crystallization; but I have never myself seen the salt in that state.

3. Carbonate of barytes. This salt is also well known. It is anhydrous, and composed of Carbonate,

1 atom carbonic acid	2·75
1 atom barytes	9·75
	12·5

4. Phosphate of barytes. This is a tasteless white powder, insoluble in water, and therefore not capable of being obtained in the state of crystals. It is anhydrous, and composed of Phosphate,

1 atom phosphoric acid	3·5
1 atom barytes	9·75
	13·25

Biphosphate,

5. Biphosphate of barytes. This salt, first noticed by Berzelius, crystallizes in four-sided rectangular prisms with square bases. I have not analyzed it; but from the experiments of Berzelius, I consider it as a compound of

2 atoms phosphoric acid	7
1 atom barytes . .	9·75
2 atoms water . .	2·25
	19

Chromate,

6. Chromate of barytes. This is a pale yellow powder, without either beauty or intensity of colour. It is tasteless and anhydrous, and is composed of

1 atom chromic acid	6·5
1 atom barytes	9·75
	16·25

I have not made any attempts to prepare a bichromate of barytes.

Sesquicolumbate,

7. Sesquicolumbate of barytes. This is a tasteless white powder, composed of

1½ atom columbic acid	28·5
1 atom barytes	9·75
	38·25

Acetate,

8. Acetate of barytes. This salt usually crystallizes in long needles, so very slender that it

is difficult to make out the form. Its constituents are

1 atom acetic acid	6·25
1 atom barytes	9·75
3 atoms water	3·375
	19·375

It is not sensibly altered by exposure to the air, at least in my laboratory which is rather damp.

Oxalate,

9. Oxalate of barytes is a white tasteless powder, obtained when oxalate of ammonia and nitrate or muriate of barytes are mixed in the atomic proportions. It is not sensibly soluble in water, and does not affect vegetable blues. When 17·625 grains of it are exposed to a red heat in a platinum crucible, there remain 12·5 grains of carbonate of barytes, equivalent to 9·75 grains of barytes. Hence, the constituents of the salt are

1 atom oxalic acid	4·5
1 atom barytes	9·75
3 atoms water	3·375
	17·625

Binoxalate,

10. Binoxalate of barytes was formed by decomposing the muriate of barytes, and digesting the precipitate with twice the atomic quantity of oxalic acid requisite to saturate the base. It crystallizes in needles so irregular that their shape could not be determined; it has but little

taste, is very sparingly soluble in water, but strongly reddens vegetable blues. 22·175 grains of this salt when heated to redness in a platinum crucible, left 12·5 grains of carbonate of barytes. Hence, the constituents are

2 atoms oxalic acid	9
1 atom barytes	9·75
3 atoms water	3·375
	22·125

Tartrate, 11. Tartrate of barytes forms irregular crystalline grains; it is tasteless, and does not alter the colour of vegetable blues. It loses no weight unless it be exposed to a heat sufficiently high to decompose the acid. 18 grains of the salt in powder, kept in a red heat till it had become white, were reduced to 12·5 grains, which were carbonate of barytes. Hence, the salt is anhydrous, and composed of

1 atom tartaric acid	8·25
1 atom barytes	9·75
	18

Bitartrate. 12. Bitartrate of barytes forms transparent crystals in the form of right prisms with bases apparently square. Taste acid, and reddens vegetable blues slowly, on account of its little solubility. 100 parts of water, at the temperature of 65°, dissolve 1·24 parts of this salt. Its con-

stituents, determined both analytically and synthetically, were

2 atoms acid	16·5
1 atom base	9·75
2 atoms water	2·25
	28·5

From the preceding catalogue it appears that a considerable proportion of the salts of barytes are anhydrous. Indeed, it would have been easy to have added to the list of anhydrous barytes salts, if I had not been anxious to confine myself to those which I have myself examined. For the arseniate, tungstate, molybdate, seleniate, and sulphite of barytes are all anhydrous. So also is the borate, which I believe to be a compound of

1 atom boracic acid	3
1 atom barytes	9·75
	12·75

Those barytes salts which contain water seem never to have more than 1, 2, or at most 3 atoms of that liquid; so that barytes in this respect agrees with ammonia and potash.

5. SALTS OF STRONTIAN.

1. Sulphate. This salt, like the sulphate of barytes, contains no water of crystallization; Sulphate,

even the precipitated salt is perfectly anhydrous, if it be dried in a temperature of 212°. Its constituents are

1 atom sulphuric acid	5
1 atom strontian	6·5
	11·5

When the precipitated sulphate of strontian is dried in the open air, it retains about $\frac{1}{144}$th part of its weight of water mechanically lodged among its particles. This amounts to about $\frac{1}{8}$th of an atom.

Nitrate,

2. Nitrate of strontian. Of this salt there are two species, distinguished from each other by the presence or absence of water of crystallization.

Anhydrous;

(1.) Anhydrous nitrate of strontian crystallizes in dodecahedrons composed of two six-sided pyramids applied base to base. The apices of the pyramids are deeply truncated, so as to give the crystal the appearance of a six-sided table with bevilled edges; it is not altered by exposure to the air. Its constituents are

1 atom nitric acid	6·75
1 atom strontian	6·5
	13·25

Hydrous.

(2.) Hydrous nitrate of strontian is a transparent salt, crystallized in acute rhomboids. Its lustre is glassy, and it effloresces when exposed to the air. Its constituents are

1 atom nitric acid	6·75
1 atom strontian	6·5
4 atoms water	4·5
	17·75

Carbonate,

3. Carbonate of strontian. This salt, like the carbonate of barytes, is anhydrous; the water contained in the native carbonate amounts certainly to less than $\frac{1}{1000}$th part of the whole. The constituents of the pure carbonate are

1 atom carbonic acid	2·75
1 atom strontian	6·5
	9·25

The carbonate of strontian, from Strontian in Argyleshire, contains rather more than 6 per cent. of carbonate of lime; or it is a compound of very nearly

10 atoms carbonate of strontian	92·5
1 atom carbonate of lime	6·25
	98·75

Whether this mineral be a chemical compound, or only a mixture, I cannot say; but, from its appearance, one would be disposed to believe that the two carbonates are in chemical union.

This mineral, it is well known, has a fine green colour. The only metallic bodies which I can find in it are, protoxide of manganese, which is green, and perhaps a trace of iron. Is it probable that the green colour is furnished by the protoxide of manganese?

Phosphate, 4. Phosphate of strontian. This salt is easily obtained by mixing together solutions of phosphate of soda and nitrate of strontian in the atomic proportions. The phosphate of strontian precipitates in the state of a white powder, which must be edulcorated, and dried in the open air. The phosphate of strontian is a fine white light powder, having scarcely any taste, and producing no change on vegetable blues.

When exposed to the greatest temperature of the sand bath (about 600°), it loses no weight. 10 grains of it, when exposed to a red heat, lose 0·84 grain of weight, consisting of water driven off. Hence, 11·125 grains of the salt would have lost 0·9345 grain. This approaches so nearly to 1 atom of water, that I consider the composition of the salt to be

1 atom phosphoric acid	3·5
1 atom strontian .	6·5
1 atom water .	1·125
	11·125

Biphosphate, 5. Biphosphate of strontian. This salt was formed by dissolving phosphate of strontian in phosphoric acid, and mixing the solution with alcohol. The biphosphate precipitated in the state of a fine white soft powder, which had an acid taste, and strongly reddened vegetable blues. 15·75 grains of this salt, dried in the open air, lost, when exposed to an incipient red heat, 2·25 grains of water. From this it is obvious that the constituents of the salt are

2 atoms phosphoric acid	7
1 atom strontian .	6·5
2 atoms water .	2·25
	15·75

When the alcoholic solution, from which the biphosphate of strontian had precipitated, was concentrated and set aside, it deposited a number of transparent crystals, which had a very acid taste, and consisted of phosphoric acid and strontian. The result of an analysis of them led me to consider these crystals as a quadrophosphate of strontian; but the quantity which I possessed was too small to enable me to determine the point in a satisfactory manner.

6. Arseniate of strontian. This salt was obtained by mixing together solutions of nitrate of strontian and arseniate of soda in the atomic proportions. No immediate precipitate appeared; but in 24 hours a number of small crystals were Arseniate,

deposited on the sides of the vessel. These crystals proved, on examination, to be arseniate of strontian. They were very minute rectangular four-sided prisms, having no taste, and producing no change on vegetable blues. The salt dissolves very sparingly in water—100 grains of that liquid, at the temperature of 60°, dissolving only 0·284 grain of the crystals. When 23·25 grains of these crystals were exposed to a heat gradually raised to redness, the loss of weight, owing to the escape of moisture, was 9 grains. Hence, the constituents of the salt are

1 atom arsenic acid	7·75
1 atom strontian .	6·5
8 atoms water .	9·0
	23·25

Chromate, 7. Chromate of strontian. This salt is easily formed by mixing together solutions of chromate of potash and nitrate of strontian—the chromate of strontian immediately falls down. When edulcorated and dried in the open air, it is a powder, having a fine yellow colour, destitute of taste, and not sensibly soluble in water. It loses no weight by exposure to a red heat, and is, therefore, anhydrous. Its constituents are

1 atom chromic acid	6·5
1 atom strontian .	6·5
	13

8. Acetate of strontian crystallizes in thin flat transparent plates ; but, by spontaneous evaporation, it may be obtained in long quadrangular prisms with rectangular bases. Its taste is sharp, and it gives an impression of bitterness. The salt does not affect vegetable blues. It has a silky lustre, is pretty soluble in water, and is not altered by exposure to the atmosphere. 13·875 grains of this salt were exposed to a red heat in a platinum crucible ; the residual matter was digested in a solution of carbonate of ammonia till the whole liquid was driven off. It was then exposed to a heat sufficient to expel the whole ammonia. The carbonate of strontian thus obtained weighed 9·25 grains, equivalent to 6·5 grains of strontian. Hence, the constituents of the salt are **Acetate,**

1 atom acetic acid	6·25
1 atom strontian .	6·50
1 atom water .	1·125
	13·875

9. Oxalate of strontian is a white tasteless insoluble powder, obtained by mixing oxalate of ammonia and muriate of strontian together, in the atomic proportions. 13·25 grains of this salt, dried in the open air upon paper, were exposed to a red heat in a platinum crucible. The carbonate of strontian remaining weighed 9·25 **Oxalate,**

grains, equivalent to 6·5 grains of strontian. Hence, the constituents of the salt are

1 atom oxalic acid .	4·5
1 atom strontian .	6·5
2 atoms water .	2·25
	13·25

Binoxalate, 10. Binoxalate of strontian was formed by employing twice the requisite quantity of oxalic acid to saturate the strontian. It crystallizes in pretty large four-sided prisms, too rough on the surface to admit of measuring the angles; feels harsh, reddens vegetable blues, but dissolves very sparingly in water. 15·5 grains of the salt, heated to redness, left 9·25 of carbonate of strontian. Hence, the salt is anhydrous, and composed of

2 atoms oxalic acid .	9
1 atom strontian .	6·5
	15·5

Tartrate, 11. Tartrate of strontian. This salt was obtained by mixing tartrate of potash and nitrate of strontian in the atomic proportions, each in pretty concentrated solutions. The tartrate of strontian was gradually deposited in oblique rhomboids, with angles of 113° 20′, and 66° 40′. This salt is tasteless, and insoluble in water. It was analyzed by exposing 18·125 grains of it to redness in an open platinum crucible, and keeping up the heat till the carbonate of strontian became white. It weighed 9·25 grains. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom strontian .	6·5
3 atoms water .	3·375
	18·125

The salts of strontian resemble those of barytes, though there is a tendency in these salts to contain more water. Six of the salts described above, or one half of the whole, are anhydrous; two contain 1 atom water; and we have a single salt with 2, 3, 4, and 8 atoms of water respectively.

6. SALTS OF LIME.

Sulphate,

1. Sulphate of lime. Of this salt there are two species, both found native; namely, the anhydrous and hydrous.

Anhydrous;

(1.) Anhydrous sulphate of lime, distinguished by mineralogists by the name of *anhydrite*, crystallizes in right rectangular prisms. Its constituents are

1 atom sulphuric acid	5
1 atom lime . .	3·5
	8·5

Hydrous. (2.) Hydrous sulphate of lime, long familiar to chemists and mineralogists under the names of gypsum and selenite, crystallizes in right oblique angled prisms; and, when formed artificially, it crystallizes in small silky needles, so minute, that their shape is not easily determined. The constituents of this salt are

1 atom acid .	5
1 atom lime .	3·5
2 atoms water .	2·25
	10·75

The water of crystallization may be driven on by a temperature not exceeding 500°. In a red heat, some of the sulphuric acid is driven off; and, if water be poured on the salt thus treated, it will be found to give a violet colour to cudbear paper. This circumstance long perplexed me in the analyses of minerals, when I was searching for an alkali. The liquid containing the supposed alkali was filtered, evaporated to dryness, and water digested upon the residual matter. This water, by giving a violet colour to cudbear paper, gave an indication of an alkali; but the most careful examination of what the water had dissolved frequently discovered nothing but lime. I found at last, that all the filtering paper which I could procure contained sulphate of lime; a little of this was dissolved by the liquid which passed through the filter—hence the appearances. The presence of sulphate of lime in the filters is a very great annoyance, and stands a good deal in the way of accurate analyses. I diminish the evil, but do not remove it completely, by washing the filter, first in dilute nitric or muriatic acid, and then in water.

Nitrate,

2. Nitrate of lime. This salt is exceedingly soluble in water, and very difficult to procure in regular crystals. But it is easy, by concentrating the solution sufficiently and then setting it aside in a cool place, to obtain the salt in the state of a beautiful fibrous white mass, not unlike mesolite. In this state it is composed of

1 atom nitric acid	6·75
1 atom lime	3·5
3 atoms water	3·375
	13·625

When a solution of this salt is put under the exhausted receiver of an air pump along with sulphuric acid, it becomes a thick syrup, which, on the least agitation, concretes into a white solid mass, with the evolution of a good deal of heat. In this state it consists of

1 atom nitric acid	6·75
1 atom lime	3·5
6 atoms water	6·75
	17

The water actually present in our analysis of this mass exceeded 6 atoms by rather less than half an atom. Had the action of the acid continued for a little longer, we should probably have obtained the exact atomic quantity contained in the preceding table. The small surplus water was doubtless lodged mechanically in the pores of the dry mass.

Carbonate, 3. Carbonate of lime. This well known mineral, when pure, is anhydrous. It may, indeed, contain a little water lodged mechanically between the plates of the crystals; but such, when it exists, is very small, and is easily driven off by exposing the salt to a moderate heat. Its constituents are

1 atom carbonic acid	2·75
1 atom lime .	3·5
	6·25

When carbonate of lime is rendered soluble in water by means of carbonic acid gas, a bicarbonate is formed, which seems only capable of existing in solution,—at least, I have never succeeded in obtaining it in a concrete state. Perhaps if it were crystallized under great compression this bicarbonate might be obtained.

Phosphate, 4. Phosphate of lime. This salt can only be formed artificially in the state of a white powder. It is neutral, insoluble, and anhydrous, being composed of

1 atom phosphoric acid	3·5
1 atom lime . .	3·5
	7

Arseniate,

5. Arseniate of lime. This salt may be formed by dropping arsenic acid into lime water. It is a white anhydrous tasteless powder, composed of

1 atom arsenic acid	7·75
1 atom lime . .	3·5
	11·25

There is, likewise, a binarseniate of lime which crystallizes; but I have not subjected it to analysis.

Chromate,

6. Chromate of lime. This is rather a fine yellow powder, which is insoluble in water and anhydrous,—it would probably answer as a pigment. Its constituents are

1 atom chromic acid	6·5
1 atom lime . .	3·5
	10

Tungstate,

7. Tungstate of lime. This salt, which is occasionally met with in native octahedral crystals, is likewise anhydrous, and is undoubtedly a compound of

1 atom tungstic acid	18·75
1 atom lime ·	3·5
	22·25

Acetate,

8. Acetate of lime. When a solution of this salt is kept for some time in vacuo over sulphuric acid, it is gradually converted into a mamillated mass, which, internally, has a silky lustre, and somewhat the appearance of asbestus. 16·5 grains of the salt, in this state, give 6·25 grains of carbonate of lime. Hence, the constituents of acetate of lime are

1 atom acetic acid	6·25
1 atom lime . .	3·5
6 atoms water .	6·75
	16·5

Oxalate,

9. Oxalate of lime. This salt is a white heavy tasteless powder, quite insoluble in water. When dried in the open air its constituents are

1 atom oxalic acid	4·5
1 atom lime . .	3·5
2 atoms water .	2·25
	10·25

It requires exposure to a heat rather above 500° to drive off the water from this salt.

Tartrate,

10. Tartrate of lime. This is also a white tasteless insoluble powder. When dried in the open air its constituents are

1 atom tartaric acid	8·25
1 atom lime . .	3·5
4 atoms water .	4·5
	16·25

It is scarcely possible to drive off the whole water, without affecting the acid, which is much more easily decomposed than either acetic or oxalic acid. It was analyzed by keeping 16·25 grains of it in a low red heat till the carbonate of lime became white. It weighed 6·25 grains very nearly.

From the preceding list it appears, that many of the salts of lime are anhydrous. The water of crystallization, when it exists, amounts to 2, 3, 4, or 6 atoms. No salt of lime is known which contains more than 6 atoms.

7. SALTS OF MAGNESIA.

1. Sulphate of magnesia. This well known salt crystallizes in right square prisms, and is not altered by exposure to the air. Its constituents are Sulphate,

1 atom sulphuric acid	5
1 atom magnesia	2·5
7 atoms water .	7·875
	15·375

2. Nitrate of magnesia, though it crystallizes readily enough, is so deliquescent a salt that it is very difficult to obtain it in a state proper for analysis. 16 grains of the crystals, dried by pressure between folds of blotting paper, were Nitrate,

heated in a platinum crucible till every thing was expelled except the base: the residual magnesia weighed 2·5 grains. Hence, the salt is a compound of

1 atom nitric acid	6·75
1 atom magnesia	2·5
6 atoms water	6·75
	16

Carbonate,

3. Carbonate of magnesia. This salt occurs native in great abundance in Hindostan, where it constitutes a range of rocks extending a considerable way.* Its colour is snow white, and its specific gravity 2·7374; it is rather harder than fluor spar, and it dissolves very slowly in acids, unless it be reduced to powder, and the action of the acid promoted by heat. I found the constituents of a very good specimen of this mineral as follows:

Carbonic acid	51·627
Magnesia	47·566
Deutoxide of manganese	0·807
	100

Stromeyer analyzed a specimen of the same mineral from Baumgarten in Silesia. Its constituents were

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* For the specimen which I subjected to analysis I was indebted to the friendship of Mr. Babington of London.

Carbonic acid .	50·7512
Magnesia . .	47·6334
Deutoxide of manganese	0·2117
Water . . .	1·4037
	100*

The salt is obviously anhydrous, and composed of

1 atom carbonic acid	2·75	or	53·411
1 atom magnesia .	2·5	-	45·782
	5·25		

It would appear from comparing the constituents of the neutral salt with those of the native anhydrous carbonate, that in the native rock a little of the acid has been dissipated. My specimen was from the surface of the rock. No doubt the same was the case with the specimen analyzed by Stromeyer. It would be interesting to know whether specimens from the interior parts of the rock would be found to contain their full complement of carbonic acid.

It is obvious from Berzelius' analysis, that the artificial carbonate of magnesia (obtained by exposing a solution of magnesia in carbonic acid to spontaneous crystallization) is a compound of

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* Untersuchungen, p. 120.

1 atom carbonic acid	2·75
1 atom magnesia	2·5
3 atoms water	3·375
	8·625 *

I find that this artificial carbonate becomes anhydrous by simple exposure to the air, and falls down into powder.

Hydrate,

4. Hydrate of magnesia. This beautiful mineral is obviously analogous to a salt. It was first discovered by Dr. Bruce in the serpentine at Hoboken in New Jersey; more lately, magnificent specimens have been detected in the Shetland Islands by Dr. Hibbert—I believe, in the serpentine of the island of Unst. It has a beautiful snow white colour, sometimes with a shade of green; a pearly lustre; is composed of thin semitransparent folia, and has a specific gravity of 2·13. Its constituents, according to the analysis of Stromeyer which I repeated with scarcely any difference in the result, are

1 atom water . .	1·125
1 atom magnesia . .	2·5
Water	0·00546
Oxides of iron and manganese	0·00762

The small excess of water was probably combined with the oxides of iron and manganese present in the mineral. The whole of the fo-

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* Afhandlingar, VI. 21.

reign matter amounts only to $\frac{1}{280}$th of the mineral.

Magnesia alba.

5. Magnesia alba of the shops. It is obvious, from the analysis of this powder by different chemists, that its composition varies considerably. Berzelius has shown that the composition is regulated by the quantity of water employed, and by the temperature: for the powder is obtained by precipitating the sulphate and muriate of magnesia by an alkaline carbonate. Berzelius analyzed a portion of it washed in boiling water, till the liquid ceased to dissolve any more. He found it a compound of

Magnesia	44·58	or	3·434
Carbonic acid	35·70	-	2·75
Water	19·72	-	1·519
	100·00		

This approaches

1 atom carbonic acid	2·75
1½ atom magnesia	3·75
1½ atom water	1·6875

But Berzelius considers it as a compound of 3 atoms carbonate of magnesia and of 1 atom of quadrohydrate—

3 atoms carbonate of magnesia	15·75
1 atom quadrohydrate	7
	22·75 *

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* Afhandlingar, VI. 24.

The constituents per cent. according to this view of the subject, would be

Carbonic acid	36·263
Magnesia	43·956
Water	19·781
	100·000

numbers which approach sufficiently near the result of the analysis to give much probability to the opinion.

Biborate,

6. Borate of magnesia. The mineral called boracite, which crystallizes in cubes, having their alternate angles truncated, and which has a specific gravity of 2·566, is a compound of boracic acid and magnesia, and from the best analyses of it hitherto made, it seems to be a biborate of magnesia, composed of

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

It is destitute of water.

Phosphate,

7. Phosphate of magnesia. When this salt is obtained by mixing together solutions of sulphate of magnesia and phosphate of soda, it crystallizes in small flat four-sided prisms, having a silky lustre, and destitute of taste. It is composed of

1 atom phosphoric acid	3·5
1 atom magnesia	2·5
7 atoms water	7·875
	13·875

8. Arseniate of magnesia may be prepared by mixing together rather diluted solutions of sulphate of magnesia and arseniate of soda in the atomic proportions. Little immediate change is produced, but a portion of arseniate of magnesia gradually precipitates in a fine white loose state, very similar in appearance to native hydrate of magnesia. When the mixture is set aside for twenty-four hours, a number of crystals of arseniate of magnesia make their appearance in it. They are small transparent four-sided flat prisms, with very oblique terminations; they constitute tufts of crystals, radiating from a centre, and are formed in the portion of the salt which has the form of a powder. These crystals, when dry, are transparent and tasteless. They are slightly soluble in water—though that liquid after being saturated with the salt in a boiling heat, has no perceptible taste, and 1000 parts of boiling water dissolve only 1·5 parts of these crystals. 19·25 grains of these crystals, when exposed on the sand bath to a heat of about 500°, lose 6·75 grains of weight, and when exposed to a low red heat the loss amounts to 9 grains. As these crystals have no action on vegetable blues, they are evidently neutral: hence, the constituents are

Arseniate,

1 atom arsenic acid	7·75
1 atom magnesia	2·5
8 atoms water	9·0
	19·25

At the temperature of about 500° they part with 6 atoms water, but still retain 2 atoms which are disengaged in a red heat.

Chromate,

9. Chromate of magnesia. This is a fine transparent yellow coloured salt, which crystallizes in flat rhomboids, the obtuse angles of which are usually truncated. It is very soluble in water; its constituents are as follows:

1 atom chromic acid	6·5
1 atom magnesia	2·5
2 atoms water	2·25
	11·25

When this salt is exposed to a strong red heat it is partially decomposed; for it is no longer completely soluble in water.

Acetate,

10. Acetate of magnesia. A neutral solution of this salt was left in vacuo over sulphuric acid. It gradually inspissated into a thick transparent jelly, which was exposed for some time to the heat of the sand bath. Being laid in a cool place it became solid on the surface, but remained liquid below. Being stirred with a glass rod, the whole concreted into a white opaque crystalline looking mass, not unlike loaf sugar; it did not deliquesce, though left for a week in an open vessel. The taste of this salt is hot and bitter; at first it gives a slight impression of acetic acid which soon passes off, leaving a very disagreeable taste behind.

14·375 grains of this salt were kept in a red heat till nothing remained but pure magnesia, which weighed 2·5 grains. As the salt was neutral, its constituents are obviously

1 atom acetic acid	6·25
1 atom magnesia	2·50
5 atoms water	5·625
	14·375

11. Oxalate of magnesia is a tasteless salt, which can only be obtained in the state of a white powder. To determine its composition I took 9·25 grains of the salt in a state in which it did not alter the colour of vegetable blues, and exposed them to a strong red heat in a platinum crucible; there remained behind 2·5 grains of pure magnesia. This being equivalent to an atom of magnesia, it is obvious that the oxalic acid in the salt amounted to 4·5, or an atom. Hence, the constituents of oxalate of magnesia are **Oxalate,**

1 atom oxalic acid	4·5
1 atom magnesia	2·5
2 atoms water	2·25
	9·25

If the oxalate of magnesia be dried by means of artificial heat, the water contained in it is always less than two atoms.

12. Binoxalate of magnesia. This salt may **Binoxalate,**

be obtained by mixing together solutions of binoxalate of potash and sulphate of magnesia in the atomic proportions. No immediate precipitate falls; but when the liquid is concentrated, crystals of binoxalate of magnesia are gradually deposited. They have the form of pretty large flat rectangular four-sided prisms. The taste of this salt is acid, and it strongly reddens vegetable blues. It does not dissolve completely in water; but when digested in that liquid, a considerable portion of the oxalic acid and some of the magnesia is washed off, and an insoluble oxalate of magnesia remains behind. When heated, oxalic acid readily sublimes. 19·375 grains of this salt were digested in water till the liquid would take up no more; the undissolved oxalate of magnesia weighed 5·054 grains, and contained 2·469 grains of oxalic acid. The dissolved portion of the salt was mixed with muriate of lime. The oxalate of lime precipitated weighed, after being washed and dried in a heat of 83°, 14·489 grains, equivalent to 6·361 grains of oxalic acid. Thus the oxalic acid contained in 19·375 grains of the salt, amounted to 8·83 grains, or very nearly 2 atoms. 19·375 grains of the salt were exposed to a strong red heat in a platinum crucible, the magnesia remaining weighed 2·69 grains. But it effervesced for a little with nitric acid, and therefore was not quite free from carbonic acid. From these experiments I consider the constituents of the salt to be

2 atoms oxalic acid	9
1 atom magnesia	2·5
7 atoms water	7·875
	19·375

Tartrate,

13. Tartrate of magnesia. This salt, which is a white tasteless powder, is composed of

1 atom tartaric acid	8·25
1 atom magnesia	2·5
2 atoms water	2·25
	13

Bitartrate.

14. Bitartrate of magnesia. This salt was formed by dissolving tartrate of magnesia in tartaric acid and crystallizing the solution. The bitartrate is deposited in small acicular crystals; it has a slightly acid taste, and reddens vegetable blues. 20·125 grains of these crystals were kept in a red heat till nothing remained but the magnesia, which weighed 2·5 grains. Hence, the salt is composed of

2 atoms tartaric acid	16·5
1 atom magnesia	2·5
1 atom water	1·125
	20·125

The water of crystallization in the salts of magnesia varies more in the different species, than in any of the preceding genera of salts. Two of the species are anhydrous—three contain 1 atom of water—three contain 2 atoms—one contains 3—one 5—one 6—two contain 7, and one contains 8 atoms.

8. SALTS OF ALUMINA.

Sulphate,

1. Sulphate of alumina. This salt does not crystallize regularly; but if we digest dilute sulphuric acid over hydrate of alumina for two or three days, and set the solution aside after having concentrated it sufficiently, it gradually congeals into a beautiful, white, soft, light, semi-transparent mass, which may be dried upon blotting paper, and is not altered by exposure to the air. It always reddens vegetable blues how long soever the liquid be digested over the alumina; I continued the digestion for a month without altering this property. All the salts of alumina, so far as I have tried them, redden vegetable blues. Sulphate of alumina is composed of

1 atom sulphuric acid	5
1 atom alumina	2·25
7 atoms water	7·875
	15·125

This salt is capable of congealing though it contains a slight excess of acid. I have obtained it composed of

Sulphuric acid	5·625
Alumina	2·25
Water	7·875
	15·75

The excess was just the $\frac{1}{8}$th of an atom of sulphuric acid. To prevent any such excess we must continue the digestion over alumina for a considerable time; for the action of the acid, when nearly saturated, becomes very feeble.

Trisulphate,

2. Trisulphate of alumina. This is a fine white aluminous looking mineral, found in Sussex and in other places, and distinguished among mineralogists by the name of *aluminite*. Its constituents, as appears from the analysis of Stromeyer, are

1 atom sulphuric acid	5
3 atoms alumina	6·75
9 atoms water	10·125
	21·875

I have already noticed disulphate of alumina in a preceding chapter.

Dinitrate,

3. Dinitrate of alumina. This salt was obtained by digesting hydrate of alumina in dilute nitric acid till the acid refused to dissolve any more of the hydrate; the liquid was then con-

centrated and set aside. It concreted into a white solid matter, which was dried by pressure between folds of blotting paper. Thus prepared, it was a fine white crystalline powder exceedingly soluble in water, and reddening vegetable blues. Its taste was astringent and sweet, with an impression of acidity. This salt was analyzed in the following manner:

22·5 grains of it were exposed to a red heat, and kept at that temperature till nothing remained but the alumina, which weighed exactly 4·5 grains.

22·5 grains of the salt were dissolved in water, and the solution digested in a flask with carbonate of barytes—the alumina was thrown down, and a solution of nitrate of barytes formed. This solution being evaporated to dryness, left 16·245 grains of nitrate of barytes. Now, 16·245 grains of nitrate of barytes contain 6·645 grains of nitric acid. This approaches so near 6·75, that it is evident the salt is a dinitrate, and composed of

1 atom nitric acid	6·75
2 atoms alumina	4·5
10 atoms water	11·25
	22·5

I made different attempts to form a nitrate of alumina, but they were all unsuccessful.

Trisnitrate, 4. Trisnitrate of alumina. I formed this salt by keeping the dinitrate of alumina on the sand bath till it lost its liquid form, and became a white dry crust. In this state it was nearly insoluble in water, though it was not quite destitute of taste; it did not deliquesce when exposed to the air.

20·25 grains of this salt being kept for half an hour in a strong red heat, left 6·75 grains of alumina, equivalent to 3 atoms of that earth.

20·25 grains being digested with carbonate of barytes, and the solution filtered and evaporated to dryness, left 16·4025 grains of nitrate of barytes, which contains 6·7 grains of nitric acid. This approaches so near 6·75 grains, that it is evident the constituents of the salt are

1 atom nitric acid	6·75
3 atoms alumina	6·75
6 atoms water	6·75
	20·25

Phosphate,

5. Phosphate of alumina. This salt was obtained by mixing together solutions of alum, and phosphate of soda in the atomic proportions—no precipitate appears at first; but if the mixture be heated a white powder gradually falls, which is phosphate of alumina. It is tasteless, and insoluble in water; but it reddens vegetable blues powerfully. 9·125 grains of this powder, well washed, and dried in the open air, being heated to redness lost 3·375 grains. Hence, the constituents are

1 atom phosphoric acid	3·5
1 atom alumina	2·25
3 atoms water	3·375
	9·125

Arseniate,

6. Arseniate of alumina. This salt was obtained by mixing together solutions of alum and arseniate of soda in the atomic proportions. It is a white, tasteless, insoluble powder, not unlike phosphate of lime; but it strongly reddens vegetable blues.

16·75 grains of this salt being exposed to a red heat, lost 6·75 grains of its weight, and still reddened vegetable blues. Hence, the constituents of the salt are

1 atom arsenic acid	7·75
1 atom alumina	2·25
6 atoms water	6·75
	16·75

Chromate,

7. Chromate of alumina. This salt being very soluble in water, I could not form it by double decomposition; but when chromic acid and hydrate of alumina are long digested together, a fine yellow solution is obtained, which, however, I did not succeed in analyzing in a satisfactory manner. I ascertained merely that the salt is soluble in water, and that it has a yellow colour.

Acetate,

8. Acetate of alumina. This salt was formed

by digesting a mixture of acetic acid and hydrate of alumina till the acid was saturated. No heat must be applied, because it occasions a precipitation of a portion of the alumina from the solution, which, however, again dissolves when the liquid cools. A portion of solution of acetate of alumina, thus formed, was left in a covered Wedgewood evaporating dish for six weeks during the summer of 1824. The whole liquid evaporated away, and left the acetate of alumina crystallized in long transparent four-sided prisms, which were so firmly attached to the dish, that they could not be removed without destroying their shape. This is the only simple salt of alumina which I have yet succeeded in obtaining in regular crystals.

The portion of this salt which I subjected to analysis was not in crystals, but in the state of a powder obtained by exposure to a very gentle heat. 9·625 grains of it kept for some time in a red heat, left 2·25 grains of alumina. Hence the constituents of the salt are

1 atom acetic acid	6·25
1 atom alumina	2·25
1 atom water	1·125
	9·625

The salt has a sweet and astringent taste, with something of the flavour of acetic acid, dissolves very readily in water, and reddens vegetable blues.

Oxalate, 9. Oxalate of alumina. Oxalic acid dissolves hydrate of alumina with facility. The saturated solution is transparent and colourless; it has a sweet and astringent taste, and reddens vegetable blues. When evaporated, the oxalate of alumina remains behind in the state of a semi-transparent amber-coloured crust, very similar in appearance to gum, or albumen which has been dried in a low heat. It dissolves with facility in water, but may be exposed to the air without absorbing moisture.

