X.—*On the Atomic Weights of Oxygen and Water.**

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WHETHER an atom of water contains the same quantity, or double the quantity, of hydrogen that is contained in an atom of hydrochloric acid, and whether the atomic weight of oxygen is 8 or 16, are concrete examples of the many disputed questions which lie at the very basis of scientific chemistry. These many primary questions are so intimately connected with one another, that if the answer to nearly any one of them were fully agreed upon, that

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single unanimity might almost determine an entire unanimity. But to arrive at such a desirable consummation, it is necessary for some one or other of these questions to be fairly argued out upon premises that are admitted by all to be indisputable. And herein lies the great difficulty, because, in reality, each one of us has formed his opinion upon the single question, rather by its bearings upon all the other disputed questions, than from well defined premises of any kind. Each party has assumed instinctively certain points that are not proven, or are disallowed, and from these assumptions has deduced in great measure his conclusion upon all the questions. Moreover, to no one question can there be given an answer the correctness of which is proveable to demonstration. Almost every fact may be interpreted in several different ways; and it becomes an argument, from probability, from analogy, from simplicity, from consequences, as to which interpretation is most exact. But, apart from the absolute accuracy or falsity of any explanation, it is evidently most inconsequent to interpret, as many chemists do, a certain set of facts in one special manner, and a precisely similar set of facts in an opposite manner. Now, it is to this time-honoured inconsistency that I wish particularly to direct your attention.

Allow me, for a few moments, to occupy your time with such an elementary introduction to the doctrine of combination in definite proportions, as we might all agree to put before a student commencing the study of chemistry. Thus, we are acquainted with about sixty different kinds of matter which have hitherto proved undecomposable, and which we consequently term simple bodies or elements. These elements unite with one another in certain fixed or definite proportions to form an infinite variety of compound bodies. We can illustrate our meaning very well by reference to hydrogen, chlorine, and sodium; three elements that are possessed of highly characteristic properties. We find by experiment that 1 part of hydrogen unites with 35.5 parts of chlorine to form the compound body, chloride of hydrogen, or chlorhydric acid; and that 35.5 parts of chlorine unite with 23 parts of sodium to form the compound body, chloride of sodium, or common salt. We take the numbers, 1, 35.5, and 23, to represent the combining proportions of hydrogen, chlorine, and sodium respectively: and, in a similar manner, there have been assigned, to other of the elements, certain numbers which express, respectively, the least proportion of the ele-

ment that unites with 1 part of hydrogen,—or that replaces 1 part of hydrogen to unite with 35·5 parts of chlorine. Thus,

1 part of hydrogen unites with	$\left\{ \begin{array}{l} 35\cdot5 \text{ parts of chlorine,} \\ \text{or } 19 \text{ parts of fluorine,} \\ \text{or } 80 \text{ parts of bromine,} \\ \text{or } 127 \text{ parts of iodine,} \end{array} \right.$	
and 1 part of hydrogen	$\left\{ \begin{array}{l} \\ \\ \\ \end{array} \right.$	unite with 35·5 parts of chlorine.
or 23 parts of sodium		
or 32·5 parts of zinc		
or 108 parts of silver		

The proportion in which hydrogen enters into a combination, being less than that of any other element, is assumed as unity; and as the quantity of sodium, or zinc, or silver, that displaces 1 part of hydrogen from its combination with 35·5 parts of chlorine, also displaces it from its combination with 19 parts of fluorine, or with 80 parts of bromine, or with 127 parts of iodine, it is evident that the numbers 1, 19, 23, 32·5, 35·5, 80, 108, and 127, indicate generally the proportions in which the elements hydrogen, fluorine, sodium, zinc, chlorine, bromine, silver, and iodine, unite with one another. The above proportional numbers result from a common well defined relation to the standard of comparison; they are mere results of experiment uncontrolled by any theory whatever. So far as we have yet gone, our idea of the combining proportion of an element is the least quantity of the element that can unite with, or replace, 1 part of hydrogen. But this simple idea has very speedily to receive an important modification. We find the smallest quantity of nitrogen that can unite with 1 part of hydrogen, to be 4·7 parts, but the combining proportion of nitrogen is fixed, not at 4·7 parts, but at three times that quantity, or 14 parts. We find that 1 part of hydrogen unites with 35·5 parts of chlorine to form the compound chlorhydric acid, and that one part of hydrogen unites with 4·7 parts of nitrogen to form the compound ammonia. We take 35·5 as the proportional number for chlorine, why do we not take 4·7 as the proportional number for nitrogen? Why do we not express the compound body ammonia by the formula HN, precisely as we express the compound body chlorhydric acid by the formula HCl? To avoid the confusion that would arise from using the same letter to express two different quantities, we will take the symbol Az to represent 4·7 parts of nitrogen; so that

$3 \text{ HAz} = \text{H}_3\text{N}$. Now the formula HAz is in accordance with all the considerations hitherto presented to our notice, it is more simple than the formula H_3N , and, by its means, ammoniacal compounds in general might be represented as analogous to chlorine and fluorine compounds; thus,

Ammonia	HAz	HCl
Trizincamide	ZnAz	ZnCl
Trimercuramide	HgAz	HgCl
Potassamide	KAz.2HAz	KCl.2HgCl
Sal-ammoniac	HCl.3HAz	KI. 3HgCl

Why then have chemists unanimously rejected the formula HAz , and adopted the formula H_3N ? Now, although this last formula may have originated in part from accident, and have been retained in part from habit, yet we have no lack of real arguments to show the necessity, or at any rate advisability, of maintaining it. I believe the principal arguments are the following:—

1°. Because it is found that a given bulk of gaseous ammonia contains three times as much hydrogen as the same bulk of chlorhydric acid.

