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THE SPECIFIC GRAVITIES OF THE ELEMENTS CONSIDERED IN THEIR RELATION TO THE PERIODIC SYSTEM.[1]

PART I. ATOMIC VOLUMES.

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Introductory.

The periodic system of the elements, as established by the separate papers of Mendeléeff and Meyer in 1869, is based upon three important arguments:

1. Recurrence of chemical properties.
2. Similarities of valence.
3. Recurrence of physical properties.

In regard to the first argument, the fact that chemical properties are shared by certain elements in groups had been already noted long before 1869, but as a pioneer it had proved too weak an argument to suggest a complete system of the elements in families. The second appeal was of greater influence. The gradual awakening in the minds of chemists to the significance of the term valence through the work of Frankland, Kekulé, Couper, Wurtz, LeBel and van't Hoff, and of Erlenmeyer, did much to guide the thoughts of critics towards the final acceptance of the completed periodic system. Against this, however, nothing has acted so strongly in the way of a counter-argument as the necessity of accepting with valence the accompanying conception of variable valence. Thus the second appeal lost much of its persuasive force. Historically, no one contribution has been of such lasting influence as the third of the above arguments—the recurrence of physical

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[1] The essentials of this paper were first presented before the Science Club of Amherst in December, 1907, and the paper was then presented in abstract before the American Chemical Society at the New Haven meeting in July, 1908.

properties—especially as developed by Meyer's curve of atomic volumes. The fact that physical properties, as well as chemical, could be shown to vary periodically with the atomic weights was early accepted as a strong argument in favor of the fundamental periodicity, and the forty years which have followed have only confirmed chemists in this favorable attitude. The first test, therefore, to which any system of atomic weights has been, or is likely to be subjected, is that of its agreement with or explanation of this historically important curve of atomic volumes.

It is proposed in the present paper to discuss the real meaning of this relationship—atomic volumes; and in the second paper following, the bearing of the conclusions in the first paper upon the form of the periodic system.

Significance of Atomic Volumes.

It is remarkable, considering the fundamental importance of the curve of atomic volumes, that no careful analysis of it has ever been published. The simple interpretation, given in the succeeding pages, may have been previously grasped by students, may even have been assumed by Meyer;[1] but it is evident that the real significance of the curve has not been clear to the writers succeeding him. It will not be amiss, therefore, to express in as few words as possible some fundamental thoughts beyond the bare statement, so often repeated, of the remarkable fact of the existence of the curve.

If we examine Chart I, we find that Meyer has charted atomic volumes on the one axis and atomic weights on the other (see page 1007).

There is a direct relation between these two values for we have

$$\text{Atomic volumes} = \frac{\text{atomic weight}}{\text{specific gravity}}, \text{ or}$$

$$\text{Atomic volume} = \text{atomic weight} \times \text{specific volume},$$

and when we place

$$\text{Atomic weight} \times \text{specific volume}$$

on the axis of ordinates, and

$$\text{Atomic weight}$$

on the axis of abscissas, we have a curve every point of which has an x and y such that the ratio y/x = specific volume.

Meyer's curve owes its periodicity to the variation in specific volumes. For the emphasis which he desired—to establish the importance of atomic weights—he was right in drawing the curve as he did, complicated by the atomic weights. Yet because of this desire he has allowed this complication to cloud an important simple thought which may be stated as follows:

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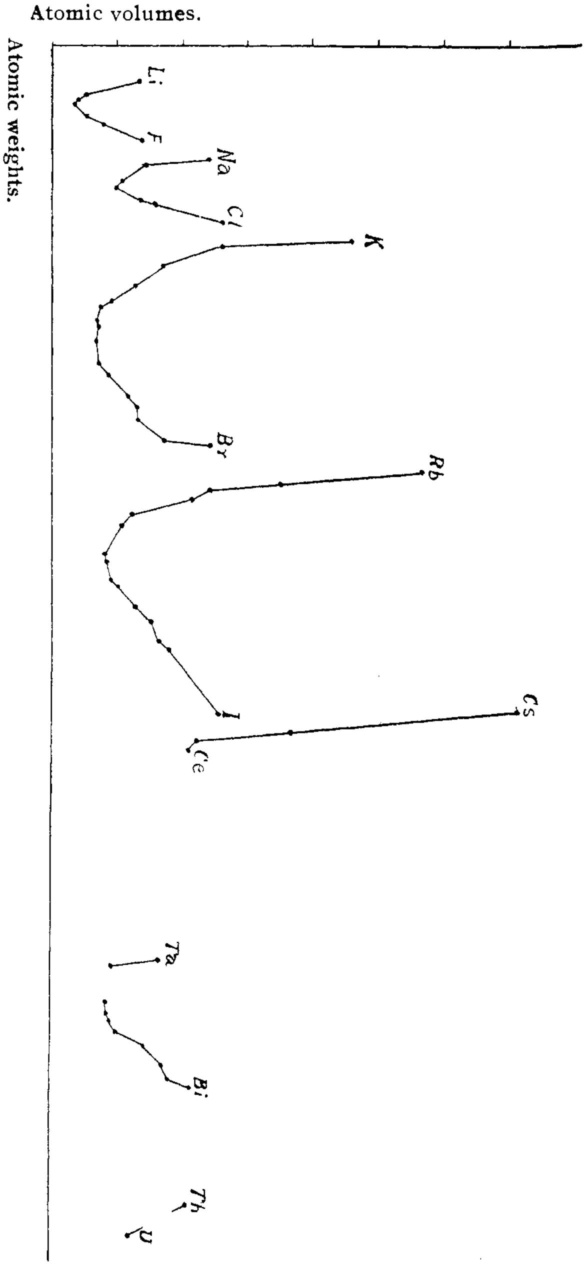
[1] Meyer makes nowhere a statement to this effect and his argument was perhaps left clearer without this complication.

Given the orderly succession of the atomic weights,
The periodic character of the curve of atomic volumes is due
to specific gravity alone.



"The atomic volumes are periodic functions of the atomic weights."

Chart I. Meyer.