10·125 grains of this salt, when kept in a red heat for some time, leave 2·25 grains of alumina. 10·125 grains of the same salt were dissolved in water, and mixed with a sufficient quantity of muriate of lime. No precipitate fell; but a slight white powder appeared when the liquid was heated. It was evaporated to dryness in a gentle heat, digested in water, and thrown on the filter. The weight of the oxalate of lime retained on the filter was 10 grains. This is very nearly equivalent to 4·5 grains of oxalic acid. From these experiments it is obvious that the constituents of the salt are

1 atom oxalic acid	4·5
1 atom alumina .	2·25
3 atoms water .	3·375
	10·125

10. Tartrate of alumina. Tartaric acid dissolves hydrate of alumina with facility. The saturated solution has an acid, astringent, and sweet taste. Being evaporated to dryness, the tartrate assumed the form of a white semitransparent viscid mass, having a slight shade of yellow, and very like gum-arabic in appearance. On exposure to the air, it became brittle; but still continued to redden vegetable blues. Tartrate,

11·625 grains of this salt, when kept for half an hour in a red heat, left 2·25 grains of alumina. I found, by another experiment, that the acid contained in 11·625 grains of this salt just saturate 4 grains of pure soda. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom alumina .	2·25
1 atom water .	1·125
	11·625

If any consequences can be drawn from the preceding list of aluminous salts, they seem all to contain water of crystallization, though the number of atoms is very various. Two of the salts contain only 1 atom of water—two contain 3—two 6—one contains 7—and one 10.

9. PROTOSALTS OF IRON.

Iron combines with two proportions of oxygen, and both oxides are capable of combining with acids. I shall in this section consider only the salts which contain protoxide of iron for their basis.

Protosulphate,

1. Protosulphate of iron. This well known salt, when pure, is transparent, and has a light green colour; and is crystallized in oblique prisms, having a rhomb for their base. Its constituents are

1 atom sulphuric acid	5
1 atom protoxide of iron	4·5
7 atoms water .	7·875
	17·375

Protonitrate,

2. Protonitrate of iron. I obtained this salt by dissolving iron in dilute nitric acid till the acid refused to take up any more of the metal. The solution, which was at first brown and opaque, became gradually transparent by the escape of nitrous gas, and assumed a light green colour, with a shade of yellow. It was concentrated under the exhausted receiver of an air pump, over sulphuric acid. A small quantity of peroxide of iron precipitated when the greatest part of the liquid had evaporated, and pretty regular crystals of protonitrate of iron were formed.

They were in rhomboidal prisms, were transparent, and had a light green colour; so that in appearance they bore some resemblance to protosulphate of iron. This salt reddened vegetable blues, as is the case with all the soluble salts of iron. Its taste was sweet and astringent, like that of the protosulphate of iron, but harsher.

34·8 grains of these crystals, dried on blotting paper, were exposed to the heat of a spirit lamp in a platinum vessel. The salt melted, became yellow, then brown, and fumes of nitric acid escaped. The residue was black, had the metallic lustre, and was not attracted by the magnet. It was, therefore, peroxide of iron, and weighed 8·8 grains, equivalent to 7·92 grains of protoxide of iron. The weight of the nitric acid and water contained in the 34·8 grains of salt was obviously 26·88. Now, the protoxide of iron in the salt was saturated with nitric acid. Hence, it is easy to deduce from the preceding experiment the constituents of the salt; namely,

1 atom nitric acid	6·75
1 atom protoxide of iron	4·5
7½ atoms water	8·4375
	19·6875

Probably the crystals contained only 7 atoms of water chemically combined in the salt; for, as the crystals were only dried on blotting paper, without much pressure, I think it likely that they might retain a little water lodged mechanically between their plates. If that supposition be correct, the true atomic weight of these crystals will be 19·125.

This salt cannot be preserved. The iron is gradually peroxydized, and the crystals deliquesce.

Protocarbonate,

3. Protocarbonate of iron. It would be difficult to form this salt artificially; but it has been found native at Eulenloh in Bareuth, and in other places, crystallized in rhombs. It has a greenish yellow colour, a certain degree of transparency, and a specific gravity of 3·333. Bucholz analyzed this mineral in the year 1803, and found its constituents as follows:

Carbonic acid .	36
Protoxide of iron .	59
Lime . . .	3
Water . . .	2
	100 *

The carbonic acid was estimated by the weight lost during the solution of the salt in muriatic acid. The water was obtained by heating the salt to redness in a receiver. The lime was cal-

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* Gehlen's Jour. I. 231.

culated from 5½ grains of carbonate obtained during the experiment. Bucholz estimated it at 2·5 grains, but the true quantity is obviously 3 grains. The protoxide of iron was the quantity requisite to make up the 100 grains analyzed. Now, if the salt were a compound of

1 atom carbonic acid	.	2·75	or	36
1 atom protoxide of iron		4·5	-	59
		7·25		

we obtain the very constituents of Bucholz. The lime, consequently, must have been accidentally present, and not in the state of combination. The water, amounting only to ⅛th atom, must have been mechanically mixed.

Protophosphate,

4. Protophosphate of iron. This salt, in beautiful transparent crystals of a light blue colour, and having the shape of right oblique prisms, has been found in Cornwall, and likewise in Brazil and the Isle of France. A variety from Eckartsberg, in round nodules, and not crystallized, was analyzed by Klaproth, who found its constituents

Phosphoric acid	.	32
Protoxide of iron	.	47·5
Water . .	.	20
		99·5 [*]

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[*] Beitrage, IV. 122.

This approaches

1 atom phosphoric acid	3·5
1 atom protoxide of iron	4·5
2 atoms water . .	2·25
	10·25

But this differs a good deal from the result of Laugier's analysis of the crystals.

The phosphate of iron, which occurs in fine transparent blue crystals, was analyzed by Stromeyer, and found composed of

Phosphoric acid .	2·73
Protoxide of iron .	3·64
Water . .	2·42
	8·79*

This is obviously

1 atom phosphoric acid	3·5
1 atom protoxide of iron	4·5
3 atoms water . .	3·375
	11·375

Diprotarseniate,

5. Diprotarseniate of iron. This salt is found native, crystallized in small cubes, which have a dark green colour, and a specific gravity of 3. It may be formed artificially by mixing together solutions of arseniate of ammonia and pro-

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* Untersuchungen, I. p. 274.

tosulphate of iron. Its constituents, according to the analysis of Chenevix, are

Arsenic acid	38	or	7·75
Protoxide of iron	43	-	8·77
Water	19	-	3·875
	100		

The last column gives the proportions of the constituents, supposing the quantity of arsenic acid to be 7·75, or an atom. 8·77 approaches very near 9, which is 2 atoms protoxide of iron; and 3·875 is very near 3·9375, or 3½ atoms water. The true constitution of the salt is probably

1 atom arsenic acid	7·75
2 atoms protoxide of iron	9
3 atoms water	3·375
	20·125

Protacetate,

6. Protacetate of iron. This salt was first described many years ago by Sir Humphrey Davy, who gave an account of it in his *Researches.* When iron, or sulphuret of iron is dissolved in acetic acid, the solution has a light green colour, and is transparent. I attempted to filter this liquid to get rid of the undissolved iron; but the liquid absorbed oxygen from the atmosphere with inconceivable rapidity, and

passed through the filter opaque and almost black. I, therefore, put a quantity of the unfiltered liquid under the receiver of an air pump along with sulphuric acid, and kept it in a good vacuum till the salt became dry. By this process a portion of the salt at the surface became dark coloured; but the portion next the bottom of the vessel was in a beautiful fibrous form, and nearly white, at least the shade of green was very slight. The salt, when thus dry, might be left exposed to the air for days without undergoing any alteration. Its taste was sweet, astringent, and acid, and it reddened vegetable blues. It dissolved readily in water, and the solution becomes immediately dark coloured.

To determine its composition I dissolved 14·125 grains of it in water, and added to the solution 18 grains of crystallized carbonate of soda. The oxide of iron was all precipitated, the residual liquid contained no iron, and did not alter the colour of vegetable blues. Now, 18 grains of crystallized carbonate of soda contain 4 grains of soda, which require for saturation 6·25 grains of acetic acid, present in 14·125 grains of the salt. The iron being collected and peroxided, weighed almost exactly 5 grains, equivalent to 4·5 grains of peroxide of iron. From these experiments the salt was obviously composed of

1 atom acetic acid	6·25
1 atom soda	4·5
3 atoms water	3·375
	14·125

No doubt the crystals of protacetate of iron described by Davy, contain more water than my fibrous salt, but I had not an opportunity of examining them, as no crystals formed when the solution was evaporated under the air pump.

Protoxalate,

7. Protoxalate of iron. This salt is easily obtained by pouring oxalic acid into a solution of protosulphate of iron; it instantly falls in the state of a beautiful yellow powder. When heated moderately on the sand bath it gives off water and becomes brown—soon after, it catches fire and burns like tinder. Its constituents are

1 atom oxalic acid	4·5
1 atom protoxide of iron	4·5
2 atoms water	2·25
	11·25

Prototartrate.

8. Prototartrate of iron. This salt was obtained by mixing rather concentrated solutions of protosulphate of iron and tartrate of potash in the atomic proportions. On setting the mixture aside for twenty-four hours, a considerable deposite of tartrate of iron was found encrusting the bottom and sides of the vessel. This salt was in transparent crystals, but so irregular,

that their shape could not be ascertained; the greater number of them were nearly globular. They were hard, not altered by exposure to the air, and had an inky, though weak taste. 20 grains of these crystals, when exposed to as strong a heat as they could bear without decomposition, lost 3·8 grains. When the heat was raised to about 600°, the salt blackened, and lost about 12 grains—being exposed to a red heat, the residuum was reduced to 6·3 grains—it was sensibly magnetic. It was therefore drenched with nitric acid, and exposed to a heat raised gradually almost to redness. The weight of the residue was now increased to 6·688 grains, equivalent to 6·012 grains of protoxide of iron, and 6·012 : 4·5 : : 20 : 14·97. From this it is obvious, that 15 grains of the salt contain just 4·5 grains of protoxide of iron. Consequently, its constituents must be

1 atom tartaric acid	8·25
1 atom protoxide of iron	4·5
2 atoms water	2·25
	15

The preceding list is rather too scanty to permit us to draw any inferences with respect to the water of crystallization of the ferruginous salts.

One salt, the carbonate, is anhydrous.

Two, the protoxalate and prototartrate, contain 2 atoms water.

Three, the phosphate, diprotarseniate, and acetate, contain 3 atoms water.

Two, the sulphate and nitrate, contain 7 atoms water.

It has been already observed, that the chromate of iron does not exist.

10. PERSALTS OF IRON.

Few of these salts being capable of crystallizing, they have not hitherto been subjected to a rigid examination; most of them, as far as my experience goes, are sesquisalts, agreeing with Gay-Lussac's law, that the quantity of acid necessary to saturate an oxide increases with its oxygen; but to this rule there occur many exceptions.

1. Persesquisulphate of iron. When a portion of protosulphate of iron is peroxidized by means of nitric acid, and cautiously concentrated till the whole nitric acid is dissipated, we obtain a red coloured mass, which dissolves only partially in water. The solution has a red colour with a tint of yellow—the taste is astringent and very harsh. When evaporated to dryness it speedily absorbs moisture, and deliquesces into a liquid—alcohol dissolves it readily. It strongly red- Persesquisulphate,

dens vegetable blues. This salt, abstracting the water which could not be determined, is composed of

1½ atom sulphuric acid	7·5
1 atom peroxide of iron	5
	12·5

Pertetrasulphate,

2. Pertetrasulphate of iron. The insoluble portion remaining after the persesquisulphate of iron has been extracted, is a red coloured powder destitute of taste, and insoluble in water. It is anhydrous, and composed of

1 atom sulphuric acid	5
4 atoms peroxide of iron	20
	25

It is, therefore, a pertetrasulphate of iron.

Persesquinitrate,

3. Persesquinitrate of iron. This salt forms large and pretty regular crystals. It was first noticed by Vauquelin, above 20 years ago, who formed it by leaving nitric acid for a long period in contact with black oxide of iron. The crystals form spontaneously in the liquid. The crystals, when first formed, are transparent and colourless, but when kept for some time they acquire a brownish tinge; I have obtained them in flat colourless rhomboids, and in four-sided right prisms with square bases. The prisms are frequently six-sided from the truncature of two

of the edges of the prism, or eight-sided from the truncature of all the edges. The taste is astringent and acid, and the crystals redden vegetable blues very powerfully. They deliquesce rapidly when exposed to the air; when heated, they melt in their water of crystallization, and the liquid has a deep yellowish red colour. The rapidity with which these crystals absorb water makes it difficult to analyze them with perfect accuracy.

I found that 50 grains of them, when gradually evaporated to dryness and finally exposed to a red heat, leave very nearly 10 grains of peroxide of iron.

24·125 grains of the crystals were dissolved in water, and the solution mixed with a solution of 10·125 grains of anhydrous carbonate of soda. When the iron had subsided and the carbonic acid had been allowed time to dissipate, the residual liquid was found to have the property of giving a slightly purple colour to cudbear paper; but when one drop of muriatic acid was added this property was destroyed, and the liquid reddened litmus paper. Hence, I conceive that the acid in 24·125 grains of the salt is just neutralized by the soda in 10·125 grains of anhydrous carbonate of soda. But 10·125 carbonate of soda is equivalent to 1½ atom of soda; consequently, 24·125 of the salt must contain 1½ atom of nitric acid. The water absorbed by the crystals, while weighing, accounts for the small surplus of soda in the liquid after mixture: this is also the reason of the slight deficiency of oxide of iron found in the first part of the analysis. The salt is obviously composed of

1½ atom nitric acid	10·125
1 atom peroxide of iron	5
8 atoms water .	9
	24·125

Subpernitrate,

4. Subpernitrate of iron. This salt, obtained by drying the pernitrate in rather a high temperature, has been analyzed by M. Grouselle, who found its constituents as follows:

1 atom nitric acid	6·75
8 atoms peroxide of iron	40
2 atoms water .	2·25
	49*

Persesquiphosphate,

5. Persesquiphosphate of iron. This salt is easily formed by mixing solutions of persulphate of iron and phosphate of soda together in the requisite proportions. It is a white powder, tasteless and insoluble in water.

To determine the composition of this salt I proceeded in the following way:—173·75 grains (equivalent to 10 atoms) of the crystals of pro-

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* Ann. de Chim. et de Phys. XIX. 138.

tosulphate of iron were dissolved in water, and the oxide peroxidized by digesting the solution with a little nitric acid. After the peroxidation was completed, I saturated the excess of nitric acid still remaining, as nearly as possible, by ammonia, and added a solution of 315 grains (equivalent to 15 atoms) of phosphate of soda. After the perphosphate of iron had subsided, I found that the residual liquid still contained iron, owing to an excess of nitric acid which it still contained; but on adding a few drops of ammonia, a little perphosphate of iron precipitated, and the liquid was now perfectly free from iron. The perphosphate of iron thus obtained, was dried on the filter in a gentle heat; when it ceased to lose weight it was weighed, and then exposed to a red heat; the loss of weight was noted, and considered as water. The anhydrous salt was now composed of peroxide of iron and phosphoric acid.

The peroxide of iron from 173·75 grains of protosulphate of iron is 50 grains; the phosphoric acid in 315 grains of phosphate of soda is 52·5 grains. Now, the anhydrous salt only exceeded 102·5 grains by about 2 grains; hence, it is evident that the anhydrous salt is a persesquiphosphate of iron. 19·25 grains of the salt, as dried on the filter, when exposed to a strong red heat, underwent a kind of semifusion, and lost 9 grains of its weight. Hence, the constituents of this salt are

1½ atom phosphoric acid	5·25
1 atom peroxide of iron	5
8 atoms water . .	9
	19·25

Pertris-phosphate.

6. Pertrisphosphate of iron. When the preceding salt is digested in caustic potash ley it assumes a deep brownish red colour. The new salt thus formed is tasteless and insoluble in water. When heated to redness, the colour becomes darker, indeed almost black. I find, that when 21·875 grains of this salt, dried on the filter in a gentle heat, are heated to redness in a platinum crucible, the loss of weight is 3·5 grains; which is equivalent to 3 atoms water very nearly. I found that 50 grains of persesquiphosphate of iron, when digested in potash ley, left 19 grains of the red salt after exposure to redness;—knowing the quantity of peroxide of iron in the persesquiphosphate, it is easy to see that the red salt is composed of

1 atom phosphoric acid	3·5
3 atoms peroxide of iron	15
3 atoms water . .	3·375
	21·875

It is, therefore, a pertrisphosphate of iron.

11. SALTS OF NICKEL.

Only the protoxide of nickel, as far as is known, combines with bases. These salts have hitherto been very imperfectly investigated.

Sulphate,

1. Sulphate of nickel. This salt has a beautiful grass green colour, and crystallizes in two forms: 1. Rhombic prisms, exactly similar to those of sulphate of zinc. 2. In square prisms. This last is the form which they assume when there is an excess of acid in the solution;—I have analyzed both without finding any difference between them. Mr. R. Phillips found a very slight excess of acid in the square prisms, which was probably only mechanically lodged between the plates of the crystals. The constituents of this salt are

1 atom sulphuric acid	5
1 atom protoxide of nickel	4·25
7 atoms water . .	7·875
	17·125

Nitrate,

2. Nitrate of nickel. This salt crystallizes in four-sided oblique prisms; it has a green colour, not quite so fine as that of sulphate of nickel. I do not find it to undergo any alteration though left exposed to the air. Its composition, according to the analysis of it made in my laboratory, is as follows:

1 atom nitric acid .	6·75
1 atom protoxide of nickel	4·25
5 atoms water . .	5·625
	16·625

Carbonate,

3. Carbonate of nickel. This salt is easily obtained by precipitating a solution of sulphate of nickel by carbonate of soda, collecting the precipitate upon a filter, and allowing it to dry in the open air, after having been thoroughly washed. It is a light green tasteless powder, insoluble in water; but dissolving with effervescence in acids. 20 grains of it, when exposed to the heat of a spirit lamp in a platinum crucible, give out water and carbonic acid; and a black powder remains, weighing 10·58 grains, equivalent to 9·466 grains protoxide of nickel. Hence, the constituents of the salt are

Carbonic acid	6·125	or	2·75
Protoxide of nickel	9·466	-	4·25
Water . .	4·409	-	3·385
	20·000		

The last column, giving us the ratios of the constituents, shows that the composition of the salt is

1 atom carbonic acid .	2·75
1 atom protoxide of nickel	4·25
3 atoms water .	3·375
	10·375

4. Phosphate of nickel. This salt was obtained by mixing together solutions of sulphate of nickel and phosphate of soda in the atomic proportions. The phosphate of nickel immediately falls in the state of a green light powder. When dried on the filter, after having been well washed, it has a light pea green colour; is tasteless, but adheres to the tongue; and is insoluble in water. 11·375 grains of it, exposed to a red heat, lost 3·375 grains of their weight. Hence, the constituents of this salt are **Phosphate,**

1 atom phosphoric acid	3·5
1 atom protoxide of nickel	4·25
3 atoms water . .	3·375
	11·125

5. Arseniate of nickel. This salt may be obtained by mixing together solutions of sulphate of nickel and arseniate of soda in the atomic proportions. The arseniate, while moist, has a light green colour; but, when the salt is dried upon the filter, the colour deepens into a dark leek green. It is tasteless, and insoluble in water; yet it slightly reddens vegetable blues. When heated on the sand bath in a temperature of about 500°, it gives out two-thirds of its water, and becomes dark brownish yellow. In a red heat it loses the whole of its water, and becomes dark brown. Its constituents are **Arseniate,**

1 atom arsenic acid .	7·75
1 atom protoxide of nickel	4·25
6 atoms water	6·75
	18·75

At the temperature of 500°, it parts with 4 atoms of water; but retains 2 atoms.

Binarseniate,

6. Binarseniate of nickel. When arsenic acid is digested upon carbonate of nickel, no apparent action is perceptible for some time; but in a few days the liquid acquires a fine green colour, and the portion of carbonate of nickel which does not dissolve assumes the peculiar shade of green which characterizes the arseniate of nickel while moist. When all action was at an end, the liquid was filtered, and gently evaporated to dryness, on the sand bath. No crystals appeared; but a yellowish green matter was deposited, rather bulky, and having a good deal of clamminess. To free it from adhering moisture, it was placed between the folds of blotting paper, and exposed for 24 hours to considerable pressure. In this state it was insoluble in water, had a slightly acid taste, and reddened vegetable blues powerfully. It was, therefore, a binarseniate of nickel. 50 grains of it, when exposed to a red heat, became yellow, and lost 18·5 grains of its weight; but it still reddened vegetable blues as powerfully as ever. From this experiment I consider the salt as a compound of

2 atoms arsenic acid	15·5
1 atom oxide of nickel	4·25
10 atoms water .	11·25
	31

Chromate,

7. Chromate of nickel. This salt was obtained by mixing together solutions of chromate of potash and sulphate of nickel. No precipitate appears at first, but a reddish brown powder gradually falls; and the precipitate is increased by evaporating the liquid. This deposite, when washed and dried, is rather a beautiful reddish brown powder, destitute of taste, and not affecting vegetable blues. 15·2 grains of it, when heated to redness, assumed an olive green colour, and lost 4·45 grains of weight. Hence it was a compound of

1 atom chromic acid	6·5
1 atom oxide of nickel	4·25
4 atoms water .	4·5
	15·25

Acetate,

8. Acetate of nickel. This salt was obtained by dissolving carbonate of nickel in very strong acetic acid. The carbonate dissolved rapidly with a strong effervescence. The saturated solution is dark green. When set aside, it gradually deposites acetate of nickel in light green crystals. The form of these crystals is a rhom-

boid; but the salt has a great tendency to concrete at the bottom of the vessel in the form of saline crusts, without any regular form. This salt is very soluble in water, and slightly reddens vegetable blues, even after having been twice crystallized. Its taste is at first sweetish, then it leaves an impression similar to that of sulphate of zinc, but much weaker. When exposed in a platinum crucible to the heat of a spirit lamp, it did not melt; but gave out water, having a slight smell of acetic acid, and a weak acidulous taste, and gradually assumed a yellowish green colour. It then took fire, and burned like tinder, leaving an oxide, which was digested in nitric acid to convert it into peroxide of nickel. 50 grains of the crystals, when treated in this way, left 14·71 grains of peroxide of nickel, equivalent to 13·1615 grains of protoxide. From this experiment it follows, that acetate of nickel is composed of

Acetic	19·3551	or	6·25
Protoxide of nickel	13·1615	-	4·25
Water .	17·4834	-	5·645
	50·0000		

5·645 differs so little from 5·625, or 5 atoms of water, that we can have no hesitation about considering the salt as composed of

1 atom acetic acid .	6·25
1 atom protoxide of nickel	4·25
5 atoms water .	5·625
	16·125

Oxalate,

9. Oxalate of nickel. This salt was obtained by mixing together solutions of sulphate of nickel and oxalate of ammonia in the atomic proportions. For some minutes the mixture retained its transparency, but by degrees it became opaque, and oxalate of nickel was slowly deposited. Very nearly the whole oxalic acid and oxide of nickel were deposited; only traces of them could be detected in the supernatant liquid. The oxalate of nickel, when well washed and dried in the air, was a light green powder destitute of taste, and insoluble in water.

20 grains of this salt when heated on the sand bath lost 1·66 grains. It was now exposed to a red heat till thoroughly calcined. There remained a dark brown powder which did not effervesce nor dissolve in cold nitric acid, though a solution was slowly effected by the assistance of heat: hence, it was peroxide of nickel. It weighed 7 grains, equivalent to 6·263 grains of protoxide of nickel. The constituents of the salt from this experiment, were

Oxalic acid	6·631	or	4·5
Protoxide of nickel	6·263	-	4·25
Water	7·106	-	4·822
	20·000		

Hence, there can be no doubt that the salt is a compound of

1 atom oxalic acid	4·5
1 atom protoxide of nickel	4·25
4 atoms water	4·5
	13·25

The 0·322 of surplus water found by experiment, was no doubt lodged mechanically in the powder. It is scarcely possible to avoid such slight excesses of water, when we examine a salt which forms only a powder, because there is no criterion by which we can know when all the hygrometrical water is driven off; and in many cases it would be hazardous to attempt to drive it off by heat. On the sand bath the salt loses very nearly, but not quite, an atom of water: for 13·25 grains would have lost 1·09975 grains. Probably, had the heat been continued long enough, the loss would have amounted to exactly an atom, leaving 3 atoms of water still united to the salt.

Tartrate. 10. Tartrate of nickel. This salt was formed by dissolving carbonate of nickel in tartaric acid; a green solution was obtained, which, when evaporated to dryness, left a light olive green powder, which was tasteless, insoluble in water, and producing no alteration on vegetable blues. It was anhydrous, for 12·88 grains, when exposed to the strongest heat which it could bear without decomposition, lost only 0·38 grain, equivalent to one-third of an atom, evidently hygrometrical. Hence, the constituents of the salt are

1 atom tartaric acid	8·25
1 atom protoxide of nickel	4·25
	12·5

The salts of nickel, in general, contain a good deal of water of crystallization, though like the other genera, there is a considerable difference in this respect between the species. The tartrate alone is anhydrous—the carbonate and phosphate contain 3 atoms water—the oxalate and chromate 4—the nitrate and acetate 5—the arseniate contains 6—the sulphate 7, and the binarseniate 10.

12. SALTS OF COBALT.

1. Sulphate of cobalt. This salt has a deep red colour, and crystallizes in rhombic prisms, similar to the form of sulphate of iron. Its constituents are

Sulphate,

1 atom sulphuric acid	5
1 atom protoxide of cobalt	4·25
7 atoms water	7·875
	17·125

Bisulphate, 2. Bisulphate of cobalt. When sulphate of cobalt is crystallized in an excess of acid, long four-sided prisms are obtained, which speedily effloresce on the surface when exposed to the air, but do not fall to powder. These crystals contain twice as much acid as the neutral salt, and are composed of

2 atoms sulphuric acid	10
1 atom protoxide of cobalt	4·2
3 atoms water	3·375
	17·625

Nitrate, 3. Nitrate of cobalt. This salt is easily obtained by dissolving cobalt or its oxide in nitric acid. The solution has a deep red colour, and when sufficiently concentrated, deposites crystals of nitrate of cobalt, which have a red colour with a shade of brown. They seem to be rhomboids, but are always so interwoven and irregular, that it is difficult to recognise the true form. They deliquesce rather rapidly when exposed to the air. Their taste is acrid and bitter, and they redden vegetable blues.

17·75 grains of the crystals of this salt were heated in a platinum crucible. In a moderate heat they melted in their water of crystallization, and continued for a considerable time to give out nothing but pure water. At last when the greatest part of the water was dissipated, and the heat rather increased, fumes of nitric acid came over in abundance, and the matter in the crucible concreted into a black mass, which, after exposure to a red heat, weighed 4·8 grains: it was peroxide, and equivalent very nearly to 4·25 grains of protoxide of cobalt. 17·75 grains of the crystals were dissolved in water, and digested with carbonate of barytes till the liquid became colourless. The supernatant liquid being then drawn off and evaporated to dryness, left 15·5 grains of nitrate of barytes, equivalent to 6·34 grains of nitric acid. This is somewhat less than 6·75, the atomic weight of nitric acid. The cause of this diminution of weight is the filter, through which the solution of nitrate of barytes was passed. It contained some sulphate of lime which decomposed a portion of nitrate of barytes, substituting nitrate of lime in its place. From the preceding analysis it is evident, that the constituents of this salt are

1 atom nitric acid .	6·75
1 atom protoxide of cobalt	4·25
6 atoms water .	6·75
	17·75

Carbonate,

4. Carbonate of cobalt. This salt was obtained by precipitating the nitrate of cobalt by carbonate of soda, collecting the precipitate on a filter, and washing it thoroughly with water. When dry, it is a light powder having a pink

colour of no great depth of shade, and destitute of beauty. It is tasteless, insoluble in water, and not altered by exposure to the air. It does not alter vegetable blues, but dissolves in acids with a strong effervescence.

8·125 grains of this salt were exposed to a red heat in a platinum crucible; there remained a black powder weighing 4·75 grains. It was peroxide of cobalt, and equivalent to 4·25 grains of protoxide: hence, the constituents of the salt are

1 atom carbonic acid	2·75
1 atom protoxide of cobalt	4·25
1 atom water	1·125
	8·125

Phosphate,

5. Phosphate of cobalt. This salt was prepared by dissolving carbonate of cobalt in phosphoric acid and mixing the solution with alcohol. A copious precipitate falls, which was collected on a filter, and edulcorated first with alcohol and then with water. It was gelatinous, and had a fine crimson colour. When dried, it concreted into a hard dark red matter, which reddened vegetable blues. 10 grains of it, when heated to redness, lost very nearly 2·25 grains; hence, I consider the salt as composed of

1 atom phosphoric acid	3·5
1 atom protoxide of cobalt	4·25
2 atoms water	2·25
	10

6. Arseniate of cobalt. This salt is easily obtained by mixing together solutions of nitrate of cobalt and arseniate of soda, and evaporating the solution. The arseniate falls in the state of a crimson coloured jelly, which, when washed and dried, assumes the form of scales. It is light, and has a fine crimson colour; is tasteless, and does not alter the colour of vegetable blues. When 16·5 grains of this salt were exposed to a red heat, the loss of weight was 5 grains; hence, I am disposed to consider it as a compound of

Arseniate,

1 atom arsenic acid	7·75
1 atom protoxide of cobalt	4·25
4 atoms water	4·5
	16·5

The loss of weight would indicate very nearly 4½ atoms water; but the half atom was probably only mechanically lodged between the particles of the salt.

7. Binantimoniate of cobalt. This is a red coloured salt not quite insoluble in water, which was analyzed by Berzelius; and from his experiments it appears that it is a compound of

Binantimoniate,

2 atoms antimonic acid	15
1 atom protoxide of cobalt	4·25
8 atoms water	9
	28·25

The water found by Berzelius amounted to one third the weight of the salt; which exceeds 8 atoms a little. Probably the excess, which amounts to about half an atom, was only mechanically mixed with the salt and not chemically combined.

Chromate, 8. Chromate of cobalt. This salt was obtained by mixing solutions of chromate of potash and nitrate of cobalt together. The chromate gradually fell down, of a reddish brown colour; it had no taste, and produced no change on vegetable blue colours. 12·85 grains of it when exposed to a red heat, assumed an olive green colour, and lost 2·1 grains of its weight. Hence, the constituents of the salt are

1 atom chromic acid	6·5
1 atom oxide of cobalt	4·25
2 atoms water	2·25
	13·0

Oxalate, 9. Oxalate of cobalt. This salt is easily obtained by mixing together the solutions of nitrate of cobalt and oxalate of ammonia. The precipitate is to be collected on a filter, well washed and dried in the open air. It is a light red powder, destitute of taste, insoluble in water, and incapable of altering the colour of vegetable blues. 11 grains of this salt, when heated upon the sand bath, lose 2·25 grains of water; and leave, when calcined, 4·25 grains of protoxide of cobalt. Hence, the constituents are

1 atom oxalic acid	4·5
1 atom protoxide of cobalt	4·25
2 atoms water	2·25
	11

10. Tartrate of cobalt. This salt was obtained by dissolving oxide of cobalt (from an ammoniacal solution) in tartaric acid. By digesting the acid over the oxide for twenty-four hours, a fine crimson solution was obtained, which, when concentrated by evaporation, let fall a red precipitate having a most beautiful crimson colour. This precipitate was put on a filter and washed with water two or three times to remove any excess of acid that might adhere to it; it was slightly soluble in water, for by this process its quantity was sensibly diminished, while the water with which it was washed came off red. The matter was now dried on the filter in a gentle heat; it had a fine crimson colour, little or no taste, but it reddened vegetable blues. 7·8 grains of this salt, being exposed to the highest temperature they could bear without decomposition, lost 1·25 grains of their weight: leaving 6·55 grains of tartrate still retaining its fine colour. Now, Tartrate,

6·55 : 12·5 : : 1·25 : 2·371 = water combined with an integrant particle of anhydrous salt.

This shows us that the constituents of the salt are

1 atom tartaric acid	8·25
1 atom protoxide of cobalt	4·25
2 atoms water . .	2·25
	14·75

All the salts of cobalt, if we can judge from the preceding list, contain water of crystallization. But the quantity is in general less than in the salts of nickel. The carbonate contains only 1 atom—the phosphate, oxalate, tartrate, and chromate contain 2 atoms—the bisulphate 3—the arseniate 4—the nitrate 6—the sulphate 7, and the biantimoniate 8 atoms.

13. SALTS OF MANGANESE.

The salts of manganese are most of them agreeable to the eye, particularly the sulphate and the acetate. They are transparent, and have a slight tinge of flesh red, or rather violet red, which adds greatly to their beauty.

Sulphate,

1. Sulphate of manganese. This salt crystallizes in very flat rhombic prisms, the greater angle of which is about 148°; its taste is similar to that of glauber salt, and it may be substituted for that salt as a purgative. Its constituents are

1 atom sulphuric acid	5
1 atom protoxide of manganese	4·5
5 atoms water . .	5·625
	15·125

When the solution is concentrated rather too much for crystallization, a white crust is deposited upon the bottom of the vessel: this crust is rather difficultly soluble in water, and is a compound of 1 atom of the anhydrous salt with 3 atoms of water.

2. Nitrate of manganese. This salt is not easily obtained in regular crystals; its colour is similar to that of the carbonate; when exposed to the air it speedily deliquesces. Its constituents are Nitrate,

1 atom nitric acid . .	6·75
1 atom protoxide of manganese	4·50
7 atoms water . . .	7·875
	19·125

3. Carbonate of manganese. This is a white tasteless powder, insoluble in water; when kept for some time it is partly converted into black oxide of manganese. Its constituents, according to the analysis of Dr. Forchhammer, are as follows: Carbonate,

1 atom carbonic acid . .	2·75
1 atom protoxide of manganese	4·5
1 atom water . . .	1·125
	8·375

I find, that when it is merely dried in the open air, without any artificial heat, it contains 2 atoms of water. 100 grains of this carbonate were dissolved in nitric acid, the solution was evaporated to dryness, and heated till the acid was destroyed, and black shining deutoxide of manganese remained behind. It weighed 50·55 grains, equivalent to 45·495 grains of protoxide, which would require for saturation 27·801 grains of carbonic acid; consequently, the constituents of the carbonate must have been

Carbonic acid .	27·8	or	2·75
Protoxide of manganese	45·5	-	4·50
Water	26·7	-	2·25 + 0·375
	100·0		9·5

The 0·375 of water above the 2 atoms, was probably mere hygrometric water, as no attempt was made to free it from all water mechanically lodged among its particles before dissolving it in nitric acid.