2°. Because it is found that a given bulk of nitrogen combines with three times as much hydrogen as does the same bulk of chlorine; and that the relative weights of equal bulks of nitrogen and chlorine and hydrogen are as 14 : 35·5 : 1.

3°. Because certain undoubted analogies and ratios of nitrogenised bodies are concealed by formulæ in which $\text{Az}=4\cdot7$, and are manifested by formulæ in which $\text{N}=14$.

4°. Because, in ninety-nine cases out of a hundred, the quantity of ammonia which is the agent or resultant of a reaction must contain three units of hydrogen, or some multiple of three units of hydrogen; and consequently fourteen, or some multiple of fourteen, parts of nitrogen.

5°. Because in the majority of the compounds which ammonia forms with other bodies, the ammonia must be represented with three units, or some multiple of three units, of hydrogen.

6°. Because, although the composition of some few nitrogenised bodies may be represented most simply by formulæ, in which $\text{Az}=4\cdot7$; yet the great majority are represented most simply by formulæ in which $\text{N}=14$.

7°. Because, in ammonia, the actual or potential replacement of hydrogen takes place definitely in thirds, by three successive stages.

Although the above arguments cannot be considered to prove

absolutely to demonstration that the atom of nitrogen, or the smallest indivisible quantity of nitrogen that can enter into a combination, is really fourteen times as great as the atom of hydrogen, yet they present so great a sum of probabilities in favour of that conclusion that chemists have been unanimous in accepting it. With one exception, all these arguments apply with equal force to the elements phosphorus, arsenic, antimony, and bismuth; and we consequently find that all chemists have agreed to accept for the respective atomic weights of these bodies, three times the smallest quantity of the body which unites with 1 part of hydrogen, or with 35.5 parts of chlorine. The excepted argument is that relating to the vapour densities of the elements in question. But, in default of this argument, we can bring forward another of a most cogent nature in behalf of the triplication of the atomic weights of phosphorus, arsenic, antimony, and bismuth, namely, that derived from their gradational analogies to nitrogen. If the atomic weight of nitrogen is 14 and not 4.7, the atomic weights of phosphorus, arsenic, antimony, and bismuth must be respectively 31, 75, 120, and 213, and not the thirds of these numbers.

From the above considerations concerning nitrogen and its congeners, in which all chemists are agreed, it appears that while the determination of the smallest proportion of an element that can unite with or replace one part of hydrogen is a question purely experimental, the determination of the atomic weight of an element, or of the smallest indivisible quantity of an element that can enter into a combination, is a question for the judgment, and one that can only be decided by an intimate knowledge and due consideration of very many circumstances connected with the body. Now, although the judgment of chemists has been unanimous with respect to nitrogen and its congeners, such unanimity has not prevailed in reference to many other elements. Thus, with regard to silicon,

Thomson represented chloride of silicon by the formula,

Si Cl , where the atomic weight of silicon = 7.12

Gmelin, by the formula,

Si Cl_2 , where the atomic weight of silicon = 14.25

Berzelius, by the formula,

Si Cl_3 , where the atomic weight of silicon = 21.37

Whereas, in my opinion, the balance of argument is in favour of the formula

Si Cl_4 , where the atomic weight of silicon = 28.50

In reference to a body of such doubtful analogies as silicon, whose combinations, moreover, are remarkable for their complexity, it is fit and natural that differences of opinion with regard to its atomic weight should be entertained by different chemists, according to their particular modes of viewing the subject; and, not only with regard to silicon, but to boron, to gold, to uranium, to tantalum, and indeed to all elements the analogies of which have not been well established. But, in reference to such well known elements as oxygen, sulphur, and carbon, there certainly ought to be the same unanimity that obtains in the case of nitrogen; though in reality we find the discord even more violent than in the case of silicon.

The majority of English chemists represent the atomic weight of carbon by 6, that of oxygen by 8, and that of sulphur by 16. Dr. Frankland would double the atomic weight of carbon, but would retain the old atomic weights of oxygen and sulphur. Mr. Griffin, who lays claim to priority in doubling the atomic weights of carbon and oxygen, ridicules the notion of doubling that of sulphur. Dr. Williamson, Mr. Brodie, and myself have for a long time past advocated the doubling of all three.

Let us now proceed to investigate, from undisputed data, the atomic weight of oxygen, and of its most important compound with hydrogen, namely, water. Is the atom of water $\text{HO} = 9$, or $\text{H}_2\text{O} = 18$?

All chemists admit, firstly, that the atom of chlorhydric acid consists of 1 part of hydrogen united with 35.5 parts of chlorine; secondly, that the atom of ammonia consists of 3 parts of hydrogen united with 14 parts of nitrogen; and that, as compared with 35.5 parts of chlorine, 14 parts of nitrogen is the smallest quantity of nitrogen that can enter into a combination. Now I wish to show, firstly, that if the atom of chlorhydric acid consists of 1 part of hydrogen united with 35.5 parts of chlorine, and if the atom of ammonia consists of 3 parts of hydrogen united with 14 parts of nitrogen, then the atom of water must consist of 2 parts of hydrogen united with 16 parts of oxygen; secondly, that if 35.5 parts of chlorine constitute the smallest indivisible quantity of chlorine that can enter into a combination, and if 14 parts of nitrogen constitute the smallest indivisible quantity of nitrogen that can enter into a combination, then 16 parts of oxygen constitute the smallest indivisible quantity of oxygen that can enter into a combination; or, in other words, that the atomic weight of oxygen is 16, when

compared with the atomic weight of hydrogen as 1, of chlorine as 35.5, and of nitrogen as 14. Every argument that induces us to accord to the atom of nitrogen the number 14, rather than the number 4.7, should also induce us to accord to the atom of oxygen the number 16, rather than the number 8.