Another proof of this same fact may be reached by the method of elimination; for if in plotting $\frac{\text{atomic weights}}{\text{specific gravities}}$ on the axis of ordinates and atomic weights alone on the axis of abscissas, we consider the item

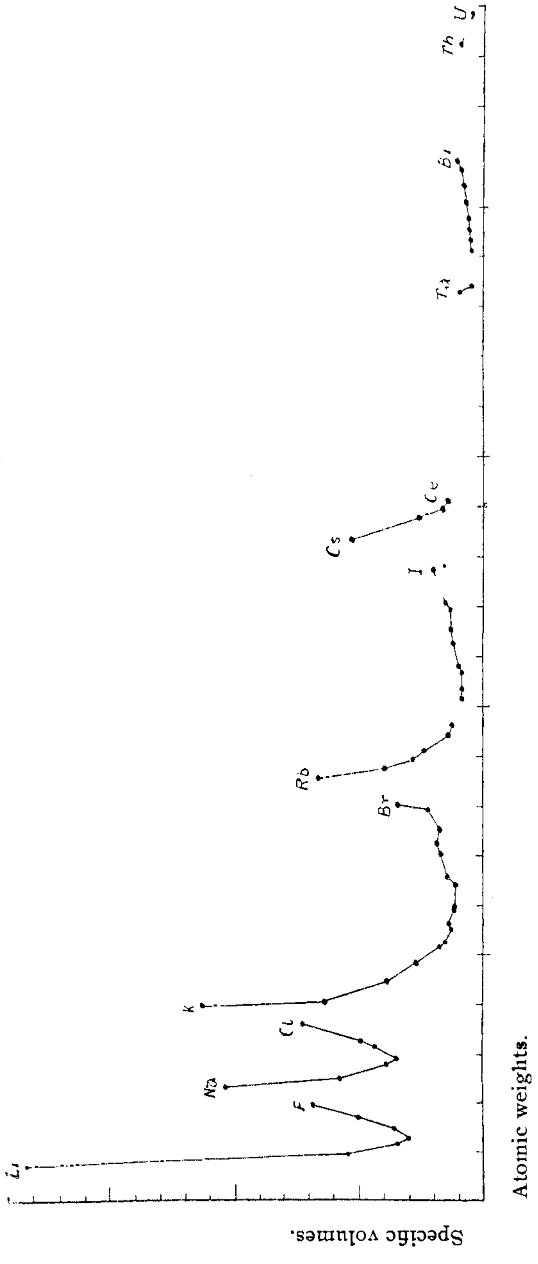
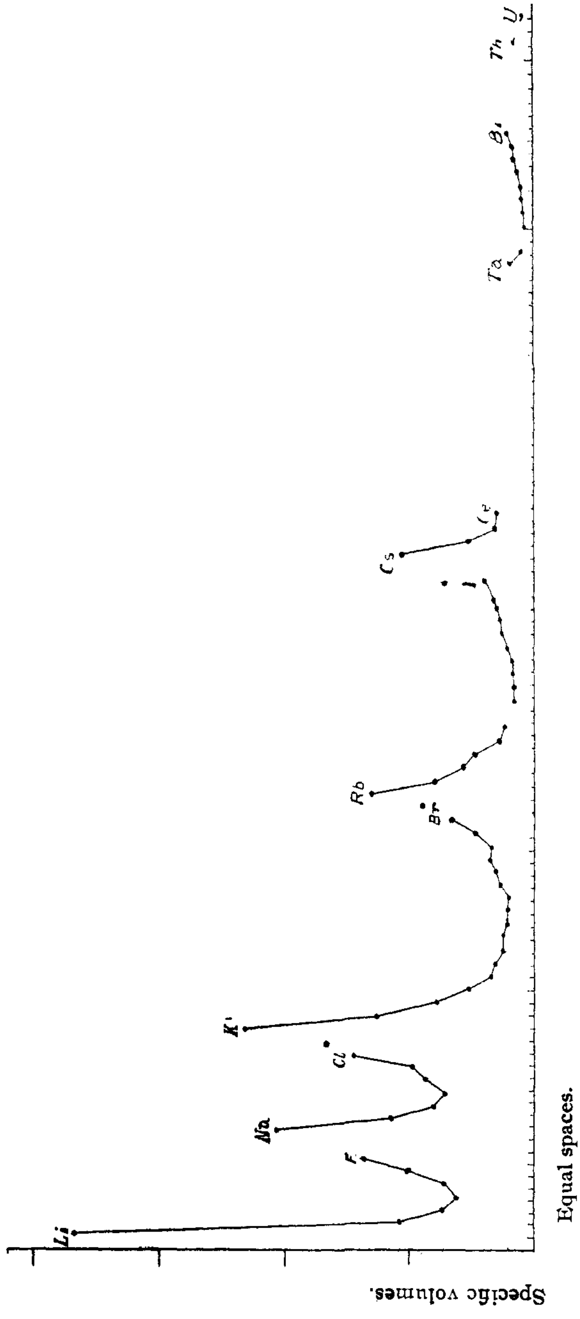


Chart II. Specific volumes to atomic weights.

specific gravities to remain a constant, periodicity entirely disappears, for we are now plotting atomic weights on the one axis against atomic weights on the other axis; and the curve is a right line.

Chart III. Specific volumes to equal spaces.



Specific gravities are periodic functions of the atomic weights.

It is evident therefore that the periodic character of this curve is due wholly to the one item, specific gravity.[1] In the following chart, in the place of the expression $\frac{\text{atomic weight}}{\text{specific gravity}}$ or atomic volume, is substituted on the axis of ordinates the simpler expression $\frac{1}{\text{specific gravity}}$ or specific volume. Otherwise, the chart is the same as Meyer's. As we should expect from what has been developed, although the irregularly increasing value of the atomic weights is eliminated from the one axis (ordinates) and not from the other, the general character of the periodicity is the same as shown on Chart I (see Chart II, p. 1008).

But since the periodicity of the curve of atomic volumes has been shown to be due to specific gravities alone, it would seem more exact to eliminate atomic weights from both axes. Later in this paper it will be shown that the periodicity under discussion is dependent upon the orderly succession of the atomic weights rather than upon their actual values. Therefore it is permissible to eliminate the values of the atomic weights while retaining their sequence by plotting the expression $\frac{1}{\text{specific gravity,}}$ as in Chart II, except that equal spaces are allowed on the axis of abscissas rather than the slightly irregular differences in the values of successive atomic weights[2] (see Chart III, p. 1009).

We may therefore conclude this portion of the discussion by two statements, the one the well-known conclusion of Meyer and the other the expression of Meyer restated in the light of the facts just developed.

Meyer's Statement.—Atomic volumes are periodic functions of the atomic weights.

The Same Simplified.—The specific gravities of the elements are periodic functions of the atomic weights.

Explanation of the Periodicity.

Although, in the previous section, an analysis has been made of the periodic curve of atomic volumes, no explanation has been advanced for the periodicity in the original curve or in the one just given. On searching for such explanation, our attention is perhaps first arrested by the valence relation, *i. e.*, by the fact that on Chart III elements of low specific gravity (at the crests) are also the elements of lowest valence and that as the valence towards hydrogen increases in the short periods from

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[1] It is clear, therefore, that if our judgment is based upon this curve alone the much discussed and much quoted function, atomic volume, has little significance.