Phosphate,

4. Phosphate of manganese. This salt may be obtained by mixing together solutions of sulphate of manganese and phosphate of soda. The phosphate of manganese precipitates in the state of a white powder, which may be collected on a filter, washed and dried in the open air; it is tasteless, insoluble in water, and produces no alteration on vegetable blues. 10·7 grains of this salt, when heated to redness, give out 2·7 grains of water, and leave 8 grains of anhydrous phos-

phate of manganese. If we admit the excess of water (rather less than half an atom) to be hygrometric, the constituents of the salt will be

1 atom phosphoric acid .	3·5
1 atom protoxide of manganese	4·5
2 atoms water . . .	2·25
	10·25

Arseniate,

5. Arseniate of manganese. This salt may be obtained by mixing solutions of sulphate of manganese and arseniate of soda; it is a white tasteless powder, insoluble in water, and producing no alteration on vegetable blues. 23·5 grains of this salt being exposed to a red heat lost 11·25 grains; hence, the constituents are

1 atom arsenic acid . .	7·75
1 atom protoxide of manganese	4·5
10 atoms water . . .	11·25
	23·5

The binarseniate of manganese is soluble and easily formed. I have made no experiments to determine its composition.

Chromate,

6. Chromate of manganese. Protoxide of manganese decomposes chromic acid, so that the salt does not exist.

Acetate,

7. Acetate of manganese. This is a beautiful salt which crystallizes in flat rhombic prisms,

which are not altered by exposure to the air. They are composed of

1 atom acetic acid . .	6·25
1 atom protoxide of manganese	4·5
4 atoms water . . .	4·5
	15·25

Protoxalate,

8. Protoxalate of manganese. This salt may be formed by mixing rather concentrated solutions of oxalate of potash and sulphate of manganese. No immediate precipitation ensues; but after some time the mixture becomes muddy and the salt subsides. It is a very soft tasteless powder, having a white colour, with a very slight shade of pink; it is insoluble in water, and produces no change on vegetable blues; when moderately heated it gives out abundance of water. Being analyzed by driving off the water on the sand bath, and then calcining it in a strong red heat, its constituents were found to be

1 atom oxalic acid . .	4·5
1 atom protoxide of manganese	4·5
3 atoms water . . .	3·375
	12·375

Tartrate,

9. Tartrate of manganese. This is a beautiful transparent salt, having rather a deep brownish red colour; the crystals are four-sided prisms, exceedingly little soluble in water. This salt has

hitherto been mistaken for a triple salt, but it contains no potash. Its constituents are

1 atom tartaric acid . .	8·25
1 atom protoxide of manganese	4·5
2 atoms water . . .	2·25
	15

All the salts of manganese included in the preceding list contain water of crystallization. The smallest quantity of water is 2 atoms and the greatest 10 atoms. The carbonate, phosphate, and tartrate contain 2 atoms—the oxalate contains 3—the acetate 4—the sulphate 5—the nitrate 7—and the arseniate 10 atoms.

14. SALTS OF ZINC.

1. Sulphate of zinc. This salt crystallizes in right rhombic prisms,—frequently the prisms are terminated by four-sided pyramids. The figure of the crystals is modified a good deal by the excess of acid allowed to remain in the liquid from which the crystals are to be separated. I have never been able to obtain this salt, though ever so frequently crystallized, in a state in which it did not redden vegetable blues. **Sulphate,**

The analyses of two varieties have been detailed in the first section of the first chapter of this work ; I shall merely give the results in this place.

(1.) Sulphate of zinc deposited from a cold solution :

1 atom sulphuric acid	5
1 atom oxide of zinc .	5·25
7 atoms water . .	7·875
	18·125

(2.) Sulphate deposited from a hot solution :

1 atom sulphuric acid	5
1 atom oxide of zinc .	5·25
3 atoms water . .	3·375
	13·625

Nitrate,

2. Nitrate of zinc. This salt has an exceedingly disagreeable taste, and may be obtained, with difficulty, in flat four-sided prisms, which deliquesce so rapidly, that it is not an easy task to obtain the salt in a state fit for analysis. Its constituents are

1 atom nitric acid .	6·75
1 atom oxide of zinc .	5·25
6 atoms water . .	6·75
	18·75

Carbonate,

3. Carbonate of zinc. Two species of this salt are found native, and constitute a part of the bodies confounded by mineralogists under the name of *calamine*.

(1.) Anhydrous carbonate. It occurs crystallized in very small obtuse rhomboids. It has a yellowish white colour, and a specific gravity of 4·334; it dissolves with effervescence in sulphuric acid, and is composed of

1 atom carbonic acid	2·75
1 atom oxide of zinc	5·25
	8

Carbonate of zinc, obtained by precipitating sulphate of zinc by carbonate of soda, washing the precipitate, and drying it at 212°, is likewise anhydrous.

(2.) Hydrous carbonate of zinc. It has not yet been met with in crystals; but it has a white colour, or yellowish white colour, and is most commonly stalactical. Its specific gravity is 3·584; it dissolves with effervescence in sulphuric acid, and does not gelatinize with acids. Its constituents are

1 atom carbonic acid .	2·75
1 atom oxide of zinc .	5·25
1 atom water . .	1·125
	9·125

Phosphate,

4. Phosphate of zinc. This salt may be obtained by mixing together solutions of sulphate of zinc and phosphate of soda in the atomic proportions. The phosphate of zinc immediately appears in white flocks, which are soon deposited in a pulverulent form. When dried in the

open air it is a white tasteless powder, which does not alter vegetable blues; it is insoluble in water. 11 grains of this salt, when exposed to a red heat, give out 2·25 grains of water; hence, the constituents are

1 atom phosphoric acid	3·5
1 atom oxide of zinc .	5·25
2 atoms water . .	2·25
	11·0

Biphosphate,

5. Biphosphate of zinc. I formed this salt by dissolving phosphate of zinc in phosphoric acid, and evaporating the solution. Small white coloured scales, with a silky lustre, were deposited, which constituted the salt in question. It has scarcely any taste, reddens vegetable blues, and is slightly soluble in water. When 16·75 grains of this salt were exposed to a heat gradually raised to redness, they lose 4·5 grains of weight; hence, the constituents must be

2 atoms phosphoric acid	7
1 atom oxide of zinc .	5·25
4 atoms water . .	4·5
	16·75

Arseniate,

6. Arseniate of zinc. This salt was formed by mixing solutions of sulphate of zinc and arseniate of soda in the atomic proportions. The arseniate of zinc was immediately deposited in a

gelatinous state, which gradually assumed the form of a light milk white deposite; it continued gelatinous and transparent (exactly like silica) even after it had been collected on the filter, and washed for some hours. When dried in the open air it became an opaque white matter, like enamel; it was tasteless, insoluble in water, and did not affect vegetable blues. 22 grains of this salt being exposed to a red heat, lost 9 grains of its weight; hence its constituents are

1 atom arsenic acid	7·75
1 atom oxide of zinc	5·25
8 atoms water	9·00
	22

7. Chromate of zinc. This salt was obtained by mixing solutions of sulphate of zinc and chromate of potash in the atomic proportions. The chromate of zinc precipitated in the state of a fine yellow powder; the supernatant liquid being still yellow, was concentrated. It yielded two distinct sets of crystals intimately mixed with each other; namely, bichromate of potash, and sulphate of zinc tinged yellow by chromate of potash. Chromate of zinc is nearly tasteless, but it is soluble in water; for the liquid with which it was washed was yellow, and yielded, when evaporated, chromate of zinc. Chromate of zinc dried in the open air loses no weight Chromate,

when exposed to a red heat. Hence, the salt is anhydrous, and its constituents are

1 atom chromic acid	.	6·5
1 atom oxide of zinc	.	5·25
		11·75

Acetate, 8. Acetate of zinc. This salt crystallizes in large very oblique rhombs. It has a silky lustre, and, indeed, bears a very close resemblance to talc in its appearance; when kept for some time it is apt to lose a little of its acid. Its constituents, supposing it examined when in a state of purity, are

1 atom acetic acid	.	6·25
1 atom oxide of zinc	.	5·25
7 atoms water	.	7·875
		19·375

Oxalate, 9. Oxalate of zinc. This salt may be obtained by mixing together solutions of sulphate of zinc and oxalate of ammonia in the atomic proportions. For a few seconds the mixture continues transparent, but it gradually becomes muddy, and deposites oxalate of zinc in abundance: the decomposition is complete, for no traces of oxalic acid or oxide of zinc can be found in the supernatant liquid. 181·25 grains of sulphate of zinc and 88·75 grains of oxalate of ammonia, gave 118 grains of oxalate of zinc;—had the quantity been 120 grains, it is obvious that its constituents would have been

1 atom oxalic acid .	4·5
1 atom oxide of zinc .	5·25
2 atoms water . .	2·25
	12·0

The loss of the two grains was owing to the filter on which the oxalate of zinc was collected.

Tartrate,

10. Tartrate of zinc. This is a soft white tasteless powder like chalk. It is anhydrous; for 13·5 grains of it being calcined in a platinum crucible left 5·25 grains of oxide of zinc. Hence, its constituents are

1 atom tartaric acid .	8·25
1 atom oxide of zinc .	5·25
	13·5

The salts of zinc, as far as we can judge from the preceding list, vary a good deal in their water of crystallization, though the quantity is rather small,—eight atoms of water being the greatest number found in any salt hitherto analyzed. Carbonate, chromate, and tartrate, are anhydrous—hydrous carbonate contains 1 atom water—phosphate and oxalate 2 atoms—sulphate, from a hot solution, 3—biphosphate 4—nitrate 6—sulphate and acetate 7—and arseniate

8 atoms. No salt of zinc examined contains 5 atoms of water.

15. SALTS OF CADMIUM.

I have mentioned in a former chapter of this work, that by the kindness of Mr. Harepath of Bristol, I was favoured with a quantity of the sublimation that attaches itself to the roof of the apartment in which zinc is smelted. This sublimate had a pretty deep brown colour, and contained a good deal of vegetable matter. After a few preliminary trials, I found that it contained about ten per cent. of oxide of cadmium; by far the greatest portion of the remainder was oxide of zinc. I therefore dissolved it in sulphuric acid, and precipitated the cadmium by means of a plate of zinc. I obtained by this simple process, about 500 grains of metallic cadmium, which enabled me, not merely to verify the experiments of Stromeyer, but to make a set of experiments on the salts of that metal: for with the exception of the sulphate and nitrate, Stromeyer has not determined the water of crystallization which they contain. I shall here state the results of these investigations.

Sulphate, 1. Sulphate of cadmium. I have given a description of this salt in a former part of this work. Its constituents, when in crystals, are

1 atom sulphuric acid	5
1 atom oxide of cadmium	8
4 atoms water	4·5
	17·5

It is so apt to lose a portion of its water of crystallization, that its analysis is not easily made; when it precipitates in a white crust it contains only 2 atoms of water.

Nitrate,

2. Nitrate of cadmium. This salt, crystallized in vacuo over sulphuric acid, formed thin transparent plates; they deliquesce when exposed to the air, as Stromeyer had observed. 19·25 grains of these crystals were dissolved in water, and precipitated at a boiling temperature by carbonate of soda. The carbonate of cadmium, after ignition, weighed in one experiment 7·955 grains, and in another 7·912 grains. Hence, it is obvious, that the constituents are

1 atom nitric acid	6·75
1 atom oxide of cadmium	8·0
4 atoms water	4·5
	19·25

The constituents, as stated by Stromeyer, are as follows:

Nitric acid	6·884
Oxide of cadmium	8·114
Water	4·208
	19·206

While the analysis in my laboratory gave

Nitric acid	6·750
Oxide of cadmium	7·933
Water	4·608
	19·291

The mean of both gives the atomic weight of cadmium 8·023, and of the salt 19·2485; both of which are exceedingly near the truth.

Carbonate, 3. Carbonate of cadmium. This is a white tasteless powder, having a certain resemblance in colour to white lead. It is destitute of combined water, but when dried in the open air retains the fifth part of an atom of water, no doubt hygrometrically united to the salt. Its constituents (abstracting this water) are

1 atom carbonic acid	2·75
1 atom oxide of cadmium	8
	10·75

Phosphate, 4. Phosphate of cadmium. This salt was formed by mixing together solutions of nitrate of cadmium and phosphate of soda. The precipitate is at first very bulky, but afterwards dimishes much in volume; it is tasteless and insoluble in water. 21·12 grains of this salt dried in the air, when exposed for 20 minutes to a low red heat, were reduced to 18·905 grains. In a very strong red heat it was reduced to a semiopaque glass, and weighed 18·63 grains. From this experiment I consider it as a compound of

1 atom phosphoric acid	3·5
1 atom oxide of cadmium	8
1 atom water	1·125
	12·625

There was about one-third of an atom of surplus water, which was of course hygrometrical.

5. Arseniate of cadmium. When arseniate of soda is added to a solution of nitrate of cadmium, a white precipitate falls, at first very bulky, but in a few hours it contracts much in size. This salt is a white tasteless powder, which is insoluble in water. 21·84 grains of this salt dried in the open air, when exposed to a pretty strong red heat, were reduced to 20·01 grains; hence, 15·75 grains of the anhydrous salt must unite to 1·44 grains of water to be brought into the state of the precipitated salt dried in the open air. The constituents of this salt then are **Arseniate,**

1 atom arsenic acid	7·75
1 atom oxide of cadmium	8
1 atom water	1·125
	16·875

The 0·315 of superfluous water was of course mechanically lodged among the particles of the salt.

Chromate, 6. Chromate of cadmium. This salt was obtained by mixing together solutions of sulphate of cadmium and chromate of potash. The chromate falls in the state of a most beautiful yellow coloured powder; it has little or no taste, yet it is not absolutely insoluble in water: for when washed on the filter, the liquid always passes through of a yellow colour. And in one of my experiments, I dissolved almost the whole of a quantity of chromate of cadmium by persisting in trying to wash it till the liquid should pass through colourless. 20·525 grains of this salt, when exposed to a red heat, assumed a darker yellow colour, and lost 6 grains of its weight: hence, its constituents are

1 atom chromic acid	6·5
1 atom oxide of cadmium	8
5 atoms water	5·625
	20·125

The small surplus water was doubtless hygrometrical.

Acetate, 7. Acetate of cadmium. When a very concentrated solution of this salt is exposed for about ten days to the air, it is gradually converted into a crystalline mass, while a thick liquid remains floating above it. These crystals are very soluble in water, and undergo little change from exposure to the air. 22·13 grains of these crystals, previously dried upon blotting paper, were decomposed by sulphuric acid. The anhydrous sulphate of cadmium weighed 17·4 grains, equivalent to 10·7007 grains of oxide of cadmium. Hence, the constituents of the salt are

1 atom acetic acid	6·25
1 atom oxide of cadmium	8·00
2 atoms water	2·25
	16·5

Oxalate,

8. Oxalate of cadmium. This salt is precipitated when oxalate of potash is dropped into nitrate of cadmium; it is a white, tasteless powder, insoluble in water. When 17·06 grains of this salt, previously dried in the open air, were cautiously heated on the sand bath in a platinum crucible, the loss of weight was 3·62 grains: hence, the constituents of this salt are

1 atom oxalic acid	4·5
1 atom oxide of cadmium	8·0
3 atoms water	3·375
	15·875

Tartrate,

9. Tartrate of cadmium. If tartrate of potash be added in slight excess to a solution of nitrate of cadmium, there instantly falls a pretty bulky precipitate. The liquid separated from this precipitate by filtration, deposites at the end of twenty-four hours a small quantity of transparent granular crystals; the supernatant liquid still gives a slight precipitate with carbonate of

soda. Hence, tartrate of cadmium is slightly soluble in water; probably nearly as soluble as tartrate of manganese. These crystals are tasteless; 10·225 grains of them heated on the sand bath for about two hours, lost their crystalline form and became white and opaque, and had lost 1·17 grain of their weight. Hence, the constituents of this salt are

1 atom tartaric acid	8·25
1 atom oxide of cadmium	8
2 atoms water	2·25
	18·5

Citrate,

10. Citrate of cadmium. Citrate of ammonia produces a remarkably bulky gelatinous precipitate in nitrate of cadmium. When 17·34 grains of this salt, previously dried in the open air upon blotting paper, were exposed to the heat of the sand bath, they lost 2·17 grains of their weight: hence, the constituents of this salt are

1 atom citric acid	7·25
1 atom oxide of cadmium	8
2 atoms water	2·25
	17·5

We see from the preceding details that the greatest quantity of water in any of the salts of cadmium is 4 atoms. One salt of cadmium, the carbonate, is anhydrous—two, the phosphate and arseniate, contain 1 atom of water—four, acetate, tartrate, citrate and muriate, contain 2 atoms—one, oxalate, contains 3—and two, sulphate and nitrate, contain 4 atoms.

16. SALTS OF LEAD.

1. Sulphate of lead. This salt occurs native in regular crystals, though from its insolubility it cannot be crystallized artificially. The primary form of the crystals is a right rhombic prism. It is anhydrous, though it usually con tains a trace of water mechanically lodged between the plates of the crystals. Its constituents are **Sulphate,**

1 atom sulphuric acid	5
1 atom protoxide of lead	14
	19

2. Nitrate of lead. This salt is easily soluble in water, and may be obtained without difficulty in large white opaque crystals having a vitreous lustre, and the shape of regular octahedrons with a square basis; it is likewise anhydrous. Its constituents are **Nitrate,**

1 atom nitric acid .	6·75
1 atom protoxide of lead	14
	20·75

Dinitrite,

3. Dinitrite of lead. When nitric acid is digested for a long time on an excess of litharge, a yellow coloured solution is obtained, from which precipitate beautiful yellow coloured crystals in small shining scales. The constituents of these crystals are as follows:

1 atom nitrous acid .	5·75
2 atoms protoxide of lead	28
2 atoms water . .	2·25
	36

Dinitrate,

4. Dinitrate of lead. This salt was obtained by Berzelius by precipitating nitrate of lead by too small a quantity of ammonia to throw down the whole lead. Chevreul obtained it by boiling together equal weights of nitrate of lead and protoxide, filtrating the liquid while hot, and allowing it to crystallize in close vessels. The crystals were pearl coloured scales. This salt is soluble in water, and has the sweet and astringent taste of nitrate. Its constituents are

1 atom nitric acid .	6·75
2 atoms protoxide of lead	28
	34·75

Hyponitrite,

5. Hyponitrite of lead. Berzelius obtained this salt by dissolving a given quantity of dinitrite of lead in water, adding as much sulphuric acid as would deprive it of half its lead, filter-

ing the solution, and allowing it to crystallize spontaneously—octahedral crystals of a deep yellow colour were deposited. He analyzed these crystals, and found the constituents

Acid . .	23·925
Protoxide of lead	70·375
Water . .	5·700
	100·000

If we consider them as composed of

1 atom hyponitrous acid	4·75
1 atom protoxide of lead	14·00
1 atom water . .	1·125
	19·875

the constituents in 100 parts of the salt will be

Acid .	23·90
Oxide .	70·44
Water .	5·66
	100

Now, these numbers almost coincide with those of Berzelius, and induced me to consider the salt as a hyponitrite rather than a nitrite, which is the view taken both by Berzelius and Chevreul.

6. Carbonate of lead. This salt occurs native, and is known by the name of white lead. Its primary form is a right rhombic prism. It is anhydrous, and is composed of Carbonate,

1 atom carbonic acid	2·75
1 atom protoxide of lead	14
	16·75

Phosphate, 7. Phosphate of lead. This salt exists native, and is often crystallized in six-sided prisms. It is anhydrous; but never quite pure, containing a little muriatic acid and some oxide of iron. It is very difficult to form a neutral phosphate of lead artificially, for the acid and oxide are capable of combining in two proportions; namely, 1 atom acid and 1 atom oxide, and 1 atom acid and 2 atoms oxide; and in general variable proportions of the diphosphate mix themselves with the neutral phosphate, and render the result uncertain and inconstant. The constituents of the neutral phosphate are

1 atom phosphoric acid	3·5
1 atom protoxide of lead	14
	17·5

The constituents of the diphosphate are

1 atom phosphoric acid	3·5
2 atoms protoxide of lead	28
	31·5

Arseniate, 8. Arseniate of lead. This salt has been found native in different places. Fine crystals of it in large six-sided prisms of a yellowish colour, and translucent, occur in Huel Unity in Cornwall. If any confidence can be put in the analysis of these crystals by the late Mr. Gregor, they are composed of

1 atom arsenic acid	7·75
1½ atom protoxide of lead	21
	28·75

But the native arseniate of lead from Johann-Georgenstadt, analyzed by Chenevix and Thenard, was a compound of

1 atom arsenic acid	7·75
1 atom protoxide of lead	14
	21·75

It remains, therefore, to determine whether Mr. Gregor's results be accurate; if they be, there are obviously two native species of arseniates of lead—namely, the neutral and the sesquiarseniate.

Chromate,

9. Chromate of lead. This salt also occurs native, crystallized in transparent prisms having a fine orange colour. The salt is anhydrous, and composed of

1 atom chromic acid	6·5
1 atom protoxide of lead	14
	20·5

It is anhydrous also when obtained by precipitation. It is not unlikely that there occurs also a bichromate of a red colour, composed of

2 atoms chromic acid	13
1 atom protoxide of lead	14
	27

Molybdate,

10. Molybdate of lead. This salt occurs native in Corinthia. It is usually crystallized in small rhomboidal plates; it has a pale yellow colour, and a certain degree of transparency; it is tasteless and insoluble in water, and perfectly anhydrous. Its constituents are

1 atom molybdic acid	9
1 atom protoxide of lead	14
	23

Bitungstate,

11. Bitungstate of lead. This salt likewise occurs native; for it has been found at Zinnwalde in Bohemia in very acute four-sided pyramids, having a brown colour, and perfectly tasteless, and insoluble in water. I am not aware that any analysis of the native tungstate of lead has been made; but the artificial tungstate, formed by mixing solutions of bitungstate of ammonia and nitrate of lead, was examined by Berzelius. From his experiments it appears to be a bitungstate; consequently, its constituents must be

2 atoms tungstic acid .	37·5
1 atom protoxide of lead	14
	51·5

12. Acetate of lead. The constituents of this salt have been stated in a former part of this work. They are as follows: Acetate,

1 atom acetic acid .	6·25
1 atom protoxide of lead	14
3 atoms water . .	3·375
	23·625

13. Diacetate of lead. This salt was obtained by boiling crystals of acetate of lead and litharge, mixed each in the requisite proportions in a sufficient quantity of distilled water. The litharge was entirely dissolved; and, by evaporating the solution in a gentle heat, the diacetate was deposited in the state of a beautiful white sediment, which had the aspect of crystals, although I could not recognise any regular form. It had a sweet and astringent taste, and was soluble in pure water. I dried this salt, by pressing it between folds of blotting paper, till it ceased to give out any moisture. 45·5 grains of the matter thus treated being subjected to a red heat in a platinum crucible, left 27·9 grains of fused protoxide of lead. From this experiment I consider the constituents of the salt to be Diacetate,

1 atom acetic acid	6·25
2 atoms protoxide of lead	28
10 atoms water	11·25
	45·5

Trisacetate,

14. Trisacetate of lead. This salt was first obtained by Thenard. His method was to boil 23·625 parts of crystallized acetate of lead with 35·44 parts of litharge, deprived of its carbonic acid by heat. The liquid thus obtained when evaporated deposited the trisacetate in white plates. It is still soluble in water, but less so, and has a less sweet taste, than common acetate of lead. I have not myself made any experiments on this salt; but Berzelius analyzed it, and found its constituents

Acetic acid	6·25
Protoxide of lead	41

Three atoms of protoxide of lead weigh 42. Hence it is obvious, that the salt was a compound of 1 atom acid and 3 atoms protoxide of lead. If any confidence can be put in Thenard's analysis, it contains 2 atoms water.

Benzoate,

15. Benzoate of lead. This salt forms crystals of a brilliant white colour, soluble both in water and alcohol. From the analysis of Berzelius, its constituents are

1 atom benzoic acid .	15
1 atom protoxide of lead	14
1 atom water . .	1·125
	30·125

Succinate,

16. Succinate of lead forms long slender crystals, scarcely soluble in water. They seem to be anhydrous, and are composed of

1 atom succinic acid .	6·25
1 atom protoxide of lead	14
	20·25

Formate,

17. Formate of lead. This salt is composed of

1 atom formic acid .	4·625
1 atom protoxide of lead	14
1 atom water . .	1·125
	19·75

Oxalate,

18. Oxalate of lead. This salt is an insoluble and tasteless anhydrous powder, composed of

1 atom oxalic acid .	4·5
1 atom protoxide of lead	14
	18·5

Tartrate,

19. The same observations apply to tartrate of lead, the constituents of which are

1 atom tartaric acid .	8·25
1 atom protoxide of lead	14
	22·25

From the preceding details we see that the greater number of the salts of lead are anhydrous; and the few which contain water seldom have more than 1 or 2 atoms in the integrant particle of salt. The acetate of lead is the salt which contains most water. The quantity amounts to 3 atoms to the integrant particle of acetate, while the diacetate (if we suppose it sufficiently dried) contains 10 atoms.

17. SALTS OF COPPER.

The black oxide of copper alone seems capable of combining with acids and forming salts; for, except the protomuriate, we do not know any salt of copper containing the suboxide for a base. From the composition of the salts of copper, there can be no reason to doubt that 5 represents the atomic weight of black oxide of copper.

Sulphate, 1. Sulphate of copper. This well known and beautiful salt has been often described. It always reddens vegetable blues, however carefully prepared; and by long boiling its aqueous solution with peroxide of copper in the requisite proportion, we form an insoluble sulphate of copper, containing twice as much oxide united to the acid as in the soluble salt. It must therefore be a disulphate. Sulphate of copper is composed of

1 atom sulphuric acid	5
1 atom peroxide of copper	5
5 atoms water . .	5·625
	15·625

2. Nitrate of copper. This is also a well known and beautiful salt. It is so deliquescent, that it is not easy to obtain it in well defined crystals. Its constituents are **Nitrate.**

1 atom nitric acid .	6·75
1 atom peroxide of copper	5
7 atoms water . .	7·875
	19·625

3. Carbonate of copper. Of this salt there are three species met with native; namely, the anhydrous carbonate, which has a brown colour; the green carbonate, and the blue carbonate. The constituents of the anhydrous carbonate are as follows: **Carbonates,**

1 atom carbonic acid .	2·75
2 atoms peroxide .	10
	12·75

It is therefore a dicarbonate.

(2.) The green carbonate of copper constitutes the beautiful ore of copper called malachite. When pure, its constituents are

1 atom carbonic acid .	2·75
2 atoms peroxide of copper	10
1 atom water . .	1·125
	13·875

(3.) The blue carbonate of copper occurs crystallized in oblique rhombic prisms of a beautiful blue colour. It has been repeatedly analyzed. I shall take the experiments of Mr. Phillips as sufficiently exact to show the constituents of this rather complicated salt. He found 100 parts of the crystals composed of

Peroxide of copper	69·08
Carbonic acid	25·46
Water	5·46
	100·00 *

Now, if we consider the salt as composed of

2 atoms carbonate of copper	15·5
1 atom protohydrate of copper	6·125
	21·625

we obtain the following for its constituents per cent.

Peroxide of copper	69·364
Carbonic acid	25·433
Water	5·203
	100

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* Institution Journal, IV. 276.

which corresponds so nearly with the result obtained by Mr. Phillips that there seems no reason to doubt that the salt is really a compound of 2 atoms anhydrous carbonate, and 1 atom of protohydrate of copper.

We see from this native mineral that the oxide of copper and carbonic acid are capable of combining atom to atom; although hitherto chemists have not succeeded in forming any such compounds artificially.

Phosphates,

4. Phosphate of copper. This salt, though very rare, is occasionally met with in small dark green crystals, and two species have been recognized by mineralogists; viz. the anhydrous phosphate and the hydrous. The primary form of the first species is considered by Mr. Brooke as a right rhombic prism, while Mr. Levy has shown that the primary form of the other is an oblique rhombic prism.

From the analysis of Mr. Lunn, it appears that the anhydrous phosphate is composed of

1 atom phosphoric acid	3·5
1 atom oxide of copper	5
	8·5

We have no good analysis of the native hydrous phosphate; but Chenevix has given us an analysis of the artificial phosphate, and from his result it appears to be a compound of

1 atom phosphoric acid	3·5
1 atom peroxide of copper	5
1 atom water	1·125
	9·625

His water exceeded an atom by one third; but as the salt was in the state of powder, this surplus was no doubt mechanical.

Arseniates,

5. Arseniate of copper. This salt has been met with in considerable quantity in Huel Garland copper mine, in the parish of Gwennap, Cornwall. It was analyzed by Chenevix, who found it to consist of four different varieties, distinguished also by the shape of the crystals and the colour. He formed, likewise, an arseniate of copper differing from any of these four varieties, by mixing solutions of arseniate of ammonia and nitrate of copper together, filtrating the mixture, and adding alcohol to the liquid which passed through the filter: rhomboidal crystals of a blue colour gradually precipitated.

These analyses were made at a time when the data were not quite so accurate as at present, and no modern chemist has had it in his power to repeat them. But I think it probable, from Mr. Chenevix's analyses, that these five kinds of arseniates were composed as follows:

(1.) Artificial arseniate,

1 atom arsenic acid	7·75
1 atom oxide of copper	5
4 atoms water	4·5
	17·25

Sesquarseniate,

(2.) The second variety of Chenevix is usually called copper mica. It has a deep emerald green colour, a specific gravity of 2·548, and is crystallized in six-sided plates. Its primary form is an acute rhomboid. It is a subsesquarseniate, being composed of

1 atom arsenic acid	7·75
1½ atom oxide of copper	7·75
3 atoms water	3·375
	18·875

(3.) The third variety of Chenevix is usually called *olivenerz* from its colour, which is a dark or olive green. Its specific gravity is 4·280, and its primary form a right rhombic prism; it consists of

1 atom arsenic acid	7·75
2½ atoms oxide of copper	12·5
6 atoms water . .	6·75
	27·00

(4.) The fourth variety of Chenevix is usually in capillary crystals; its primary form is an oblique rhomb—its colour and specific gravity the same as the preceding. Its composition is also the same as the preceding, only it contains but half as much water.

1 atom arsenic acid	7·75
2½ atoms oxide of copper	12·5
3 atoms water . .	3·375
	23·625

(5.) The fifth variety of Chenevix is the *linzenerz* of mineralogists. It has a fine grass green colour, a specific gravity of 2·881, and its primary form is an obtuse octahedron with a rectangular base; it contains twice as much base and thrice as much water as the third variety of Chenevix, being composed of

1 atom arsenic acid	7·75
5 atoms oxide of copper	25
18 atoms water . .	20·25
	53

In this last salt, however, the water found by Chenevix approaches nearer to 17 than to 18 atoms.

Chromate, 6. Chromate of copper. This salt was obtained by mixing together solutions of chromate of potash and muriate of copper. A fine buff coloured precipitate with a shade of dark red fell, which was collected on a filter, washed and dried in the open air at a temperature of between 70° and 80°. This powder appeared at first tasteless, but it left a slightly sweetish impression, which was followed by a feeling of bitterness. It was not absolutely insoluble in water: for the water used for washing it always came through slightly coloured, though I continued to wash it for several days. It does not affect vegetable blues. 13·9 grains of this powder when exposed to a red heat lost 2·4 grains of its weight; hence, its constituents are

1 atom chromic acid	6·5
1 atom oxide of copper	5
2 atoms water	2·25
	13·75

Acetate,

7. Acetate of copper. This salt has a fine green colour, and crystallizes in large octahedrons with a rhomboidal base. Mr. R. Phillips found that 100 parts of this salt contain 39·5 of oxide of copper. And Berzelius' experiment, when properly corrected, exactly agrees with this statement.* Hence, the constituents of the salt must be

Acetic acid	49·375	or	6·25
Oxide of copper	39·5	-	5
Water	11·125	-	1·408
	100		

1·408 exceeds 1 atom of water by 0·283, or

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* Annals of Philosophy, (second series) VIII. 192.

about ¼th of an atom, doubtless owing to the presence of a little hygrometrical water. It is obvious, then, that the constituents of the salt are

1 atom acetic acid .	6·25
1 atom oxide of copper	5
1 atom water . .	1·125
	12·375

Diacetate,

8. The pigment called *verdigris*, occurs sometimes of a green colour and sometimes of a blue. From the analysis of Mr. Phillips, with which that of Berzelius corresponds, we find it a compound of

1 atom acetic acid .	6·25
2 atoms oxide of copper	10
6 atoms water . .	6·75
	23

Berzelius extracted from verdigris, or *diacetate of copper*, as it may be called, two different salts, the one soluble in water, the other insoluble.

Subsesquacetate,

9. The soluble salt was obtained by evaporating a solution of verdigris in distilled water by a very gentle heat, until the greater part of its saline contents were deposited: by applying heat the whole was dissolved, and the solution was mixed with alcohol. In about an hour a bulky gelatinous looking mass was deposited, consist-

ing of an aggregation of minute crystals; these were collected on a linen cloth and thoroughly washed; when dry they had rather a pale blue colour. 100 parts of this salt, when kept for some hours in the temperature of 140°, lost, in different trials, 9·5, 10, and 10·3 of its weight: the residue, which had acquired a greenish tint, was boiled for an hour with hydrate of barytes. The filtered liquid, being freed from its excess of barytes by a current of carbonic acid gas, was evaporated to dryness, redissolved and thrown down by sulphuric acid: the sulphate of barytes weighed 84, equivalent to 35·593 of acetic acid. The copper precipitated by iron was ignited in a current of common air, and then reduced by hydrogen gas: it gave 34·352 copper, equivalent to 42·937 oxide of copper. In other experiments he obtained 86·6 and 86·8 sulphate of barytes, equivalent to 43·3 and 43·4 oxide of copper. Hence, the constituents of the salt are

Acetic acid	35·593	or	6·25
Oxide of copper	43·212	-	7·588
Water . .	21·195	-	3·721
	100·000		

6·25 represents an atom of acetic acid, 7·588 differs little from 7·5, an atom and a half of oxide of copper and 3·721 is not quite a third of an atom more than 3·375, which represents 3 atoms of water. Hence, the constituents of the salt are

1 atom acetic acid .	6·25
$1\frac{1}{2}$ atom oxide of copper	7·50
3 atoms water . .	3·375
	17·125

It is, therefore, a subsesquacetate of copper.

