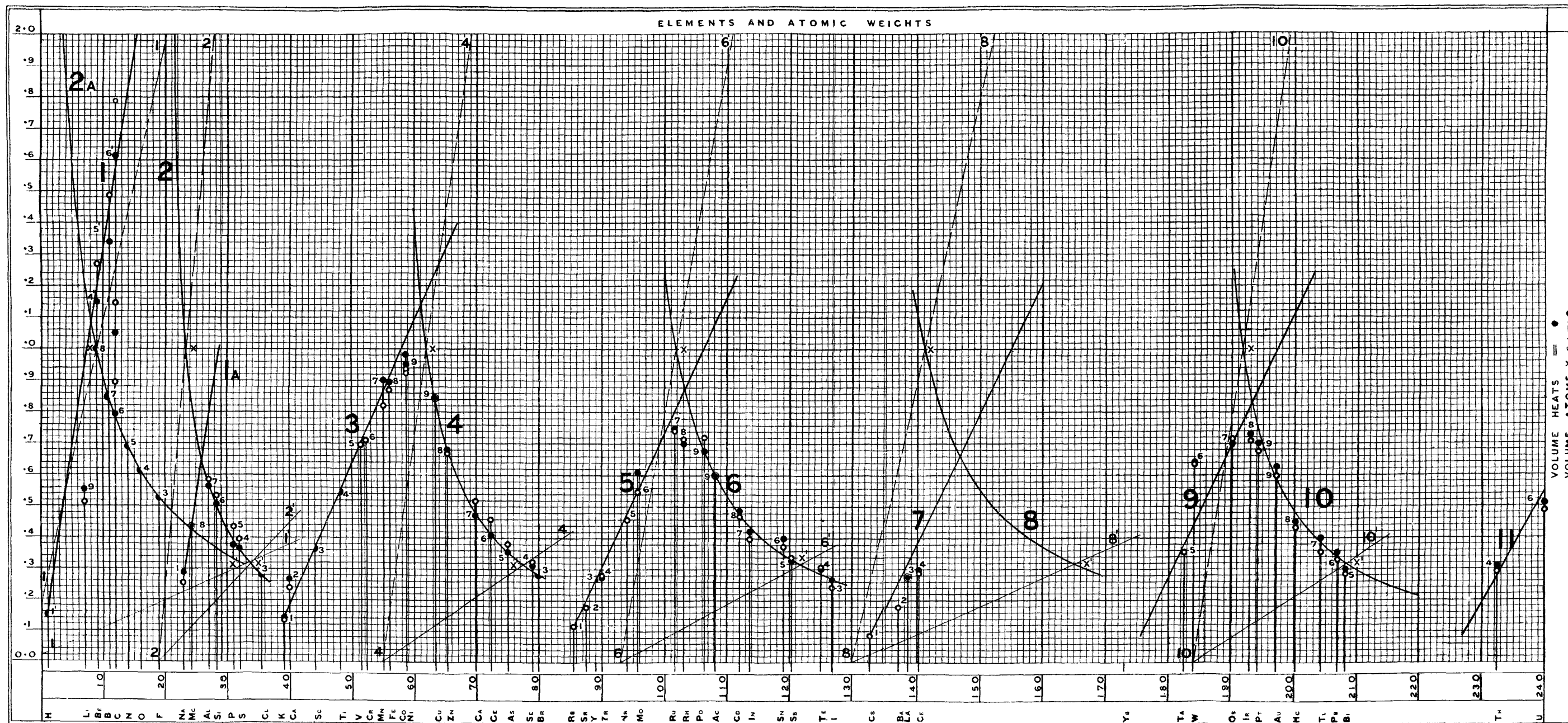LVI.—*A New Diagram and Periodic Table of the Elements.*

By R. M. DEELEY, F.G.S.

IT has been shown that almost all the physical and chemical properties exhibited by the elements of low atomic weight recur periodically, in a slightly modified degree, in elements higher in the atomic scale, and a number of tables and diagrams have been drawn to illustrate this "Periodic Law."   Of these periodic tables, that given by Mendeléeff, in his *Principles of Chemistry*, seems to be the most satisfactory.   In it he has boldly assumed the possibility of the existence of a number of elements which have not yet been isolated, and by leaving spaces for them, has been enabled for the first time to group the elements in a fairly satisfactory manner.   In this table (I, p. 863), the elements are placed in eight vertical groups and twelve horizontal rows or series; the atomic weights reading regularly from left to right.   The first seven elements (or spaces for predicted elements) of each series are spaced so that the elements of the odd series form the right-hand columns of the groups and the elements of the even series the left-hand columns.   The last group contains the remaining elements of the even series.   Unless this separation of the groups into two columns be effected, the grouping is not very satisfactory, for the elements of the odd series are generally much more closely allied to each other than they are with those of the even series, and *vice versâ*.

In his *Modern Theories of Chemistry* Lothar Meyer gives a diagram in which the abscissæ are atomic weights and the ordinates atomic volumes.   When the "atomic volumes" are thus plotted, the

DIAGRAM I View Article Online

VOLUME HEATS, VOLUME ATOMS, CLASSES, & SERIES

● = SPECIFIC GRAVITY × SPECIFIC HEAT.   ○ = 6·1 × SPECIFIC GRAVITY ÷ ATOMIC WEIGHT.

lengths of the ordinates are found to increase and diminish periodic- ally with considerable regularity as the atomic weight rises, and lines drawn through the summits of the ordinates form irregular curves.