[2] This has the advantage of presenting an arrangement strictly in accord with the usual arrangement of the periodic system in which the elements are allotted equal spaces on the chart (see Chart XI).

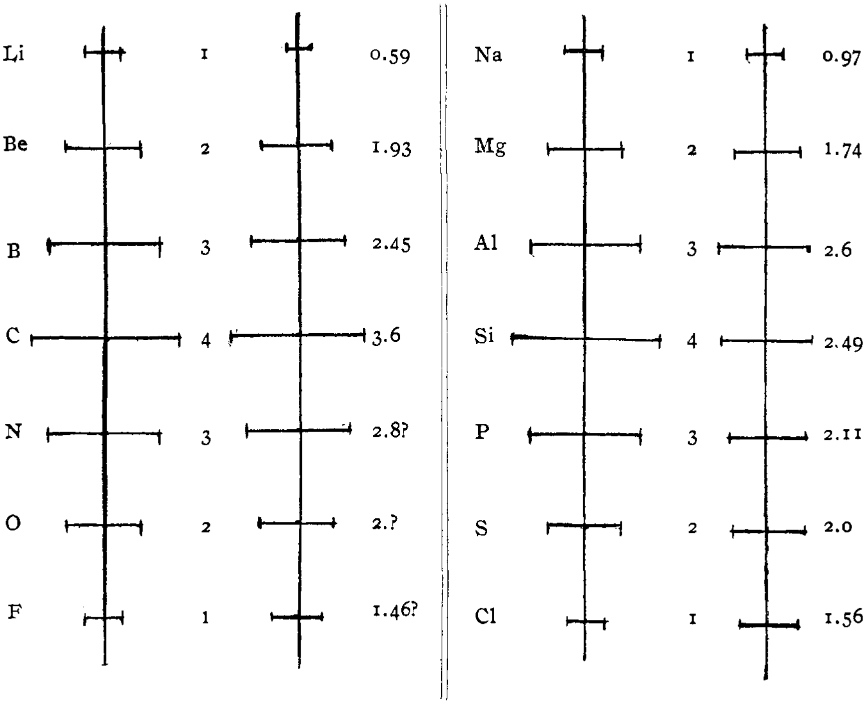
one to four and then falls to one (or zero), exactly so does the specific gravity vary, so that we may be permitted to number the positions of the elements in the short periods in the same sequence as that indicated by both valence and specific gravity. The position-numbers would then read

1—2—3—4—3—2—1—0

With this numbering established for reference, we may find the influence which position-number may be said to have on specific gravity. It is a remarkable fact that in the case of each element in the short periods the ratio of the position-number (which is established only by the succession of atomic weights in the period) to the valence of the element towards hydrogen is a constant; and again to the specific gravity is (nearly) a constant. This similarity in sequence may be shown by the following parallel columns in which the lengths of the lines show for the successive elements in the two short periods: first the position-number of valence; and second the specific gravity.

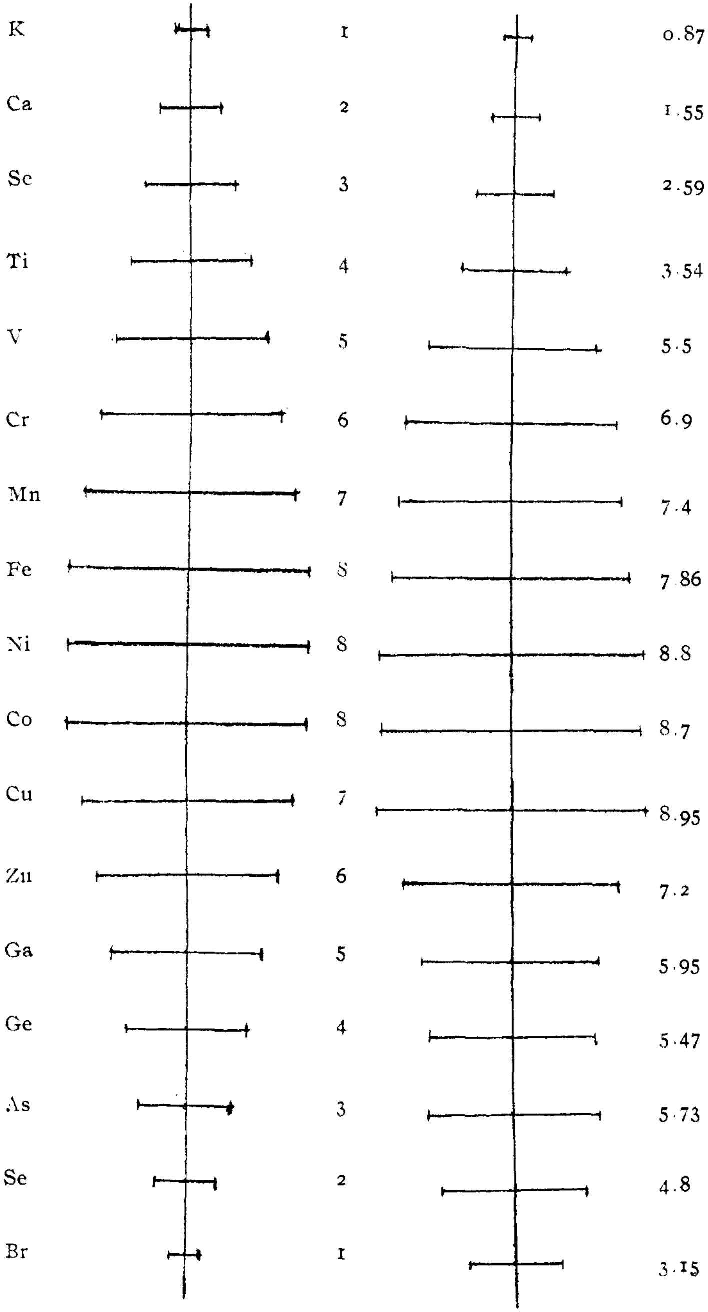
Valence and position-numbers; and specific gravities.

1st Period. 2nd Period.



Valence and Position-numbers; and Specific Gravities.

3rd Period.



This may be better shown by plotting on one chart two curves, one of position-number and one of specific gravity. For the first two periods, the curves are as follows:

Chart IV (1).

Curves of position number and specific gravity.