I propose to review briefly all the arguments we have admitted in the case of nitrogen, and to prove that they are equally applicable in the case of oxygen; or to show why it is that ammonia must be written H_3N , and water H_2O , as compared with chlorhydric acid HCl .

NITROGEN.

a. Because it is found that a given bulk of gaseous ammonia contains three times as much hydrogen as the same bulk of chlorhydric acid.

β. Because it is found that a given bulk of nitrogen combines with three times as much hydrogen as does the same bulk of chlorine, and that the relative weight of equal bulks of nitrogen and of chlorine are as 14 to 35.5.

OXYGEN.

a. Because it is found that a given bulk of gaseous water contains twice as much hydrogen as the same bulk of chlorhydric acid.

β. Because it is found that a given bulk of oxygen combines with twice as much hydrogen as does the same bulk of chlorine; and that the relative weights of equal bulks of oxygen and of chlorine are as 16 to 35.5.

I attach very great importance to these first two arguments, which apply with equal force to the duplication of oxygen and the triplication of nitrogen; to the binhydric character of water and the terhydric character of ammonia.

γ. Because certain undoubted analogies and ratios of nitrogenised bodies are concealed by formulæ in which $\text{Az}=4.7$, and are manifested by formulæ in which $\text{N}=14$.

γ. Because certain undoubted analogies and ratios of oxidised bodies are concealed by formulæ in which $\text{O}=8$, and are manifested by formulæ in which $\text{O}=16$.

These reasons apply with about equal force, though in a somewhat different manner, to nitrogen and to oxygen respectively. Thus with $\text{Az}=4.7$, the analogies of nitrogen and chlorine compounds would be concealed by the formulæ, for we should have—

Nitrous acid.

Chlorous acid.

 $\text{HAz}_3\Theta_2$ instead of $\text{HN}\Theta_2$ analagous to $\text{HCl}\Theta_2$.

Nitric acid.

Chloric acid.

 $\text{HAz}_3\Theta_3$ instead of $\text{HN}\Theta_3$ analagous to $\text{HCl}\Theta_3$.

Pernitric oxide.

Perchloric oxide.

 $\text{Az}_6\Theta_4$ instead of $\text{N}_2\Theta_4$ analagous to $\text{Cl}_2\Theta_4$.

With $\text{O}=8$, the relation of water to the alcohols as the undoubted vanishing point of the series would not be manifested, as it is in the formulæ with $\Theta=16$.

Thus, if we write alcohol $\text{C}_4\text{H}_6\text{O}_2$, wood spirit $\text{C}_2\text{H}_4\text{O}_2$, and water HO , the relation of water to the alcohols does not appear, but in the following series of formulæ it is perfectly apparent:—

$\text{C}_5\text{H}_{12}\Theta$	Amylic alcohol.
$\text{C}_4\text{H}_{10}\Theta$	Butylic „
$\text{C}_3\text{H}_8\Theta$	Propylic „
$\text{C}_2\text{H}_6\Theta$	Ethylic „
$\text{C}\text{H}_4\Theta$	Methylic „
$\text{H}_2\Theta$	Hydric „

The relation of water to the alcohols, as shown in the above formulæ, is not a mere paper relation, but has its foundation in experiment. When alcohol and water respectively are acted upon by potassium, by chloride of benzoyl, by pentachloride of phosphorus, and by a host of other re-agents, the reactions are acknowledged by all to be precisely parallel. All chemists, no matter what formulæ they employ, recognise the fact that the quantity of water which, in a reaction, corresponds to one proportion of alcohol, must contain two units of hydrogen.

Similarly with regard to the hydrated bases and acids. If we write hydrate of potass KHO_2 , hydrated hypochlorous acid HClO_2 , and water HO , the relation of the formulæ as representing comparable quantities does not appear. But in the following series it is perfectly evident:—

$\text{K K}\Theta$	Potass oxide.
$\text{K H}\Theta$	Potass hydrate.
$\text{H H}\Theta$	Water.
$\text{H Cl}\Theta$	Hypochlorous acid.
$\text{K Cl}\Theta$	Potass hypochlorite.
$\text{Cl Cl}\Theta$	Hypochlorous anhydride.

The following reactions, among many others, show that the quantity of water which corresponds to one proportion of hydrate of potass, or of hypochlorous acid, must contain two units of hydrogen:—

1. *Action of Chloride of Benzoyl.*

2. *Action of Chlorine.*

δ. Because, in ninety - nine cases out of a hundred, the quantity of ammonia which is the agent or resultant of a reaction must contain H₃, or some multiple of H₃; and consequently 14, or some multiple of 14 parts of nitrogen.

δ. Because, in ninety - nine cases out of a hundred, the quantity of water which is the agent or resultant of a reaction must contain H₂, or some multiple of H₂; and consequently 16, or some multiple of 16 parts of oxygen.

This argument is one of the most cogent that can be adduced. It is well illustrated in the case of nitrogenized, but infinitely better in the case of oxidised compounds. Let us adduce some nitrogenous reactions.

1. *Formation of Ammonia from Sal Ammoniac.*

2. *Formation of Ammonia from Nitrate of Potass.*

3. *Formation of Cyanogen from Oxalate of Ammonia.*

4. *Formation of Benzamide.*

Express the above reactions howsoever you please, you cannot represent any one of them with a proportion of ammonia containing less than 3 units of hydrogen, nor consequently with less than 14 parts of nitrogen. And, whenever more than 3 units of hydrogen are required, you must take some multiple of three units of hydrogen, and some multiple of 14 parts of nitrogen; and ninety-nine cases out of a hundred will yield the same result. As an example of those cases in which it is possible to represent the acting or resulting proportion of ammonia with less than three units of hydrogen, I may adduce the—

5. *Formation of Triethylamine.*

And similarly with trimercuramine, $\text{NHg}_3 = 3 \text{ AzHg}$; though no one really thinks of writing the formulæ of these bodies with only one unit of ethyl or of mercury respectively.