Trisacetate, 10. The insoluble salt is obtained by allowing verdigris to swell up in water, filtering through coarse linen, which retains the impurities, and lets the salt pass through. The crystalline scales are now separated by pouring the whole of the filtered solution on fine cambric;—they should be pressed closely together and washed a few times with water; after this they must be transferred to a paper filter and thoroughly washed with alcohol. When thus obtained, the salt constitutes a mass of small light blue shining crystalline scales, having a deeper and purer blue colour than the subsesquacetate of copper. When dried in 212°, it loses a very little hygroscopic water, and does not alter its apppearance. From 100 parts of this salt Berzelius obtained 64·25, and in another experiment 64·7 parts of oxide of copper: the acetic acid determined, as in the preceding salt, amounted to 26·995 per cent. Hence, the constituents of the salt are

Acetic acid	26·995	or	6·25
Oxide of copper	64·475	-	14·928
Water . .	8·530	-	1·975
	100·000		

14·928 is very nearly 15, or 3 atoms of oxide of copper; and 1·975 wants a very little of 2·25; this deficit was probably owing to the previous exposure of the salt to a heat of 212°. The constituents are obviously

1 atom acetic acid .	6·25
3 atoms oxide of copper	15
2 atoms water .	2·25
	23·5*

This salt, is therefore, a trisacetate of copper.

11. Berzelius obtained another insoluble acetate of copper by heating a dilute solution of subsesquacetate of copper. The salt is deposited in liver brown flocks, which become black when collected on the filter and dried. 100 parts of this salt, previously dried in the temperature of 150°, gave from 91·6 to 92·5 of oxide of copper; and the acetic acid, determined by means of hydrate of barytes, was 2·392 per cent. Hence, the constituents of the salt are

Acetic acid .	2·392	or	6·25
Oxide of copper	92·050	-	240·51
Water . .	5·558	-	14·522
	100·000		

240·51 corresponds very nearly with 240, or 48 atoms oxide of copper; and 14·522 differs but

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* Annals of Philosophy, (second series) VIII. 195.

little from 14·625, or 13 atoms of water. Hence, the constituents of the salt are

1 atom acetic acid .	6·25
48 atoms oxide of copper	240·00
13 atoms water . .	14·625
	260·875

unless we be rather disposed to consider it as a mechanical mixture of oxide of copper and a little trisacetate of copper;—this I think the most probable supposition.

Oxalate, 12. Oxalate of copper. This is a green tasteless insoluble powder, which, when dried in the open air, is a compound of

1 atom oxalic acid .	4·5
1 atom oxide of copper	5
1 atom water . .	1·125
	10·625

One half of the water is very easily expelled by heat; but the remainder continues obstinately fixed till the acid undergoes decomposition.

Tartrate, 13. Tartrate of copper. This salt is easily formed by mixing dilute solutions of sulphate of copper and tartrate of potash. Small green crystals by degrees form, which are very little soluble in water. The constituents of this salt are

1 atom tartaric acid .	8·25
1 atom oxide of copper .	5
3 atoms water . .	3·375
	16·625

14. Formate of copper. This salt has a greenish blue colour, and forms flat six-sided prisms terminated by four-sided pyramids. Its constituents, from Berzelius' analysis, appear to be Formate.

1 atom formic acid .	4·625
1 atom oxide of copper	5
4 atoms water . .	4·5
	14·125

From the preceding list, which includes a considerable number of native cupreous salts, it appears that most of the salts of this genus contain water of crystallization. In general the quantity of water is small, for more than half the salts in the list contain only 1, 2, or 3 atoms. One of the carbonates and one of the phosphates are anhydrous—green dicarbonate, a phosphate, acetate, and oxalate, contain 1 atom—chromate and trisacetate contain 2 atoms—two arseniates, subsesquacetate and tartrate, 3—an arseniate and formate 4—sulphate 5—an arseniate and verdigris 6—nitrate 7—an arseniate 18. With the exception of this last arseniate, 7 is the greatest number of atoms of water in any cupreous salt hitherto analyzed.

18. SALTS OF BISMUTH.

1. Sulphate of bismuth. This salt is usually in the state of a white powder, though it may be Sulphate,

obtained also in needles. It is usually anhydrous, and consists of

1 atom sulphuric acid	5
1 atom oxide of bismuth	10
	15

Nitrate,

2. Nitrate of bismuth. This salt may be obtained from a solution of the salt, formed by dissolving bismuth in nitric acid in water, by evaporating the solution. It forms very beautiful transparent colourless crystals having the shape of pretty oblique rhombs.

The constituents of these crystals are

1 atom nitric acid .	6·75
1 atom oxide of bismuth	10
3 atoms water . .	3·375
	20·125

Dinitrate,

3. Dinitrate of bismuth. The crystals that form when bismuth is dissolved in rather concentrated nitric acid, have an excess of acid from which they may be freed by pressure between folds of blotting paper. I analyzed them thus purified as much as possible, and found the constituents

1 atom nitric acid .	6·75
2 atoms oxide of bismuth	20
2 atoms water . .	2·25
	29

4. Carbonate of bismuth. This salt was obtained by decomposing nitrate of bismuth by an alkaline carbonate. The white precipitate, being collected on a filter, washed, and dried, was a white tasteless powder, quite insoluble in water. Carbonate,

100 grains of it being dissolved in nitric acid, the loss of weight was 7·5 grains. 100 grains of the same salt were gradually heated to redness in a platinum crucible, the oxide remaining was partially fused, and the loss of weight was 13·8 grains. Hence, the constituents of this salt are

Carbonic acid .	7·5	or	2·75
Oxide of bismuth	86·2	-	31·606
Water . .	6·3	-	2·31
	100·0		

From this analysis there can be little doubt that the constituents of this salt are

1 atom carbonic acid .	2·75
3 atoms oxide of bismuth	30
2 atoms water . .	2·25
	35

It is therefore a triscarbonate. The small excess of oxide observable in the analysis, was probably mechanically mixed with the salt, and the very slight excess of water was undoubtedly hygrometrical.

5. Phosphate of bismuth. This salt was obtained by adding as much nitric acid to a solu- Phosphate,

tion of nitrate of bismuth as prevented the salt from being thrown down by water. Phosphate of soda being poured into this solution, a white precipitate fell, which was phosphate of bismuth. When collected on the filter, washed, and dried in the open air, it constituted a white tasteless powder, insoluble in water, and apparently neutral; 5·22 grains of this salt when exposed to a red head did not melt, but lost 1 grain of moisture. Hence, its constituents are

Anhydrous phosphate	4·22	or	13·5
Water . .	1	-	3·199
	5·22		

I consider its constituents to be

1 atom phosphoric acid	3·5
1 atom oxide of bismuth	10
3 atoms water . .	3·375
	16·875

Arseniate,

6. Arseniate of bismuth. This salt was formed by the same process as the last, merely substituting arseniate of soda for phosphate of soda. When the arseniate of bismuth was collected on the filter, washed, and dried in the open air, it constituted a white powder with a slight shade of yellow. It was tasteless and insoluble in water, and did not alter vegetable blues; hence, I consider it as a neutral salt. 19·75 grains of

it, when exposed to a red heat, underwent no apparent change, but lost 2·01 grains of weight. Hence, I am disposed to consider the salt as composed of

1 atom arsenic acid	7·75
1 atom oxide of bismuth	10
2 atoms water . . .	2·25
	20

7. Chromate of bismuth. This salt was formed in the same way as the two last, chromate of potash being substituted for phosphate of soda. When collected on the filter, washed, and dried, it constituted a fine yellow tasteless powder, insoluble in water, and not altering vegetable blues. 18·86 grains of this salt being heated to redness, did not melt, but lost its fine yellow colour, and became light yellowish brown. The loss of weight was 2·364 grains. Hence, the constituents of the salt must be Chromate,

1 atom chromic acid .	6·5
1 atom oxide of bismuth	10
2 atoms water . .	2·25
	18·75

8. Oxalate of bismuth. This salt was formed in the same way as the preceding one, substituting oxalate of ammonia for chromate of potash. When collected on the filter, washed, and dried Oxalate,

in the open air, it is a fine white tasteless powder, insoluble in water, and producing no change on vegetable blues. 14·89 grains of this salt, exposed to the greatest heat of the sand bath, gave out water, and lost 0·39 grain of weight. This was water mechanically lodged. The salt is anhydrous, and composed of

1 atom oxalic acid .	4·5
1 atom oxide of bismuth	10
	14·5

Tartrate,

9. Tartrate of bismuth. Formed in the same way—a fine white tasteless insoluble powder. 23·7 grains when heated on the sand bath gave out 5·45 grains water: hence, the constituents are

1 atom tartaric acid .	8·25
1 atom oxide of bismuth	10
5 atoms water . .	5·625
	23·875

The salts of bismuth, if any consequences can be drawn from the preceding list, seem in general to contain 2 or 3 atoms of water. Two of the salts, the sulphate and oxalate, are anhydrous—four, the dinitrate, carbonate, arseniate, and chromate, contain 2 atoms—two, the nitrate and phosphate, contain 3 atoms, while the tartrate contains 5 atoms.

19. SALTS OF MERCURY.

Both of the oxides of mercury combine with acids and form salts, several of which are capable of crystallizing.

(1.) PROTOSALTS.

Protosulphate,

1. Protosulphate of mercury. This salt is formed when sulphuric acid is heated on mercury. Sulphurous acid exhales, and protosulphate of mercury is gradually deposited in fine white crystals. When these crystals are washed with a little water they may be dried on blotting paper; in this state they constitute a white salt in scales. It has very little taste, reddens vegetable blues, and when heated on the sand bath the colour becomes darker, the salt assumes a silky lustre, and the scaly structure is much more conspicuous. 32·725 grains heated on the sand bath lost 1·725 grain. Probably the constituents are

1 atom sulphuric acid .	5
1 atom protoxide of mercury	26
2 atoms water . . .	2·25
	33·25

Nitrate,

2. Nitrate of mercury. This salt is easily obtained by dissolving in nitric acid of the specific gravity 1·42, as much mercury as it will take

up: the quantity exceeds twice the weight of the acid—heat is produced during the solution—the liquid is transparent and colourless like water; on cooling, it deposites a very considerable number of white crystals, which constitute the salt in question. I have not myself been able to determine the shape of these crystals; but they are said to be octahedrons with their apexes truncated. I have always obtained them in prisms, seemingly four-sided. This salt is not altered by exposure to the air; it has the disagreeable taste which distinguishes the soluble mercurial salts. When digested in water, it dissolves only partially, leaving a green powder which is a subnitrate of mercury; but it dissolves with facility in water acidulated with nitric acid. 50 grains of this salt were decomposed by caustic potash. The protoxide of mercury (not quite free from peroxide) weighed 37·6 grains. Now, as the atomic weight of protoxide of mercury is 26, we have 26 : 6·75 : : 37·6 : 9·76 = nitric acid of the salt. 50 — 37·6 = 12·4, and 12·4 — 9·76 = 2·64, the water contained in 50 grains of the salt. Hence, the constituents ought to be

Nitric acid .	9·76	or	6·75
Protoxide of mercury	37·60	-	26
Water . .	2·64	-	1·825
	50		

The water amounts to 1⅝ atom. As the oxide of mercury was mixed with some peroxide, I am disposed to consider the salt as a compound of

1 atom nitric acid .	6·75
1 atom protoxide of mercury	26
2 atoms water . .	2·25
	35

I attempted to determine the quantity of nitric acid in 50 grains of this salt by means of carbonate of barytes, and by means of ammonia; but neither of the results was satisfactory.

M. Grouvelle has examined the diprotonitrate of mercury, obtained by decomposing the protonitrate, by means of water, and shown it to be a compound of

1 atom nitric acid .	6·75
2 atoms protoxide of mercury	52
	58·75

It contains no water.*

Protocarbonate,

3. Protocarbonate of mercury. This salt was obtained by precipitating a solution of nitrate of mercury by carbonate of soda. It is a white, tasteless powder, insoluble in water. 41·4 grains of it were dissolved in nitric acid in a small two mouthed phial, previously accurately poised in a balance; the loss of weight was 6 grains, or

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* Ann. de Chim. et de Phys. XIX. 139.

rather 5·98 grains. Now, 35·4 : 6 : : 26 : 4·406 = carbonic acid united to 26 grains of protoxide of mercury. 4·406 approaches so near 4·125, which is equivalent to an atom and a half of carbonic acid, that there seems no doubt that the salt was a sesquicarbonate, composed of

1½ atom carbonic acid .	4·125
1 atom protoxide of mercury	26
	30·125

Protophosphate,

4. Protophosphate of mercury. This salt was obtained by decomposing nitrate of mercury by phosphate of soda. It is a white tasteless powder, insoluble in water. From 96·2 grains of nitrate of mercury I got 85·3 grains of phosphate of mercury; the phosphate, after being dried in the open air, lost scarcely any weight on the sand bath. From this it is obvious, that the phosphate of mercury is anhydrous, and the weight of the salt from 96·2 of nitrate shows that it is composed of

1 atom nitric acid .	6·75
1 atom protoxide of mercury	26
	32·75

Protarseniate,

5. Protarseniate of mercury. It is obtained when arseniate of soda is poured into a solution of protonitrate of mercury. It is a grey powder, destitute of taste, and insoluble in water. As it

loses no weight when heated on the sand bath, it is anhydrous, and is composed of

1 atom arsenic acid .	7·75
1 atom protoxide of mercury	26
	33·75

Protochromate,

6. Protochromate of mercury. This is a fine red coloured insoluble powder, obtained by mixing together solutions of protonitrate of mercury and chromate of potash. 50 grains of this salt dried in the open air, were digested in a solution of caustic potash; the protoxide of mercury was separated in the state of a black powder, which, dried in a gentle heat, weighed 38·57 grains. The potash liquid assumed a yellow colour; it was neutralized by nitric acid, and mixed with a solution of nitrate of lead till the whole chromic acid was thrown down. The chromate of lead dried on the sand bath weighed 31·57 grains, equivalent to 10·01 grains of chromic acid. Thus it appears, that the constituents of the salt are

Chromic acid	10·01	or	6·5
Protoxide of mercury	38·57	-	25·05
Water	1·42	-	0·922
	50·00		

The water being less than an atom, it is obvious that the salt is anhydrous, and that the small quantity of moisture present is merely hygrometrical. Doubtless the true constituents of this salt are

1 atom chromic acid	6·5
1 atom protoxide of mercury	26
	32·5

The reason why the weight of the protoxide of mercury appears less than the truth, is that a certain portion of it was reduced to the metallic state during the drying. This likewise increased the apparent quantity of water, by occasioning a loss.

Protacetate,

7. Protacetate of mercury. This salt is immediately deposited in beautiful silky scales, when solutions of nitrate of mercury and acetate of soda are mixed together. It has the disagreeable taste of the mercurial salts; but it is the least soluble of all the acetates, requiring about six hundred times its weight of water to dissolve it. On this account, nitrate of mercury may be employed as a good reagent to discover the presence of acetic acid in saline solutions. If the quantity of acetic acid present exceed $\frac{1}{600}$th of the weight of the liquid, the silvery scales of acetate of mercury almost always present themselves. 10 grains of these scales being digested in a flask with caustic potash gave 6·98 grains of protoxide of mercury; hence, the acid and water in these 10 grains amounted to 3·02

grains. But 26 : 6·25 : : 6·98 : 1·678 = acid in the 10 grains of salt: And 3·02 — 1·678 = 1·342 = water in the 10 grains. Hence, the constituents are

Acetic acid	1·678	or	6·25
Protoxide of mercury	6·98	-	26
Water	1·342	-	4·99

From this it follows, that the constituents of the salt are

1 atom acetic acid	6·25
1 atom protoxide of mercury	26
4 atoms water . .	4·5
	36·75

The excess of water in the experimental result is owing to the cause pointed out, while giving an account of the constituents of protochromate of mercury.

Protoxalate,

8. Protoxalate of mercury. This salt may be easily obtained by mixing together solutions of nitrate of mercury and oxalate of ammonia. It precipitates in the state of a white powder, which is nearly tasteless and insoluble in water. When dried in a heat of about 100°, it is a beautiful white powder, which when placed on the sand bath gives out a little water; it then explodes with considerable violence. In consequence of this property I did not succeed in determining the water of crystallization. But

judging from the quantity of water actually given out, I consider the constituents to be

1 atom oxalic acid	4·5
1 atom protoxide of mercury	26
1 atom water	1·125
	31·625

Prototartrate,

9. Prototartrate of mercury. This salt precipitates when tartrate of potash is mixed with solution of protonitrate of mercury. The precipitate, when it first falls, is snow white; but in a few minutes it blackens considerably, and, when collected on the filter, washed and dried in the open air, it is grey. It has scarcely any taste, and does not appear soluble in water. 50 grains of this salt were exposed in a platinum crucible on the sand bath. No water was exhaled; but the salt blackened, in consequence of the decomposition of the tartaric acid, and lost 1·9 grain of its weight. From this experiment I consider the salt as anhydrous, and composed of

1 atom tartaric acid .	8·25
1 atom protoxide of mercury	26
	34·25

From the preceding list of the protosalts of mercury it appears that, as far as their water of crystallization is concerned, they bear a great resemblance to the salts of lead. Most of them are anhydrous, and the rest contain 1, 2, or 4 atoms of water.

Six species, viz. Diprotonitrate, protocarbonate, protophosphate, protarseniate, protochromate, and prototartrate, are anhydrous—one, the oxalate, contains 1 atom water—two, the protosulphate and protonitrate, contain 2—and one, protacetate, contains 4.

(2.) PERSALTS OF MERCURY.

1. Persulphate of mercury. This salt, according to the observations of Fourcroy, which are to a considerable extent correct, exists in various states; but the neutral salt is the beautiful yellow powder, known by the name of turpeth mineral, or queen's yellow. It is a tasteless insoluble powder, the constituents of which are Persulphate,

1 atom sulphuric acid .	5
1 atom peroxide of mercury	27
	32

2. Bipersulphate of mercury. In white irregular crystals. I found them composed of Bipersulphate,

2 atoms sulphuric acid .	10
1 atom peroxide of mercury	27
1 atom water . .	1·125
	38·125

3. Pernitrate of mercury. This is a beautiful Pernitrate,

transparent and colourless salt, which crystallizes in rhombic prisms, with angles of about 74° and 106°. I formed it by accident some years ago. When thrown into water it is decomposed, peroxide of mercury remaining. When heated, it becomes first opaque, then yellow, and is at last dissipated. Its constituents are as follows:

1 atom nitric acid .	6·75
1 atom peroxide of mercury	27
	33·75

Dipernitrate.

4. Dipernitrate of mercury. This salt was examined by M. Grouvelle, who informs us that it is anhydrous, and composed of

1 atom nitric acid .	6·75
2 atoms peroxide of mercury	54
	60·75 *

20. SALTS OF SILVER.

The only good solvent of silver is nitric acid. The combinations of the oxide of silver, with most of the other acids, are insoluble in water, or at least require a great deal of that liquid to dissolve them.

Nitrate,

1. Nitrate of silver. This well known and beautiful salt crystallizes in rhombs, which are usually flat; and the angles of the large face,

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* Ann. de Chim. et de Phys. XIX. 140.

measured as carefully as possible with the common goniometer, are 70° 37′, and 109° 23′. The usual plates in which its crystals appear, if attentively examined, show clearly enough that the shape is rhomboidal, and the angles of the larger faces may easily be observed; but, by spontaneous crystallization, I have obtained large and very regular crystals—though the faces were not smooth enough to admit of measurement by the reflecting goniometer. The properties of this salt are sufficiently known. It dissolves in its own weight of cold water, and in about four times its weight of alcohol. Its taste is exceedingly acrid, and it constitutes a violent poison. When heated it melts, and, on cooling, congeals into a mass of a grey colour, and composed of small needle-form crystals. In this state it is used by surgeons as an escharotic, under the name of *lunar caustic.* I have never yet met with lunar caustic, as it is prepared for sale, absolutely pure. It always contains some gold, and often a little copper. Both of these metals separate in dark flocks when the caustic is dissolved in water. Not unfrequently it contains nitrate of potash; and perhaps there may be other occasional impurities, which I have not detected. This salt is anhydrous, both when crystallized and in the state of lunar caustic. 21·5 grains of the crystals, dried upon blotting paper, when kept for 20 minutes in a state of fusion in a platinum crucible, lost 0·201 grain of water. This is somewhat less than $\frac{1}{5}$th of an atom, and was doubtless lodged mechanically between the plates of the crystals. The constituents of nitrate of silver are

1 atom nitric acid .	6·75
1 atom oxide of silver .	14·75
	21·5

Sulphate,

2. Sulphate of silver. I obtained this salt both by digesting sulphuric acid over oxide of silver, and by mixing together concentrated solutions of nitrate of silver and sulphate of soda. The salt falls in the state of a white powder, which may be dissolved in about 88 times its weight of boiling water. When the solution cools the salt is partly deposited in the state of small needles. This salt has the peculiarly disagreeable taste which characterizes all the soluble salts of silver. Sulphate of silver melts when exposed to a moderate heat; and if the temperature be raised, the oxide is reduced to the metallic state. The salt is anhydrous; for, 19·82 grains of it, being heated on the sand bath till it became yellow, and consequently till it began to be decomposed, lost 0·07 grain of its weight. Now, this quantity, supposing it all water, would amount only to rather less than $\frac{1}{16}$th of an atom. The constituents of the salt are

1 atom sulphuric acid .	5
1 atom oxide of silver	14·75
	19·75

Carbonate,

3. Carbonate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver, and an alkaline carbonate. It constitutes a white insoluble powder, with a slight shade of blue. When this salt is mixed with dilute nitric acid, a pretty rapid effervescence takes place, owing to the escape of the carbonic acid gas, and a colourless solution is obtained. I found that 38·7 grains of carbonate of silver yielded 47·87 grains of fused nitrate of silver. This is equivalent to 32·841 grains of oxide of silver. Now, 14·75 : 2·57 : : 32·841 : 6·122 = carbonic acid united to the oxide of silver. But, 32·841 + 6·122 = 38·963, which rather exceeds the weight of carbonate of silver employed. It is obvious from this that the salt is anhydrous, and that its constituents are

1 atom carbonic acid .	2·75
1 atom oxide of silver .	14·75
	17·5

Phosphate,

4. Phosphate of silver. When nitrate of silver and phosphate of soda are dissolved in separate portions of water, and the solutions are mixed, there falls down a fine yellow coloured precipi-

tate, which is phosphate of silver. This powder is insoluble in water; but not quite destitute of the peculiar taste which characterizes the salts of silver. 43 grains of anhydrous nitrate of silver were mixed with a solution of 42 grains of phosphate of soda. The yellow coloured precipitate, when washed and dried on the filter, weighed 27·74 grains. When exposed to heat on the sand bath, it gave out no water, and did not lose any sensible weight. A little carbonate of soda being dropt into the liquid from which the yellow precipitate fell, a new portion of yellow precipitate appeared, which, being collected on a filter, washed, and dried, weighed 8·5 grains. It was rather paler coloured than the first precipitate, but in other respects similar. It was also anhydrous.

Thus, the precipitate from 43 grains of nitrate of silver weighed 36·24 grains; it lost, when heated to redness, 0·624 grain, and was reduced to 35·616 grains; it contained all the oxide of silver in 43 grains of nitrate, or 29·5 grains—the remainder of the weight consisted of phosphoric acid. Hence, the phosphate of silver obtained in this way, was composed of

Oxide of silver	.	29·5	or	14·75
Phosphoric acid	.	6·116	-	3·058

14·75 is the weight of an atom of oxide of silver, and 3·058 is not quite ⅐th less than the weight of an atom of phosphoric acid. It is obvious that neutral phosphate of silver is composed of

1 atom phosphoric acid	3·5
1 atom oxide of silver	14·75
	18·25

There was an excess of oxide in the salt which I obtained; for that salt was composed of

1 atom phosphoric acid	3·5
1 atom oxide of silver	14·75 + 2·13

This surplus amounts nearly to ⅐th part, which I consider as too small to constitute an atomic addition.

When the yellow phosphate of silver is digested in phosphoric acid, we obtain a white salt, which I have not analyzed, but which is certainly either a neutral phosphate or a biphospate of silver,—probably the latter.

If we were to suppose the yellow phosphate of silver a mixture of 6 atoms neutral phosphate of silver and 1 atom diphosphate of silver, we would obtain very nearly the same constituents that I procured. For

6 atoms phosphate of silver weigh	Phosphoric acid	21	109·5
	Oxide of silver	88·5	
1 atom diphosphate	Acid . .	3·5	33
	Oxide . .	29·5	

So that the oxide amounts to . . .	118
And the acid to	24·5

Now, $\frac{24 \cdot 5}{7} = 3 \cdot 5$, and $\frac{118}{7} = 17$, which approaches very nearly to 16·88, the quantity of silver contained in the salt which I examined.

Arseniate, 5. Arseniate of silver. When solutions of nitrate of silver and arseniate of soda are mixed together in the atomic proportions, a flesh coloured precipitate falls in large flocks. This precipitate is arseniate of silver; it is tasteless, or nearly so, and is insoluble in water. When dried it becomes reddish brown; when heated to redness it becomes nearly black; and 34·4 grains, when thus treated, lost 0·5 grain of water, which was obviously merely lodged mechanically in the powder. By this treatment the powder assumes nearly a black colour.

43 grains of anhydrous nitrate of silver were dissolved in water, and mixed with a solution of 41·5 grains of the crystals of arseniate of soda: the flesh red powder which precipitated being collected, washed, and dried on the filter, weighed 37·75 grains. Ammonia being poured into the residual liquid an additional flesh red precipitate fell, which weighed, when dry, 2 grains; so that the whole arseniate of silver obtained from 43 grains of nitrate of silver was 39·75 grains; which, by exposure to a red heat, was reduced to 39·22 grains. As it contained all the silver

in the 43 grains of nitrate it was obviously composed of

Oxide of silver	29·5	or	14·75
Arsenic acid .	9·72	-	4·86
	39·22		

14·75 represents an atom of oxide of silver, but 4·86 is less than an atom of arsenic acid by 2·89, which is rather more than the third of an atom. We see from this, that the arseniate of silver, (like the phosphate) when obtained by precipitation, is not an accurate atomic compound;—it is doubtless a mixture of two or more arseniates in different states of saturation. It is composed of

1 atom arsenic acid .	7·75
1 atom oxide of silver .	14·75 + 8·771

8·771 exceeds half an atom by only 1·396; hence, it is obvious that the greater part of the precipitate is a subsesquarseniate of silver, composed of

1 atom arsenic acid .	7·75
1½ atom oxide of silver	22·125
	29·875

With this subsesquarseniate there is mixed a small portion of di-arseniate of silver.

Chromate,

6. Chromate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver and chromate of potash. The chromate of silver falls in the state of a dark red powder, which is insoluble in water, or nearly so, and not altered by exposure to heat. 43 grains of anhydrous nitrate of silver being dissolved in water and mixed with a solution of 25 grains of chromate of potash, the chromate of silver obtained by precipitation, after being washed and dried, weighed 39·67 grains. Carbonate of soda being dropped into the residual liquid a slight additional precipitate was obtained, which weighed very nearly 2½ grains; so that the whole chromate of silver obtained weighed 42·17 grains. Now, if we suppose it to be a compound of

1 atom chromic acid .	6·5
1 atom oxide of silver .	14·75
	21·25

the whole of it would have amounted to 42·5 grains. This approaches so near the quantity actually obtained, that there seems no room for doubting that the correct constituents of the salt are those just stated.

Acetate,

7. Acetate of silver. This salt may be obtained by digesting oxide of silver in acetic acid. The solution is colourless, but yields, by evaporation, white crystals having a silky lustre, and

the form of long but small four-sided flat prisms. The salt is extremely light, and very sparingly soluble in water.

76 grains of these crystals were digested in nitric acid till the acetic acid was disengaged, and then evaporated to dryness,—the anhydrous nitrate of silver weighed 78 grains. Now, 78 : 21·5 : : 76 : 20·95 = atomic weight of acetate of silver. Hence, its constituents must be

1 atom acetic acid .	6·25
1 atom oxide of silver .	14·75
	21

For the 0·05 wanting was doubtless owing to an error in the experiment. It is obvious from this, that acetate of silver is anhydrous.

Oxalate,

8. Oxalate of silver. This salt is easily obtained by mixing together solutions of nitrate of silver, and oxalate of ammonia. It falls down in the state of an exceedingly fine and very white powder, quite different in appearance from chloride of silver. The colour is very apt to become dark when heat is applied, owing probably to a commencement of decomposition; this salt is scarcely soluble in water. 43 grains of anhydrous nitrate of silver were dissolved in water and mixed with a solution of 17·75 grains of oxalate of ammonia. The precipitate obtained being well washed and dried, weighed 37·86 grains. Carbonate of soda being dropped into

the residual liquid, a little more oxalate of silver fell, weighing very nearly half a grain. Thus, the whole oxalate of silver obtained from 43 grains of nitrate was 38·36 grains. This is so near 38·5, the quantity which would have been obtained on the supposition that the salt is a compound of an atom of each constituent, that we cannot hesitate about adopting the following as exhibiting its true constitution :

1 atom oxalic acid .	4·5
1 atom oxide of silver .	14·75
	19·25

Oxalate of silver is obviously anhydrous.

Tartrate, 9. Tartrate of silver. When solutions of nitrate of silver and tartrate of potash are mixed together, a fine white powder falls. If we raise the temperature of the liquid a very little, the colour of the precipitate becomes dark brown; indeed, this change takes place spontaneously, if the powder be allowed to remain for twenty-four hours in contact with the liquid from which it was thrown down. When this powder is dried upon the filter it is anhydrous; for 18 grains of it, when heated strongly on the sand bath, became black, gave out no water, but lost 0·5 grain of weight, owing obviously to a commencement of decomposition.

43 grains of nitrate of silver being dissolved in water, and mixed with a solution of 33 grains

of tartrate of potash, the tartrate of silver precipitated, after being washed and dried, weighed 42·9 grains. Ammonia being dropt into the residual liquid, no immediate change was produced, but after an interval of twenty-four hours the inside of the glass was lined with a deep brown deposite, having a semimetallic lustre, and adhering so firmly to the glass that I could not weigh it with accuracy; but it certainly amounted to 3 grains. From this experiment I consider the tartrate of silver as a neutral salt, composed of

1 atom tartaric acid	8·25
1 atom oxide of silver	14·75
	23

From the preceding detail, we see that all the salts of silver hitherto examined are anhydrous. This is a peculiarity which belongs to no other genus of salts except those of silver.

SECT. II.

OF THE COMPOSITION OF THE COMPOUND SALTS.

Nature of compound salts.

The compounds, usually distinguished by the name of *triple salts*, are formed by the union of two simple salts with each other. These two salts have in most cases the same acid combined in each with a different base; though there are a few examples of the union of two salts differing from each other both in their acids and bases. There are perhaps, examples likewise of two salts uniting, formed of the same base each, but containing different acids, though I do not at present recollect any such. It is obvious from this account of their constitution, that the term *triple salts* cannot with precision apply to these bodies. The name *double salts,* by which Berzelius distinguishes them, is more correct; though even it may probably be ultimately found rather too limited to include the whole of these saline bodies; perhaps, therefore, it may be better to apply to them the term *compound salts,* by which I have distinguished them in the title affixed to this section.

The compound salts are extremely numerous, much more so, I have reason to believe, than the simple salts. In general they crystallize more readily, and more regularly than the simple salts; many of them are exceedingly beautiful, and such of them as act as purgatives, are both more elegant and more useful medicines than the simple salts from which they were formed; almost all the salts of ammonia and of potash have the property of forming compounds with other simple salts, and constituting compound salts. Soda, and the alkaline earths, do not enter so readily into these combinations; but a considerable number of compound salts containing these bases are known, and perhaps, if sufficient pains were bestowed upon the investigations, methods might be found of causing the salts of these bases to enter into as many combinations with other salts as the salts of ammonia and potash.

Most commonly the compound salts consist of an integrant particle of each of the simple salts united together; but to this law there are many exceptions. It is not uncommon for three integrant particles of one of the salts to be united with one integrant particle of the other salt. The water of crystallization is seldom the amount of the water in the two salts before combination; most commonly it is less, but in some rare instances considerably greater.

I shall divide this section into three parts. In the first part, I shall exhibit the composition of the compound salts which contain ammonia; in the second, of those which contain potash; and in the third, I shall give the constituents of a few compound salts which contain neither of these bases.

I. OF COMPOUND SALTS CONTAINING AMMONIA.

Ammonio-sulphate of potash.

1. Ammonio-sulphate of potash. This salt may be easily formed by dissolving

1 atom sulphate of potash = 11
1 atom sulphate of ammonia = 8·25

or any equimultiples of these weights in water, evaporating the mixed solutions to the crystallizing point. The salt is deposited in small beautiful crystals, which crystallize in four-sided prisms with square bases—taste bitter—specific gravity 2·64. 13·68 grains dissolve in 100 water of temperature 61°. Their constituents are

1 atom sulphate of potash	11
1 atom sulphate of ammonia	7·125
4 atoms water . .	4·5
	22·625

Here the water of crystallization considerably exceeds that of the salts of which it is composed.

Ammonio-sulphate of soda.

2. Ammonio-sulphate of soda. The same process may be followed successfully in forming this salt. The taste of this salt is pungent and bitter. It crystallizes in oblique prisms with rhombic bases.

The crystals are not altered by exposure to the air. Its constituents are

1 atom sulphate of soda	9
1 atom sulphate of ammonia	7·125
6 atoms water . .	6·75
	22·875

In this salt the water of crystallization does not much exceed half the quantity contained in the salts before combination; for sulphate of soda contains ten atoms, and sulphate of ammonia one atom of water.

Ammonio-sulphate of magnesia.

3. Ammonio-sulphate of magnesia. This salt, which may be obtained by the same process as the preceding, crystallizes in beautiful rhomboids, which are not altered by exposure to the air. It has a bitter taste, a specific gravity of 1·721, and its constituents are

1 atom sulphate of magnesia	7·5
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	22·5

Ammonio-sulphate of alumina.