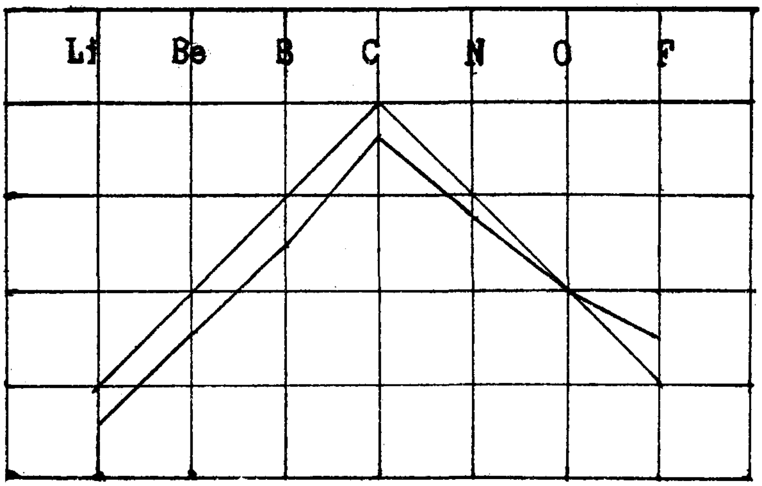
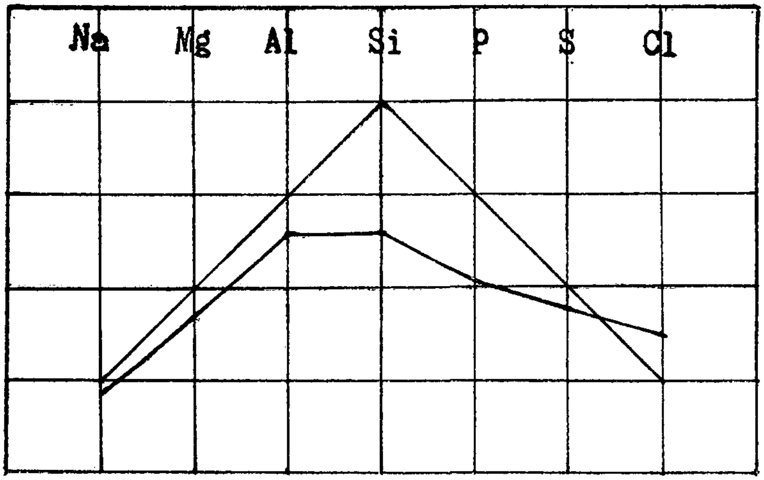


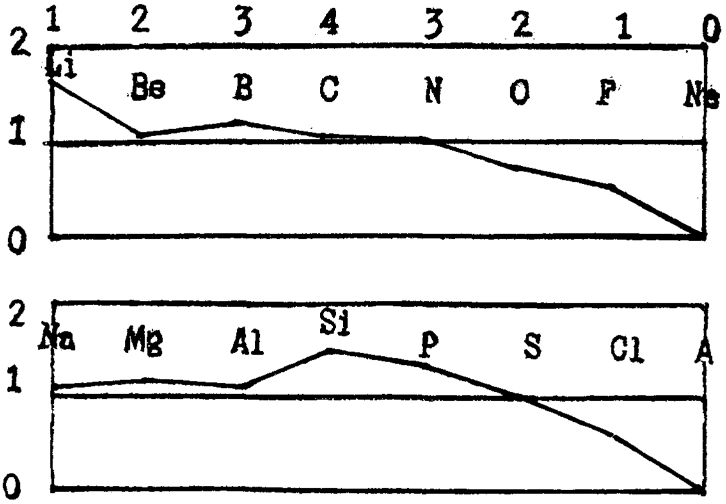
Chart IV (2).



If further we plot these two curves as a ratio, by dividing in each case position-number by specific gravity, and plot this ratio to equal spaces, the marked periodicity of Meyer's curve has disappeared[1] and the resulting ratio curve is found to be nearly horizontal:

Chart V.

Position number times specific volume.



If we compare this curve with the curve in Chart III for specific volumes (choosing this in order that both curves compared may be plotted to equal spaces) we are led to the conclusion that the remarkable flattening of the specific volume curve is due either to the fact that valence is a function of specific gravity, or to the more probable fact that these two properties are, each and singly, functions of the fundamental position of the element in the period. In whatever way the relation be expressed, even a numerical connection between valence, a chemical property, and specific gravity, a physical property, is unexpected.[2] That their values are nearly equal is even more unexpected. Moreover, it is a necessary corollary that those many other physical properties which Meyer enumerated,[3] as far as they are dependent upon specific gravity, must be related to valence and also to position-number.

The Fundamental Character of Position-Number.

Since the position of the elements in any period on Chart V (the num-

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[1] Meyer's curve, Chart I, should be compared with Chart V, remembering that the periodicity is caused by specific gravity as already shown on Chart III.

[1] It is like the connection, in the case of gases, between molecular weights, and atomic or chemical property, and densities which are found experimentally by comparing physical volumes.

[3] Besides valence and atomic volume, Meyer discusses states of aggregation, ductility, malleability, volatility, electrochemical behavior, expansion by heat, refraction of light, conductivities of heat and light and magnetic properties.

bers of which may be taken as decreasing from a central maximum) are fixed, being determined by the succession of the atomic weights, I regard position in the period as the fundamental property; and specific gravities, valences (and all properties dependent upon these) as functions of it. At a time when it was customary to calculate properties against *mass*, Meyer took a step in advance, teaching that physical phenomena are to be regarded as functions of the atomic weights. But now, in further advance upon the above teaching of Meyer, we may assert that physical properties are to be regarded as functions of the position-numbers; and that in calculations involving certain physical properties the position-numbers are the only determining factors and are therefore in these cases more important than the atomic weights.

So far, we have given attention to the curves for the short periods only. But the ratio curves plotted on Chart V are typical of those to follow as the succeeding statements will show. They have the same general character. The ratio of position-number to specific gravity on Chart V does not vary much from the limits of 1.0 and 1.2, except that at the end it falls gradually to zero.[1] In the succeeding periods also we shall find, for each, a nearly constant ratio; but as we go down the chart, the average of the specific gravities of the elements in each of the successive periods increases faster than the increase in average atomic weights, so that this ratio becomes less. From the first period to the last it has fallen from 1.1 to 0.4. But the horizontal character of the curves appears again, in each period, as it did in the first two. We get, for all the periods, curves of the same character as those just plotted. But these may be obtained only by distinguishing between short periods and long periods, as they are distinguished in Meyer's curve, Chart I, as well as in Charts II and III. This requires in the long periods positions from one to eight rather than from one to four. In Meyer's chart, in the first two periods, both valence- and position-number rise from one to a maximum of four and fall from that maximum gradually to zero; and in the following periods the position-number and valence rise step by step to a possible "maximum of eight" and then (valence being irregular) position-number falls to zero. That the rise and fall of specific gravities keep pretty regular step with the position-numbers may be seen by the following parallel columns for the first long period, which may be taken, without further repetition, as typical of similar columns which may be easily constructed for the succeeding periods.