Let us now revert to oxygenous reactions. I wish to show that, in ninety-nine cases out of a hundred, where water appears as the agent or resultant of a reaction, it is impossible to represent that water with less than two atoms of hydrogen.

1°. Whenever an alcohol, ketone, or other oxidised organic compound yields a hydrocarbon by dehydration, the water eliminated contains two, or some multiple of two, units of hydrogen.

1. *Formation of Olefiant Gas from Alcohol.*

2. *Formation of Mesitylene from Acetone.*

3. *Formation of Cymene from Camphor.*

Other compounds than hydrocarbons result from similar equations, thus—

4. *Formation of Acrolein from Glycerin.*

2° Whenever an organic acid yields a pyroacid, or other pyrogenous product, by dehydration :—

1. *Formation of Carbonic Oxide from Formic Acid.* 2. *Formation of Maleic, from Malic Acid.* 3. *Formation of Pyruvic, from Tartaric Acid.* 4. *Formation of Aconitic, from Citric Acid.* 5. *Formation of Pyromucic, from Mucic Acid.*

3°. Whenever two compounds act upon one another to form a new compound, with simultaneous elimination of water.

*Action of an Acid upon a Hydrocarbon.*1. *Sulphobenzide.* 2. *Sulphobenzidic Acid.*

3. *Nitro-naphthaline.* *Action of an Acid upon an Alcohol.*4. *Phosphovinic Acid.* 5. *Benzoic Ether.* *Action of an Acid upon an Alkali.*6. *Sulph-anilic Acid.* 7. *Nitraneline.* *Action of an Acid upon an Acid.*8. *Nitrosalicylic Acid.* *Action of an Acid upon an Aldehyd.*9. *Nitro-benzoic Aldehyd.* *Action of an Alkali upon an Aldehyd.*10. *Hydrobenzamide.*

4°. Whenever a salt of ammonia, aniline, or other volatile alkali loses water.

1. *Formation of Cyanhydric Acid.*

2. *Formation of Benzanilide.*

3. *Formation of Aceto-nitrile.*

In all the illustrations hitherto brought forward, the water has been the resultant of the reaction. Many of these reactions are capable of being reversed, and the water then appears as the agent of the reaction.

But we can also adduce an abundance of other and most varied instances in which water is the agent of a reaction.

1. *Decomposition of Hippuric Acid.*

2. *Decomposition of Pentachloride of Phosphorus.*

3. *Decomposition of Chloride of Benzoyl.*

4. *Decomposition of Zinc-ethyl.*

The circumstance that 2HO are invariably associated, is strongly suggestive of their being inseparably associated, of their constituting in fact but one atom.

ε. Because, in the majority of the compounds which ammonia forms with other bodies, the ammonia must be represented with three units, or some multiple of three units, of hydrogen.

ε. Because, in the majority of the compounds which water forms with other bodies, the water must be represented with two units, or some multiple of two units, of hydrogen.

We may take aldehyd-ammonia $\text{C}_2\text{H}_4\text{O}_2\cdot\text{NH}_3$, and ammoniacal sulphate of zinc, $\text{Zn}_2\text{SO}_4\cdot 4\text{NH}_3$, as nitrogenous illustrations. The oxygenous illustrations are innumerable, including nearly all cases of water of crystallization. We may take as examples:—

{ Fructose ..	$\text{C}_6\text{H}_{12}\text{O}_6$;	or, $\text{C}_{12}\text{H}_{12}\text{O}_{12}$.
{ Glucose ..	$\text{C}_6\text{H}_{12}\text{O}_6\cdot\text{H}_2\text{O}$;	or, $\text{C}_{12}\text{H}_{12}\text{O}_{12}\cdot 2\text{HO}$.
{ Dextrine ..	$\text{C}_6\text{H}_{10}\text{O}_5$	or, $\text{C}_{12}\text{H}_{10}\text{O}_{10}$.
{ Lactine ..	$\text{C}_6\text{H}_{10}\text{O}_5\cdot\text{H}_2\text{O}$;	or, $\text{C}_{12}\text{H}_{10}\text{O}_{10}\cdot 2\text{HO}$.
Hydrate of turpentine	$\text{C}_{10}\text{H}_{16}\cdot 3\text{H}_2\text{O}$;	or, $\text{C}_{20}\text{H}_{16}\cdot 6\text{HO}$.
Hydrate of alloxan	$\text{C}_4\text{H}_2\text{N}_2\text{O}_4\cdot\text{H}_2\text{O}$;	or, $\text{C}_8\text{H}_2\text{N}_2\text{O}_8\cdot 2\text{HO}$.

ζ. Because, although the formulæ of some few nitrogenized bodies may be represented most simply by formulæ in which $\text{Az}=4\cdot 7$, yet the great majority are represented most simply by formulæ in which $\text{N}=14$.

ζ. Because, although the formulæ of some few oxidized bodies may be represented most simply by formulæ in which $\text{O}=8$, yet the great majority are represented most simply by formulæ in which $\text{O}=16$.

This argument applies strongly in the case of nitrogenized, but much more strongly in the case of oxydized compounds.

Ammonia, and all derivatives of ammonia in which the whole of the hydrogen is replaced by one single kind of metal, or hydrocarbon, or haloid, might be represented more simply by formulæ in which $\text{Az}=4\cdot 7$, than by formulæ in which $\text{N}=14$. Thus triethylaminic is written most simply $\text{Az}\text{C}_2\text{H}_5$, though most correctly by $\text{N}\ 3\text{C}_2\text{H}_5$.