On comparing Lothar Meyer's diagram with Mendeléeff's table, a striking agreement is manifest between the periodic waves and the division of the elements into groups and series, the series representing the rising and falling curves of the periodic waves, and the groups elements occurring in similar positions on the several curves.

Although the work of Mendeléeff has placed the periodic law on a firm foundation, and the discovery of several of the elements predicted by him has proved the general soundness of his conclusions, there are still many weak points in his system, more especially in the arrange- ment of what he calls the "typical elements." Some authors have, indeed, gone so far as to maintain that the elements of lower atomic weight than sodium ought more properly to be called "anomalous elements." In his generalisations, Mendeléeff treats the elements of Series 2 apart from the other elements, placing them, it would seem, in their positions in the table for reasons of symmetry. For instance, hydrogen can scarcely be said to be typical of the other odd series elements of Group I, or lithium of the even series elements of the same group. Again, beryllium is more closely allied to magnesium than to calcium, boron rather to aluminium than to scandium, carbon more to silicon than to titanium, nitrogen to phosphorus rather than to vanadium, oxygen more to sulphur than to chromium, and fluorine more to chlorine than to manganese. I make these references to Mendeléeff's table, and to Lothar Meyer's diagram, as, in the present paper, I propose describing a diagram constructed on somewhat similar lines, and also a table based upon it which appears to afford a classification of the elements more in accordance with their chemical and physical properties.

Although the regularity with which the ordinates vary in Lothar Meyer's diagram is very striking, the lines joining their summits do not form very regular curves. This might result from the inexact- ness of our data concerning the relative densities of the elements in a pure state ; or what is more likely to be the fact, that some correc- tion should be made in the figures for the temperature as compared with the melting point. The diagram I shall describe (Diagram 1, p. 858) is constructed in much the same manner as that drawn by Lothar Meyer, but the periodic variations of some other of the physical constants of the elements, that are marked by even greater regularity in their periodic variations than are the atomic volumes, are plotted upon it. The two constants, the periodic changes in the values of which with increasing atomic weight I shall call particular attention

to, are deduced from the atomic weight, the relative density, and the specific heat. These constants are called the *volume heats* and *volume atoms.*

The volume heats are the quantities of heat required to raise equal volumes of the elements, in the solid condition, through equal temperatures, whilst the volume atoms give the relative numbers of atoms in equal volumes.

The term "volume atoms" was used by Berzelius to imply that one volume in the gaseous state corresponds with one atom ; but the more correct generalisation of Avogadro has rendered this meaning obsolete, and as the term never came into general use, it may, I think, be revived without leading to misconception.

Of the three physical constants, atomic weight, relative density, and specific heat, the density is the only one which changes periodically with increasing atomic weight. Unlike the relative density, the specific heat does not vary periodically. On the other hand, the relative density, in addition to increasing rapidly with increasing atomic weight, is a markedly periodic value. To satisfactorily and graphically illustrate this periodicity of the relative density, the regular increase of density resulting from increasing atomic weight must be eliminated from the ordinates. This is accomplished by making them volume atoms.

It will be seen when we come to consider in detail the periodic curves obtained by plotting the volume heats on the diagram that they give even more regular curves than do the volume atoms.

In all cases, the relative densities and specific heats have been taken in the solid state, so that the comparisons may be made throughout in the same physical conditions.

As many of the elements are known to exist in two or more allotropic forms having different specific heats or densities, the same element may have more than one volume heat or volume atom. The most stable form at ordinary temperatures and pressures is generally that form the volume heat and volume atom of which agree most nearly with the values obtained for neighbouring elements. This form is regarded for convenience as the *normal* form.

In Table IV, pp. 866—867, are given the determinations of atomic weights, relative densities, and specific heats which have been used in constructing the diagram ; also the volume heats, volume atoms, and classes.

The relationships between the atomic weights, specific heats, relative densities, volume heats, volume atoms, and atomic heats are shown by the following equations.

$$\text{Volume atoms} = \frac{1}{\text{atomic weight} \div \text{relative density}}$$
$$= \frac{\text{relative density}}{\text{atomic weight}}.$$

Volume heats = relative density × specific heat.

$$\text{Atomic heat} = \frac{\text{volume heat}}{\text{volume atoms}}.$$

The atomic heat, according to Neumann, is very little altered when the element enters into combination with other elements.

Athough the periodic variation of the volume heats and volume atoms, and their close agreement the one with the other, can be well seen by an inspection of Table 1V, pp. 866—867, the figures have been plotted on Diagram 1 in a manner similar to that adopted by Lothar Meyer. Such a diagram enables the mind to grasp the numerous relationships between the various figures plotted on it much more clearly and certainly than does a table, but it need only be regarded as a means of visually impressing upon the mind quantitative relationships which might otherwise pass unnoticed, and thus enable the full significance of the figures to be grasped with greater ease.

On Diagram 1, p. 858, the abscissæ are atomic weights and the or-dinates are volume heats and volume atoms. To enable a close com-parison to be made between these two values, the volume atoms have been multiplied by 6·1. By this means, the two sets of ordinates are brought approximately to the same scale. Of course 6·1 is really the mean atomic heat of Dulong and Petit, and the distance between the small circles on the diagram which indicate volume atoms and the small spots which indicate volume heats is a measure of the error of Dulong and Petit's law. When the volume heats and volume atoms are almost identical, the spots have been surrounded by circles.