If we plot these values on one chart, we will continue Chart IV for the third (or first long) period as follows:

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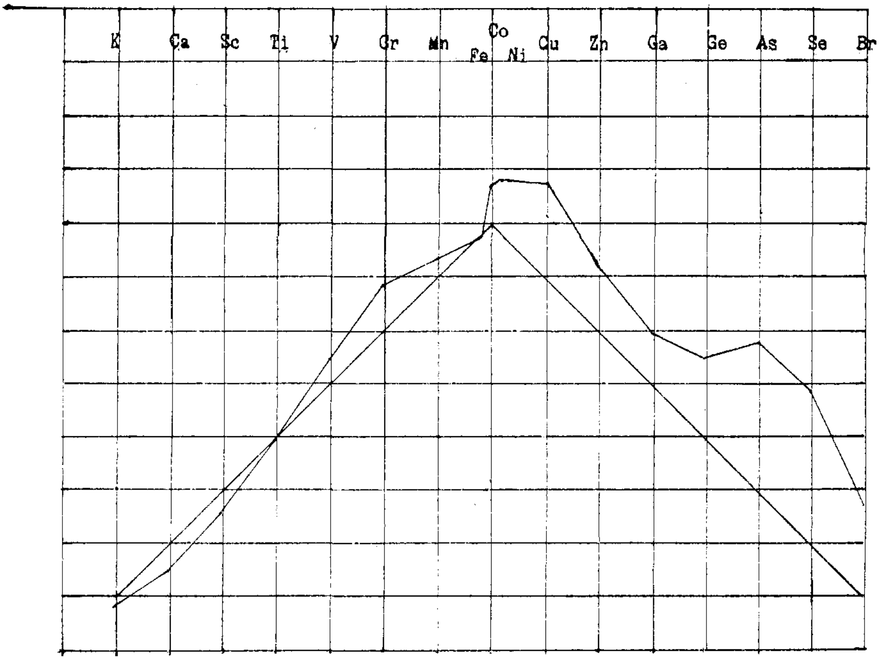
[1] Lithium alone, as far as we know, of all the elements plotted by Meyer in the whole chart (see Chart VI) occupies a position which we must regard as anomalous.

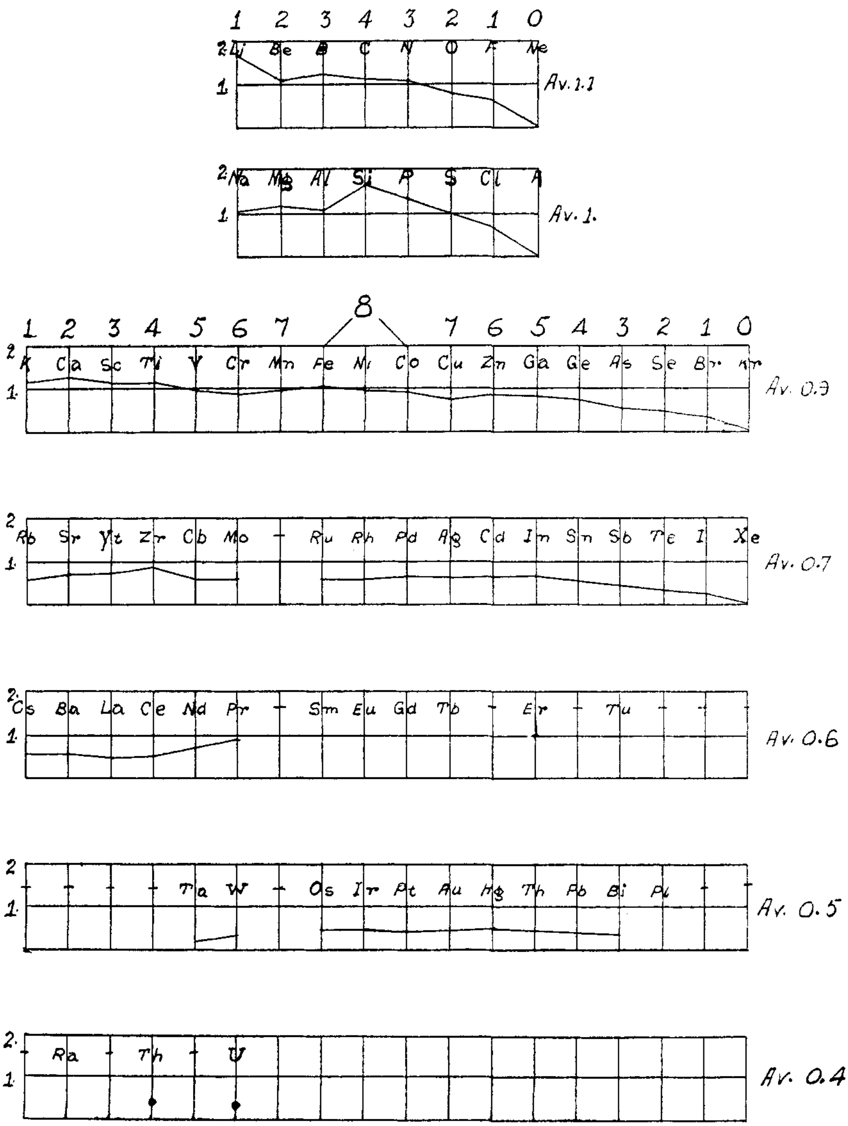
Chart IV (3).



Continuing with the ratio curves, such as were shown on Chart V for the short periods only, we have in the following, Chart VI, for all periods, a complete exhibit of this ratio, position-number to specific gravity. Assigning, in the long periods, position-numbers from one to a maximum of eight, the character of the curves proves much the same as in the short periods—nearly horizontal but gradually falling off towards the end to zero (see Chart VI, p. 1017).