I believe that all other nitrogenized bodies are necessarily represented most simply by formulæ in which $\text{N}=14$.

With regard to oxygen, all hydrated oxides, double oxides, hydrated acids, oxy-salts, aldehyds, ketones, alcohols, pseudo-saline ethers, and various other descriptions of compounds, doubt-

less forming together 99 per cent. of all known compounds of oxygen, cannot be represented so simply by formulæ in which $O=8$ as by formulæ in which $\Theta=16$.

I have contended that if the comparable atoms of nitrogenized bodies were correctly formulated, they would all of them be represented more simply by formulæ in which $N=14$, than by formulæ in which $Az=4.7$; and I now contend that if the comparable atoms of oxidized bodies were correctly formulated, they would all be represented more simply by formulæ in which $\Theta=16$, than by formulæ in which $O=8$. But precisely as there are some few nitrogenized bodies which, with the symbol $Az=4.7$, may be divided into thirds, and can thus receive simpler formulæ than with the symbol $N=14$, so are there some comparatively few oxidized bodies which, with the symbol $O=8$, may be divided into halves, and can thus receive simpler formulæ than with the symbol $\Theta=16$. These bodies are the following:—

1°. Most compounds in which oxygen is united with one kind of matter only, including nearly all the simple metallic oxides.

Thus with $\Theta=16$, water and lime must be written respectively $H_2\Theta$ and $Ca_2\Theta$, analogous to hydrate of lime $CaH\Theta$; but with $O=8$ they may be written thus— H_2O_2 and Ca_2O_2 , analogous to hydrate of lime $CaHO_2$; or thus— HO and CaO . I do not propose to argue the point whether CaO , or Ca_2O_2 ($=Ca_2\Theta$), is the correct expression for a metallic oxide, lime; any more than I have argued the point whether $HgAz$, or Hg_3Az_3 ($=Hg_3N$), is the correct expression for a metallic nitride, mercuramine. We are at present discussing whether the formula of water is HO or H_2O_2 ($=H_2\Theta$), and the decision upon this point will determine that of the metallic and other simple oxides. It may be observed, however, that many strictly comparable reactions can be effected by means of lime, hydrate of lime, and water respectively, and that in these cases we always require $2HO$, or $2CaO$, to effect the reaction. Of course, if Ca_2O_2 is the correct expression for the atom of lime, the formula with $\Theta=16$ is simpler than that with $O=8$, and similarly with other homogeneous oxides.

2°. Bodies analogous to ordinary ether and the homogeneous anhydrides. With $\Theta=16$, ether and benzoic anhydride must be written respectively—

and $\text{Bz}_2\Theta$ analogous to $\text{H Bz } \Theta$ and $\text{Ot Bz } \Theta$
Benz-anhydride. Benzoic acid Othyl-benz-anhydride;

but with $\text{O}=8$ they may be written thus:—

$\text{Et}_2 \text{O}_2$ analogous to H Et O_2 and Me Et O_2 ;
and $\text{Bz}_2 \text{O}_2$ analogous to H Bz O_2 and Ot Bz O_2 ;
or thus :— Et O and Bz O .

Now all arguments, founded on mode of formation, on reactions, on vapour-densities, on seriated position and properties, &c., tend to show that EtO and BzO are not correct expressions of the nature of the bodies represented;* and if Et_2O_2 and Bz_2O_2 are the correct expressions, it is at once evident that in these cases formulæ with $\Theta=16$ are simpler than formulæ with $\text{O}=8$.

3°. Certain acids, and their salts of one metal, heretofore usually considered monobasic, but which in reality are bibasic. Thus with $\Theta=16$ the hydrated carbonic, sulphurous, and sulphuric acids must be represented respectively by the formulæ:—

But with $\text{O}=8$ they may be represented thus,

But, in these cases, we can adduce strong evidence to show that the simple formulæ HCO_3 , HSO_3 , and HSO_4 , are not correct expressions of the nature of the bodies; and if the correct expressions are $\text{H}_2\text{C}_2\text{O}_6$, $\text{H}_2\text{S}_2\text{O}_6$, and $\text{H}_2\text{S}_2\text{O}_8$, that is to say, if the acids are bibasic, then the formulæ with $\Theta=16$ are evidently more simple than those with $\text{O}=8$. We shall presently advert to the distinctions between monobasic and bibasic acids.

* I mean to say that ether, by its mode of formation and chemical reactions, by its vapour density and other physical properties, belongs to the following series of strictly comparable substances, and that its formula is not $\text{C}_4\text{H}_5\text{O}$, but $\text{C}_8\text{H}_{10}\text{O}_2 = \text{C}_4\text{H}_{10}\Theta$, *vide* Williamson, Journal of Chemical Society, vol. iv.

Vinic Ethers.

$\text{H O. C}_4\text{H}_5\text{O}$	$\text{H. C}_2\text{H}_5\Theta$	Hydro-ethylic.
$\text{C}_2\text{H}_3\text{O. C}_4\text{H}_5\text{O}$	$\text{C}_2\text{H}_3.\text{C}_2\text{H}_5\Theta$	Methyl-ethylic.
$\text{C}_4\text{H}_5\text{O. C}_4\text{H}_5\text{O}$	$\text{C}_2\text{H}_5.\text{C}_2\text{H}_5\Theta$	Ethyl-ethylic.
$\text{C}_6\text{H}_7\text{O. C}_4\text{H}_5\text{O}$	$\text{C}_3\text{H}_7.\text{C}_2\text{H}_5\Theta$	Propyl-ethylic.
$\text{C}_8\text{H}_9\text{O. C}_4\text{H}_5\text{O}$	$\text{C}_4\text{H}_9.\text{C}_2\text{H}_5\Theta$	Butyl-ethylic.
$\text{C}_{10}\text{H}_{11}\text{O. C}_4\text{H}_5\text{O}$	$\text{C}_5\text{H}_{11}.\text{C}_2\text{H}_5\Theta$	Amyl-ethylic.