When the ordinates had all been plotted on the diagram, it was evident that although there were some notable exceptions, the ordinates of the majority of the elements fell very near to certain periodic straight lines indicated by the large odd numerals, or periodic curves indicated by the large even numerals: the lines and curves making 11 series following each other alternately with great regularity, and forming periodic waves. As the volume heat ordinates seemed to vary more regularly than the ordinates of the volume atoms, the curves and lines were drawn in to the volume heats alone. In the diagram thus obtained, the regular nature of the periodic change in the physical properties of the elements with in-creasing atomic weight is brought out much more clearly than they are by atomic volume curves. It is possible that to obtain a regular diagram of volume atoms, some correction should be made for tem-

perature reckoning from the melting points.   This correction for changes due to temperature is in some measure effected in calculating the volume heats, for, as a rule, the specific heat increases, whilst the density decreases, with rise of temperature.

Before drawing in the curves of the even series (indicated by the large even numerals), the reciprocals of their ordinates were plotted in to a different vertical scale for convenience, and as they proved to fall very near the straight dotted lines indicated by the smaller numerals 2—2′ to 10—10′, the curves were finally drawn with straight lines as reciprocals.   It will be noticed that the points marked × ′, where the curves cross the lines 2—2′ to 10—10′, are almost exactly equal to distances apart on the atomic scale.   In the case of mercury, the volume heat ordinate may be too small, owing to the fact that the density in the solid state has been taken without correction.   Had the ordinates of this element and bismuth been ignored, the agreement would have been almost perfect throughout the scale at the ordinates whose length is about $\sqrt{0\cdot1}$. The curves and straight lines of the diagram were put in before this and some other relationships were recognised, or they might have been made more geometrically perfect, as shown on Diagram 3, p. 862, without unduly departing from the positions indicated by the ordinates of each series.   The straight lines of the odd series cannot be so regularly arranged, owing, probably, to our want of exact knowledge concerning the relative densities and specific heats of many of the rare elements.   The third, fifth, seventh, and eleventh series do approximately occupy positions which are multiples of a common number, but the first and ninth are not in agreement with them.   At first sight, one would be led to think that the space occupied by the curve of the eighth series is really a natural blank in the atomic series, but until we have a more accurate knowledge of the physical constants of the rare elements, no opinion on this point can, with safety, be expressed.

It has been pointed out to me that what I have called the lines and curves of the odd and even series may really be portions of a series of continuous curves such as would be given by the equation $y = a\mathrm{B}^{-x}\dfrac{x}{x + c}$. This would be the equation of a hyperbola multiplied by an exponential factor.

Some support is given to this view by the fact that several of the elements classed as belonging to the odd series really fall on the upper portions of the curves of the even series, but there really seems to be a true break between each odd and even series.   This will be seen more clearly when we come to consider sodium and fluorine.

By dividing the molecular weights of compounds by the numbers

of atoms they contain we obtain *ideal* atomic weights which have atomic heats in agreement with Dulong and Petit's and Naumann's laws. Of course this does not hold good when the compound contains an element the specific heat of which varies greatly with change of temperature. We may also calculate the *ideal* volume atoms, as well as the *ideal* volume heats, by dividing the relative densities of the compounds by their ideal atomic weights. Although the curves on Diagram I have been drawn in to the volume heats, a fairly satisfactory result might have been obtained by using the volume atoms instead. In cases where compounds, such as the oxides, have to be dealt with, and there is reason to suppose that the specific heats at low temperatures are low, it is better to use the *ideal* volume atoms for purposes of comparison. The ideal volume atoms of all the oxides the gravities of which are known have been calculated and plotted on a diagram similar to Diagram I, but the ordinates do not fall in such positions that any regularity can be detected when they are regarded as a whole. There is, consequently, a very great difference between elements and compounds ; for the elements do not behave as though they were compounds with *ideal* atomic weights.

With the exception of certain peculiar features, which are shown by the elements of lower atomic weight than aluminium, the elements fall naturally into 11 series, indicated by the large numerals on Diagrams 1, 2, and 3. These series we have seen may be divided into an odd set falling upon what appear to be straight lines inclined somewhat from the vertical, and an even set falling on intermediate curves. The following list gives the number of elements in each series :—

Series	1	2	3	4	5	6	7	8	9	10	11
Elements........	8	7	10	7	9	7	4	0	6	5	2

Most of the rare elements about which very little is known with certainty are omitted. On comparing the elements of the several even series, the one with the other, their chemical properties seem to justify the following classification :—

Series 2	Cl	S	P	Si	Al	Mg	Na
,, 4	Br	Se	As	Ge	Ga	Zn	Cu
,, 6	I	Te	Sb	Sn	In	Cd	Ag
,, 8	?	?	?	?	?	?	?
,, 10	?	?	Bi	Pb	Tl	Hg	Au
	R_2O_3	R_2O_4	R_2O_5	R_2O_4	R_2O_3	R_2O_2	R_2O

Cl, Br, and I do not readily form oxides, and although when in combination with elements of other groups they are generally monovalent, they are most conveniently considered in the group R_2O_3.