From these curves we must conclude that the position-numbers (which denote only the orderly succession of the atomic weights) change *pari passu* with the specific gravities of the elements occupying those positions. This points to a remarkable numerical relation between the position of the element in its period and its specific gravity. So simple is this that in order to calculate the position of an element in its period we have in most cases only to consider its specific gravity and take the nearest integer. For example, in the first two periods the average may be taken roughly for the ratio $\frac{\text{position-number}}{\text{specific gravity}}$ as 1.1, which means that the position-number will be in each case a little larger than the figure for specific gravity. Since the specific gravity of beryllium is 1.85, therefore its position is 2; that of boron is 2.85, therefore its position is 3; that of carbon (diamond) is 3.6, therefore its position is 4. The specific

Chart VI. Position number × specific volume.



gravities of sodium, magnesium and aluminum are respectively 0.97, 1.74, and 2.60, which assigns them respectively the positions in the second period one, two and three, which we know they occupy. Conversely, from the position-number in the first long period, where the ratio is about 0.9, we may judge of iron that its specific gravity is a little less than eight. It is given as 7.86. We have thus a memory-guide to the specific gravities of the elements. This applies especially to the first four periods, as our knowledge of the proper arrangement of the elements beyond this as well as of the specific gravities of the rare-earth elements is not as complete as it is in the first portion.

Meyer's greatest contribution to this subject was the importance which he attached to atomic weights in calculation—in place of mass alone. But we now see that they should be introduced with care into calculations of physical properties.[1] They need enter in only so far as they determine the orderly succession of the elements in the periods—that is, so far as they determine position-numbers. Since position-numbers are nearly identical with specific gravities, and often with valences, it is not surprising that formulas for physical properties have been empirically derived which involve specific gravities only or valencies only, to the exclusion of the atomic weights. Each successive formula of this nature confirms the argument of this paper, *i. e.*, that the position of an element in a period determines the specific gravity of the element and through it other physical properties; and that in calculations involving atomic volumes the atomic weights may be neglected, provided the position-number is introduced, for it is only indirectly that atomic weights, which are all-important in chemical calculations, are involved in these purely physical relations.

As illustrations of such empirical formulas as have been referred to, the following have recently come to notice:

Longinescu in 1901[2] published a formula for the calculation of the boiling points of liquids and the melting points of solids, involving specific gravities and the number of atoms in the molecule (the atomic weights not appearing in the calculation), and showed the application of his formula to the degree of dissociation.

Barlow and Pope in 1906,[3] in their theory of valence and crystallography, have used valence in the place of atomic volume in their calculations of the shape of crystals; and here again the atomic weights do not appear in the calculations.[4]

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[1] Physical properties may involve specific gravities simply; or these complicated by internal motion. We may also have physical properties in which specific gravities do not function (*e. g.*, specific heat). Wherever this item enters at all, the figures for valence or position may be substituted without any serious change of ratio. As an important illustration of this, we have the equivalent (= At. wt./valence) and atomic volume (= At. wt./sp. gr.)—one a purely chemical quantity and the other so often used with purely physical significance. Yet they are arithmetically nearly identical!

[2] Annales scientifiques de l'universite de Jasy.

[3] *J. Chem. Soc.*, p. 1675.

[4] Barlow and Pope seem however to advance a theory the reverse of that of Meyer's and of that advanced in this paper. According to their paper valence and atomic volume vary together while in the Meyer curve the valence is a minimum when the atomic volume is a maximum; and in this paper, when specific volume is a maximum.

Richards and his students published, in 1907,[1] a paper on the compressibilities of the elements and their periodic relations in which he showed a periodic curve, similar to the curve of atomic volumes, plotted by calculating compressibilities against atomic weights. This paper will be discussed in Part II.

Verschoyle, in 1908,[2] in an article on the periodic system, insists on the influence of specific gravity on the position of elements in the system.

Traube, in 1909,[3] contends that atomic volumes (*i. e.*, specific gravities) must be used in the place of atomic weights in periodic relationships.

Conclusion.

In Part I of this paper, the author has attempted to make clear:

1. That the following values are interchangeable: for atomic volume, the ratio of atomic weight to valence (equivalent), the ratio of atomic weight to position-number; for specific volume, the reciprocal of valence or of position-number; for specific gravity, valence or position-number.

2. That in all relations involving atomic volume we may eliminate atomic weight and then substitute the reciprocals of specific gravity, valence or position-number.

3. That the periodicity of the atomic volumes curve is not directly dependent upon the item atomic weights, as might be inferred from the writings of Meyer, but is due to the physical property specific gravity.

4. That among the numerically closely related figures for specific gravity, valence and position-number, the latter may be considered fundamental since the orderly succession of the atomic weights is fundamental.

PART II.—THE FORM OF THE PERIODIC SYSTEM.

Historical.

From the date of the first publication of the periodic system by the authors, many suggestions have appeared tending to modify the fundamental arrangement. The recent years which include the discovery of the rare-earth elements and that of the members of the argon family have been productive of valuable papers bearing upon the position of these elements in the system and upon the proper form of the table. Suggestions and discussions of this nature, which will repay careful study, are to be found in the work of Thomsen in 1895,[4] Steele in 1901,[5] Staigmuller[6] and Biltz[7] and Braunes[8] and Rudorf in 1902,[9] Gooch in his

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[1] *Car. Pub. Inst.*, 76.

[2] *Chem. News*, **97**, 226.

[3] *Physik. Z.*, **10**, 667.

[4] *Z. anorg. Chem.*, **1895**, 190 and 293.

[5] *Chem. News*, **1901**, 245.

[6] *Z. physik. Chem.*, **1902**, 245.

[7] *Ber.*, **1902**, 562.

[8] *Z. anorg. Chem.*, **1902**, 1.

[9] *Ibid.*, **1902**, 107.

recent text,[1] Benedicks in 1904,[2] Abegg in 1904 and 1905,[3] Werner in 1905,[4] Verschoyle in 1908,[5] Egerton in 1909[6] and of Loring in 1909.[7]

Those proposed forms which disrupt the short periods, leaving a necessary blank space in the middle, *e. g.*, between carbon and nitrogen and between silicon and phosphorus, may be dismissed from consideration, for blank spaces always stand in other portions of the chart for possible elements, and the differences in the numerical values of the atomic weights of the elements so separated is too small to allow of this possibility, as Abegg has already stated.

Recognition of Short and Long Periods.

The arrangement which can alone be satisfactory is one which is concise and in which allowance is made for short and long periods. The necessity for this latter requirement was not so realized by Mendeléeff as to modify his periodic arrangement. Referring to Part I, it will be found that specific gravity numbers confirm the existence of short and long periods, already indicated in the atomic-volume curve of Meyer. The crests of this curve are found to occur first with lithium, sodium and potassium, nearly equidistant (resulting from which we have two short equal periods); but then not again until, after quite a distance, down the catalogue of the elements arranged according to the increasing atomic weights, rubidium is reached. Next, after a similar long distance, the crest occurs with caesium. This important fact of the inequality of the periods is found hidden in the curve of Meyer; as well as the accompanying fact that in the first periods the sinus of the Meyer curve, where $dy/dx = 0$, is at the fourth family of elements, and in the following periods this sinus occurs with the eighth family of elements. In Part I it was shown that the periodicity of the atomic-volume curve was due to the complementary periodicity of the curve of specific gravity; and it was also developed that it is convenient to recognize, as the cause of the periodicity in both cases, the position-numbers of the elements; and that it is more convenient to take these numbers as decreasing from a central maximum in both short and long periods, thus putting them in accord with the observed specific gravities and valencies.