4. Ammonio-sulphate of alumina. This salt is precisely similar in its appearance and properties to common *alum*. Its crystals are regular octahedrons; its solubility in cold water is rather less than that of alum. I analyzed this salt with much care, and found its constituents

3 atoms sulphate of alumina	21·75
1 atom sulphate of ammonia	7·125
25 atoms water	28·125
	57

This approaches as near the weight of an integrant particle of common alum as the constituents will admit. The only difference is the substitution of an atom of sulphate of ammonia for an atom of sulphate of potash.

5. Ammonio-trisulphate of alumina. This salt may be obtained by precipitating a boiling solution of ammoniacal alum by an alkali. It is an insoluble powder, which I have not particularly examined.

Ammonio-persulphate of iron.

6. Ammonio-persulphate of iron. This salt was first prepared by Mr. Cooper, who described it as a simple persulphate of iron; but for our first knowledge of its constituents and its properties we are indebted to Dr. Forchhammer. As soon as I became acquainted with Dr. Forchhammer's experiments,* I examined some of Mr. Cooper's crystals, which he had been kind enough to send me several years ago, and found them to contain abundance of ammonia, and to be in fact the very same triple salt as that described by Dr. Forchhammer.

This salt is easily obtained by mixing together solutions of persesquisulphate of iron and sulphate of ammonia in the proportion of two integrant particles of the former to one of the latter, concentrating the mixture somewhat, and setting it aside. The double salt is deposited in very regular crystals; it is transparent and colourless, and is crystallized in octahedrons precisely similar to those of alum. It is soluble

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* Annals of Philosophy (second series) V. 409.

in about three times its weight of water at 60°; it has a taste very similar to that of alum, and may in fact be considered as an ammoniacal alum, with persulphate of iron substituted for sulphate of alumina. I analyzed it in the same way as soda alum, and found its constituents to be

2 atoms persesquisulphate of iron	25
1 atom sulphate of ammonia	7·125
25 atoms water . . .	28·125
	60·25

It comes therefore as near as possible to the atomical weight of ammoniacal alum. Yet it is not analogous to that alum in its composition: for the alum consists of 3 atoms of sulphate of alumina united to 1 atom of sulphate of ammonia; whereas this salt contains only 2 atoms of sesquisulphate of iron united to 1 atom of sulphate of ammonia. The quantity of sulphuric acid in an integrant particle of both salts is the same, namely 4 atoms; 2 atoms of peroxide of iron are substituted for 3 atoms of alumina.

Ammonio-sulphate of nickel.

7. Ammonio-sulphate of nickel. This is a beautiful green coloured salt, crystallized in flat rhombs. It dissolves readily in water, and crystallizes with facility; its specific gravity is 1·801. Its constituents are

1 atom sulphate of nickel	9·25
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	24·25

In this salt the water of crystallization is the same as in sulphate of nickel. The sulphate of ammonia is anhydrous.

Ammonio-sulphate of manganese.

8. Ammonio-sulphate of manganese. This salt likewise crystallizes in rhombs, and is very easily obtained by mixing together solutions of the two salts constituting it, in the atomic proportions, and concentrating the mixture. Its specific gravity is 1·93. Its constituents are as follows:

1 atom sulphate of manganese	9·5
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	24·5

So that the water exceeds by 1 atom the water of crystallization in both the constituents.

Ammonio-sulphate of zinc.

9. Ammonio-sulphate of zinc. This salt was obtained by mixing solutions of the two constituent salts in the atomic proportions, and concentrating the solution. It crystallizes in fine white rhomboids, which have the peculiar taste of the zinc salts, and dissolve readily in water. The constituents of this salt are as follows:

1 atom sulphate of zinc	10·25
1 atom sulphate of ammonia	7·125
7 atoms water	7·875
	25·25

Here the sulphate of zinc retains its usual proportion of water, and the sulphate of ammonia unites to it anhydrous.

Ammonio-sulphate of copper.

10. Ammonio-sulphate of copper. The constituents of this salt, according to the analysis of it in my laboratory, are as follows:

1 atom sulphate of copper	10
1 atom sulphate of ammonia	7·125
6 atoms water . . .	6·75
	23·875

And this analysis exactly agrees with the statement previously given by Berzelius, that both salts retain their water of crystallization.

Ammonio-carbonate of uranium.

11. Ammonio-carbonate of uranium. This beautiful salt has been described in volume II. page 4. of this work. Its constituents were there shown to be

1 atom percarbonate of uranium	30·75
3 atoms carbonate of ammonia	14·625
4 atoms water	4·500
	49·875

So that each integrant particle of salt in the compound retains an atom of water.

Ammonio-phosphate of soda.

12. Ammonio-phosphate of soda. This salt, which has been so long known under the name of *microcosmic salt*, and is so useful to mineralogists as a flux in experiments made by the blowpipe, is easily obtained by mixing solutions of phosphate of soda and phosphate of ammonia in the atomic proportions, and concentrating the mixture. The compound salt crystallizes in fine four-sided rectangular prisms, terminated by rectangles; the solution yields these crystals to the very last drop, showing that the salt contains just an integrant particle of each constituent. It has a saline and cooling taste, and dissolves with facility in water; when heated it melts in its water of crystallization; if the heat be continued the water is dissipated; in a red heat the ammonia likewise escapes, leaving biphosphate of soda, which melts into a transparent glass, dissolves in water, and reddens vegetable blues. 20 grains of the crystals of this salt, when thus treated, lose 13 grains of their weight. Now, 11 is the atomic weight of anhydrous biphosphate of soda; and 7 : 11 : : 13 : 20·43 = water and ammonia combined with 11 of anhydrous bisulphate of soda to constitute microcosmic salt. The ammonia amounts to 2·125, which, added to 11, make 13·125; and 20·43 — 2·125 = 18·305. Thus it appears, that ammonio-phosphate of soda is composed of

1 atom phosphate of soda	7·5
1 atom phosphate of ammonia	5·625
16 atoms water . .	18
	31·125

Ammonio-phosphate of magnesia.

13. Ammonio-phosphate of magnesia. This salt occasionally crystallizes in stale urine. In such cases it is transparent and colourless, and composed of four-sided rectangular prisms with bases which I believe to be squares. It is formed, likewise, when a soluble phosphate and an ammoniacal salt are added to sulphate of magnesia. It precipitates in the state of a white powder; it is tasteless and insoluble in water. When this powder is dried in the open air I find it composed of

1 atom phosphate of magnesia	6
1 atom phosphate of ammonia	5·625
4 atoms water . .	4·5
	16·125

The water exceeds 4 atoms by a quantity which varies from ¼ to ½ atom. This excess is doubtless hygrometrical water.

It would appear, from a set of experiments by M. Riffault, that another salt composed of the same acid and bases is occasionally obtained, containing only half the phosphoric acid in the preceding salt. He states the composition of the salt which he analyzed as follows:

1 atom diphosphate of magnesia	8·5
1 atom diphosphate of ammonia	7·75
5 atoms water . .	5·625
	11·875*

Though I have prepared this compound salt many times, and analyzed it repeatedly, I have never met with any salt composed in the same manner as that examined by Riffault.

Ammonio-arseniate of soda.

14. Ammonio-arseniate of soda. This salt was obtained by M. Mitcherlich, by mixing solutions of arseniate of ammonia and arseniate of soda together. By evaporation the salt crystallizes. The primary form of the crystals is an oblique prism with rhombic bases; the inclination of the faces of the prism is 38° 44′. And, Mitcherlich says, that the ammonio-phosphate of soda crystallizes under the same form.

From the experiments of Mitcherlich, it is evident that the constituents of this salt are

1 atom arseniate of soda	11·750
1 atom arseniate of ammonia	9·875
8 atoms water . .	9·000
	30·625†

Ammonio-permuriate of iron.

15. Ammonio-permuriate of iron. This salt is obtained by mixing permuriate of iron and sal-ammoniac in the atomic proportions, and con-

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[*] Ann. de Chim. et de Phys. XIX. 90.

[†] Ibid. 400.

centrating the mixture by evaporation. Beautiful octahedrons of a ruby red colour separate by crystallization. This salt is permanent, soluble in water, and its constituents are

1 atom persesquimuriate of iron	11·9375
1 atom sal-ammoniac . .	6·75
	18·6875

It is remarkable that this salt contains no water, though the permuriate of iron has such a tendency to combine with that liquid that it deliquesces when exposed to the air. Indeed, the compound salt itself gradually attracts moisture from the atmosphere.

Ammonio-muriate of copper.

16. Ammonio-muriate of copper. This salt crystallizes in rectangular prisms terminated by four-sided pyramids. It has a fine green colour, and is composed of

2 atoms muriate of copper	19·25
1 atom sal-ammoniac .	6·75
9 atoms water	10·125
	36·125

Ammonio-muriate of platinum.

17. Ammonio-muriate of platinum. This fine yellow salt is anhydrous, and consists of

1 atom bichloride of platinum	21
1 atom sal-ammoniac . .	6·75
	27·75

Ammonio-oxalate of copper.

18. Ammonio-oxalate of copper. This salt may be obtained by mixing together oxalates of copper and ammonia in the atomic proportions, and digesting the mixture. By evaporation the salt is obtained in rhomboidal plates; it has a blue colour, and is insoluble in water. Vogel of Bareuth first formed it. Water decomposes it. When suddenly heated it detonates loudly, according to Vogel; but this did not take place in my laboratory. Its constituents are

1 atom oxalate of copper	9·5
1 atom oxalate of ammonia	6·625
3 atoms water . .	3·375
	19·5

19. Efflorescing ammonio-oxalate of copper. This salt was formed by Vogel of Bareuth, by agitating oxalate of copper in caustic ammonia till a saturated solution was obtained. When this solution is placed in a flat dish it deposites dark blue crystals, having the form of six-sided prisms, with two broad and two narrow faces. When exposed to the air it loses 18 per cent. of its weight; this loss is partly water partly ammonia. The constituents of this salt are as follows:

1 atom oxalic acid .	4·5
1 atom oxide of copper	5
1 atom ammonia .	2·125
1 atom water . .	1·125
	12·75

From the colour of this salt one would be tempted to consider it as a compound of

1 atom oxalate of ammonia	6·625
1 atom hydrate of copper	6·125
	12·75

But the escape of the ammonia, when the salt is exposed to the air, will not admit of that explanation. It is probably a triple compound of the acid with the two bases at once.

20. Pulverulent ammonio-oxalate of copper. This is a blue powder like *smalt*, formed by Vogel of Bareuth, by putting a greater quantity of oxalate of copper into ammonia than that liquid is capable of dissolving. This salt is anhydrous, and its constituents, according to Vogel's analysis, are as follows:

1 atom oxalate of ammonia	6·625
1 atom dioxalate of copper	14·5
	21·125

II. OF COMPOUND SALTS CONTAINING POTASH.

Potash-sulphate of magnesia.

1. Potash-sulphate of magnesia. This salt crystallizes in transparent rhombs. The taste is weak but sensibly bitter; its specific gravity is 2·112; it is not altered by exposure to the atmosphere. Its constituents are

1 atom sulphate of potash	11
1 atom sulphate of magnesia	7·5
7 atoms water . .	7·875
	26·375

It is, therefore, a compound of 1 integrant particle of sulphate of potash with 1 integrant particle of sulphate of magnesia, retaining all its water of crystallization.

Potash-sulphate of alumina.

2. Potash-sulphate of alumina, or *common alum*. The constituents of this well known salt are

3 atoms sulphate of alumina	21·75
1 atom sulphate of potash	11
25 atoms water . .	28·125
	60·875

Potash-trisulphate of alumina.

3. Potash-trisulphate of alumina. This salt, formerly called *alum saturated with its earth*, may be obtained by adding potash to a boiling solution of alum, and washing the precipitate till the liquid used ceases to act on muriate of barytes. According to Riffault this salt is a compound of

3 atoms trisulphate of alumina	35·25
1 atom sulphate of potash	11·00
9 atoms water .	10·125
	56·375 *

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* Ann. de Chim. et de Phys. XVI. 355.

Potash-protosulphate of iron.

4. Potash-protosulphate of iron. This salt was obtained by mixing solutions of protosulphate of iron, and sulphate of potash in the atomic proportions, and concentrating the solution—beautiful crystals of the compound salt were deposited. They had a very light green colour, and were much harder and firmer than the protosulphate of iron,—were more opaque, and not liable to undergo any alteration from exposure to the air. The crystals were so irregular that it was difficult to make out the shape; at first view they had a lenticular appearance, but when closely examined, faces appeared which corresponded with those of an octahedron, apparently low, and somewhat broader on two sides than on the other two. The taste of this salt was similar to that of protosulphate of iron; but it was less soluble in water, and the solution, which was almost colourless, had a tendency especially when heated to deposite flocks of peroxide of iron. This salt was analyzed in the following way:

26·125 grains of the crystals were exposed on a glass capsule to the heat of a spirit lamp, cautiously applied till they ceased to give out moisture. By this treatment they became opaque, and of a dull white colour, and the loss of weight was 5·878 grains. The residual salt was dissolved in water, and the liquid mixed with a solution of 26·5 grains of chloride of barium.

After the sulphate of barytes had subsided, the residual liquid was neither affected by sulphate of soda nor muriate of barytes. Consequently, 26·125 grains of the salt contain 10 grains of sulphuric acid. Hence, the constituents of the salt are

1 atom protosulphate of iron	9·5
1 atom sulphate of potash .	11
5 atoms water	5·625
	26·125

Potash-persesquisulphate of iron.

5. Potash-persesquisulphate of iron. This salt may be obtained by mixing together solutions of persulphate of iron and sulphate of potash in the requisite proportions, and crystallizing under the vacuum of the air pump along with sulphuric acid to absorb the vapour. The crystals are transparent and colourless, and have the regular octahedral form like alum. The taste is astringent, sour, and sweetish, similar to that of alum, but harsher. The salt dissolves in water, and the liquid containing it has a brownish red colour. I have never succeeded in getting crystals after once dissolving this salt in water. The crystals redden vegetable blues, and are not altered by exposure to the air.

I found by a process quite similar to what has been so often stated, that 64·125 grains of these crystals were just decomposed by 53 grains (13·25 × 4) of chloride of barium, and consequently, contain just 20 grains of sulphuric acid. I precipitated a solution of 64·125 grains of the salt by ammonia, and the peroxide of iron separated, after being washed, dried, and exposed to a red heat, weighed almost exactly 10 grains. The residual liquid being evaporated to dryness, and the salt remaining exposed to a red heat, left 11½ grains of sulphate of potash; but it was not quite free from iron. I conclude from this analysis, (which was only once performed) that the constituents of the salt are

2 atoms persesquisulphate of iron	25
1 atom sulphate of potash .	11
25 atoms water . . .	28·125
	64·125

This is the fourth compound salt which we have met with having the regular octahedral form of alum; and all of them contain just 25 atoms of water.

Potash-persulphate of iron.

6. Potash-persulphate of iron. During the crystallization of the last described salt, I frequently got, in the first place, a deposition at the bottom of the vessel consisting of a greenish brown matter, obviously crystalline, though the shape was not sufficiently regular to admit of measurement. When this crust was dried in the open air, it had a fine greenish yellow colour, and was composed of grains seemingly cubical, often having the solid angles rounded off, so as

to approach to a spherical form. The taste was astringent, sweetish, and acid. The salt reddened vegetable blues, and underwent no sensible alteration from exposure to the air. It dissolved in water, with the exception of a very small flocky sediment too insignificant to be weighed, and doubtless consisting of some accidental impurity. The solution had a yellow colour, and was never transparent even though passed through the filter.

I found that 23·25 grains of this salt were just decomposed by 26·5 grains of chloride of barium, showing that it contained just 10 grains of sulphuric acid. From the same weight of the salt I got very nearly 5 grains of peroxide of iron, and 11 grains of sulphate of potash. Hence, the constituents are

1 atom persulphate of iron	10
1 atom sulphate of potash	11
2 atoms water . .	2·25
	23·25

This is the only persalt of iron which I have examined, in which an atom of the peroxide is combined with an atom of iron.

Potash-sulphate of nickel.

7. Potash-sulphate of nickel. This salt crystallizes in rhomboids having a fine emerald colour. Its taste is sweet, with an impression of bitterness, and it is not altered by exposure to

the air. Its specific gravity is 2·264. Its constituents, from the analysis of Proust, seem to be

1 atom sulphate of potash	11
1 atom sulphate of nickel	9·25
6 atoms water . .	6·75
	27

Potash-sulphate of manganese.

8. Potash-sulphate of manganese. This salt crystallizes in thin rhombic plates, having a fine flesh colour. It is not altered by exposure to the air. Its constituents are

1 atom sulphate of potash	11
1 atom sulphate of manganese	9·5
5 atoms water	5·625
	26·125

It is therefore a combination of the two salts with the water of crystallization contained in the latter.

Potash-sulphate of zinc.

9. Potash-sulphate of zinc. This salt crystallizes in long flat rhomboids with angles of 75° and 105°. Its taste is similar to that of sulphate of zinc; it is not altered by exposure to the air. Its constituents are

1 atom sulphate of potash	11
1 atom sulphate of zinc	10·25
7 atoms water . . .	7·875
	29·125

Potash-sulphate of copper.

10. Potash-sulphate of copper. This salt crystallizes in blue coloured rhomboids, with angles of 82° 30′, and 97° 30′. It suffers no change by exposure to the air: its specific gravity is 2·116. According to the analysis of Vogel of Bareuth, which was confirmed in my laboratory, its constituents are

1 atom sulphate of potash	11
1 atom sulphate of copper	10
6 atoms water . . .	6·75
	27·75

Potash carbonate of magnesia.

11. Potash-carbonate of magnesia. When a solution of bicarbonate of potash is poured into a solution of muriate of magnesia, both in the atomic proportions, no precipitate appears at first, but in about twenty-four hours there is a deposite of irregular crystals in groups, which constitute a compound salt. When put into the mouth it appears at first tasteless, but speedily gives an alkaline impression; when cold water is poured on it, the crystals gradually fall to powder, bicarbonate of potash is dissolved, and carbonate of magnesia remains undissolved. When heat is applied to this salt, it gives out water and becomes opaque. If the heat be still farther elevated, carbonic acid gas is driven off, and at a red heat a semifusion takes place. This salt, which is apt to form in chemical analyses of magnesian minerals, has been very carefully

analyzed by Berzelius, who obtained the following constituents:

Potash	18·233
Magnesia	15·990
Carbonic acid	34·537
Water	31·240
	100·000 *

This salt is undoubtedly a compound of

1 atom bicarbonate of potash	11·5
2 atoms carbonate of magnesia	10·5
9 atoms water	10·125
	32·125

For if we calculate the constituents per cent. of such a compound salt, we obtain

Potash	18·677
Magnesia	15·564
Carbonic acid	34·241
Water	31·518
	100·000

Numbers which are sufficiently near those of Berzelius, to satisfy us that the constituents have been rightly appreciated.

12. Potash-phosphate of soda. This salt was Potash-phosphate of soda.

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* Afhandlingar, VI. 11. There is a translation of the paper of Berzelius in the 1st vol. of the Edinburgh Philosophical Journal, p. 63; but the translation is often erroneous, obviously from the translator's ignorance of the subject.

formed by M. Mitcherlich, by saturating the biphosphate of potash with carbonate of soda, and crystallizing the solution. The primary form of the crystal is an oblique prism with a rhombic base. The inclination of the faces of the prism is, according to Mitcherlich's measurement, 78° 40′. The constituents of the salt from Mitcherlich's experiments, seem to be the following:

1 atom phosphate of potash	9·5
1 atom phosphate of soda	7·5
15 atoms water	16·875
	33·875

The quantity of water found by Mitcherlich, somewhat exceeded 15 atoms: for it was 17·272, which exceeds 15 atoms by about one-third of an atom.

Potash-arseniate of soda.

13. Potash-arseniate of soda. This salt was formed by Mitcherlich in the same way as the preceding; the form of its crystals is the same also. Its constituents, according to Mitcherlich's analysis, are as follows:

1 atom arseniate of potash	13·75
1 atom arseniate of soda	11·75
18 atoms water	20·25
	45·75 *

Potash-oxalate of copper.

14. Potash-oxalate of copper. This salt was

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* Ann. de Chim. et de Phys. XIX. 396.

first formed by Vogel of Bareuth, by digesting together binoxalate of potash and carbonate of copper. When the solution is concentrated, two species of salts are obtained.

The first species crystallizes in long slender six-sided prisms, which effloresce in the air. They are composed of

1 atom oxalate of potash	10·5
1 atom oxalate of copper	9·5
4 atoms water	4·5
	24·5

The second species forms oblique four-sided prisms with rhombic bases. It has a greener colour than the first species, and is not altered by exposure to the air. Its constituents are

1 atom oxalate of potash	10·5
1 atom oxalate of copper	9·5
2 atoms water	2·25
	22·25

Potash tartrate of soda.

15. Potash-tartrate of soda. This is the well known salt formed by saturating bitartrate of potash with carbonate of soda and crystallizing the solution. It forms large crystals, which seem to have for a primary form, a right prism with a rectangular base; it has a bitter taste, is very soluble in water, and effloresces slightly, when exposed to the air. Its constituents are

1 atom tartrate of potash	14·25
1 atom tartrate of soda	12·25
8 atoms water	9·00
	35·5

Here the water of crystallization is twice as great as in the two salts uncombined: for the two salts contain each 2 atoms of water.*

Tartar emetic.

16. Tartar emetic. This well known salt is formed by boiling together cream of tartar and glass of antimony in fine powder. The filtered solution, when sufficiently concentrated, deposites white coloured crystals of tartar emetic; the crystals are usually tetrahedrons; it is commonly opaque, and very irregular in its shape; it requires about 14½ times its weight of cold water to dissolve it, but it is much more soluble in hot water. No accurate analysis of this useful salt having been hitherto made, I took the following method of ascertaining its constituents:

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* I have analyzed crystals of this salt after standing for a fortnight on blotting paper in my laboratory, and found them composed of

1 atom tartrate of potash	14·25
1 atom tartrate of soda	12·25
10 atoms water . .	11·25
	37·75

But I ascribed this difference to the difficulty of getting rid of the hygrometrical moisture. The crystals containing 8 atoms water, were large and firm, and consequently, much freer from adhering moisture than the small crystals formed in my laboratory.

50 grains of picked crystals of tartar emetic were dissolved in distilled water, and a current of sulphuretted hydrogen gas passed through the liquid as long as any precipitate fell. The hydro-sulphuret of antimony thus obtained, when dried in the open air, weighed 42·21 grains; but when heated in a glass tube, water was driven off, and a black matter remained, which weighed 24·59 grains, and which was sulphuret of antimony, equivalent to 18·032 grains of antimony, or 21·31 grains of protoxide of antimony.

The liquid thus freed from antimony, was evaporated cautiously, and a quantity of bitartrate of potash obtained, which weighed 28·69 grains. But the integrant particle of bitartrate of potash weighs 24·75; and 28·60 : 24·75 : : 21·31 : 18·384 = the protoxide of antimony united to an integrant particle of bitartrate of potash. Now, the protoxide of antimony weighs 6·5, and 6·5 × 3 = 19·5; this is a little more than I actually found, because part of the sulphuret in my experiment adhered to the glass tube, and could not be collected without loss. From this experiment, which I thrice repeated, I have no doubt that the constituents of tartar emetic are

2 atoms tartaric acid .	16·5
3 atoms protoxide of antimony	19·5
1 atom potash . .	6·0
2 atoms water . .	2·25
	44·25

This must be acknowledged a very curious combination. It might be called a *ditartrate of potash and antimony;* for 1 atom of tartaric acid must be combined with 2 atoms of protoxide of antimony, while the other atom of acid is divided between the atom of potash and the remaining atoms of protoxide of antimony.

Sulpho-chromate of potash.

17. Sulpho-chromate of potash. This salt was obtained by mixing together solutions of chromate of potash and sulphate of potash, in the proportion of 3 atoms of the former to 1 atom of the latter. On concentrating the mixture and setting it aside, the first crystals which were deposited had a greenish yellow colour, and were either in octahedrons or four-sided rectangular prisms terminated by four-sided pyramids. These last were obviously the regular octahedron with a prism interposed between its pyramids. The crystals were small, but very regular and transparent; the taste was saline and bitter; and the salt was not very soluble in water. When this salt was heated to redness it became opaque, but did not lose any weight,—it was therefore anhydrous. After some unsuccessful attempts to analyze this salt by means of tartaric acid it was treated in the following way:

78·5 grains of it were dissolved in water, and precipitated by a neutral solution of protonitrate of mercury. The precipitate being edulcorated, and dried, weighed almost exactly 32·5 grains, equivalent to 6·5 grains of chromic acid.

The liquid thus freed from chromic acid was evaporated to dryness, and heated to redness in a platinum vessel to get rid of any excess of mercury that might have been added. It was then dissolved in water, and the sulphuric acid precipitated by muriate of barytes. The precipitate, after being washed, dried, and heated to redness, weighed 88·55 grains, containing 30 grains of sulphuric acid. But 30 grains of this acid is equivalent to 6 atoms, requiring for saturation 6 atoms or 36 grains of potash; while the 6·5 grains of chromic acid require for saturation 6 grains of potash. It is obvious, from this analysis, that the constituents of this compound salt are

6 atoms sulphate of potash	66
1 atom chromate of potash	12·5
	78·5

III. OF COMPOUND SALTS CONTAINING NEITHER POTASH NOR AMMONIA.

Carbo-tartrate of alumina-and-soda.

1. Carbo-tartrate of alumina-and-soda. When solutions of tartrate of alumina and carbonate of soda, each in the atomic proportions, are mixed together, no precipitate falls; but when the mix-

ture is left to spontaneous evaporation a transparent colourless salt gradually appears, crystallized in long prisms, apparently four-sided but rather indistinct. These crystals do not affect litmus or cudbear paper; they have a disagreeable taste bearing a certain resemblance to that of sulphate of zinc. As the whole of the liquid shoots into these crystals, it is evident, that the compound salt consists of an integrant particle of tartrate of alumina and an integrant particle of carbonate of soda united together. From the weight of the compound salt, compared with that of the two constituents, it was easy to infer that it contained 9 atoms water. Hence, the constituents of the salt are

1 atom tartrate of alumina	10·5
1 atom carbonate of soda	6·75
9 atoms water . .	10·125
	27·375

Magnesio-carbonate of lime.

2. Magnesio-carbonate of lime. The mineral known by the name of dolomite, when amorphous, and of rhombspar or bitter spar, when in crystals, is too well known to require any particular description. If any confidence can be put in Klaproth's analyses, there are two distinct species of this mineral:

(1.) The common dolomite and magnesian limestone, are composed of

1 atom carbonate of lime	6·25
1 atom carbonate of magnesia	5·25
	11·5

I find the magnesian limestone of Sunderland is composed of these proportions.

(2.) Rhombspar, on the other hand, as is obvious from the analyses of Klaproth, is a compound of

2 atoms carbonate of lime	12·5
1 atom carbonate of magnesia	5·25
	17·75

Boro-tartrate of potash-and-soda.

3. Boro-tartrate of potash-and-soda.* This is the well known salt which has a place in several of the foreign pharmacopœias under the name of *cremor tartari solubilis.* It is made by dissolving 1 part of borax in 8 parts of boiling water, and adding to the solution as much bitartrate of potash as it will dissolve. The solution is filtered and evaporated to dryness in a gentle heat. The compound salt thus prepared, is employed in dropsy and amenorrhæa, and possesses nearly the same virtues as bitartrate of potash. Its taste is cooling, bitter, and much more disagreeable than that of cream of tartar,

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* Though this salt contains potash, I have thought it better to place it here than among the compound salts of potash, for reasons that will be easily perceived by the attentive reader.

without any of the sourness which distinguishes that salt. When exposed to a moderate heat on the sand bath, it gradually becomes solid, without exhibiting any tendency to crystallization or losing any of its transparency. Its colour becomes slightly yellow, and it bears some resemblance to nut oil prepared for printers' ink, and the process continued till the oil becomes solid. When the compound salt is weighed in this state, it is found precisely equal to the weight of the two salts employed to form it. Consequently, each salt retains its water of crystallization. By exposure to the air it slowly deliquesces. The constituents are

1 atom biborate of soda	10
2 atoms bitartrate of potash	22·5
12 atoms water	13·5
	46

Soda-sulphate of lime.

4. Soda-sulphate of lime. This is the name which designates the substance known to mineralogists by the name of Glauberite, and found originally embedded in rock salt, about ten leagues south of Madrid, at Vela Rubia, and more lately, in the blue salt of Ischel in Upper Austria. It is crystallized in oblique rhombic prisms, and is composed of

1 atom sulphate of lime	8·5
1 atom sulphate of soda	9
	17·5

As is evident from the analysis of Brogniart.

5. Soda-sulphate of alumina, or soda-alum. Soda-alum. This species of alum has been hitherto overlooked by chemists, in consequence of its great solubility, and the consequent difficulty of obtaining it in regular crystals. I have been informed by my friend, Charles Macintosh, Esq. of Glasgow, that he made it more than twenty years ago. For the specimen which I examined, I am indebted to Mr. John Wilson of Hurlet, who first drew my attention to it, and furnished me with very pure specimens. The salt was noticed in 1810, by Mr. Winter, in his account of the Whitby alum processes.* In appearance, *soda-alum* cannot be distinguished from common alum; the crystals are regular octahedrons, or forms obviously derived from the common octahedron: the taste is the same as that of common alum. It undergoes no alteration from exposure to the air, if pure, but it is frequently impure, and in that case effloresces on the surface. The great solubility of this alum is its great characteristic property. It is more than thirty times more soluble in cold water than ammoniacal alum, and more than twenty times

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* Nicholson's Jour. XXV. 254, 255.

more soluble than potash alum. For I find that at the temperatue of 60°, 100 parts of water dissolve

9·37	parts of ammoniacal alum
14·79	parts of potash alum
327·6	parts of soda alum.

This great solubility would make soda-alum more convenient for the use of dyers and printers than common alum, if it could be procured with the same facility. When soda-alum is heated on the sand bath, it undergoes very nearly the same loss of weight as common alum. For 100 parts in my trials lost 44·1 parts of water of crystallization.

I found by experiment that 58·875 grains of the crystals of this alum are just decomposed by 53 grains (13·25 × 4) of chloride of barium, and consequently, contain exactly 20 grains of sulphuric acid. From 58·875 grains of the same crystals, I got almost exactly 6·75 grains of alumina and 9·5 grains of anhydrous sulphate of soda; the excess, amounting to 0·5 grain, was owing to sulphate of lime obviously derived from the filter. From this analysis it follows that the constituents of soda-alum are

3 atoms sulphate of alumina	21·75
1 atom sulphate of soda	9
25 atoms water	28·125
	58·875

Thus, there are no fewer than five species of compound salts, having each the form of the regular octahedron, and containing each the same number of atoms of water. These are

1. Ammoniacal alum,
2. Potash alum,
3. Soda alum,
4. Ammonio-persesquisulphate of iron,
5. Potash-persesquisulphate of iron.

Were we to confine our views to the first three species, we would be tempted to conclude with M. Mitcherlich, that sulphate of ammonia, sulphate of potash, and sulphate of soda are isomorphous salts; while in the fourth and fifth species the alumina is replaced by peroxide of iron. And Mitcherlich has shown that alumina and peroxide of iron are isomorphous substances.

In consequence of this last circumstance, it is obvious that alum is very likely to contain peroxide of iron, unless very great care indeed be taken in preparing it. The only certain way of obtaining it quite free from iron would be to dissolve clay free from iron in sulphuric acid, and to crystallize the solution by adding the requisite quantity of sulphate of ammonia and sulphate of potash. I am satisfied that at the present price of sulphuric acid, such a manufactory might be established with advantage.

Calcareo-acetate of copper.

6. Calcareo-acetate of copper. This is an exceedingly beautiful salt of a fine deep blue co-

lour, and crystallized in six-sided prisms, which Mr. Ramsay of Glasgow prepares for the use of the calico printers. It is pretty soluble in water, and has the peculiar disagreeable taste which distinguishes the cupreous salts. It seems to have been crystallized from a liquid containing an excess of acetate of lime: for when the crystals are kept for some time, they become spotted on the surface with small white crusts, which I find to consist of acetate of lime. The result of a careful analysis of this salt in my laboratory gives the constituents as follows:

1 atom acetate of lime	9·75
1 atom acetate of copper	11·25
6 atoms water	6·75
	27·75

Soda-oxalate of copper.

7. Soda-oxalate of copper. M. Vogel of Bareuth prepared this salt by saturating bin-oxalate of potash with soda, and pouring a saturated solution of sulphate of copper into the liquid. A pulverulent precipitate fell, which was redissolved by agitation; the liquid being concentrated, the potash-oxalate of copper first crystallized; afterwards, crystals of soda-oxalate of copper were deposited. They were feather shaped, and consisted of four-sided prisms sometimes flattened. This salt is insoluble in water. At first it has a sky blue colour, but by exposure to

the light it becomes first green, and afterwards brown, without any other apparent alteration. I have not myself made any experiments on this salt; but from the analysis of it by Mr. Vogel, there can be no doubt that it is composed of

1 atom oxalate of soda	8·5
1 atom oxalate of copper	9·5
2 atoms water	2·25
	20·25

Carbono-phosphate of soda.

8. Carbono-phosphate of soda. There is a prussian blue manufactory in the neighbourhood of Glasgow belonging to Mr. Macintosh, in which, likewise, prussiate of potash is made in very considerable quantities. The acid is obtained by the combustion of the hoofs of black cattle, imported chiefly from Ireland; and the hoofs of a thousand cattle are required for every day's consumption in the manufactory. The slaughtering of cattle in Ireland having considerably diminished at the end of the last war, hoofs became scarce. This induced Mr. Macintosh to substitute the animal substance called cracknales, procured chiefly, I believe, from the candle makers. Soon after this substitution, considerable quantities of a white salt in fine needles began to make their appearance in the prussiate of potash leys, and incommoded the process considerably. These crystals exhibiting appearances different from any of the common

salts, Mr. Macintosh sent me a quantity of them to ascertain their nature.

The crystals were pretty regular six-sided prisms, which were obtained of a pretty large size by a second crystallization. The taste was cooling, and alkaline, and they rendered cudbear paper violet, indicating the presence of an alkali. The salt was pretty soluble in water, and the crystals were not altered by exposure to the air. They effervesced slightly, but distinctly in nitric acid.