η Because, in ammonia, the actual or potential replacement of hydrogen takes place definitely in thirds, by three successive stages.

η Because, in water, the actual or potential replacement of hydrogen takes place definitely in halves, by two successive stages.

We have no definite nitride that can be represented as ammonia in which one-half the hydrogen is replaced, as we might expect if the atomic weight of nitrogen were 4.7. We have no definite oxide that can be represented as water, in which one-third the hydrogen is replaced, as we might expect if the atomic weight of oxygen were 8. Thus,

Chloride.	Oxide.	Nitride.
KCl	KO	HAz
KCl.HgCl	KO.HO	Wanting
KCl.2HgCl	Wanting	HAz.2PtAz

If we write water $\left. \begin{smallmatrix} \text{H} \\ \text{H} \end{smallmatrix} \right\} \Theta$, and ammonia $\left. \begin{smallmatrix} \text{H} \\ \text{H} \end{smallmatrix} \right\} \text{N}$, we at once see the

necessity or reason for the vacancies. In water we can replace a half, but not a third. In ammonia we can replace one-third or

two-thirds, but not a half; whereas in marsh gas $\left. \begin{smallmatrix} \text{H} \\ \text{H} \\ \text{H} \end{smallmatrix} \right\} \text{C}$, we can

replace one-fourth, two-fourths, or three-fourths, but not one-third, or two-thirds of the hydrogen. We are acquainted with many ammonias in which 1, 2, and 3 thirds of the hydrogen are replaced, such, for instance, as

NH_2K	Potassamide
NHI_2	Biniodamide
NHg_3	Trimercuramine

But the most striking illustration of replacement by thirds is afforded by Hofmann's researches on the volatile alkaloids, in which he successively replaced 1, 2, and 3 atoms of hydrogen by a mere continuation of one and the same process.

Ammonia.	Ethylia.	Diethylia.	Triethylia.	Ethyl methyl-aniline.
$\text{N} \left\{ \begin{smallmatrix} \text{H} \\ \text{H} \\ \text{H} \end{smallmatrix} \right.$	$\text{N} \left\{ \begin{smallmatrix} \text{H} \\ \text{H} \\ \text{Et} \end{smallmatrix} \right.$	$\text{N} \left\{ \begin{smallmatrix} \text{H} \\ \text{Et} \\ \text{Et} \end{smallmatrix} \right.$	$\text{N} \left\{ \begin{smallmatrix} \text{Et} \\ \text{Et} \\ \text{Et} \end{smallmatrix} \right.$	$\text{N} \left\{ \begin{smallmatrix} \text{Ph} \\ \text{Et} \\ \text{Me} \end{smallmatrix} \right.$

We are acquainted with many oxides that may be considered as derivatives of water, in which one half the hydrogen is replaced, or in which both halves are replaced by different elements or groupings. Thus,

Water.	Alcohol.	Ether.	Methyl-ether.	Phenyl-ether.	Ethylate of potass.
$\ominus \begin{Bmatrix} \text{H} \\ \text{H} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{H} \\ \text{Et} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Et} \\ \text{Et} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Et} \\ \text{Me} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Et} \\ \text{Ph} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Et} \\ \text{K} \end{Bmatrix}$
Hydrate of potass.	Oxide of potass.	Zinc oxide of potass.	Hypochlorite of potass.	Hypochlorous acid.	Hypochlorous anhydride.
$\ominus \begin{Bmatrix} \text{H} \\ \text{K} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{K} \\ \text{K} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Zn} \\ \text{K} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{K} \\ \text{Cl} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{H} \\ \text{Cl} \end{Bmatrix}$	$\ominus \begin{Bmatrix} \text{Cl} \\ \text{Cl} \end{Bmatrix}$

In many cases we can effect the total replacement by the same element or grouping at two successive stages. Thus,

	$\ominus \begin{Bmatrix} \text{H} \\ \text{H} \end{Bmatrix}$	Water
Water and potassium yield	$\ominus \begin{Bmatrix} \text{H} \\ \text{K} \end{Bmatrix}$	Hydrate of potass
Hydrate of potass and iodide of ethyl yield	$\ominus \begin{Bmatrix} \text{H} \\ \text{Et} \end{Bmatrix}$	Alcohol
Alcohol and potassium yield	$\ominus \begin{Bmatrix} \text{K} \\ \text{Et} \end{Bmatrix}$	Ethylate of potass
Ethylate of potass and iodide of ethyl yield	$\ominus \begin{Bmatrix} \text{Et} \\ \text{Et} \end{Bmatrix}$	Ether
Ethylate of potass and iodide of methyl yield	$\ominus \begin{Bmatrix} \text{Et} \\ \text{Me} \end{Bmatrix}$	Methylate of ethyl
Hydrate of potass and potassium yield	$\ominus \begin{Bmatrix} \text{K} \\ \text{K} \end{Bmatrix}$	Oxide of potass.

This brings to a conclusion my arguments upon the atomic weights of oxygen and water, founded on a comparison of the arguments which apply in the case of nitrogen and ammonia. The point that I urge is not so much the absolute point, namely, that the atomic weight of oxygen must be 16, as the relative point, namely, that if the atomic weight of nitrogen is 14 and not 4.7,

the atomic weight of oxygen must be 16 and not 8. Every argument that applies to the first case, applies with equal, if not greater force, to the second. I know very well that some of the arguments I have adduced, as that from analogy, for instance, may be apparently subverted by the subterfuge of writing water H_2O_2 ; but I also know that chemists who make use of the formula H_2O_2 to represent water, act most inconsistently, if they do not also make use of the formulæ H_3Az_3 to represent ammonia. There are three consequent methods of formulating chlorhydric acid, water, and ammonia in respect to one another, namely,

I.	II.	III.
HCl	HCl	HCl
HO	H_2O_2	H_2O
HAz	H_3Az_3	H_3N

The first method was that employed by Dalton, who wrote ammonia $\text{O}\oplus=1+5$, and water $\text{O}\odot=1+7$.