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The anhydride of Cl_2O_3 is known, and in the compound ICl_3 we seem
to have Cl monovalent and I trivalent. S, Se, and Te all form stable
oxides of the composition R_2O_4. P, As, Sb, and Bi all form R_2O_5; Si,
Ge, Sn, and Pb, R_2O_4; Al, Ga, In, and Tl, R_2O_3; Mg, Zn, Cd, and Hg,
R_2O_2; and Cu, Ag, and Au, R_2O. Na also forms an oxide, Na_2O, but its
hydrate or hydroxide, unlike those of Cu, Ag, and Au, is very soluble
and also highly caustic.   The other elements of the last group also
form CuO_2, AgO, and Au_2O_3. In the majority of cases, the class oxides
given may be said to be the most stable, characteristic, and highest
oxides.   The halides of these elements also show a similar rise and
fall of valency with the increasing atomic weights of the groups.
When dealing with these elements, Mendeléeff places them in the
opposite order, and gives oxides of the form R_2O_6 to S, Se, and Te.
SO_3 and TeO_3 are known, but SO_2 is the only oxide occurring native,
and TeO_3, when strongly heated, loses oxygen and produces TeO_2.
Again, if the elements of this group should properly produce oxides
of the class R_2O_6, they should also form halides RCl_6. But they do
not, the highest halides being RCl_4. He also makes Cl, Br, and I
form R_2O_7, but the highest oxides known are ClO_2 and IO_2.   Silver
and gold form the halides $AgCl_2$ and $AuCl_3$, in this respect agreeing
with the oxides in departing somewhat from the class type.

Dealing with the elements of the odd series in the same manner,
that is, placing those elements having analogous properties in similar
columns, we obtain the following.   The elements of Series 1 have
been omitted for the present.

Series 3 ...	K	Ca	Sc	Ti	V	Cr	Fe	Mn	Ni / Co
,, 5 ...	Rb	Sr	Y	Zr	Nb	Mo	Ru	Rh	Pd
,, 7 ...	Cs	Ba	La	Ce	?	?	?	?	?
,, 9 ...	?	?	Yb	?	Ta	W	Os	Ir	Pt
,, 11 ...	?	?	?	Th	?	U	?	?	?
	R_2O	R_2O_2	R_2O_3	R_2O_4	R_2O_5	R_2O_4	R_2O_3	R_2O_2	R_2O

There seems to be a redundant element in Series 3.   Ni and Co
have, therefore, been placed previously in the same group and series.

Although the oxides given under each class are, on the whole, the
most stable and characteristic, they are by no means the only ones,
and though the order in which they read is the same, with the excep-
tion of Fe, Mn, Ni, and Co, as that adopted by Mendeléeff, it seems
better, from a valency point of view, to allow the oxide-forming
power of the groups to fall off again after reaching the group at the
head of which is vanadium.

For potassium, RCl is the group type of the halide, although it
forms K_2O_4, and a subchloride of a purple colour is said to be pro-

duced by the action of chlorine on metallic potassium. Ca, Sr, and Ba form CaO_2, SrO_2, and BaO_2, but the monoxides are produced by burning the pure elements in air. Halides of the form RCl_2 are the only ones known. Sc, Y, and La all form R_2O_3, and, although there are peroxides of Y and La, they part with the excess of oxygen when heated. TeO_2, ZrO_2, and ThO_2 are found native. Cerium has been placed in this group, but it forms similar stable oxides and halides, such as $CeCl_3$, to those of the previous group. Of course it is possible that one of these elements, La or Ce, is out of place; that is, that the atomic weight is not correct, or that one of them is not an element. The highest oxides of V, Nb, and Ta are of the class R_2O_5, and the highest halides RCl_4 or RCl_5. Cr, Mo, W, and U all form oxides R_2O_4. They also form R_2O_6, some of which occur native, and there are halides of Mo and W corresponding to these higher oxides, although U forms UCl_5 and Cr $CrCl_3$ only. Fe, Ru, and Os all form R_2O_3, and Ru and Os RuO_4 and OsO_4 as well. The highest halide of iron is $FeCl_3$, of ruthenium, $RuCl_3$, and of osmium, $OsCl_4$. Mn and Rh form monoxides which occur native. They also form higher oxides. Although Mn forms MnF_4, $MnCl_2$, $MnBr_2$, and MnI_2 are the highest of the other halides. Rhodium forms $RhCl_3$, and iridium $IrCl_4$. Nickel and palladium are the only two elements of the last group which form oxides R_2O; Co forming Co_2O_3, and platinum, PtO_2. The halides of cobalt and nickel are $CoCl_2$ and $NiCl_2$; of palladium, $PdCl_4$, and platinum, $PtCl_4$.

When considering the elements of the even series, it was noticed that in the last class a tendency showed itself to form higher oxides and halides than are given to it. In the odd series, this also shows itself, but with greater intensity; for instead of R_2O_4 we get R_2O_6. Indeed, it seems as though R_2O_7, R_2O_8, &c., are possible oxides for the higher classes.