I neutralized a portion of these crystals by means of nitric acid, and then mixed the solution with a sufficient quantity of nitrate of barytes—a white precipitate fell, which, when washed, and dried on the filter, was a beautiful white soft powder, which dissolved without effervescence in nitric acid, was again precipitated by ammonia, and exhibited all the properties of phosphate of barytes. I therefore decomposed a portion of it by means of sulphuric acid. The acid which I obtained possessed the following properties:

It threw down nitrate of barytes, and nitrate of lead white, and both precipitates were dissolved by nitric acid. Persulphate of iron was thrown down white, and the precipitate became red when digested in potash ley. Nitrate of silver was thrown down yellow, and the precipitate was dissolved in nitric acid. Muriate of lime, muriate of magnesia, nitrate of strontian, sulphate of copper, sulphate of zinc, nitrate of mercury, were not precipitated. From these properties, there could be no doubt that the acid in the salt was chiefly the phosphoric.—I now dissolved a quantity of the salt in water, and neutralized it exactly with sulphuric acid; the solution was then concentrated, and set aside. It shot out into crystals of sulphate of soda, and phosphate of soda, easily recognized by their shape.

To ascertain the proportions of the constituents, I dissolved 200 grains of the crystals in water, neutralized the solution with nitric acid, and precipitated by nitrate of lead. The precipitate weighed 141·3 grains, equivalent to 28·26 grains of phosphoric acid. The residual liquid contained no lead, but was entirely nitrate of soda, weighing 109·5 grains, equivalent to 40·74 grains of soda. Now, 28·26 grains of phosphoric acid require for saturation 32·297 grains of soda. There remain 7·443 grains of soda, which require for saturation 5·117 grains of carbonic acid.

Thus, the constituents of the salt are

Phosphoric acid	28·260	or	14
Carbonic acid	5·117	-	2·535
Soda . .	40·740	-	20·182
Water . .	125·883	-	62·36
	200·000		

Now,

4 atoms phosphoric acid = 14
1 atom carbonic acid = 2·75
5 atoms soda . . = 20
55 atoms water . = 61·875

Hence, I am disposed to consider the salt as a compound of

4 atoms phosphate of soda	30
1 atom carbonate of soda	6·75
55 atoms water . .	61·875
	98·625

If this be really a compound of phosphate and carbonate of soda, the union is very slight; for I found that by repeated solutions, and crystallizations, I could separate from it phosphate of soda in the usual rhomboidal form. What leads to the notion that it is a compound salt, is the form of the crystals—a six-sided prism apparently regular, which could not be derived from the primary form of phosphate of soda. Nor is the water of crystallization what it would be if the salt were a mere mixture of 4 atoms of phosphate of soda, and 1 atom of carbonate of soda; for phosphate of soda containing 12 atoms, and carbonate of soda 10 atoms, the water of crystallization should have amounted to 58 atoms, instead of 55—the quantity found, unless there was an error in the analysis. I do not well see, however, how any supposed error could serve to diminish the apparent quantity of water in the salt; but it is possible that the salt may have sustained a loss of water before I began to examine it.

CHAP. XIX.

SOME GENERAL OBSERVATIONS ON THE ATOMIC WEIGHTS OF CHEMICAL BODIES.

1. Hydrogen is the lightest of all known bodies. Its atomic weight is 0·125.

2. The atomic weights of all the other simple bodies are multiples of 0·25 = 2 atoms of hydrogen. Consequently, the number denoting the atomic weight of each is either a whole number, or a mixed number, ending with one or other of these decimals:—0·25, 0·5, 0·75.

3. The atomic weights of the supporters are as follows:

Oxygen	1
Chlorine	4·5
Iodine	15·5

They are all multiples of 0·5, or of 4 atoms of hydrogen.

4. The atomic weights of the acidifiable combustibles are as follows (omitting hydrogen):

Acidifiable combustibles.

1. Carbon . .	0·75
2. Boron . .	1
3. Silicon . .	1
4. Phosphorus .	1·5
5. Azote . .	1·75
6. Sulphur .	2
7. Tellurium .	4
8. Arsenic .	4·75
9. Selenium .	5

They are all whole numbers, or terminate in 0·5 or 0·75—they never terminate in 0·25.

5 are multiples of 8 atoms of hydrogen.
1 is a multiple of 4 — —
3 are multiples of 2 — —

Intermediate combustibles.

5. The atomic weights of the intermediate combustibles are as follows:

1. Chromium	3·5	5. Tungsten	15·75
2. Titanium	4	6. Columbium	18
3. Antimony	5·5	7. Uranium	26
4. Molybdenum	6		

These, like the former set, are either whole numbers, or they end in 0·5 or 0·75, and never in 0·25.

4 are multiples of 8 atoms hydrogen.
2 are multiples of 4 — —
1 is a multiple of 2 — —

Alkalifiable combustibles.

6. The atomic weights of the alkalifiable combustibles are as follows:

1. Lithium	1·25	10. Manganese	3·5
2. Aluminum	1·25	11. Iridium	3·75
3. Magnesium	1·5	12. Copper	4
4. Glucinum	2·25	13. Yttrium	4·25
5. Calcium	2·5	14. Zinc	4·25
6. Sodium	3	15. Potassium	5
7. Nickel	3·25	16. Zirconium	5
8. Cobalt	3·25	17. Strontium	5·5
9. Iron	3·5	18. Rhodium	5·5

19.	Cerium	6·25
20.	Cadmium	7
21.	Palladium	7
22.	Tin	7·25
23.	Barium	8·75
24.	Bismuth	9
25.	Platinum	12
26.	Lead	13
27.	Silver	13·75
28.	Mercury	25
29.	Gold	25

They are either whole numbers, or they terminate in 0·25 or 0·5; and very rarely in 0·75.

11 are multiples of 8 atoms of hydrogen,
6 are multiples of 4 — —
12 are multiples of 2 — —

Only 3 of them end in 0·75; namely, iridium, barium, and silver.

7. The simple combustibles (excluding hydrogen) amount to 44. Of these

20 (or almost the half) are multiples of oxygen, and conseqently whole numbers.
9 are multiples of 4 atoms of hydrogen, and consequently terminate in 0·5.
9 terminate in 0·25, being multiples of 2 atoms of hydrogen.
6 terminate in 0·75, being likewise multiples of 2 atoms hydrogen.

8. When an acidifiable combustible terminates in 0·75, the acid, which it forms, does not act with much energy; but when an alkalifiable combustible terminates in 0·75 the base formed is usually energetic. How far this applies to iridium is uncertain; but it applies well both to barytes and oxide of silver.

Acids.

9. The acids are all compound bodies. They may, with reference to their atomic weights, be divided into three classes: 1. Combinations of a simple acidifiable or intermediate combustible with oxygen. 2. Acids, consisting of oxygen united to two bases at once, or undecomposed acids. 3. Hydracids, consisting of a simple or compound supporter united to an atom of hydrogen. The following table exhibits the atomic weights of all these acids :

1. OXYGEN UNITED TO A SINGLE BASE.

1. Silicic	2	14. Chromic	6·5
2. Phosphorous	2·5	15. Arsenious	6·75
3. Carbonic	2·75	16. Nitric	6·75
4. Boracic	3	17. Selenic	7
5. Hyposulphurous	3	18. Antimonic	7·5
6. Phosphoric	3·5	19. Manganesic	7·5
7. Sulphurous	4	20. Arsenic	7·75
8. Oxalic	4·5	21. Molybdous	8
9. Hyponitrous acid	4·75	22. Hyposulphuric	9
10. Sulphuric	5	23. Molybdic	9
11. Oxide of tellurium	5	24. Tungstic	18·75
12. Nitrous acid	5·75	25. Columbic	19
13. Titanic	6	26. Uranitic	28

2. OXYGEN UNITED TO A DOUBLE BASE—AND UNDECOMPOSED ACID.

1. Fluoric	1·25	6. Citric	7·25
2. Fluosilicic	3·25	7. Tartaric	8·25
3. Fluoboric	4·25	8. Uric	9
4. Acetic	6·25	9. Saclactic	13
5. Succinic	6·25	10. Benzoic	15

3. HYDRACIDS.

1.	Hydrocianic	3·375	3.	Muriatic	4·625
2.	Formic	4·625	5.	Hydriodic	15·625

Of the first set 12 are whole numbers; 6 end in 0·5 and 4 in 0·75. Or, in other words,

12 are multiples of oxygen,
6 are multiples of 4 atoms of hydrogen,
4 are multiples of 2 atoms of hydrogen.

Of the second set 3 are whole numbers, and the other 7 end in 0·25. Or, in other words,

3 are multiples of 1 atom of oxygen,
7 are multiples of 2 atoms of hydrogen.

The third set containing an atom of hydrogen united to an atom of a simple or compound supporter or acid, it is obvious that they can only be multiples of 1 atom of hydrogen. Accordingly, they end either in 0·625 or in 0·375.

10. The atomic weights of the bases (excluding ammonia) are as follows: Bases.

1.	Lithia	2·25	10.	Protoxide of manganese	4·5
2.	Alumina	2·25	11.	Protoxide of chromium	4·5
3.	Magnesia	2·5	12.	Peroxide of iron	5
4.	Glucina	3·25	13.	Deutoxide of manganese	5
5.	Lime	3·5	14.	Oxide of copper	5
6.	Soda	4	15.	Yttria	5·25
7.	Protoxide of nickel	4·25			
8.	Protoxide of cobalt	4·25			
9.	Protoxide of iron	4·5			

16.	Oxide of zinc	5·25
17.	Potash	6
18.	Zirconia	6
19.	Strontian	6·5
20.	Protoxide of antimony	6·5
21.	Protoxide of cerium	7·25
22.	Deutoxide of rhodium	7·5
23.	Peroxide of cerium	7·75
24.	Oxide of palladium	8
25.	Protoxide of tin	8·25
26.	Peroxide of tin	9·25
27.	Barytes	9·75
28.	Oxide of bismuth	10
29.	Peroxide of platinum	14
30.	Protoxide of lead	14
31.	Oxide of silver	14·75
32.	Protoxide of ☿	26
33.	Peroxide of ☿	27
34.	Protoxide of uranium	27
35.	Peroxide of uranium	28

14 of these are whole numbers; 8 end in 0·5, 10 in 0·25, and 3 in 0·75. Or, in other words,

14 are multiples of an atom of oxygen,
8 are multiples of 4 atoms of hydrogen,
13 are multiples of 2 atoms of hydrogen.

Ammonia being a compound of hydrogen, and containing 3 atoms of it, is obviously only a multiple of 1 atom of hydrogen.

11. Thus it appears, that out of 117 bodies, the atomic weights of which have been accurately determined in this work, there are only 5 which are merely multiples of 1 atom of hydrogen,—these are the four hydracids and ammonia. The four acids contain each 1 atom of hydrogen, and ammonia contains 3 atoms of hydrogen. 37 are multiples of 2 atoms of hydrogen, 11 of which are acids and 11 bases. The rest simple bodies.

25 are multiples of 4 atoms of hydrogen. Of these 6 are acids, 8 bases; 2 supporters, 3 acidifiable combustibles, and 6 alkalifiable.

50 are multiples of an atom of oxygen, and consequently whole numbers. Of these 15 are acids, 14 bases, 1 supporter, 9 acidifiable combustibles, and 11 alkalifiable combustibles.

12. It is obvious that all those bodies whose atomic weights are represented by whole numbers are multiples of the atomic weight of oxygen.

18 simple bodies are in this predicament, namely,

Boron,
Silicon,
Sulphur,
Tellurium,
Selenium,
Molybdenum,
Columbium,
Uranium,
Sodium,
Copper,
Potassium,
Zirconium,
Cadmium,
Palladium,
Bismuth,
Platinum,
Lead,
Titanium.

Most of the compounds of these bodies (to the amount of 28) are also whole numbers, and of course multiples of oxygen. This is the case also with three combustible acids; namely, uric, saclactic, and benzoic.

Whether 1½ atom of oxygen unite to bodies.

13. There are five or six of the simple bodies which we have found to combine both with 1 atom and with 1½ atom of oxygen. This anomaly, I have no doubt, will startle many of my readers, and may even induce several persons to reject the whole system without farther exami-

nation. I have sometimes thought that the anomaly might be obviated by admitting, that oxygen in reality has an atomic weight amounting to 0·5 instead of 1;—on that supposition, it will have the property of usually entering into combinations by 2 atoms at a time. All those compounds which I have considered as containing only 1 atom of oxygen, will in reality contain 2; and those which I suppose to contain $1\frac{1}{2}$ atom will contain 3 atoms. This supposition, if admitted, will make no alteration in the atomic weights given in this work; it will only alter our way of viewing them, and 1, instead of denoting the weight of 1 atom oxygen will represent 2 atoms. It will be more convenient to retain these atomic weights even if this new view of the subject should be ultimately adopted; because, it is but very seldom that a less quantity of oxygen enters into combination with other bodies than what we have denoted by 1. One, then, may still be considered as the representative of a compound atom of oxygen, because it is the common multiple of it which enters into combinations; though in a few rare instances we find that 0·5, or a simple atom of it, also unites with other bodies. Such combinations constitute the peroxides of iron, nickel, cobalt, cerium, and sodium, and likewise the deutoxide of manganese.

Atom of oxygen may be = 0·5.

If we embrace this view of the subject, which in the present state of our knowledge is by far the most probable, then, not only those simple bodies whose atomic weights are whole numbers, but those likewise, whose weights end in 0·5, are multiples of oxygen. These constitute the whole of the supporters of combustion, and all the acidifiable and intermediate combustibles, except three; namely, carbon, arsenic, and tungsten. Of the alkalifiable combustibles, amounting to 29, 17 would be multiples of oxygen, leaving altogether, 15 simple bodies, which are multiples of 2 atoms of hydrogen. Thus 31 simple bodies would be multiples of oxygen, and 15 multiples of 2 atoms of hydrogen.

14. There are only 5 simple bodies which are multiples of 2 atoms of water, or 2·25. These are

Chlorine	4·5	or	4	water.
Tungsten	15·75	-	14	-
Columbium	18	-	16	-
Glucinum	2·25	-	2	-
Bismuth	9	-	8	-

But there are 12 compound bodies in the same predicament: viz.

Oxalic acid .	4·5	or	4	water.
Arsenious acid .	6·75	-	6	-
Hyposulphuric .	9	-	8	-
Molybdic . .	9	-	8	-
Uric acid . .	9	-	8	-

Lithia	2·25	or	2 water.
Alumina	2·25	-	2 -
Protoxide of iron	4·5	-	4 -
Protoxide of manganese	4·5	-	4 -
Peroxide of mercury	27	-	24 -
Protoxide of uranium	27	-	24 -

These comparisons might be carried a good deal farther. A bare inspection of the tables at the beginning of this chapter will enable the reader to perceive the relations which exist between the atomic weights of different bodies. Thus

The atomic weight of carbon is		0·75
That of phosphorus is	0·75 × 2 =	1·5
sodium	1·5 × 2 =	3
molybdenum	3 × 2 =	6
platinum	6 × 2 =	12

Or, in other words, the atom of

Phosphorus is = 2 carbon.
Sodium = 4 -
Molybdenum = 8 -
Platinum = 16 -

In like manner, the atom of

Glucinum is = 3 carbon.
Oxalic acid, Protoxide of iron, Protoxide of manganese } = 6 -
Bismuth = 12 -

These, and many other similar relations between the atomic weights of the different bodies, will be obvious by barely inspecting the tables, and need not therefore be pointed out.

Water of crystallization of the salt.

15. Though the seventeenth and eighteenth chapters of this work exhibit the composition of 307 salts, a greater number than has ever before been subjected to actual analysis by any individual, yet they do not enable us to detect any law with respect to the number of atoms of water which exist in the salts in the state of water of crystallization. Of these 307 species of salts, eighty are anhydrous—thirty-one contain 1 atom of water—fifty contain 2 atoms—twenty-seven 3 atoms—eighteen 4 atoms—twelve 5 atoms—nineteen 6 atoms—eighteen 7 atoms—ten 8 atoms—four 9 atoms; all of which are compound salts—six contain 10 atoms—none contain 11 atoms—and two contain 12 atoms. No simple salt has been met with containing more than 12 atoms, except the sesquinitrate of uranium, which seems to contain 17 atoms. But the compound salts are found with a much greater quantity of water. Thus, one contains 16 atoms of water—five contain 25 atoms—and one contains 55 atoms. Next to the anhydrous salts, by far the most abundant are the salts which contain 2 atoms of water. The salts containing 1, 2, and 3 atoms, added together,

constitute about the half of the whole, if we exclude the anhydrous salts.

If we except acetate of ammonia and quadroxalate of potash, none of the salts of ammonia, potash, soda, barytes, strontian, or lime, contain 7 atoms of water. And, except phosphate of magnesia, all the salts which contain 7 atoms water are either sulphates or nitrates. The metalline sulphates seem to affect 7 atoms water.

No salt of barytes, strontian, iron, manganese, bismuth, or mercury, contains 6 atoms of water; and only 14 simple salts occur containing that quantity of water. The other five are compound salts.

Salts containing 5, 8, 10, and 12 atoms are very rare. No salt has been met with containing 11 atoms.

The oxalates are either anhydrous, or they contain 1, 2, or 3 atoms of water. Only 2 salts contain more: namely, the oxalate of nickel, which contains 4, and the quadroxalate of potash, which contains 7 atoms.

The tartrates are either anhydrous, or they contain 1, 2, or 3 atoms of water. One salt contains 4 atoms, the tartrate of lime, and one contains 5 atoms, the tartrate of bismuth.

The acetates vary much more in their composition. They occur with 1, 2, 3, 4, 6, and 7 atoms water; but very rarely anhydrous.

Inquiry into the accuracy of Berzelius' empyrical law.

16. Before concluding these general observations, I may say a few words respecting Berzelius' law, that "in all salts the atoms of oxygen in the acid constitute a multiple by a whole number of the atoms of oxygen in the base." This law was founded upon the first set of exact analyses of neutral salts which Berzelius made. Now, as neutral salts in general are combinations of an atom of a protoxide with an atom of an acid, it is obvious that the atoms of oxygen in the acid must in all such salts be multiples of the atom of oxygen in the base; because every whole number is a multiple of unity. Neutral salts, therefore, are not the kind of salts by means of which the precision of this supposed law can be put to the test.

Even in the subsalts, composed of 1 atom of acid united to 2 atoms of base, it is obvious enough, that the law will hold whenever the acid combined with the base happens to contain 2 or 4, or any even number of atoms; because all even numbers are multiples of 2. Now, this is the case with the following acids :

Phosphoric,
Carbonic,
Boracic,
Sulphurous,
Nitrous,
Titanic,
Arsenious,
Selenic,
Antimonic,
Manganesic,
Molybdous,
Uranitic,
Citric,
Saclactic,
Chromous.

Consequently, the law must hold good in all combinations of 1 atom of these acids with 2 atoms of base.

In the case of all those acids which contain only 1 atom of oxygen, all the subsalts composed of 1 atom of the acid united to 2 atoms of base, the law will also in some sort hold; for the atoms of the oxygen in such acids being 1, this number will always be a submultiple of 2, the number of atoms of oxygen in 2 atoms of base. This is the case with the following acids:

Silicic,
Hyposulphurous,
Phosphorous,
Oxide of tellurium.

It is only in the subsalts of acids containing an odd number of atoms of oxygen, that exceptions to the law can exist. It is to them, therefore, that we must have recourse when we wish to determine whether this empyrical law of Berzelius be founded in nature or not. Now, there are thirteen acids, the integrant particles of which contain an odd number of atoms of oxygen. The following table exhibits the names of these acids, together with the number of atoms of oxygen in each.

	ATOMS OF OXYGEN.
Sulphuric acid	3
Arsenic	3
Chromic	3
Molybdic	3
Tungstic	3
Oxalic	3
Formic	3
Acetic acid	3
Succinic	3
Benzoic	3
Nitric	5
Tartaric	5
Hyposulphuric	$2\frac{1}{2}$

Now, although the number of subsalts which I have examined is exceedingly small, because my object was not to investigate the truth of Berzelius' law, but to determine the quantity of water of crystallization which the salts contain, yet there occur several which are inconsistent with Berzelius' law. This is the case, for example, with the disulphate of alumina, the atoms of oxygen in the base being 2, and those in the acid 3. The following subsalts are precisely in the same predicament:

	ATOMS OF OXYGEN IN BASE.	DITTO IN ACID.
Dinitrate of alumina	2	5
Trisnitrate of alumina	3	5
Diprotarseniate of iron	2	3
Dinitrate of lead	2	5
Diacetate of lead	2	3
Diacetate of copper (verdigris)	2	3
Dinitrate of bismuth	2	5

These examples comprehend not only nitric acid, which Berzelius has recognised as an exception to his law; but likewise, sulphuric acid, arsenic acid, and acetic acid.

It would certainly be a most remarkable circumstance if 2 atoms of any protoxide were incapable of combining with 1 atom of any of the 13 acids in the preceding list. I have given seven examples of such combinations; and am persuaded that many more will be discovered whenever the attention of chemists is particularly turned to the subsalts.

There is another kind of saline combination in which exceptions to the law of Berzelius may also be looked for; I mean those salts which I have distinguished by the epithet *sesquisalts* or *subsesquisalts*. In the sesquisalts, 1½ atom of acid unite with 1 atom of base; or, which comes to the same thing, 3 atoms of acid unite with 2 atoms of base. In the subsesquisalts, 1½ atom of the base unite with 1 atom of the acid; for example, the *sesquicolumbate* of barytes is composed of

3 atoms columbic acid,	containing	3 atoms oxygen.
2 atoms barytes	———	2 ——— ———

Here we see, that the oxygen of the acid is not a multiple of that in the base.

When the acid contains 2 atoms of oxygen, and the base 1 atom, it is plain that the sesquisalts must all come under Berzelius' law; because 1½ atom of acid will contain 3 atoms of oxygen, and 3 is, of course, a multiple of 1; but in acids containing 1 or 3 atoms of oxygen, the law of Berzelius cannot hold.

With respect to the subsesquisalts they will all come under Berzelius' law when the acid happens to contain 3 atoms oxygen, and the base only 1 atom; but they will deviate from it whenever the acid contains 1 or 2 atoms of oxygen.

Upon the whole, though the subsalts and sesquisalts have not been sufficiently investigated to enable us to decide upon the point with perfect certainty; yet from what we do know, there appears sufficient evidence that Berzelius' rule cannot be considered as a general chemical law; and that we run the risk of falling into most egregious mistakes, if we make use of such a law in calculating the atomic weight and chemical constitution of the acids or bases. I pointed out some remarkable examples of this error when treating of uranium, to which it is merely necessary to refer the reader.

APPENDIX,

EXHIBITING THE

SPECIFIC GRAVITIES OF THE GASES,

AND THE

ATOMIC WEIGHTS,

DETERMINED IN THE PRECEDING CHAPTERS OF THIS WORK.

TABLE I.

SPECIFIC GRAVITY OF THE GASES.

	SP. GRAVITY AT 60°.	WEIGHT OF 100 CUBIC INCHES IN GRAINS.
Air	1	30·5
Hydrogen	$0{\cdot}069\dot{4}$	2·1180
Carbon vapour	$0{\cdot}416\dot{6}$	$12{\cdot}608\dot{3}$
Carburetted Hydrogen	$0{\cdot}555\dot{5}$	$16{\cdot}944\dot{4}$
Ammonia	$0{\cdot}5902\dot{7}$	$18{\cdot}003\dot{5}$
Steam	0·625	19·0620
Subphosphuretted hydrogen	$0{\cdot}694\dot{4}$	$21{\cdot}180\dot{5}$
Phosphorus vapour	$0{\cdot}833\dot{3}$	$25{\cdot}416\dot{6}$
Phosphuretted hydrogen	$0{\cdot}902\dot{7}$	27·5376
Hydrocyanic acid vapour	0·9375	28·5720
Bihydroguret of phosphorus	$0{\cdot}972\dot{2}$	$29{\cdot}652\dot{7}$
Carbonic oxide	$0{\cdot}972\dot{2}$	$29{\cdot}652\dot{7}$
Azotic gas	$0{\cdot}972\dot{2}$	$29{\cdot}652\dot{7}$
Olefiant gas	$0{\cdot}972\dot{2}$	$29{\cdot}652\dot{7}$
Deutoxide of azote	$1{\cdot}0416\dot{6}$	31·7708
Oxygen	$1{\cdot}111\dot{1}$	$33{\cdot}888\dot{8}$
Sulphur vapour	$1{\cdot}111\dot{1}$	$33{\cdot}888\dot{8}$
Sulphuretted hydrogen	$1{\cdot}180\dot{5}$	36·0069
Muriatic acid	$1{\cdot}2847\dot{2}$	39·1839
Oil gas	$1{\cdot}458\dot{3}$	$44{\cdot}4791\dot{7}$
Carbonic acid	$1{\cdot}527\dot{7}$	$46{\cdot}597\dot{2}$
Protoxide of azote	$1{\cdot}527\dot{7}$	$46{\cdot}597\dot{2}$
Cyanogen	$1{\cdot}805\dot{5}$	$55{\cdot}069\dot{4}$
Sulphurous acid	$2{\cdot}222\dot{2}$	$67{\cdot}777\dot{7}$
Tellurium vapour	$2{\cdot}222\dot{2}$	$67{\cdot}777\dot{7}$
Telluretted hydrogen	$2{\cdot}291\dot{6}$	$69{\cdot}8958\dot{3}$
Fluoboric acid	$2{\cdot}361\dot{1}$	$72{\cdot}013\dot{5}$
Protoxide of chlorine	$2{\cdot}444\dot{4}$	$74{\cdot}555\dot{5}$
Chlorine	2·5	76·25
Arsenic vapour	$2{\cdot}638\dot{8}$	$80{\cdot}486\dot{1}$
Bisulphuret of carbon vapour	$2{\cdot}638\dot{8}$	$80{\cdot}486\dot{1}$
Arsenietted Hydrogen	$2{\cdot}708\dot{3}$	$82{\cdot}6041\dot{6}$
Selenium vapour	$2{\cdot}777\dot{7}$	84·6980
Sulphuric acid vapour	$2{\cdot}777\dot{7}$	84·6980
Selenietted hydrogen	$2{\cdot}852\dot{2}$	$86{\cdot}992\dot{7}$
Naphtha vapour	$2{\cdot}916\dot{6}$	$88{\cdot}958\dot{3}$
Chlorocarbonic acid	$3{\cdot}472\dot{2}$	105·9020
Fluosilicic acid	$3{\cdot}611\dot{1}$	110·1385
Nitric acid vapour	3·75	114·375
Hydriodic acid	$4{\cdot}3402\dot{7}$	132·3785
Oil of turpentine vapour	5·0130	152·8960
Iodine vapour	$8{\cdot}611\dot{1}$	262·6308

TABLE II.

SPECIFIC GRAVITY AND ATOMIC WEIGHTS OF THE GASES REFERRED TO OXYGEN GAS AS UNITY.

I. GASES WHOSE ATOMIC WEIGHT = SPECIFIC GRAVITY.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Oxygen gas . . .	1	1
Fluosilicic acid . . .	3·25	3·25

II. GASES WHOSE ATOMIC WEIGHT IS DOUBLE THE SPECIFIC GRAVITY.

a. Simple Bodies.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Hydrogen gas . . .	0·125	0·0625
Carbon vapour . . .	0·75	0·375
Phosphorus vapour . . .	1·5	0·75
Azotic gas . . .	1·75	0·875
Sulphur vapour . . .	2	1
Tellurium vapour . . .	4	2
Chlorine gas . . .	4·5	2·25
Arsenic vapour . . .	4·75	2·375
Selenium vapour . . .	5	2·5
Iodine vapour . . .	15·5	7·75

b. Compounds of Simple Combustibles and Hydrogen.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Carburetted hydrogen . .	1	0·5
Phosphuretted hydrogen . .	1·625	0·8125
Subphosphuretted hydrogen . .	1·25	0·625
Bihydroguret of phosphorus . .	1·75	0·875
Olefiant gas . . .	1·75	0·875
Oil gas	2·625?	1·3175?
Sulphuretted hydrogen . .	2·125	1·0625
Telluretted hydrogen . .	4·125	2·0625
Oil of turpentine . . .	9·125?	4·5625?
Arsenietted hydrogen . .	4·875	2·4375
Selenietted hydrogen . .	5·125	2·5625

c. Compounds of Simple Combustibles and Oxygen.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Steam	1·125	0·5625
Carbonic oxide gas . . .	1·75	0·875
Carbonic acid . . .	2·75	1·375
Protoxide of azote . . .	2·75	1·375
Nitric acid vapour . . .	6·75	3·375
Sulphurous acid . . .	4	2
Sulphuric acid vapour . . .	5	2·5

d. Miscellaneous Compounds.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Cyanogen . . .	3·25	1·625
Fluoboric acid . . .	4·25	2·125
Bisulphuret of carbon . .	4·75	2·375
Chlorocarbonic acid . . .	6·25	3·125

III. GASES WHOSE ATOMIC WEIGHT IS QUADRUPLE THE SPECIFIC GRAVITY.

	ATOMIC WEIGHT.	SPECIFIC GRAVITY.
Ammoniacal gas . . .	2·125	0·53125
Hydrocyanic acid vapour . .	3·375	0·84375
Deutoxide of azote . . .	3·75	0·9375
Muriatic acid . . .	4·625	1·15625
Hydriodic acid . . .	15·625	3·90625

TABLE III.

EXHIBITING THE ATOMIC WEIGHTS OF BODIES.