But both the following modes are most inconsequent, and therefore reprehensible:—

IV.	V.
HCl = 2 vol.	HCl = 2 vol.
HO = 1 vol.	$\text{H}_2\text{O}_2=2$ vol.
$\text{H}_3\text{N}=2$ vol.	$\text{H}_3\text{N}=2$ vol.

Series IV. represents irrelative quantities, and series V. accords irrelative formulæ to comparable quantities. I would observe, in reference to series I., II., and III., that the selection of one or other of them involves both a question of fact and a question of convenience. Whether the first or the second series really represents comparable quantities, that is to say, whether the atom of water, or the smallest proportion of water that is the agent or resultant of a reaction, contains twice as much hydrogen as the atom, or smallest reacting and resulting proportion of hydrochloric acid, is a question of fact. Whether the formula in the second, or that in the third series is the most appropriate mode of expressing the fact, may be, to some extent, at least, a question of convenience, though at the same time it is one of very considerable importance. The same remarks apply to the formulæ for ammonia.

But we have an additional argument in favour of the duplication of the atom of oxygen, derived from the series into which it

enters. Thus in all compounds of oxygen with two other kinds of matter, as particularly instanced by ox-acids and oxy-salts, the oxygen increases by 16 parts; and in none of these compounds can we add, subtract, or replace a less quantity than 16 parts of oxygen. Why this should be, unless the 16 parts constitute an indivisible proportion, or chemical atom, I am at a loss to conceive. The following are illustrations :—

Chlor-hydric acid	..	..	..	HCl	or HCl
Hypochlorous acid	..	..	..	HClO	or HClO ₂
Chlorous acid	..	..	..	HClO ₂	or HClO ₄
Chloric acid	..	..	..	HClO ₃	or HClO ₆
Perchloric acid	..	..	..	HClO ₄	or HClO ₈
Phosphuretted hydrogen	..	..	..	H ₃ P	or H ₃ P
Chlorophosphoric aldehyd	..	..	..	Cl ₃ PO	or Cl ₃ PO ₂
Hypophosphorous acid	..	..	..	H ₃ PO ₂	or H ₃ PO ₄
Phosphorous acid	..	..	..	H ₃ PO ₃	or H ₃ PO ₆
Phosphoric acid	..	..	..	H ₃ PO ₄	or H ₃ PO ₈
Ethylene	..	..	..	H ₄ C ₂	or H ₄ C ₄
Aldehyd	..	..	..	H ₄ C ₂ O	or H ₄ C ₄ O ₂
Acetic acid	..	..	..	H ₄ C ₂ O ₂	or H ₄ C ₄ O ₄
Glycolic acid	..	..	..	H ₄ C ₂ O ₃	or H ₄ C ₄ O ₆
Chloride of carbon	..	..	..	Cl ₂ C	or Cl ₂ C ₂
Phosgene	..	..	..	Cl ₂ CO	or Cl ₂ C ₂ O ₂
Formic acid	..	..	..	H ₂ CO ₂	or H ₂ C ₂ O ₄
Carbonic acid (hydrated)	..	..	..	H ₂ CO ₃	or H ₂ C ₂ O ₆

Precisely as the triplication of nitrogen necessarily leads to the triplication of phosphorus and its congeners, so must the duplication of oxygen lead to the duplication of sulphur and its congeners. Every argument that applies to the duplication of oxygen applies with almost equal force to the duplication of sulphur, even that argument derived from the combining volume of sulphur vapour, provided the researches of Bineau are trustworthy. One important consequence arises from the duplication of the atomic weight of sulphur, namely, the necessary representation of the sulphurous and sulphuric acids as bibasic. Now the question of basity is a purely experimental one. If we find the sulphurous

and sulphuric acids to have the properties of bibasic acids, we have a strong corroboration of the high atomic weights of sulphur and oxygen. But if we should find the sulphurous and sulphuric acids to have the properties of monobasic acids, that single circumstance would be of itself almost sufficient to discredit the view which accords to oxygen the atomic weight 16, and to sulphur the atomic weight 32.

I.

Certain oxacids have the following properties:—

a. Each of them can form *but one* kind of ether. This is neutral in its properties. Within two volumes of its vapour there is contained *but one* volume of ethyl or alcohol residue.

β. Each of them can form a chloride, or rather chloraldehyd, within two volumes of the vapour of which is contained *but one* volume of chlorine. Each chloraldehyd can exchange chlorine for peroxide of hydrogen to reform the normal acid, but *there is not* any compound intermediate between the chloraldehyd and the normal acid.

γ. Each of them, by reacting with ammonia, can form *but one* primary amide. This is neutral in its properties.

δ. They *cannot* any of them form stable well-defined acid salts, or salts with two or more metallic bases.

ε. They *cannot* any of them form

II.

Certain other oxacids have the following properties:—

a. Each of them can form *two* ethers, the one neutral, the other acid; for example, sulphatic ether and sulpho-vinic acid. Within two volumes of the neutral ether there are contained *two* volumes of alcohol residue.