So far the typical elements have not been considered. Those whose atomic weights lie between H and F should properly belong to the odd series. They ought, therefore, to read as follows, when compared with Series 3:—

H	?	Li	Be	B	C	N	O	F
K	Ca	Sc	Ti	V	Cr	Fe	Mn	$\{\begin{matrix} Ni \\ Co \end{matrix}$
R_2O	R_2O_2	R_2O_3	R_2O_4	R_2O_5	R_2O_4	R_2O_3	R_2O_2	R_2O

But lithium does not form an oxide R_2O_3, nor does Be form R_2O_4, or B R_2O_5. Not only is this the case, but oxygen and nitrogen differ considerably from Mn and Fe, as also does fluorine from nickel or cobalt. On the other hand, if we read the elements of the first odd

series backwards and compare them with the elements of the first even series, we get—

Series 1..	F	O	N	C	B	Be	Li	?	H
„ 2..	Cl	S	P	Si	Al	Mg	Na	—	—
	R_2O_3	R_2O_4	R_2O_5	R_2O_4	R_2O_3	R_2O_2	R_2O_1		R_2O_1

By arranging the typical elements in this manner, the agreement becomes fairly satisfactory, but we still have differences, differences arising from the fact that elements which should stand on the odd series line 1 of the Diagrams 1, 2, and 3 have taken upon themselves characteristics which place them in agreement with the elements on curves 2, 4, 6, and 10. Hydrogen is thrown into a group or class column of which it is the only member, for each of the even series only consists of seven elements against nine for each odd series. The curve 2A of the diagrams has been drawn in the following manner. From its alloy with palladium, the specific heat and specific gravity of hydrogen have been calculated. From the figures so obtained, we get 3.64 and $\frac{3.75}{6.1}$ as the volume heat and volume atom of hydrogen in its solid condition. To bring this element into agreement with potassium the volume heat should have been about $0.15°$. Solid oxygen should also have a large volume heat to bring it into agreement with manganese, whereas the true figure is probably somewhere between 1 and 2 Carbon, in its diamond form, and boron in its crystalline form, fall on the line of Series 1, but the amorphous form of carbon has a much lower specific gravity than the diamond, and it seems probable that the solid form of oxygen, which might be artificially produced, bears the same relation to the denser form, which would fall on the line of the first series, that amorphous carbon does to the diamond. On the supposition that this is the case, I have drawn the curve for Series 2A through the volume heats of hydrogen and amorphous carbon, although the volume heats and volume atoms of some of the typical elements appear to be normal and to fall on the line of Series 1. On Diagram 2, both the line 1 and the curve 2A have been drawn to show the alternative possible values for the volume heats of the typical elements. It would appear that if the elements of Series 1 were placed under such conditions that their active properties were those due to their possible positions on the line 1, they would agree in their chemical properties with the elements of the other odd series, but under existing conditions of temperature and pressure their chemical properties are those arising from their positions on the curve 2A, that is, similar to the even series elements.

It will also be seen that the last two elements of Series 2, sodium and magnesium, have departed from their proper positions on the

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ATOMIC WEICHT

POSSIBLE ALTERNATIVE VOLUME HEATS
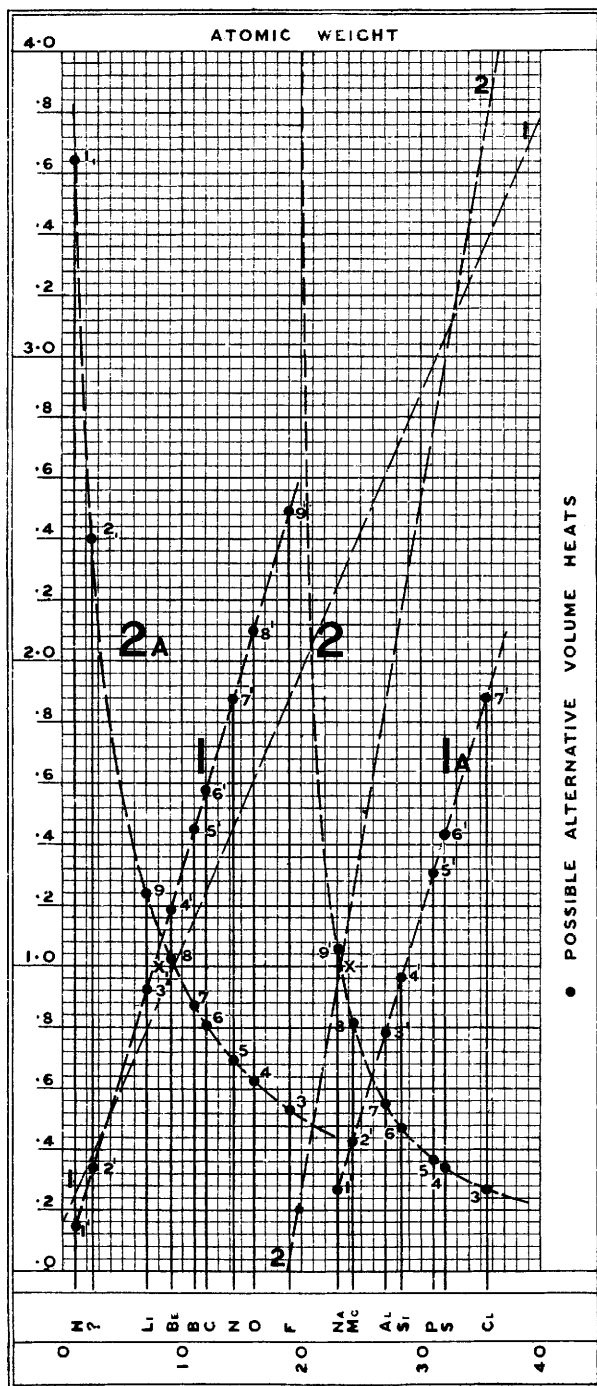
curve of Series 2 and placed themselves on a line, 1A, similar to the line of the first odd series. The result is that Na has become the first element of an odd series, and magnesium, in its physical properties, the second. On Diagram 2, the change has been completed for the rest of the elements of the second series, and their alternative positions on the line 1A as well as the curve 2 are given. From this there seems no reason why, under some conditions, all the other curves should not be reversed to form lines, and all the other lines to form curves. But even this does not seem to exhaust all the possible changes of gravity and valency, for lithium does not fall on either the line or the curve; and, again, there are many allotropic forms of the other elements which also do not. A line drawn from what should be about the normal position of hydrogen through the volume heats of lithium and amorphous carbon would have an inclination approaching that of the line of Series 3. Indeed, I am inclined to think that there are several lines for the same series, having fixed inclinations the one to the other, and also corresponding sets of possible curves.