In the present state of our knowledge of physical constants, it is impossible to decide whether any one constant involves such a factor as atomic volume—*i. e.*, whether the complexity of the constant may be simplified by elimination of such a factor as specific gravity, valence or

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[1] "Outlines of Inorganic Chemistry," Gooch and Walker.

[2] *Z. anorg. Chem.*, **1904**, 41.

[3] *Ibid.*, **1904**, 366; *Ber.*, **1905**, 1386.

[4] *Ber.*, **1905**, 914.

[5] *Chem. News*, **1909**, 226.

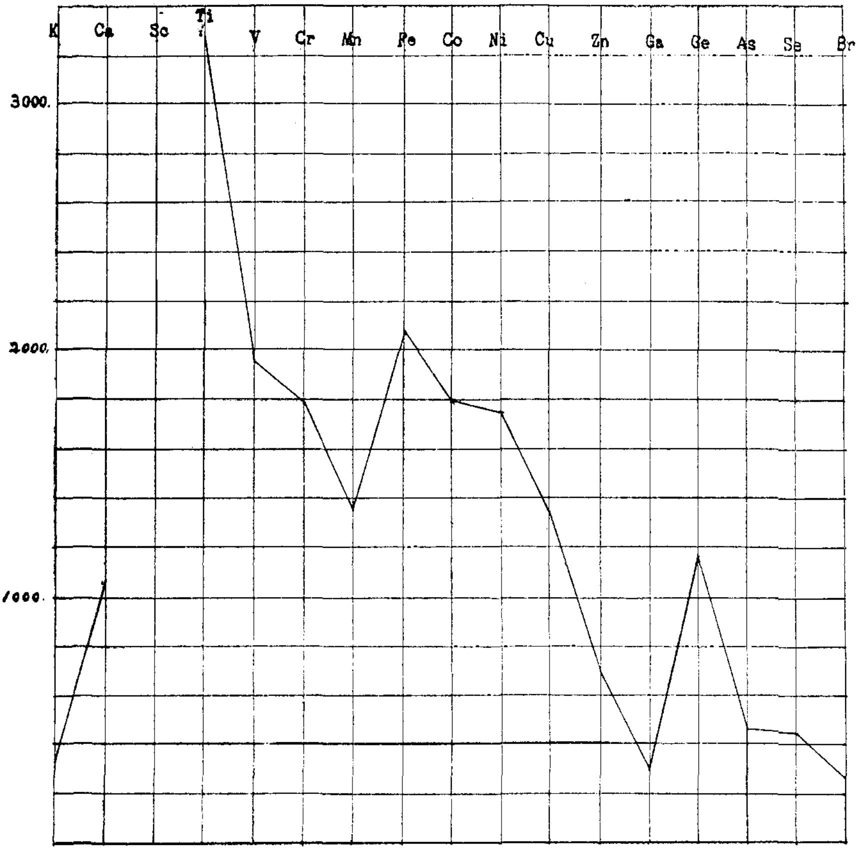
[6] *J. Chem. Soc.*, **1909**, 238.

[7] *Chem. News*, **1909**, 148.

position-number, except by the old test of trial and error. I propose to test in this crude way two constants to see whether their periodic curves are flattened by position-numbers; and by doing this with the long K - - - - Br period to determine whether the positions in that period run to four or to eight.

The melting points of the elements were first arranged to show a periodic curve by Meyer and later by Carnelly. This curve for the first long period (K - - - Br), our basis of illustration, is shown on Chart VII:

Chart VII. Melting points.



It is probable that the temperature of the melting point of any element is fixed by other factors than specific gravity, valence or position-number. Pictet[1] gave a formula involving atomic volume together with the coefficient of expansion of the element. Deer[2] then eliminated

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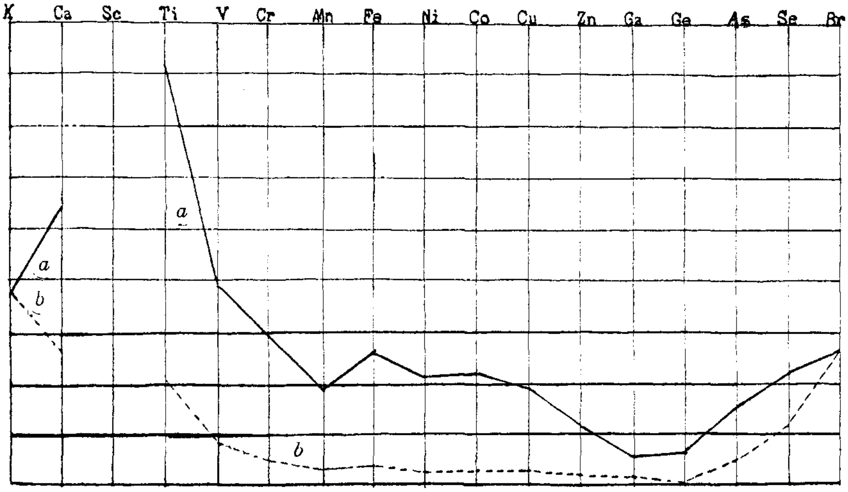
[1] *Compt. rend.*, 1879, 855.

[2] *Chem. News*, 1897, 234.

atomic volume from this and obtained portions of a curve which seemed periodic. J. W. Richards[1] introduced the latent heat of fusion, derived from specific heat, into his formula, and Crompton[2] varied the previous formulas by introducing the ratio atomic weight over valence. If, therefore, the curve should be flattened by applying the factor position-number, it would seem as if its periodicity were in part at least determined by the factor which is generally called atomic volume. We may thus get another indication of whether the sequence of numbers used should be those falling from a maximum of four or those falling from a maximum of eight.