β. Each of them can form a chloraldehyd, within two volumes of the vapour of which are contained *two* volumes of chlorine. These chloraldehyds can each exchange chlorine for peroxide of hydrogen to reform the normal acid; but *there is* a compound intermediate between the chloraldehyd and the normal acid, so that the conversion may be effected at two successive stages. Thus chloro-sulphuric aldehyd can produce first, chlorhydro-sulphuric acid, and then, normal sulphuric acid.

γ. Each of them, by reacting with ammonia, can form *two* primary amides, the one neutral, the other acid; for example, sulphamide and sulphamic acid.

δ. Each of them *can form* stable, well-defined acid salts, exactly intermediate in composition between the neutral salt and the free acid, such for instance as the bisulphate of potass. Each of them *can form* well defined double salts, in which either one-half or one-fourth the basic hydrogen is replaced by a basylous metal, the quantity of reacting acid, however, being twice as great in the second case as in the first. Common alum is an example of the second variety, potass-sulphate of nickel an example of the first.¹ The acids of this class, moreover, produce various ill defined hybrid salts, in which the basic hydrogen of the acid is replaced by an indefinite number of metals in indefinite proportions.

ε. Each of them *can form* double

double or multiple ethers, that is, ethers with two or more varieties of alcohol residue.

ζ. They *cannot* any of them form double or multiple amides, that is, amides with two or more varieties of ammoniacal residue.

η. They *cannot* any of them form etheramides, or compounds containing both alcoholic and ammoniacal residues.

θ. They *cannot* any of them form complex acids by reacting with hydrocarbons.

ι. As a general rule, the acids of this class are more volatile than those of the succeeding classes, while their salts are more soluble. They very rarely yield anhydrides by direct dehydration, or form anhydro-salts. They do not form distinct varieties of salts, such as have received the prefixes para-, meta-, iso-, &c. Acids which have the properties described under the above heads are classed as *monobasic* acids.

κ. It is observable that when a monobasic acid reacts upon another monobasic acid to form a new acid by the elimination of water, the new acid has also the properties of a *monobasic* acid; for example, nitro-benzoic acid.

ethers, that is, ethers with two varieties of alcohol residue in equal proportions; for example the double sulphate of ethyl and methyl, the double carbonate of ethyl and amyl, &c.

ζ. Each of them *can form* double amides, that is, amides with two varieties of ammoniacal residue in equal proportions; for example, anilo-sulphamide, or anilo-carbamide.

η. Each of them *can form* double etheramides, that is, compounds with an alcoholic and an ammoniacal residue in equal proportions; for example, sulphamethane, or sulphamethylane.

θ. Each of them *can form* complex acids by reacting with hydrocarbons; for example, the sulpho-benzidic and sulph-ethylenic acids.

ι. As a general rule, the acids of this class are less volatile than those of the preceding class, while their salts are less soluble. They yield anhydrides by direct dehydration; they form anhydro-salts, and also distinct varieties of salts, such as have received the prefixes para-, meta-, iso-, &c. Acids which have the properties described under the above heads are classed as *bibasic* acids.

κ. It is observable, that when a bibasic acid reacts upon a monobasic acid to form a new acid by the elimination of water, the new acid has also the properties of a *bibasic* acid; for example, sulpho-benzoic acid.

There are many other distinctions between the two classes of acids, but the above are the most important. Sulphurous and sulphuric acids therefore are considered to be bibasic, simply because they are possessed of certain properties which are characteristic of bibasic acids, without any reference whatever to their formulæ. The circumstance of their bibasity, as far as it goes, is in favour of the duplication of the atoms of sulphur and oxygen, from which such bibasity follows as a necessary consequence, inasmuch as with these high atomic weights it is impossible to represent the acids as being other than bibasic. With $O=8$ and $S=16$, the formulæ for the bibasic acids would be $H_2S_2O_6$ and $H_2S_2O_8$ respectively, than which the formulæ H_2SO_3 and H_2SO_4 are evidently more simple. Moreover, we are thus enabled to formulate two natural series of acids.

Chloric	HClO_3	HClO_4	Perchloric
Sulphurous	H_2SO_3	H_2SO_4	Sulphuric
Phosphorous	H_3PO_3	H_3PO_4	Phosphoric

The properties of tribasic, and quadribasic, are as well defined as are those of bibasic acids. Thus a tribasic acid can form three ethers, two of them acid and one neutral. Also, a chloraldehyd which, within two volumes of vapour, contains three volumes of chlorine. Also, three amides, two of them acid and one neutral. Also, acid and double and treble salts, in which the hydrogen and bases are related to one another by thirds. Also, treble ethers, treble amides, treble etheramides, &c., &c. In reference also to the basity of sulphuric acid, I might start from another point, and show, by parallel arguments, that for every property of phosphoric acid which causes it to be recognized as tribasic, there is a similar property of sulphuric acid which must cause it to be considered as bibasic, precisely as I have shown that the accordance of a terhydric character to ammonia necessitates the accordance of bi-hydric character to water.

With regard to the duplication of carbon, it is found that carbonic and sulpho-carbonic salts have bibasic properties, and must consequently be written HMC_2O_6 , $\text{M}_2\text{C}_2\text{O}_6$, $\text{M}_2\text{C}_2\text{S}_6$, &c. Also, that the smallest quantities of carbonic oxide, carbonic anhydride, and sulpho-carbonic anhydride, that are the agents or resultants of reactions, contain twice the quantity of substance usually represented by their respective formulæ; or, in other words, that their real formulæ are C_2O_2 , C_2O_4 , and C_2S_4 . By making these few alterations, all compounds of carbon become formulated with an even number of carbon-atoms, so that nothing is easier than to substitute one large carbon atom, C having the value 12, for two small carbon atoms, C_2 having each the value 6. In this way, the anomaly of the increment of carbon, in homologous series, always taking place by two inseparable atoms is done away with, as is also the anomaly of the atomic heat of carbon.