In Table II (p. 864), the elements of the first six series are classed on the supposition that this reversibility is possible. They are, therefore, entered in duplicate, that is, in two sets of odd series, 1, 1a, 3, 3a, 5, and 5a; and two sets of even series, 2, 2a, 4, 4a, 6, and 6a. They are, also, printed partly in italics and partly in bold type. The positions in which they appear in bold type are those in which they form the classes of oxides typical of the several groups. It will be noticed that the even series 2 may be converted into the odd series 1a without seriously interfering with the grouping according to classes of oxides; but this is not the case if the odd series 1 be changed into the even series 2a. The same holds with all the other series. In this table, hydrogen has been made the right-hand member of the first group. If the third and fifth series had also have had their properties reversed, potassium and rubidium would have fallen into the same column (as shown in italics), and they would then, probably, have had class properties similar to those of hydrogen. Calcium and strontium would also have formed the only right-hand members of Class II, there being a blank for a new element of this group in Series 2a. This element, like hydrogen, must, therefore, have properties which mark it off from all other elements. Its atomic weight is perhaps 2·5, and it belongs, normally, to the calcium group.

In Table III (p. 865), all the important elements have been entered, but not in duplicate, as in Table II. Omitting H, the atomic weights of the elements read alternately from right to left and from left to right, as we pass from series to series. The table thus reads as the diagram does, when turned through an angle of 90°, from right to left

and left to right alternately, and is divided into nine classes of double columns of elements of odd and even series. From it, all the series which, in Table II, contain elements in italics only have been omitted. It has, of course, been built up according to the plan described in detail for the separate arrangement in groups and classes of the odd and even series respectively, but Na has been made the only member of Series 1a. It differs, of course, considerably from Table I constructed by Mendeléeff, for he makes hydrogen the only member of the first series instead of the only member of a class, does not quite leave a gap for the missing element of the calcium class, and does not satisfactorily divide the classes into columns of odd and even series. The grouping of the elements is indicated by the arrow.

To show the relationships between the lines and curves, and the reciprocals of the curves satisfactorily, Diagram 3 has been drawn. The reciprocals 2, 2', &c., for the sake of clearness, have been drawn in to one-tenth the vertical scale of the diagram, and, therefore, cross the curves at the ordinate $\sqrt{0\cdot1}$. This point is marked x'. On Diagram 1 the actual reciprocals 2 2, &c., as well as the lines 2 2', &c., have been put in. It will be seen that the points x' are approximately equal distances apart throughout the atomic scale. On the other hand, the points x, where the actual reciprocals cross the curves, are only equal for the curves of the first three even series. This shows that in the case of these series the reciprocals all radiate from a common centre. Diagram 3 shows this still better, for the scale admits of the lines being continued until they intersect. The point x at the ordinate $\sqrt{0\cdot1}$ of the first curve 2A resulting from the reversal of the elements of Series 1 coincides very nearly with the same point for curve 2; but does not radiate from the same centre. When we come to curve 8, the angle of the possible reciprocal 8', radiating from A, has nearly the same angle as the reciprocal 1, 1', and might, therefore, stand for the reciprocal of a curve which would represent the reversal of Series 7. The curve of series 10 has a reciprocal which does not radiate from A, but possibly from the point B. A curve has been drawn on the assumption that this is the centre from which the reciprocal for Series 8' radiates. The lines 1 and 1A have not the same inclination as those that follow. It would have had, very nearly, if it had been drawn through lithium and amorphous carbon. In no case does the reciprocal of a curve agree in position with the lines of the odd series.

The following geometrical expression for the relations existing between the curves on the diagram may be given.

Take as axis of x the zero line of volume heats (Diagram 3), and as axis of y a line perpendicular to this through the point from which the first set of reciprocal lines radiate.

TABLE I.

Groups.