	ATOMIC WEIGHT.	
	OXYGEN = 1	HYDR. = 1
Hydrogen . .	0·125	1
Base of fluoric acid? .	0·25	2
Carbon . .	0·75	6
Boron . .	1	8
Silicon . .	1	8
Oxygen . .	1	8
Carburetted hydrogen	1	8
Water . .	1·125	9
Aluminum . .	1·25	10
Lithium . .	1·25	10
Fluoric acid . .	1·25	10
Subphosphuretted hydrogen	1·25	10
Naphthaline . .	1·25	10
Phosphorus . .	1·5	12
Magnesium . .	1·5	12
Phosphuretted hydrogen	1·625	13
Azote . .	1·75	14
Carbonic oxide .	1·75	14

	ATOMIC WEIGHT.	
	OXYGEN = 1	HYDR. = 1
Olefiant gas	1·75	14
Bihydroguret of phosphorus	1·75	14
Sulphur	2	16
Silica	2	16
Ammonia	2·125	17
Sulphuretted hydrogen	2·125	17
Deutoxide of hydrogen	2·125	17
Alumina	2·25	18
Lithia	2·25	18
Fluorine?	2·25	18
Glucinum	2·25	18
Phosphuret of carbon	2·25	18
Magnesia	2·5	20
Phosphorous acid	2·5	20
Calcium	2·5	20
Oil gas	2·625	21
Carbonic acid	2·75	22
Protoxide of azote	2·75	22
Alcohol	2·875	23
Boracic acid	3	24
Sodium	3	24
Hyposulphurous acid	3	24
Hydrate of silica	3·125	25
Sulphuret of lithium	3·25	26
Glucina	3·25	26
Cyanogen	3·25	26
Nickel	3·25	26
Cobalt	3·25	26
Fluosilicic acid	3·25	26
Hydrate of alumina	3·375	27
Hydrocyanic acid	3·375	27
Sulphuret of magnesium	3·5	28
Iron	3·5	28
Manganese	3·5	28
Chromium	3·5	28
Phosphoric acid	3·5	28
Phosphuret of sulphur	3·5	28
Lime	3·5	28
Iridium	3·75	30
Deutoxide of azote	3·75	30
Nephrin	3·75	30
Sulphurous acid	4	32
Copper	4	32
Tellurium	4	32
Titanium	4	32
Suboxide of manganese	4	32
Telluretted hydrogen	4·125	33
Zinc	4·25	34
Fluoboric acid	4·25	34
Protoxide of nickel	4·25	34
Protoxide of cobalt	4·25	34
Yttrium	4·25	34

	ATOMIC WEIGHT.	
	OXYGEN = 1	HYDR. = 1
Chlorine	4·5	36
Sulphuret of calcium	4·5	36
Protoxide of iron	4·5	36
Protoxide of manganese	4·5	36
Protoxide of chromium	4·5	36
Bihydrate of alumina	4·5	36
Oxalic acid	4·5	36
Muriatic acid	4·625	37
Formic acid	4·625	37
Sulphuric ether	4·625	37
Peroxide of nickel	4·75	38
Peroxide of cobalt	4·75	38
Arsenic	4·75	38
Protoxide of iridium	4·75?	38?
Hyponitrous acid	4·75	38
Bisulphuret of carbon	4·75	38
Arseniетted hydrogen	4·875	39
Potassium	5	40
Deutoxide of manganese	5	40
Peroxide of iron	5	40
Zirconium	5	40
Sulphuret of sodium	5	40
Sulphuric acid	5	40
Oxide of copper	5	40
Oxide of tellurium	5	40
Protoxide of titanium	5	40
Selenium	5	40
Dihydrate of silica	5·125	41
Seleniетted hydrogen	5·125	41
Yttria	5·25	42
Oxide of zinc	5·25	42
Sulphuret of nickel	5·25	42
Sulphuret of cobalt	5·25	42
Naphtha	5·25	42
Strontium	5·5	44
Rhodium	5·5	44
Tritoxide of manganese	5·5	44
Protoxide of chlorine	5·5	44
Protosulphuret of iron	5·5	44
Deutoxide of chromium	5·5	44
Sulphuret of chromium	5·5	44
Antimony	5·5	44
Nitrous acid	5·75	46
Lactic acid	5·75	46
Peroxide of iridium	5·75?	46?
Chloride of lithium	5·75	46
Zirconia	6	48
Molybdenum	6	48
Potash	6	48
Titanic acid	6	48
Sulphuret of titanium	6	48
Sulphuret of copper	6	48

	ATOMIC WEIGHT.			ATOMIC WEIGHT.	
	OXYGEN = 1	HYDR. = 1		OXYGEN = 1	HYDR. = 1
Protochloride of phosphorus	6	48	Oxide of palladium	8	64
Chloride of magnesium	6	48	Peroxide of potassium	8	64
Oxide of selenium	6	48	Chloride of iron	8	64
Protohyd. of sulphuric acid	6·125	49	Chloride of manganese	8	64
Perhydrate of iron	6·125	49	Bisulphuret of copper	8	64
Cerium	6·25	50	Molybdous acid	8	64
Sulphuret of zinc	6·25	50	Sesquisulphuret of selenium	8	64
Acetic acid	6·25	50	Tartaric acid	8·25	66
Succinic acid	6·25	50	Protoxide of tin	8·25	66
Chlorocarbonic acid	6·25	50	Quadroxide of chlorine	8·5	68
Strontian	6·5	52	Chloride of copper	8·5	68
Sesquisulphuret of iron	6·5	52	Dichloride of sulphur	8·5	68
Chromic acid	6·5	52	Chloride of zinc	8·75	70
Protoxide of antimony	6·5	52	Barium	8·75	70
Manganesous acid?	6·5?	52?	Tannin	8·75?	70?
Protoxide of rhodium	6·5	52	Bismuth	9	72
Chloride of sulphur	6·5	52	Molybdic acid	9	72
Nitric acid	6·75	54	Uric acid	9	72
Sulphuret of arsenic	6·75	54	Suboxide of copper	9	72
Arsenious acid	6·75	54	Deutosulphuret of potass.	9	72
Cadmium	7	56	Peroxide of sodium	9	72
Palladium	7	56	Sulphuret of cadmium	9	72
Protoxide of molybdenum	7	56	Sulphuret of palladium	9	72
Protosulphuret of potassium	7	56	Hyposulphuric acid	9	72
Deutoxide of antimony	7	56	Oxalic acid crystals	9	72
Chloride of calcium	7	56	Oil of turpentine	9·125?	73?
Selenic acid	7	56	Peroxide of tin	9·25	74
Trishydrate of silica	7·125	57	Protosulphuret of tin	9·25	74
Hydrate of zirconia	7·125	57	Tartaric acid crystals	9·375	75
Tin	7·25	58	Dichloride of calcium	9·5	76
Protoxide of cerium	7·25	58	Citric acid crystals	9·5	76
Citric acid	7·25	58	Chloric acid	9·5	76
Acetic acid crystals	7·375	59	Chloride of potassium	9·5	76
Peroxide of rhodium	7·5	60	Barytes	9·75	78
Peroxide of antimony	7·5	60	Seleniet of arsenic	9·75	78
Manganesic acid	7·5?	60	Oxide of bismuth	10	80
Chloride of sodium	7·5	60	Bisulphuret of molybdenum	10	80
Sulphuret of rhodium	7·5	60	Disulphuret of copper	10	80
Persulphuret of iron	7·5	60	Chloride of antimony	10	80
Sulphuret of strontium	7·5	60	Chloride of strontium	10	80
Tritoxide of chlorine	7·5	60	Sesquisulphuret of tin	10·25	82
Antimonic acid	7·5	60	Perchloride of phosphorus	10·5	84
Sulphuret of antimony	7·5	60	Sulphuret of barium	10·75	86
Kermes mineral	7·625	61	Peroxide of barium	10·75?	86?
Chloride of nickel	7·75	62	Sulphuret of bismuth	11	88
Arsenic acid	7·75	62	Tritosulphuret of potassium	11	88
Chloride of cobalt	7·75	62	Chloride of strontium	11	88
Sesquisulphuret of arsenic	7·75	62	Fuming sulphuric acid	11·125	89
Peroxide of cerium	7·75	62	Persulphuret of tin	11·25	90
Chlorocyanic acid	7·75	62	Gum	11·25	90
Gallic acid	7·75?	62?	Uric acid crystals	11·25	90
Oxide of cadmium	8	64	Perchloric acid	11.5	92

	ATOMIC WEIGHT.			ATOMIC WEIGHT.	
	OXYGEN = 1	HYDR. = 1		OXYGEN = 1	HYDR. = 1
Chloride of cadmium	11·5	92	Iodide of iron	19	152
Protochloride of tin	11·75	94	Iodide of copper	19·5	156
Platinum	12	96	Iodide of zinc	19·75	158
Perchloride of iron	12·5 ?	100	Quadrochloride of azote	19·75	158
Dichloride of copper	12·5	100	Bisulphuret of tungsten	19·75	158
Persulphuret of bismuth	13	104	Sulphuret of columbium	20	160
Quadrosulphuret of potass.	13	104	Iodic acid	20·5	164
Protoxide of platinum	13	104	Iodide of potassium	20·5	164
Lead	13	104	Bichloride of platinum	21	168
Saclactic acid	13	104	Iodide of strontium	21	168
Chloride of barium	13·25	106	Suboxide of silver	21·625	173
Chloride of bismuth	13·5	108	Iodide of cadmium	22·5	180
Silver	13·75	110	Iodide of barium	24·25	194
Protoxide of lead	14	112	Iodide of bismuth	24·5	196
Sulphuret of platinum	14	112	Chloriodic acid	24·5	196
Peroxide of platinum	14	112	Gold	25	200
Bichloride of silenium	14	112	Mercury	25	200
Deutoxide of lead	14·5	116	Protoxide of gold	26	208
Oxide of silver	14·75	118	Uranium	26	208
Peroxide of lead	15	120	Protoxide of mercury	26	208
Protosulphuret of lead	15	120	Protoxide of uranium	27	216
Quintosulphuret of potass.	15	120	Peroxide of mercury	27	216
Benzoic acid	15	120	Protosulphuret of mercury	27	216
Octohydrate of zirconia	15	120	Peroxide of gold	28	224
Iodine	15·5	124	Peroxide of uranium	28	224
Dichloride of antimony	15·5	124	Sulphuret of uranium	28	224
Hydriodic acid	15·625	125	Disulphuret of lead	28	224
Decahydrate of chlorine	15·75	126	Iodide of lead	28·5	228
Sulphuret of silver	15·75	126	Persulphuret of mercury	29	232
Tungsten	15·75	126	Iodide of silver	29·25	234
Bisulphuret of platinum	16	128	Chloride of mercury	29·5	236
Perchloride of tin	16·25	130	Chloride of gold	29·5	236
Chloride of platinum	16·5	132	Tritosulphuret of gold	31	248
Tridecahydrate of silica	16·625	133	Periodide of phosphorus	32·5	260
Persulphuret of lead	17	136	Margaric acid	33	264
Iodide of phosphorus	17	136	26 hydrate of chromium	33·75	270
Chloride of lead	17·5	140	Bichloride of mercury	34	272
Iodide of sulphur	17·5	140	Bichloride of gold	34	272
Starch	17·75	142	Oleic acid	36	288
Oxide of tungsten	17·75	142	Tritiodide of azote	37·25 ?	298
Columbium	18	144	Morphia	40·25	322
Iodide of calcium	18	144	Protiodide of mercury	40·5	324
Chloride of silver	18·25	146	Picrotoxia	45	360
Iodide of sodium	18·5	148	Strychnia	47·5 ?	380
Tungstic acid	18·75	150	Brucia	51·5	412
Columbic acid	19	152	Periodide of mercury	56	448

TABLE IV.

EXHIBITING THE COMPOSITION AND ATOMIC WEIGHT OF THE SALTS.

I. ACETATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Of alumina . .	1	1	1	6·25	2·25	1·125	9·625	77
ammonia . .	1	1	7	6·25	2·125	7·875	16·25	130
barytes . .	1	1	3	6·25	9·75	3·375	19·375	155
cadmium . .	1	1	2	6·25	8	2·25	16·5	132
copper . .	1	1	1	6·25	5	1·125	12·375	99
diacetate of copper	1	2	6	6·25	10	6·75	23	184
subsesquacetate .	1	1½	3	6·25	7·5	3·375	17·125	137
trisacetate .	1	3	2	6·25	15	2·25	23·5	188
iron . .	1	1	3	6·25	4·5	3·375	14·125	113
lead . .	1	1	3	6·25	14	3·375	23·625	159
diacetate of lead .	1	2	10	6·25	28	11·25	45·5	364
trisacetate of lead	1	3	2	6·25	42	2·25	50·5	404
lime . . .	1	1	6	6·25	3·5	6·75	16·5	132
magnesia . .	1	1	5	6·25	2·5	5·625	14·375	115
manganese . .	1	1	4	6·25	4·5	4·5	15·25	122
mercury . .	1	1	4	6·25	26	4·5	36·75	294
nickel . .	1	1	5	6·25	4·25	5·625	16·125	129
potash . .	1	1	2	6.25	6	2·25	14·5	116
binacetate of potash	2	1	6	12·5	6	6·75	25·25	202
silver . .	1	1	0	6·25	14·75	0	21	168
soda . .	1	1	6	6·25	4	6·75	17	136
strontian . .	1	1	1	6·25	6·5	1·125	13·875	111
zinc . .	1	1	7	5·25	6·25	7·875	19·375	155

II. ANTIMONIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Tritantimoniate of potash	3	1	0	22·5	6	0	28·5	228

III. ARSENIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT	
							Oxygen = 1	Hydrog. = 1
Arseniate of alumina	1	1	6	7·75	2·25	6·75	16·75	122
ammonia	1	1	0	7·75	2·125	0	9·875	79
Binarseniate of ammonia	2	1	2	15·5	2·125	2·25	19·875	159
Arseniate of bismuth	1	1	2	7·75	10	2·25	20	160
cadmium	1	1	1	7·75	8	1·125	16·875	135
cobalt	1	1	4	7·75	4·25	4·5	16·5	132
Diprotarseniate of iron	1	2	3	7·75	9	3·375	20·125	161
Arseniate of lead	1	1	0	7·75	14	0	21·75	174
Subsesquarseniate of lead	1	1½	0	7·75	21	0	28·75	230
Arseniate of lime	1	1	0	7·75	3·5	0	11·25	90
magnesia	1	1	8	7·75	2·5	9	19·25	154
manganese	1	1	10	7·75	4·5	11·25	23·5	188
mercury	1	1	0	7·75	26	0	33·75	270
nickel	1	1	6	7·75	4·25	6·75	18·75	150
Binarseniate of nickel	2	1	10	15·5	4·25	11·25	31	248
potash	2	1	1	15·5	6	1·125	22·625	181
Arseniate of soda	1	1	8	7·75	4	9	20·75	166
Binarseniate of soda	2	1	5	15·5	4	5·625	25·125	201
Arseniate of strontian	1	1	8	7·75	6·5	9	23·25	186
zinc	1	1	8	7·75	5·25	9	22	176
Subsesquarseniate of silver	1	1½	0	7·75	22·125	0	29·875	237

IV. BENZOATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Benzoate of ammonia	1	1	1	15	2·125	1·125	18·25	146
potash .	1	1	3	15	6	3·375	24·375	195
lead .	1	1	1	15	14	1·125	30·125	241

V. BORATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Borate of ammonia .	1	1	2	3	2·125	2·25	7·375	59
Biborate of barytes .	2	1	0	6	9·75	0	15·75	126
magnesia	2	1	0	6	2·5	0	8·5	68
soda .	2	1	8	6	4	9	19	157

VI. CARBONATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Carbonate of ammonia	1	1	0	2·75	2·125	0	3·875	31
Sesquicarbonate of do.	1½	1	1	4·125	2·125	1·125	7·375	59
Bicarbonate of do.	2	1	1	5·5	2·125	1·125	8·75	70
Carbonate of barytes	1	1	0	2·75	9·75	0	12·5	100
Triscarbonate of bismuth	1	3	2	2·75	30	2·25	35	280
Carbonate of cadmium	1	1	0	2·75	8	0	10·75	86
cobalt .	1	1	1	2·75	4·25	1·125	8·125	65
Dicarbonate of copper	1	2	1	2·75	10	1·125	13·875	111
Ditto (anhydrous)	1	2	0	2·75	10	0	12·75	102
Carbonate of iron .	1	1	0	2·75	4·5	0	7·25	58
lead .	1	1	0	2·75	14	0	16·75	134
lime .	1	1	0	2·75	3·5	0	6·25	50
magnesia	1	1	3	2·75	2·5	3·375	8·625	69
do. (anhydr.)	1	1	0	2·75	2·5	0	5·25	42
manganese	1	1	2	2·75	4·5	2·25	9·5	76
Sesquicarbonate of mercury	1½	1	0	4·125	26	0	30·125	241
Carbonate of nickel .	2	1	3	2·75	4·25	3·375	10·375	83
potash .	1	1	2	2·75	6	2·25	11	88
Sesquicarbonate of do.	1½	1	6	4·125	6	6·75	16·875	135
Bicarbonate of do.	2	1	1	5·5	6	1·125	12·625	101
Carbonate of silver .	1	1	0	2·75	14·75	0	17·5	140
soda .	1	1	10	2·75	4	11·25	18	144
Sesquicarbonate of do.	1½	1	2	4·125	4	2·25	10·375	83
Bicarbonate of do.	2	1	1	5·5	4	1·125	10·625	85
Carbonate of strontian	1	1	0	2·75	6·5	0	9·25	74
uranium	1	1	1	2·75	28	1·125	31·875	255
yttria .	1	1	1	2·75	5·25	1·125	9·125	73
zinc .	1	1	1	2·75	5·25	1·125	9·125	73
do. (anhydr.)	1	1	0	2·75	5·25	0	8	64

VII. CHLORIDES.

	ATOMS OF CHLORINE.	ATOMS OF BASE.	WEIGHT OF CHLORINE.	WEIGHT OF BASE.	ATOMIC WEIGHT OF CHLORIDE.	
					Oxy. = 1	Hyd. = 1
Protochloride of antimony	1	1	4·5	5·5	10	80
Dichloride of do.	1	2	4·5	11	15·5	124
Chloride of barium .	1	1	4·5	8·75	13·25	106
bismuth	1	1	4·5	9	13·5	108
cadmium	1	1	4·5	7	11·5	92
cerium .	1	1	4·5	6·25	10·75	86
chromium	1	1	4·5	3·5	8	64
cobalt .	1	1	4·5	3·25	7·75	62
copper .	1	1	4·5	4	8·5	68
Dichloride of do. .	1	2	4·5	8	12·5	100
Chloride of glucinum	1	1	4·5	2·25	6·75	54
gold .	1	1	4·5	25	29·5	236
Bichloride of do. .	2	1	9	25	34	272
Chloride of iron .	1	1	4·5	3·5	8	64
Sesquichloride of do.	1½	1	6·75	3·5	10·25	82
Chloride of lead .	1	1	4·5	13	17·5	140
lime .	1	1	4·5	2·5	7	56
lithium .	1	1	4·5	1·25	5·75	46
magnesium	1	1	4·5	1·5	6	48
manganese	1	1	4·5	3·5	8	64
Protochloride of mercury	1	1	4·5	25	29·5	236
Bichloride of do.	2	1	9	25	34	272
Chloride of nickel .	1	1	4·5	3·25	7·25	58
palladium	1	1	4·5	7	11·5	92
platinum	1	1	4·5	12	16·5	132
Bichloride of do. .	2	1	9	12	21	168
Chloride of potassium	1	1	4·5	5	9·5	76
rhodium	1	1	4·5	5·5	10	80
silver .	1	1	4·5	13·75	18·25	146
sodium .	1	1	4·5	3	7·5	60
strontium	1	1	4·5	5·5	10	80
tin .	1	1	4·5	7·25	11·75	94
Bichloride of do. .	2	1	9	7·25	16·25	130
Chloride of uranium	1	1	4·5	26	30·5	244
yttrium	1	1	4·5	4·25	8·75	70
zinc .	1	1	4·5	4·25	8·75	70
zirconium	1	1	4·5	5	9·5	76

VIII. CHROMATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Chromate of ammonia	1	1	0	6·5	2·125	0	8·625	69
Bichromate of do.	2	1	2	13	2·125	2·25	17·375	139
Chromate of barytes	1	1	0	6·5	9·75	0	16·25	130
Chromate of bismuth	1	1	2	6·5	10	2·25	18·75	150
cadmium	1	1	5	6·5	8	5·625	20·125	161
chromium	1	1	0	6·5	4·5	0	11	88
cobalt	1	1	2	6·5	4·25	2·25	13	104
copper	1	1	2	6·5	5	2·25	13·75	110
lead	1	1	0	6·5	14	0	20·5	164
lime	1	1	0	6·5	3·5	0	10	80
magnesia	1	1	2	6·5	2·5	2·25	11·25	90
mercury	1	1	0	6·5	26	0	32·5	260
nickel	1	1	4	6·5	4·25	4·5	15·25	122
potash	1	1	0	6·5	6	0	12·5	100
Bichromate of do.	2	1	0	13	6	0	19	152
Chromate of silver	1	1	0	6·5	14·75	0	21·25	170
soda	1	1	12	6·5	4	13·5	24	192
strontian	1	1	0	6·5	6·5	0	13	104
zinc	1	1	0	6·5	5·25	0	11·75	94

IX. COLUMBATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Columbate of soda	1	1	10	19	4	11·25	34·25	274

X. FLUOSILICATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Bifluosilicate of ammonia	2	1	0	6·5	2·125	0	8·625	69

XI. FLUOBORATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Fluoborate of ammonia	1	1	0	4·25	2·125	0	6·375	51
Bifluoborate of do.	2	1	0	8·5	2·125	0	10·625	85
Subsesquifluoborate of do.	1	1½	0	4·25	3·1875	0	7·4375	59½

XII. FORMATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Formate of copper .	1	1	4	4·625	5	4·5	14·125	113
lead .	1	1	1	4·625	14	1·125	19·75	158

XIII. HYPONITRITES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Hyponitrite of lead .	1	1	1	4·75	14	1·125	19·875	159

XIV. MOLYBDATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Bimolybdate of ammonia	2	1	1	18	2·125	1·125	21·25	170
Molybdate of lead .	1	1	0	9	14	0	23	184

XV. MURIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Muriate of alumina .	1	1	3	4·625	2·25	3·375	10·25	82
ammonia	1	1	0	4·625	2·125	0	6·75	54
barytes .	1	1	1	4·625	9·75	1·125	15·5	124
bismuth .	1	1	x	4·625	10	x		
cadmium	1	1	1	4·625	8	1·125	13·75	110
cerium .	1	1	x	4·625	7·25	x		
chromium	1	1	9	4·625	4·5	10·125	19·25	154
cobalt .	1	1	4	4·625	4·25	4·5	13·375	107
copper .	1	1	2	4·625	5	2·25	11·875	95
glucina .	1	1	x	4·625	3·25	x		
iron .	1	1	3	4·625	4·5	3·375	12·5	100
lime .	1	1	6	4·625	3·5	6·75	14·875	119
lithia .	1	1	x	4·625	2·25	x		
magnesia	1	1	5	4·625	2·5	5·625	12·75	102
manganese	1	1	4	4·625	4·5	4·5	13·625	109
nickel .	1	1	5	4·625	4·25	5·625	14·5	116
strontian	1	1	8	4·625	6·5	9	20·125	161
Bimuriate of tin .	2	1	3	9·25	9·25	3·375	21·875	213
Muriate of zinc .	1	1	0	4·625	5·25	0	9·875	79
zirconia .	1	1	5	4·625	6	5·625	16·25	130

XVI. NITRATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Dinitrate of alumina	1	2	10	6·75	4·5	11·25	22·5	180
Trisnitrate of do. .	1	3	6	6·75	6·75	6·75	20·25	162
Nitrate of ammonia .	1	1	1	6·75	2·125	1·125	10	80

NITRATES CONTINUED.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Nitrate of barytes .	1	1	0	6·75	9·75	0	16·5	132
bismuth .	1	1	3	6·75	10	3·375	20·125	161
Dinitrate of bismuth	1	2	2	6·75	20	2·25	29	232
Nitrate of cadmium .	1	1	4	6·75	8	4·5	19·25	154
cobalt .	1	1	6	6·75	4·25	6·75	17·75	142
copper .	1	1	7	6·75	5	7·875	19·625	157
iron .	1	1	7	6·75	4·5	7·875	19·125	153
Persesquinitrate of iron	1½	1	8	10·125	5	9	24·125	193
lead	1	1	0	6·75	14	0	20·75	166
lime	1	1	6	6·75	3·5	6·75	17	136
magnesia	1	1	6	6·75	2·5	6·75	16	128
manganese	1	1	7	6·75	4·5	7·875	19·125	153
mercury	1	1	2	6·75	26	2·25	35	280
Pernitrate of mercury	1	1	0	6·75	27	0	33·75	270
Nitrate of nickel .	1	1	5	6·75	4·25	5·625	16·625	133
potash .	1	1	0	6·75	6	0	12·75	102
silver .	1	1	0	6·75	14·75	0	21·5	172
soda .	1	1	0	6·75	4	0	10·75	86
strontian .	1	1	4	6·75	6·5	4·5	17·75	142
do. (anhydrous)	1	1	0	6·75	6·5	0	13·25	106
Sesquinitrate of uranium	1½	1	17	10·125	28	19·125	57·25	458
Nitrate of zinc .	1	1	6	6·75	5·25	6·75	18·75	140

XVII. NITRITES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Dinitrite of lead .	1	2	2	5·75	28	2·25	36	288

XVIII. OXALATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Oxalate of alumina .	1	1	3	4·5	2·25	3·375	10·125	81
ammonia	1	1	2	4·5	2·125	2·25	8·875	71
Binoxalate of do. .	2	1	8	9	2·125	9	20·125	161
Oxalate of barytes .	1	1	3	4·5	9·75	3·375	17·625	141
Binoxalate of do. .	2	1	3	9	9·75	3·375	22·125	177
Oxalate of bismuth .	1	1	0	4·5	10	0	14·5	116
cadmium	1	1	3	4·5	8	3·375	15·875	127
cobalt .	1	1	2	4·5	4·25	2·25	11	88
copper .	1	1	1	4·5	5	1·125	10·625	85
iron .	1	1	2	4·5	4·5	2·25	11·25	90
lead .	1	1	0	4·5	14	0	18·5	148
lime .	1	1	2	4·5	3·5	2·25	10·25	82
magnesia	1	1	2	4·5	2·5	2·25	9·25	74
Binoxalate of do. .	2	1	7	9	2·5	7·875	19·375	155
Oxalate of manganese	1	1	3	4·5	4·5	3·375	12·375	99
mercury	1	1	1	4·5	26	1·125	31·625	253
nickel .	1	1	4	4·5	4·25	4·5	13·25	106
potash .	1	1	1	4·5	6	1·125	11·625	93
Binoxalate of do. .	2	1	2	9	6	2·25	17·25	138
Quadroxalate of do.	4	1	7	18	6	7·875	31·875	255
Oxalate of silver .	1	1	0	4·5	14·75	0	19·25	154
soda .	1	1	0	4·5	4	0	6·5	68
Binoxalate of do. .	2	1	3	9	4	3·375	16·375	131
Oxalate of strontian .	1	1	2	4·5	6·5	2·25	13·25	106
Binoxalate of do. .	2	1	0	9	6·5	0	15·5	124
Teroxalate of uranium	3	1	0	13·5	28	0	11·5	332
Oxalate of zinc .	1	1	2	4·5	5·25	2·25	12	96

XIX. OXIDES.

	ATOMS OF OXYGEN.	ATOMS OF BASE.	WEIGHT OF OXYGEN.	WEIGHT OF BASE.	ATOMIC WEIGHT OF OXIDES.	
					Oxy. = 1	Hyd. = 1
Oxide of aluminum	1	1	1	1·25	2·25	18
Antimony, protoxide	1	1	1	5·5	6·5	52
deutoxide	1·5	1	1·5	5·5	7	56
peroxide	2	1	2	5·5	7·5	60
Barium, protoxide	1	1	1	8·75	9·75	78
peroxide	2	1	2	8·75	10·75	86
Bismuth, oxide	1	1	1	9	10	80
Cadmium, do.	1	1	1	7	8	64
Calcium, do.	1	1	1	2·5	3·5	28
Cerium, protoxide	1	1	1	6·25	7·25	58
peroxide	1·5	1	1·5	6·25	7·75	62
Chromium, protoxide	1	1	1	3·5	4·5	36
deutoxide	2	1	2	3·5	5·5	44
acid	3	1	3	3·5	6·5	52
Cobalt, protoxide	1	1	1	3·25	4·25	34
peroxide	1·5	1	1·5	3·25	4·75	38
Copper, suboxide	1	2	1	8	9	72
oxide	1	1	1	4	5	40
Glucinum, oxide	1	1	1	2·25	3·25	26
Gold, protoxide	1	1	1	25	26	208
tritoxide	3	1	3	25	28	224
Iron, protoxide	1	1	1	3·5	4·5	36
peroxide	1·5	1	1·5	3·5	5	40
Lead, protoxide	1	1	1	13	14	112
deutoxide	1·5	1	1·5	13	14·5	116
peroxide	2	1	2	13	15	120
Lithium, oxide	1	1	1	1·25	2·25	18
Magnesium, oxide	1	1	1	1·5	2·5	20
Manganese, suboxide	1	2	1	7	8	64
oxide	1	1	1	3·5	4·5	36
deutoxide	1·5	1	1·5	3·5	5	40
tritoxide	2	1	2	3·5	5·5	44
Manganesous acid?	3?	1	3	3·5	6·5	52
Manganesic acid	4	1	4	3·5	7·5	60
Mercury, protoxide	1	1	1	25	26	208
peroxide	2	1	2	25	27	216
Nickel, protoxide	1	1	1	3·25	4·25	34
peroxide	1·5	1	1·5	3·25	4·75	38
Palladium, oxide	1	1	1	7	8	64
Platinum, protoxide	1	1	1	12	13	104
peroxide	2	1	2	12	14	112
Potassium, protoxide	1	1	1	5	6	48
peroxide	3	1	3	5	8	64
Rhodium, protoxide	1	1	1	5·5	6·5	52
peroxide	2	1	2	5·5	7·5	60
Silver, oxide	1	1	1	13·75	14·75	118
Sodium, oxide	1	1	1	3	4	32
peroxide	1·5	1	1·5	3	4·5	36
Strontium, oxide	1	1	1	5·5	6·5	52
Tin, protoxide	1	1	1	7·25	8·25	66
peroxide	2	1	2	7·25	9·25	74
Uranium, protoxide	1	1	1	26	27	216
peroxide	2	1	2	26	28	224
Yttrium, oxide	1	1	1	4·25	5·25	42
Zinc, oxide	1	1	1	4·25	5·25	42
Zirconium, oxide	1	1	1	5	6	48

XX. PHOSPHATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Phosphate of alumina	1	1	3	3·5	2·25	3·375	9·125	73
ammonia	1	1	2	3·5	2·125	2·25	7·875	63
Biphosphate of do. .	2	1	0	7	2·125	0	9·125	73
Phosphate of barytes .	1	1	0	3·5	9·75	0	13·25	106
bismuth	1	1	3	3·5	10	3·375	16·875	135
cadmium	1	1	1	3·5	8	1·125	12·625	101
cobalt .	1	1	2	3·5	4·25	2·25	10	80
copper .	1	1	1	3·5	5	1·125	9·625	77
Ditto, anhydrous .	1	1	0	3·5	5	0	8·5	68
Phosphate of iron .	1	1	3	3·5	4·5	3·375	11·375	91
Pertrisphosphate of iron	1	3	3	3·5	15	3·375	21·875	175
Phosphate of lead .	1	1	0	3·5	14	0	17·5	140
Diphosphate of do. .	1	2	0	3·5	28	0	31·5	252
Phosphate of lime .	1	1	0	3·5	3·5	0	7	56
Apatite . .	1	1½	0	3·5	5·25	0	8·75	70
Phosphate of magnesia	1	1	7	3·5	2·5	7·875	13·875	111
mercury .	1	1	0	3·5	26	0	29·5	236
nickel .	1	1	3	3·5	4·25	3·375	11·125	89
potash .	1	1	1	3·5	6	1·125	10·625	85
soda .	1	1	12	3·5	4	13·5	21	168
Biphosphate of do. .	2	1	3½	7	4	3·9375	14·9375	119·5
Phosphate of strontian	1	1	1	3·5	6·5	1·125	11·125	89
Biphosphate of do. .	2	1	2	7	6·5	2·25	15·75	146
Phosphate of zinc .	1	1	2	3·5	5·25	2·25	11	88

XXI. SACLACTATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Saclactate of ammonia	1	1	1	13	2·125	1·125	16·25	130
soda .	1	1	5	13	4	5·625	22·625	181

XXII. SELENIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Seleniate of soda .	1	1	x	7	4	x		
Biseleniate of do. .	2	1	x	14	4	x		
Seleniate of barytes .	1	1	x	7	9·75	x		
Biseleniate of do. .	2	1	x	14	9·75	x		

XXIII. SILICATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Silicate of alumina .	1	1	0	2	2·25	0	4·25	34
Sesquisilicate of copper	1·5	1	1	3	5	1·125	9·125	73
Silicate of iron .	1	1	0	2	4·5	0	6·5	52
Trisilicate of do. .	3	1	0	6	4·5	0	10·5	84
Bisilicate of lime .	2	1	0	4	3·5	0	7·5	60
manganese	2	1	0	4	4·5	0	8·5	68
Sesquisilicate of soda	1·5	1	0	3	4	0	7	56
Silicate of zinc .	1	1	0	2	5·25	0	7·25	58

XXIV. SUCCINATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Succinate of ammonia	1	1	2	6·25	2·125	2·25	10·625	85
lead .	1	1	0	6·25	14	0	20·25	162
soda .	1	1	6	6·25	4	6·75	17	136

XXV. SULPHATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Sulphate of alumina .	1	1	7	5	2·25	7·875	15·125	121
Disulphate of do. .	1	2	x	5	4·5	x		
Trisulphate of do. .	1	3	9	5	6·75	10·125	21·875	215
Sulphate of ammonia	1	1	1	5	2·125	1·125	8·25	66
barytes .	1	1	0	5	9·75	0	14·75	118
bismuth	1	1	0	5	10	0	15	120
cadmium	1	1	4	5	8	4·5	17·5	140
Ditto, in crusts .	1	1	2	5	8	2·25	15·25	122
Sulphate of cerium .	1	1	3	5	7·25	3·375	15·625	125
cobalt .	1	1	7	5	4·25	7·875	17·125	137
Bisulphate of do. .	2	1	3	10	4·25	3·375	17·625	141
Sulphate of copper .	1	1	5	5	5	5·625	15·625	125
Bisulphate of glucina	2	1	5	10	3·25	5·625	18·875	151
Sulphate of iron .	1	1	7	5	4·5	7·875	17·375	139
Persesquisulphate of iron	1½	1	x	7·5	5			
Sulphate of lead .	1	1	0	5	14	0	19	152
lime .	1	1	2	5	3·5	2·25	10·75	86
Ditto, anhydrous .	1	1	0	5	3·5	0	8·5	68
Sulphate of lithia .	1	1	1	5	2·25	1·125	8·375	67
magnesia	1	1	7	5	2·5	7·875	15·375	123
manganese	1	1	5	5	4·5	5·625	15·125	121
mercury .	1	1	2	5	26	2·25	33·25	266
Persulphate of do. .	1	1	0	5	27	0	32	256
Sulphate of nickel .	1	1	7	5	4·25	7·875	17·125	137
platinum	1	1	0	5	14	0	19	152
potash .	1	1	0	5	6	0	11	88
Bisulphate of do. .	2	1	2	10	6	2·25	18·25	146
Sulphate of silver .	1	1	0	5	14·75	0	19·75	158
soda .	1	1	10	5	4	11·25	20·25	162
strontian	1	1	0	5	6·5	0	11·5	92
Sesquisulphate of uranium	1·5	1	4	7·5	28	4·5	40	320
Sulphate of yttria .	1	1	x	5	5·25	x		
zinc .	1	1	7	5	5·25	7·875	18·125	145

XXVI. SULPHURETS.

	ATOMS OF SULPHUR.	ATOMS OF BASE.	WEIGHT OF SULPHUR.	WEIGHT OF BASE.	ATOMIC WEIGHT OF SULPHURETS.	
					Oxy. = 1	Hyd. = 1
Arsenic, sulphuret	1	1	2	4·75	6·75	54
sesquisulphuret	1½	1	3	4·75	7·75	62
Sulphuret of antimony	1	1	2	5·5	7·5	60
barium	1	1	2	8·75	10·75	86
bismuth	1	1	2	9	11	88
cadmium	1	1	2	7	9	72
calcium	1	1	2	2·5	4·5	36
cerium	1	1	2	6·25	8·25 ?	66?
chromium	1	1	2	3·5	5·5	44
cobalt	1	1	2	3·25	5·25	42
Columbium, sulphuret	1	1	2	18	20	160
Copper, disulphuret	1	2	2	8	10	80
sulphuret	1	1	2	4	6	48
bisulphuret	2	1	4	4	8	64
Gold, tritosulphuret	3	1	6	25	31	248
Iron, sulphuret	1	1	2	3·5	5·5	44
sesquisulphuret	1½	1	3	3·5	6·5	52
bisulphuret	2	1	4	3·5	7·5	60
Lead, disulphuret	1	2	2	26	28	224
sulphuret	1	1	2	13	15	120
bisulphuret	2	1	4	13	17	136
Lithium, sulphuret	1	1	2	1·25	3·25 ?	26?
Magnesium, do.	1	1	2	1·5	3·5	28
Manganese, do.	1	1	2	3·5	5·5	44
Mercury, do.	1	1	2	25	27	216
bisulphuret	2	1	4	25	29	232
Nickel, sulphuret	1	1	2	3·25	5·25	42
Palladium, do.	1	1	2	7	9	72
Platinum, do.	1	1	2	12	14	112
bisulphuret	2	1	4	12	16	128
Potassium, protosulphuret	1	1	2	5	7	56
deutosulphuret	2	1	4	5	9	72
tritosulphuret	3	1	6	5	11	88
quadrosulphuret	4	1	8	5	13	104
quintosulphuret	5	1	10	5	15	120
Rhodium, sulphuret	1	1	2	5·5	7·5	60
Silver, do.	1	1	2	13·75	15·75	126
Sodium, do.	1	1	2	3	5	40
Strontium, do.	1	1	2	5·5	7·5	60
Tin, do.	1	1	2	7·25	9·25	74
sesquisulphuret	1·5	1	3	7·25	10·25	82
bisulphuret	2	1	4	7·25	11·25	90
Titanium, sulphuret	1	1	2	4	6	48
Uranium, do.	1	1	2	26	28	224
Zinc, do.	1	1	2	4·25	6·25	50

XXVII. TARTRATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Tartrate of alumina .	1	1	1	8·25	2·25	1·125	11·625	93
ammonia	1	1	0	8·25	2·125	0	10·375	83
barytes .	1	1	0	8·25	9·75	0	18	144
bismuth .	1	1	5	8·25	10	5·625	23·875	191
cadmium	1	1	2	8·25	8	2·25	18·5	148
cobalt .	1	1	2	8·25	4·25	2·25	14·75	116
copper .	1	1	3	8·25	5	3·375	16·625	133
iron .	1	1	2	8·25	4·5	2·25	15	120
lead .	1	1	0	8·25	14	0	22·25	178
lime .	1	1	4	8·25	3·5	4·5	16·25	130
magnesia	1	1	2	8·25	2·5	2·25	13	104
Bitartrate of do. .	2	1	1	16·5	2·5	1·125	20·125	161
Tartrate of manganese	1	1	2	8·25	4·5	2·25	15	120
mercury	1	1	0	8·25	26	0	34·25	284
nickel .	1	1	0	8·25	4·25	0	12·5	100
potash .	1	1	2	8·25	6	2·25	16·5	132
Bitartrate of do. .	2	1	2	16·5	6	2·25	24·75	198
Tartrate of silver .	1	1	0	8·25	14·75	0	23	184
soda .	1	1	2	8·25	4	2·25	14·5	116
strontian	1	1	3	8·25	6·5	3·375	18·125	145
zinc .	1	1	0	8·25	5·25	0	13·5	108

XXVIII. TITANIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Quintotitaniate of potash	5	1	0	30	6	0	36	288
Trititaniate of soda .	3	1	2	18	4	2·25	24·25	194

XXIX. TUNGSTATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Bitungstate of ammonia	2	1	2	37·5	2·125	2·25	41·875	335
Tungstate of lead .	1	1	0	18·75	14	0	32·75	262
Bitungstate of do. .	2	1	0	37·5	14	0	51·5	412
Tungstate of soda .	1	1	6	18·75	4	6·75	29·5	236

XXX. URANIATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Sesquiuraniate of barytes	1·5	1	0	42	9·75	0	51·75	414
Biuraniate of potash	2	1	3	56	6	3·375	65·375	523

XXXI. URATES.

	ATOMS OF ACID.	ATOMS OF BASE.	ATOMS OF WATER.	WEIGHT OF ACID.	WEIGHT OF BASE.	WEIGHT OF WATER.	ATOMIC WEIGHT OF SALT.	
							Oxygen = 1	Hydrog. = 1
Urate of soda .	1	1	1	9	4	1·125	14·125	113

TABLE V.