	1	2	3	4 RH₄	5 RH₃	6 RH₂	7 RH	8 Hydrogen compounds
1.	H	—	—					
2.	Li	Be	B	C	N	O	F	
3.	Na	Mg	Al	Si	P	S	Cl	
4.	K	Ca	Sc	Ti	V	Cr	Mn	Fe Co Ni Cu
5.	(Cu)	Zn	Ga	Ge	As	Se	Br	
6.	Rb	Sr	Y	Zr	Nb	Mo	—	Ru Rh Pd Ag
7.	(Ag)	Cd	In	Sn	Sb	Te	I	
8.	Cs	Ba	La	Ce	Di?	—	—	—
9.	—	—	—	—	—	—	—	
10.	—	—	Yb	—	Ta	W	—	Os Ir Pt Au
11.	(Au)	Hg	Tl	Pb	Bi	—	—	
12.	—	—	—	Th	—	U	—	

Series.

TABLE II.

Groups and Oxides.

Series	I R_2O_1	II R_2O_2	III R_2O_3	IV R_2O_4	V R_2O_5	VI R_2O_4	VII R_2O_3	VIII R_2O_2	IX R_2O_1
1	**H**	*?.*	**F**	**O**	**N**	**C**	**B**	**Be**	**Li**
2a	—	*Mg*	*Al*	*Si*	*P*	*S*	*Cl*		*Na*
1a		*—*	*Li*	*Be*	*B*	*C*	*N*	*O*	*F*
2	**Na**		**Cl**	**S**	**P**	**Si**	**Al**	**Mg**	
3	**K**	**Ca**	**Co Ni**	**Mn**	**Fe**	**Cr**	**V**	**Ti**	**Sc**
4a		*—*	*Ga*	*Ge*	*As*	*Se*	*Br*	*—*	*—*
3a		*—*	*Sc*	*Ti*	*V*	*Cr*	*Fe*	*Mn*	*Co Ni*
4	*Cu*	*Zr*	**Br**	**Se**	**As**	**Ge**	**Ga**	**Zn**	**Cu**
5	**Rb**	**Sr**	**Pd**	**Rh**	**Ru**	**Mo**	**Nb**	**Zr**	**Y**
6a		*—*	*In*	*Sn*	*Sb*	*Te*	*I*	*—*	*—*
5a		*Sr*	*Y*	*Zr*	*Nb*	*Mo*	*Ru*	*Rh*	*Pd*
6	**Ag**	*Cd*	**I**	**Te**	**Sb**	**Sn**	**In**	**Cd**	**Ag**

Series.

TABLE III.—*Distribution in Classes, Series, and Groups. The Grouping of the Elements is indicated by Arrows.*

Classes of Oxides.

Series	R_2O_1 (I)	R_2O_2 (II)	R_2O_3 (III)	R_2O_4 (IV)	R_2O_5 (V)	R_2O_4 (VI)	R_2O_3 (VII)	R_2O_2 (VIII)	R_2O_1 (IX)
2a	H 1·0	?	19·0 F	16·0 O	14·0 N	12·0 C →	11·0 B →	9·1 Be	7·0 Li
1a	Na 23·0	—	—	—	—	—	—	—	—
2	— →	—	35·5 Cl →	32·0 S →	31·0 P →	28·3 Si →	27·0 Al →	24·3 Mg →	—
3	K 39 →	Ca 40·1	Sc 44·1 →	Ti 48·1 →	V 51·4 →	Cr 52·3 →	Fe 56·0 →	Mn 55 →	Ni 58·6 / Co 58·7 / 63·4 Cu → →
4	— →	→	79·9 Br →	79·0 Se →	75·1 As →	72·3 Ge →	69·9 Ga →	65·3 Zn →	→ → Zn
5	Rb 85·5 →	Sr 87·5 →	Y 89·0 →	Zr 90·0 →	Nb 94·0 →	Mo 95·7 →	Ru 101·6 →	Rh 103 →	Pd 106·3 → → 107·9 Ag
6	— →	→	→ 126·8 I →	→ 125·0 Te →	→ 120·3 Sb →	↓ 119·1 Sn →	113·7 In →	112·1 Cd →	? ? → → Ag
7	Cs 132·9 →	Ba 137 →	La 138·5 →	Ce 140·3 →	? →	? →	? →	? ?	? ?
8	— →	→	? →	→	? →	→	?	?	? ?
9	? ?	? ?	Yb 173 →	? →	Ta 182·5 →	W 184 →	Os 191·3 →	Ir 193 →	Pt 194·3 → → 197·2 Au
10	— →	—	→	→	→ 208·1 Bi →	→ 206·9 Pb →	204·2 Tl →	200·2 Hg →	→ → Au
11	? ?	? ?	? ?	Th 232·5	? ?	U 240	? ?	? ?	? ?

Series of elements.

3 N 2

Let X be the abscissa of the intersection of the first of these with the axis of x, X + a that of the second, X + 2a that of the third, and so on.

And let $-$Y, be the ordinate of the radiating points.

Let α_1, α_2, α_3, &c., be the inclinations of the radiating lines repectively.

Then the equation to the curves referred to their asymptotes as axes is

$$xy = \cot \alpha.$$

Therefore the general equation to the first set of curves is

$$y(x - (X + na)) = \frac{X + na}{Y},$$

where n is any integer.

Assuming that the radiating centres occur at regular distances $= 3a$, the equation to the second set becomes

$$y(x - (X + na)) = \frac{X + (n - 3)a}{Y},$$

and that of the hypothetical set before the first is

$$y(x - (X + na)) = \frac{X + (n + 3)a}{Y}.$$

And the equation to all the hypothetical series in its most general form becomes

$$y(x - (X + na)) = \frac{X + (n - 3m)a}{Y},$$

where m and n are any integers whatever, positive or negative.

I must not close this paper without thanking Professor Ramsay for his encouragement and assistance. To Mr. L. Archbutt I am also much indebted in many ways, and to Mr. C. E. Wolff for his assistance in mathematical matters.

TABLE IV.

Element.	Atomic weight.	Specific gravity.	Specific heat.	Volume heat.	Volume atoms.	Classes.
Hydrogen......	1·0082	0·62	5·88	3·6456	0·6149	1
Lithium	7·02	0·59	0·941	0·5552	0·0806	9
Beryllium	9·1	1·85	0·62	1·147	0·2029	8
Boron	11·0	2 68	0·5	1·34	0·2429	7
Carbon D......	12·0	3 514	0·459	1·613	0 2928	6
„ G......	—	2·25	0·467	1·050	0·1875	
„ A......	—	1·7	0·467	0·794	0·1416	
Nitrogen	14·03	—	—	—	—	5
Oxygen.......	16·0	—	—	—	—	4
Fluorine.......	19·0	—	—	—	—	3
Sodium	23·043	0·985	0·293	0·2886	0·0419	1

TABLE IV—*continued.*

Element.	Atomic weight.	Specific gravity.	Specific heat.	Volume heat.	Volume atoms.	Classes.
Magnesium	24·3	1·743	0·25	0·4357	0·0716	8
Aluminium	27·01	2·583	0·218	0·5631	0·0955	7
Silicon	28·33	2·48	0·2029	0·5034	0·0875	6
Phosphorus....	31·03	2·22	0·17	0·3774	0·0714	5
Sulphur	32·06	2·07	0·1776	0·3676	0·0645	4
Chlorine	35·46	—	—	—	—	3
Potassium	39·14	—	0·166	0·1436	0·0221	1
Calcium	40·08	1·57	0·1686	0·2647	0·0390	2
Scandium	44·1	—	—	—	—	3
Titanium	48·13	—	—	—	—	4
Vanadium	51·4	5·87	—	0·696	0·1141	5
Chromium	52·3	7·0	—	0·7128	0·1168	6
Manganese	55·0	7·39	0·122	0·9015	0·1342	7
Iron............	56·02	8·00	0·112	0·896	0·1424	8
Cobalt	58·7	8·9	0·107	0·9523	0·1515	9
Nickel.........	58·6	9·0	0·109	0·981	0·1534	9
Copper	63·4	8·95	0·0933	0·835	0·1367	9
Zinc	65·3	7·15	0·95	0·6792	0·1094	8
Gallium	69·9	5·96	0·079	0·4708	0·0851	7
Germanium....	72·3	5·47	0·0749	0·4086	0·0755	6
Arsenic........	75·09	4·7	0·0758	0·3562	0·0624	5
Selenium	79·00	4·2	0·0746	0·3133	0·0531	4
Bromine.......	79·95	—	0·0843	—	—	3
Rubidium......	85·5	1·5	—	—	0·0175	1
Strontium......	87·5	2·54	—	—	0·290	2
Zirconium	90·0	4·15	0·066	0·2739	0·0461	4
Niobium.......	94·0	7·06	—	—	0·0751	5
Molybdenum ..	95·7	8·6	0·0722	0·6209	0·0897	6
Ruthenium.....	101·65	12·26	0·0611	0·7491	0·1217	7
Rhodium	103·0	12·1	0·058	0·7018	0·1173	8
Palladium......	106·35	11·4	0·0593	0·6760	0·1182	9
Silver	107·93	10·57	0·0570	0·6025	0·0987	9
Cadmium......	112·1	8·65	0·0567	0·4895	0·0771	8
Indium..	113·7	7·42	0·057	0·4229	0·0651	7
Tin	119·1	7·29	0·0562	0·4097	0·0611	6
Antimony......	120·3	6·7	0·049	0·3283	0·0556	5
Tellurium......	125·0	6·23	0·0483	0·3009	0·0497	4
Iodine.........	126·85	4·95	0·0541	0·2678	0·0393	3
Cæsium	132·9	1·88	—	—	0·0141	1
Barium........	137·0	4·0	—	—	0·0291	2
Lanthanum	138·6	6·163	0·0448	0·2761	0·0445	3
Cerium........	140·3	6·68	0·0448	0·2992	0·0476	4
Tantalum	182·5	10·78	—	—	0·0574	5
Tungsten	184·0	19·20	0·0334	0·6413	0·1042	6
Osmium	191·3	22·48	0·0311	0·6991	0·1174	7
Iridium	193·0	22·42	0·0326	0·7309	0·1161	8
Platinum	194·3	21·50	0·0324	0·6996	0·1105	9
Gold	197·22	19·33	0·0324	0·6263	0·0980	9
Mercury.......	200·2	14·19	0·0319	0·4526	0·0709	8
Thallium ,.....	204·2	11·9	0·0336	0·3998	0·0581	7
Lead	206·93	11·35	0·0314	0·3564	0·0542	6
Bismuth	208 1	9·76	0·0308	0·3006	0 0469	5
Thorium.......	232·4	11·1	0·0279	0·3097	0·0476	4
Uranium	240·0	18·7	0·0277	0·5180	0·0779	6