COMPOUND SALTS.

I. AMMONIACAL COMPOUND SALTS.

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
1. *Ammonio-Sulphate of Alumina.*			
3 atoms sulphate of alumina	21·75		
1 atom sulphate of ammonia	7·125		
25 atoms water	28·125		
		57	456
2. *Ammonio-Sulphate of Copper.*			
1 atom sulphate of copper	10		
1 atom sulphate of ammonia	7·125		
6 atoms water	6·75		
		23·875	191
3. *Ammonio-Persesquisulphate of Iron.*			
2 atoms persesquisulphate of iron	25		
1 atom sulphate of ammonia	7·125		
25 atoms water	28·125		
		60·25	482
4. *Ammonio-Sulphate of Magnesia.*			
1 atom sulphate of magnesia	7·5		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875?		
		22·5	180
5. *Ammonio-Sulphate of Manganese.*			
1 atom sulphate of manganese	9·5		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875		
		24·5	196
6. *Ammonio-Sulphate of Nickel.*			
1 atom sulphate of nickel	9·25		
1 atom sulphate of ammonia	7·125		
7 atoms water	7·875		
		24·25	194

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
7. *Ammonio-Sulphate of Potash.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of ammonia . . .	7·125		
4 atoms water	4·5		
		22·625	181
8. *Ammonio-Sulphate of Soda.*			
1 atom sulphate of soda . . .	9		
1 atom sulphate of ammonia . . .	7·125		
6 atoms water	6·75		
		22·875	183
9. *Ammonio-Sulphate of Zinc.*			
1 atom sulphate of zinc . . .	10·25		
1 atom sulphate of ammonia . . .	7·125		
7 atoms water	7·875		
		25·25	202
10. *Ammonio-Carbonate of Uranium.*			
1 atom carbonate of uranium . . .	30·75		
3 atoms carbonate of ammonia . .	14·625		
4 atoms water	4·5		
		49·875	399
11. *Ammonio-Phosphate of Magnesia.*			
1 atom phosphate of magnesia . .	6		
1 atom phosphate of ammonia . .	5·625		
4 atoms water	4·5		
		16·125	129
12. *Ammonio-Phosphate of Soda.*			
1 atom phosphate of soda . . .	7·5		
1 atom phosphate of ammonia . .	5·625		
16 atoms water	18		
		31·125	249
13. *Ammonio-Arseniate of Soda.*			
1 atom arseniate of soda . . .	11·75		
1 atom arseniate of ammonia . . .	9·875		
8 atoms water	9·000		
		30·625	245
14. *Ammonio-Muriate of Copper.*			
2 atoms muriate of copper . . .	19·25		
1 atom muriate of ammonia . . .	6·75		
9 atoms water	10·125		
		36·125	289

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
15. *Ammonio-Permuriate of Iron.*			
1 atom sesquipermuriate of iron . .	11·9375		
1 atom muriate of ammonia . . .	6·75	18·6875	149½
16. *Ammonio-Muriate of Platinum.*			
1 atom bichloride of platinum . .	21		
1 atom muriate of ammonia . . .	6·75	27·75	222
17. *Ammonio-Oxalate of Copper.*			
1 atom oxalate of copper . .	9·5		
1 atom oxalate of ammonia . . .	6·625		
3 atoms water	3·375	19·5	156
18. *Ammonio-Oxalate of Copper.*			
1 atom oxalic acid	4·5		
1 atom oxide of copper . . .	5		
1 atom ammonia	2·125		
1 atom water	1·125	12·75	102
19. *Ditto, Pulverulent.*			
1 atom oxalate of ammonia . . .	6·625		
1 atom dioxalate of copper . . .	14·5	21·125	169

II. POTASH COMPOUND SALTS.

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
1. *Alum.*			
3 atoms sulphate of alumina . . .	21·75		
1 atom sulphate of potash . . .	11		
25 atoms water	28·125	60·875	487
2. *Potash-Trisulphate of Alumina.*			
3 atoms trisulphate of alumina . .	35·25		
1 atom sulphate of potash . . .	11		
9 atoms water	10·125	56·375	451

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
3. *Potash-Sulphate of Copper.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of copper . .	10		
6 atoms water	6·75	27·75	222
4. *Potash-Protosulphate of Iron.*			
1 atom protosulphate of iron . . .	9·5		
1 atom sulphate of potash . . .	11		
5 atoms water	5·625	26·125	09
5. *Potash-Sesquisulphate of Iron.*			
2 atoms persesquisulphate of iron . .	25		
1 atom sulphate of potash . . .	11		
25 atoms water	28·125	64·125	513
6. *Potash-Persulphate of Iron.*			
1 atom persulphate of iron . . .	10		
1 atom sulphate of potash . . .	11		
2 atoms water	2·25	23·25	186
7. *Potash-Sulphate of Magnesia.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of magnesia . . .	7·5		
7 atoms water	7·875	26·375	211
8. *Potash-Sulphate of Manganese.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of manganese . .	9·5		
5 atoms water	5·625	26·125	209
9. *Potash-Sulphate of Nickel.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of nickel . . .	9·25		
6 atoms water . . .	6·75	27	216
10. *Potash-Sulphate of Zinc.*			
1 atom sulphate of potash . . .	11		
1 atom sulphate of zinc . . .	10·25		
7 atoms water . . .	7·875	29 125	233

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
11. *Potash-Persesquisulphate of Uranium.*			
1 atom persesquisulphate of uranium	35·5		
1 atom sulphate of potash	11		
4 atoms water	4·5		
		51	408
12. *Potash-Carbonate of Magnesia.*			
1 atom bicarbonate of potash	11·5		
2 atoms carbonate of magnesia	10·5		
9 atoms water	10·125		
		32·125	257
13. *Potash-Oxalate of Copper.*			
1 atom oxalate of potash	10·5		
1 atom oxalate of copper	9·5		
4 atoms water	4·5		
		24·5	196
14. *Ditto, in Oblique Prisms.*			
1 atom oxalate of potash	10·5		
1 atom oxalate of copper	9·5		
2 atoms water	2·25		
		22·25	178
15. *Potash-Phosphate of Soda.*			
1 atom phosphate of potash	9·5		
1 atom phosphate of soda	7·5		
15 atoms water	16·875		
		33·875	271
16. *Potash-Arseniate of Soda.*			
1 atom arseniate of potash	13·75		
1 atom arseniate of soda	11·75		
18 atoms water	20·25		
		45·75	376
17. *Potash-Tartrate of Soda.*			
1 atom tartrate of potash	14·25		
1 atom tartrate of soda	12·25		
8 atoms water	9		
		35·5	284
18. *Tartar Emetic.*			
2 atoms tartaric acid	16·5		
3 atoms protoxide of antimony	19·5		
1 atom potash	6		
2 atoms water	2·25		
		44·25	354

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
19. *Sulpho-Chromate of Potash.*			
6 atoms sulphate of potash	66		
1 atom chromate of potash	12·5	78·5	628
20. *Potash-Muriate of Palladium.*			
1 atom muriate of palladium	12·625		
1 atom muriate of potash	10·625		
1 atom water	1·125	24·375	195
21. *Potassium-Chloride of Platinum.*			
1 atom bichloride of platinum	21		
1 atom chloride of potassium	9·5	30·5	244

III. COMPOUND SALTS, WITHOUT POTASH OR AMMONIA.

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
1. *Boro-Tartrate of Potash and Soda.*			
1 atom biborate of soda	10		
2 atoms bitartrate of potash	22·5		
12 atoms water	13·5	46	368
2. *Calcareo-Acetate of Copper.*			
1 atom acetate of lime	9·75		
1 atom acetate of copper	11·25		
6 atoms water	6·75	27·75	222
3. *Carbo-Tartrate of Alumina and Soda.*			
1 atom tartrate of alumina	10·5		
1 atom carbonate of soda	6·75		
9 atoms water	10·125	27·375	219
4. *Magnesio-Carbonate of Lime.*			
1 atom carbonate of lime	6·25		
1 atom carbonate of magnesia.	5·35	11·5	92

		ATOMIC WEIGHTS.	
		Oxy. = 1	Hyd. = 1
5. *Ditto in Crystals*—Bitter Spar.			
2 atoms carbonate of lime . . .	12·5		
1 atom carbonate of magnesia . .	5·25		
		17·75	142
6. *Soda-Oxalate of Copper.*			
1 atom oxalate of soda . . .	8·5		
1 atom oxalate of copper . . .	9·5		
2 atoms water	2·25		
		20·25	162
7. *Soda-Sulphate of Lime.*			
1 atom sulphate of lime . . .	8·5		
1 atom sulphate of soda . . .	9·0		
		17·5	140
8. *Soda-Sulphate of Alumina.*			
3 atoms sulphate of alumina . . .	21·75		
1 atom sulphate of soda . . .	9		
25 atoms water	28·125		
		58·875	471
9. *Sodium-Chloride of Gold.*			
1 atom bichloride of gold . . .	34		
1 atom chloride of sodium . . .	7·5		
8 atoms water	9		
		50·5	404
10. *Sodium-Chloride of Platinum.*			
1 atom bichloride of platinum . . .	21		
1 atom chloride of sodium . . .	7·5		
8 atoms water	9		
		37·5	300
11. *Soda-Muriate of Rhodium.*			
1 atom permuriate of rhodium . .	12·125		
1 atom common salt	7·5		
8 atoms water	9		
		28·625	229

TABLE VI.

EXHIBITING THE SUBSTANCES IN THE THREE PRECEDING TABLES, ARRANGED ALPHABETICALLY.

	ATOMIC WEIGHTS. Oxy. = 1
A	
Acetate of alumina	9·625
ammonia	16·25
barytes	19·375
cadmium	16·5
copper	12·375
iron	14·125
lead	23·625
lime	16·5
magnesia	14·375
manganese	15·25
mercury	36·75
nickel	16·125
potash	14·5
silver	21
soda	17
strontian	13·875
zinc	19·375
Acetic acid	6·25
Ditto, in crystals	7·375
Alcohol	2·875
Alum	60·875
Alumina	2·25
Aluminum	1·25
Ammonia	2·125
Ammonio-carbonate of uranium	49·875
Ammonio-muriate of copper	36·125
Ammonio-permuriate of iron	18·6875
Ammonio-muriate of platinum	27·75
Ammonio-oxalate of copper	19·625
Ammonio-oxalate of copper	12·75
Ammonio-persesquisulphate of iron	59·125
Ammonio-phosphate of magnesia	16·125
Ammonio-phosphate of soda	31·125
Ammonio-sulphate of alumina	59·25
Ammonio-sulphate of copper	23·875
Ammonio-sulphate of magnesia	22·5
Ammonio-sulphate of manganese	24·5
Ammonio-sulphate of nickel	24·25
Ammonio-sulphate of potash	22·625
Ammonio-sulphate of soda	22·875
Ammonio-sulphate of zinc	25·25
Antimonic acid	7·5
Antimony	5·5
Apatite	8·75
Arseniate of alumina	16·75
ammonia	9·875
bismuth	20
cadmium	16·875
cobalt	16·5
lead	21·75
lime	11·25
magnesia	19·25
manganese	23·5
mercury	33·75
nickel	18·75
Subsesquarseniate of silver	29·875
Arseniate of strontian	23·25
zinc	22
Arsenic	4·75
Arsenic acid	7·75
Arsenietted hydrogen	4·875
Arsenious acid	6·75
Azote	1·75
B	
Barium	8·75
Barytes	9·75
Bichloride of mercury	34
platinum	21
selenium	14
tin	16·25
Benzoate of ammonia	18·25
lead	30·125
potash	24·375
Benzoic acid	15
Bicarbonate of ammonia	8·75
potash	12·625
soda	10·625
Bichromate of ammonia	17·375
potash	19
Bifluoborate of ammonia	10·625
Bifluosilicate of ammonia	8·625

	ATOMIC WEIGHTS. Oxy. = 1
Bihydrate of alumina	4·5
Bihydroguret of phosphorous	1·75
Bimuriate of tin	21·875
Binarseniate of ammonia	19·875
nickel	31
potash	22·625
soda	43·125
Binoxalate of ammonia	20·125
barytes	22·125
magnesia	19·375
potash	17·25
soda	16·375
strontian	15·5
Biphosphate of ammonia	7·875
strontian	15·75
Biseleniate of soda	18
barytes	23·75
Bisilicate of lime	7·5
magnesia	8·5
Bisulphate of cobalt	17·625
glucina	18·875
potash	18·25
Bismuth	9
Bisulphuret of carbon	4·75
copper	8
iron	7·5
molybdenum	10
lead	17
mercury	29
platinum	16
tin	11·25
tungsten	19·75
Bitartrate of magnesia	20·125
potash	24·75
Bitter spar	17·75
Bitungstate of ammonia	41·875
lead	51·5
Boracic acid	3
Boron	1
Boro-tartrate of potash and soda	32·5
Brucia	51·5

C

Cadmium	7
Calcareo-acetate of copper	27·75
Calcium	2·5
Carbo-tartrate of alumina and soda	27·375
Carbon	0·75

	ATOMIC WEIGHTS. Oxy. = 1
Carbonate of ammonia	3·875
barytes	12·5
cadmium	10·75
cobalt	8·125
iron	7·25
lead	16·75
lime	6·25
lithia	5
magnesia	8·625
manganese	9·5
nickel	10·375
potash	11
silver	17·5
soda	18
strontian	9·25
uranium	31·875
yttria	9·125
zinc	9·125
Carbonic acid	2·75
oxide	1·75
Carburetted hydrogen	1
Cerium	6·25
Chloric acid	9·5
Chloride of antimony	10
barium	13·25
bismuth	13·5
cadmium	11·5
cerium	10·75
chromium	8
cobalt	7·75
copper	8·5
glucinum	6·75
gold	29·5
iron	8
lead	17·5
lime	7
lithium	5·75
magnesium	6
manganese	8
mercury	29·5
nickel	7·25
palladium	11·5
platinum	16·5
potassium	9·5
rhodium	10
silver	18·25
sodium	7·5
strontium	10
sulphur	6·5
tin	11·75
uranium	30·5
yttrium	8·75

	ATOMIC WEIGHTS. Oxy. = 1
Chloride of zinc	8·75
zirconium	9·5
Chlorocarbonic acid	6·25
Chlorocyanic acid	7·75
Chlorine	4·5
Chloriodic acid	24·5
Chromate of ammonia	8·625
barytes	16·25
bismuth	18·75
cadmium	20·125
chromium	11
cobalt	13
copper	13·75
lead	20·5
lime	10
magnesia	11·25
mercury	32·5
nickel	15·25
potash	12·5
silver	21·25
soda	24
strontian	13
zinc	11·75
Chromic acid	6·5
Chromium	3·5
Citric acid	7·25
Ditto, in crystals	9·5
Cobalt	3·25
Columbate of soda	34·25
Columbic acid	19
Columbium	18
Copper	4
Cubic pyrites	7·5
Cyanogen	3·25
D	
Decahydrate of chlorine	15·75
Deutosulphuret of potassium	9
Deutoxide of azote	3·75
chromium	5·5
hydrogen	2·125
lead	14·5
manganese	5
Diacetate of copper	23
lead	34·25
Dicarbonate of copper	13·875
Dichloride of antimony	15·5
copper	12·5
Dihydrate of silica	5·125
Dinitrite of lead	36
Dinitrate of alumina	22·5
bismuth	20
Diprotarseniate of iron	20·125
Diphosphate of lead	31·5
Disulphate of alumina	9·5
Disulphuret of copper	10
lead	28
E	
Ether, sulphuric	4·625
F	
Fluoborate of ammonia	6·375
Fluoboric acid	4·25
Fluoric acid ?	1·25
Fluorine ?	2·25
Fluosilicic acid	3·25
Formate of copper	14·125
lead	19·75
Formic acid	4·625
Fuming sulphuric acid	11·125
G	
Gallic acid	7·75 ?
Glucina	3·25
Glucinum	2·25
Gold	25
Gum	11·25
H	
Hydrate of alumina	3·375
silica	3·125
zirconia	7·125
Hydriodic acid	15·625
Hydrocyanic acid	3·375
Hydrogen	0·125
Hyponitrite of lead	19·875
Hyponitrous acid	4·75
Hyposulphuric acid	9
Hyposulphurous acid	3
I	
Iodic acid	20·5

	ATOMIC WEIGHTS. Oxy. = 1
Iodide of barium	24·25
bismuth	24·5
cadmium	22·5
calcium	18
copper	19·5
iron	19
lead	28·5
phosphorus	17
potassium	20·5
silver	29·25
sodium	18·5
strontium	21
sulphur	17·5
zinc	19·75
Iodine	15·5
Iridium	3·75
Iron	3·5
K	
Kermes mineral	7·625
L	
Lactic acid	5·75 ?
Lead	13
Lime	3·5
Lithia	2·25
Lithium	1·25
M	
Magnesia	2·5
Magnesio-carbonate of lime	11·5
Magnesium	1·5
Manganese	3·5
Manganesic acid	7·5 ?
Manganesous acid	6·5 ?
Margaric acid	33
Mercury	25
Molybdate of ammonia	21·25
lead	23
Molybdenum	6
Molybdic acid	9
Molybdous acid	8
Morphia	40·25
Muriate of alumina	10·25
ammonia	6·75
barytes	15·5

	ATOMIC WEIGHTS. Oxy. = 1
Muriate of cadmium	13·75
chromium	19·25
cobalt	13·375
copper	11·875
glucina	7·875
iron	12·5
lime	14·875
lithia	6·875
magnesia	12·75
manganese	13·625
nickel	14·5
strontian	20·125
zinc	9·875
zirconia	16·25
Muriatic acid	4·625
N	
Naphtha	5·25
Naphthaline	1·25
Nephrin	3·75
Nickel	3·25
Nitrate of ammonia	10
barytes	16·5
bismuth	20·125
cadmium	19·25
cobalt	17·75
copper	19·625
iron	19·125
lead	20·75
lime	17
magnesia	16
manganese	19·125
mercury	35
nickel	16·625
potash	12·75
silver	21·5
soda	10·75
strontian	13·25
zinc	18·75
Nitrous acid	5·75
Nitric acid	6·75
O	
Octohydrate of zirconia	15
Oil gas	2·625
Olefiant gas	1·75

	ATOMIC WEIGHTS. Oxy. = 1
Oleic acid	36
Orpiment	7·75
Oxalate of alumina	10·125
ammonia	8·875
barytes	17·625
bismuth	14·5
cadmium	15·875
cobalt	11
copper	10·625
iron	11·25
lead	18·5
lime	10·25
magnesia	9·25
manganese	12·375
mercury	31·625
nickel	13·25
potash	11·625
silver	19·25
soda	8·5
strontian	13·25
zinc	12
Oxalic acid	4·5
crystals	9
Oxide of bismuth	10
cadmium	8
copper	5
palladium	8
selenium	6
silver	14·75
tellurium	5
tungsten	17·75
zinc	5·25
Oxygen	1
P	
Palladium	7
Perchloric acid	11·5
Perchloride of iron	12·5?
phosphorus	10·5
tin	16·25
Perhydrate of iron	6·125
Pernitrate of mercury	33·75
Periodide of mercury	40·5
phosphorus	32·5
Peroxide of antimony	7·5
barium	10·75?
cerium	7·75
cobalt	4·75
gold	28
iridium	5·75?

	ATOMIC WEIGHTS. Oxy. = 1
Peroxide of iron	5
lead	15
mercury	27
nickel	4·75
platinum	14
potassium	8
rhodium	7·5
sodium	4·5
tin	9·25
titanium	6
uranium	28
Persulphate of mercury	33·25
Persulphuret of copper	8
gold	31
iron	7·5
lead	17
mercury	29
platinum	16
potassium	15
tin	11·25
Phosphate of alumina	9·125
ammonia	7·875
barytes	13·25
bismuth	16·875
cadmium	12·625
cobalt	10
copper	9·625
iron	11·375
lead	17·5
lime	7
magnesia	13·875
mercury	29·5
nickel	11·125
potash	10·625
silver	18·25
soda	21
strontian	11·125
zinc	11
Phosphoric acid	3·5
Phosphorous acid	2·5
Phosphorus	1·5
Phosphuret of carbon	2·25
sulphur	3·5
Phosphuretted hydrogen	1·625
Picrotoxia	45
Platinum	12
Potash	6
Potash carbonate of magnesia	32·125
oxalate of copper	24·5
do. in oblique prisms	22·25
persesquisulphate of iron	64·125
sulphate of alumina	60·875

	ATOMIC WEIGHTS. Oxy. = 1
Potash protosulphate of iron	26·125
copper	27·75
magnesia	26·375
manganese	26·125
nickel	27
zinc	29·125
tartrate of soda	35·5
Potassium	5
Protiodide of mercury	40·5
Protochloride of phosphorus	6
tin	11·75
Protohydrate of sulphuric acid	6·125
Protosulphuret of antimony	7·5
arsenic	6·75
iron	5·5
mercury	27
platinum	14
potassium	7
tin	9·25
Protoxide of antimony	6·5
barium	9·75
cerium	7·25
chromium	4·5
cobalt	4·25
gold	26
iron	4·5
lead	14
manganese	4·5
mercury	26
nickel	4·25
platinum	13
potassium	6
rhodium	6·5
sodium	4
tin	8·25
uranium	27
Q	
Quadrochloride of azote	19:75
Quadrosulphuret of potassium	13
Quadroxalate of potash	31·875
Quadroxide of chlorine	8·5
Quintosulphuret of potassium	15
Quintotitaniate of potash	36
R	
Realgar	6·75

	ATOMIC WEIGHTS. Oxy. = 1
Red oxide of lead	14·5
Rhodium	5·5
S	
Saclactate of ammonia	16·25
soda	22·625
Saclactic acid	13
Seleniate of soda	11
barytes	10·75
Selenic acid	7
Selenium	5
Seleniet of arsenic	9·75
Selenietted hydrogen	5·125
Sesquicarbonate of ammonia	7·375
mercury	30·125
potash	16·875
soda	10·375
Sesquichloride of iron	10·25
Sesquifluoborate of ammonia	7·4375
Sesquisilicate of copper	9·125
soda	7
Sesquisulphuret of arsenic	7·75
iron	6·5
selenium	8
tin	10·25
Sesquisulphate of uranium	40
Sesquiuraniate of barytes	51·75
Silica	2
Silicate of alumina	4·25
iron	6·5
zinc	7·25
Silicon	1
Silver	13·75
Soda	4
Soda-oxalate of copper	20·25
Soda-sulphate of alumina	58·875
lime	17·5
Sodium	3
Starch	17·75
Strontian	6·5
Strontium	5·5
Strychnia	47·5?
Sub-bichloride of sulphur	8·5
Suboxide of copper	9
manganese	4
Subphosphuretted hydrogen	1·25
Subsesquacetate of copper	17·125
Subsesquarseniate of lead	28·75

	ATOMIC WEIGHTS. Oxy. = 1
Succinate of ammonia	10·625
lead	20·25
soda	17
Succinic acid	6·25
Sugar	10·125
Sulphate of alumina	15·125
ammonia	8·25
barytes	14·75
bismuth	15
cadmium	17·5
cerium	15·625
cobalt	17·125
copper	15·625
iron	17·375
lead	19
lime	10·75
lithia	8·375
magnesia	15·375
manganese	15·125
mercury	33·25
nickel	17·125
platinum	19
potash	11
silver	19·75
soda	20·25
strontian	11·5
yttria	10·25
zinc	18·125
Sulphochyazic acid	7·375 ?
Sulphur	2
Sulphuret of antimony	7·5
arsenic	6·75
barium	10·75
bismuth	11
cadmium	9
calcium	4·5
cerium	8·25 ?
chromium	5·5
cobalt	5·25
columbium	20
copper	6
iron	5·5
lead	15
lithium	3·25 ?
magnesium	3·5
manganese	5·5
mercury	27
nickel	5·25
palladium	9
platinum	14
potassium	7

	ATOMIC WEIGHTS. Oxy. = 1
Sulphuret of rhodium	7·5
silver	15·75
sodium	5
strontium	7·5
tin	9·25
titanium	6
uranium	28
zinc	6·25
Sulphuretted hydrogen	2·125
Sulphuric acid	5
ether	4·625
Sulphurous acid	4

T

Tannin	8·75 ?
Tartar emetic	44·25
Tartaric acid	8·25
crystals	9·375
Tartrate of alumina	11·625
ammonia	10·375
barytes	18
bismuth	23·875
cadmium	18·5
cobalt	14·75
copper	16·625
iron	15
lead	22·25
lime	16·25
magnesia	13
manganese	15
mercury	34·25
nickel	12·5
potash	16·5
silver	23
soda	14·5
strontian	18·125
zinc	13·5
Telluretted hydrogen	4·125
Tellurium	4
Terfluosilicate of ammonia	11·875
Tin	7·25
Titanic acid	6
Titanium	4
Tredecahydrate of silica	16·625
Trisacetate of copper	23·5
Triscarbonate of bismuth	35
Trishydrate of silica	7·125
Trisnitrate of alumina	20·25
Trisulphate of alumina	21·875

	ATOMIC WEIGHTS.
	Oxy. = 1
Trisilicate of iron	10·5
Tritantimoniate of potash	28·5
Tritiodide of azote	37·25?
Trititaniate of soda	24·25
Tritosulphuret of gold	31
potassium	11
Tritoxide of chlorine	7·5
Tungstate of lead	32·75
soda	29·5
Tungsten	15·75
Tungstic acid	18·75
U	
Uranium	26
Urate of soda	14·125

	ATOMIC WEIGHTS.
	Oxy. = 1
Uric acid	9
crystals	11·25
W	
Water	1·125
Y	
Yttria	5·25
Yttrium	4·25
Z	
Zinc	4·25
Zirconia	6
Zirconium	5

THESE tables being intended chiefly for the practical chemist, I have studied convenience of reference; and on that account have placed the chlorides, oxides, and sulphurets among the salts. The genera of salts are arranged in the alphabetical order.

The first and third of these tables are similar to two which I inserted at the end of the sixth edition of my System of Chemistry; but which I have here corrected, and considerably enlarged. The table of the *neutral* salts is new, and will be of very great use to practical chemists, as all the constituents of each salt, together with the weight of an integrant particle of it, will be seen at a glance of the eye. An example or two will show how this table is to be used. Suppose I obtain in any experiment 150 grains of dry sulphate of barytes, and that I want to know how many grains of sulphuric acid they contain, I must look among the sulphates for sulphate of barytes.

Its atomic weight is 14·75, containing 5 of sulphuric acid. I say, therefore,

14·75 : 5 : : 150 : 50·847 = sulphuric acid in 150 grains of sulphate of barytes.

For sulphate of barytes, which is a calculation of perpetual recurrence in the laboratory, a good method is, to have a part of the process ready finished, and lying at hand for use. This may be done in the following way:

The logarithm of 5 is . .	0·6989700
Subtract the log. of 14·75 . .	1·1687920
Remains . . .	—1·5301780

This constant logarithm is to be added to the logarithm of the quantity of sulphate of barytes of which you wish to know the sulphuric acid. In the present example the quantity is 150 grains.

Logarithm of 150 . . .	2·1760913
Add	—1·5301780
Sum	1·7062693

Now, this is the logarithm of 50·847, the quantity found above.

Second example.—Suppose I have a solution containing 240 grains of nitrate of silver, and that I want to know from the tables how much common salt will just precipitate the whole of the silver. We see from the second table that the atomic weight of nitrate of silver is 21·5, and that of common salt 7·5. We say, therefore,

21·5 : 7·5 : : 240 : 83·72 = the weight of common salt required.

Third example.—Suppose I have a solution of 90 grains of oxalic acid crystals, and that I wish to know how much bicarbonate of potash will be necessary just to saturate the acid.

From the third table (or last table) I find that the atomic weight of oxalic acid crystals is 9; consequently, 90 is equivalent to ten atoms. From the table of carbonates I find that the atom of bicarbonate of potash is 12·625. Consequently, 126·25, or ten atoms, is the quantity that would be required, if the bicarbonate contained only one atom of water; but, as it usually contains 1½ atom of water, 131·875 grains will be requisite.

Fourth example.—Suppose I wish to prepare oxalate of zinc by double decomposition, from oxalate of ammonia and sulphate of zinc, what are the relative quantities of these two salts in crystals that must be used? The atomic weight of oxalate of ammonia is 8·875, and of sulphate of zinc 18·125. Consequently, we have only to take any equimultiples of these numbers; for example,

88·75 grains oxalate of ammonia,
181·25 grains of sulphate of zinc.

Dissolve these two salts in different portions of water, and mix the solutions. The whole oxalic acid and oxide of zinc will precipitate in combination, and nothing will remain in the liquid but a neutral solution of sulphate of ammonia.

These are only a few of the numerous uses to which these tables may be applied. It is obvious enough that if these tables were laid down upon a sliding rule, after the manner of Dr. Wollaston's scale of chemical equivalents, all these problems would be solved at once by adjusting the slide, without any arithmetical operation whatever. But the great multiplicity of substances, amounting to several hundred, would of necessity render such a scale so confused, that more time would be lost in looking for the substances, than in performing the arithmetical calculations from the tables.

From the third table (or last table) I find that the atomic weight of oxalic acid crystals is 9; consequently, 90 is equivalent to ten atoms. From the table of carbonates I find that the atom of bicarbonate of potash is 12·625. Consequently, 126·25, or ten atoms, is the quantity that would be required, if the bicarbonate contained only one atom of water; but, as it actually contains 1½ atom of water, 131·875 grains will be requisite.

Fourth example.—Suppose I wish to prepare oxalate of zinc by double decomposition, from oxalate of ammonia and sulphate of zinc, what are the relative quantities of these two salts in crystals that must be used? The atomic weight of oxalate of ammonia is 8·875, and of sulphate of zinc 18·125. Consequently, we have only to take any equimultiples of these numbers; for example,

88·75 grains oxalate of ammonia,
181·25 grains of sulphate of zinc.

Dissolve these two salts in different portions of water, and mix the solutions. The whole oxalic acid and oxide of zinc will precipitate in combination, and nothing will remain in the liquid but a neutral solution of sulphate of ammonia.

These are only a few of the numerous uses to which these tables may be applied. It is obvious enough that if these tables were laid down upon a sliding rule, after the manner of Dr. Wollaston's scale of chemical equivalents, all these problems would be solved at once by adjusting the slide, without any arithmetical operation whatever. But the great multiplicity of substances, amounting to several hundred, would of necessity render such a scale so confused, that more time would be lost in looking for the substances, than in performing the arithmetical calculations from the tables.

INDEX.

THE END

ERRATA.—VOL. I.

Page 66, line 2 from bottom, for "$\frac{p-f}{\ }$" read "$\frac{p-f}{p}$."
78, line 5, for "1·500" read "2·500."
93, line 2, for "Here" read "Hence."
ib. line 11, for "$0{\cdot}125+0{\cdot}555\dot{5}$" read "$0{\cdot}125\times0{\cdot}555\dot{5}$."
124, line 17, for "two" read "too."
180, line 2 from bottom, for "DIOPTOSE" read "DIOPTASE."
275, line 5 from bottom, for "pape" read "paper."
302, line 1, for "of potash" read "and potash."
304, line 7, for "silicon" read silica."
336, line 6 from bottom, dele the word "owing."
364, line 2, for "11 2" read "11×2."
419, lowest line, for "Prout" read "Proust."
420, line 2 from bottom, for "copper" read "chlorine."
433, line 13, for "13·75 6·75" read "13·75+6·75."
441, line 12 from bottom, for "nitric muriatic" read "nitro-muriatic."
468, line 13, for "sulphuret" read "sulphur."

VOL. II.

273, line 12 from bottom, for "effervesces" read "effloresces."
277, line 6 from bottom, for "9·5" read "8·5."
372, line 8, for "Corinthia" read "Carinthia,"
407, line 15, for "2·57" read "2·75."