We should first stop parenthetically to recognize the difference between the two classes of periodic curves. As a convention, we may call curves like the atomic-volume curve (Chart I) concave. The periodic curve of specific gravities (Chart IV) is the opposite and may be distinguished as convex. It has been shown (*v.* Chart VI) that the concave curve of atomic volumes is flattened by multiplying by the corresponding values of specific gravities or position-numbers. The melting point curve which has just been presented is convex so that our attempt to see if this may be flattened by applying the position-numbers must be by division rather than by multiplication. This ratio curve is as follows:

Chart VIII. *a.* Melting points divided by (position-numbers).
b. Melting points divided by (position-numbers)^2.



The partial flattening of the curve indicates that melting points vary partially at least with the position-numbers; also with the specific gravities—which seems natural. But the important point is that this approx-

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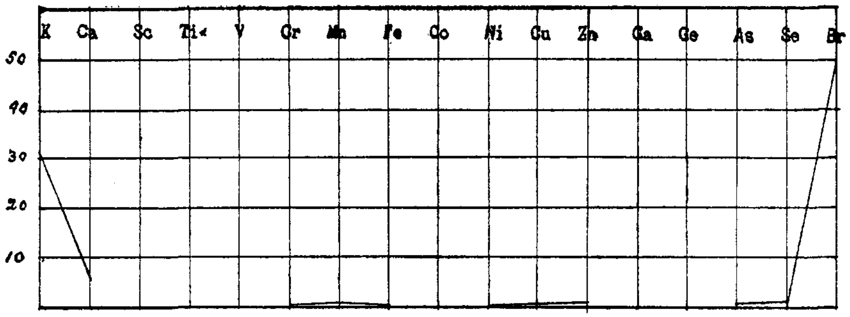
[1] *Chem. News*, 1897, 278.

[2] *Z. physik. Chem.*, 1907, 635.

imate flattening could not be obtained if we recognized for this period only position numbers from one to four.

Richards' compressibility figures, already referred to, give for the same period (K...Br) a concave curve which is plotted as follows:

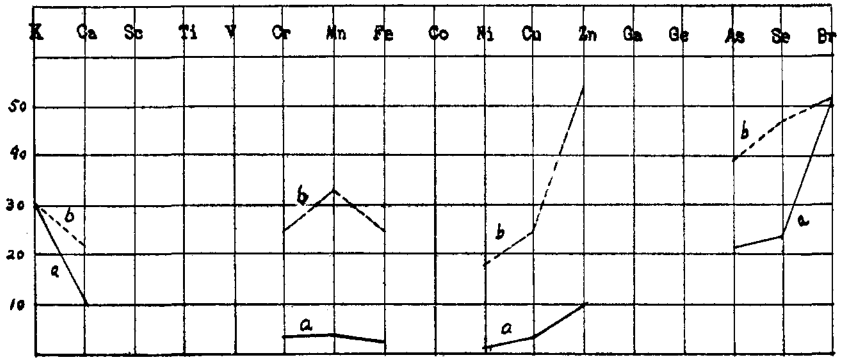
Chart IX. Compressibilities.



This curve is, according to Richards, periodic in the same way that the curve of Meyer is periodic. Let us see if it can be flattened by applying the position-numbers to it. This must be done by multiplying. The result is given as Curve *a* in the following chart:

Chart X.

a. Compressibilities x (position-number); *b*. Compress's x (position-number).[2]



The value $y =$ *constant* is evidently more closely approximated in this curve than in the original one; and this would indicate, if it were perfect, that compressibilities vary with specific volumes. This would seem natural also and is the reverse of the finding for melting points. I have found that a better result is obtained by multiplying by the square of the position-numbers as shown by curve *b* in Chart X above. The values plotted are closer to a constant value in this case and indicate that compressibilities vary approximately with the squares of specific volumes or inversely as the squares of specific gravities. Fessenden[1] published a formula for rigidity in which this property is shown to vary inversely as (atomic volumes)$^{5/3}$, but when temperature is taken into consideratio nrigidity varies inversely as (atomic volumes)^2, which is effectively the factor used in curve *b* above. From this work he derives figures in good accord with those experimentally determined for Young's modulus for elasticity. These results, however imperfect, would be simply impossible with position-numbers from four to one.[2]

Establishment of Sequence Numbers.

Since these results call in short periods for four different grades of specific gravities and in the long periods for eight different grades of specific gravities, and these give respectively four and eight different values of atomic volumes, four and eight different values of melting points and approximately four and eight different values of compressibilities, it is probable that the same distribution into four and eight values will be found for many other physical properties which may be said to depend upon the fundamental physical property, specific gravity; and since this is seen to be connected with the orderly sequence of the elements according to their atomic weights, the position-number which indicates this chemical relation (and which binds together all the above physical properties) has been chosen in the previous section as the fundamental chemical property; and in this connection it is emphatically evident that the position-numbers which in the short periods run from one to four must in the long periods continue to eight, else none of the facts cited above are explicable.

Conformity Attained by Placing the Centers of the Long Periods Immediately below the Centers of the Short Periods.

The separation into short and long periods is not given, is only suggested, by the original tables of Mendeléeff and of Meyer and there are relationships in these tables which are not in accord with this idea.[3]

There is only one concise arrangement which conforms to the requirements imposed by the curve of atomic volumes and by all the arguments which lead up to the recognition of position-numbers. The eighth family of the long periods must be placed immediately below the middle ele-

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[1] *Chem. News*, 1892, 206, 217.

[2] The effect of (sequence numbers)^2 on the melting points is shown by curve VIII (*b*) above.

[3] The eighth family has always been beyond the system. Attempts to establish a "valence of eight" for members of this family have failed to impress students of this subject. Also, the discovery of the non-valent family, falling as it does in the periods of the Mendeléeff table in alternation with the eighth family, failed to give the expected assistance, since there is no similarity between these families.

ments of the short periods—the eighth family below carbon and silicon.[1] The elements of highest specific gravity are thus placed on a common axis and the other elements range out from this axis symmetrically on either side according to their gradually decreasing specific gravities.

Arrangement in Accord with Position-Numbers and Specific Gravities.

The table proposed is arranged according to the requirements enumerated above. Thomsen in 1895[2] published a table founded upon purely arithmetical grounds, similar to this but more extended in the lower portion. This was approved by Richards[3] but modified for simplicity in this same lower portion, so that Richards' table is in all essentials identical with the one now proposed. For the arrangement of the elements of the rare earths in the lower portion of the table, I am indebted to a printed wall-chart of the elements published by Baskerville. The figures at the heads of the columns indicate not only position numbers but also approximate specific gravities. They indicate also in certain cases the valence towards hydrogen and in other cases (by subtracting these figures from eight) in general the upper valences towards oxygen, as shown in the succeeding paragraph.

CHART XI.—THE PERIODIC SYSTEM.

1	2	3	4	3	2	1	0
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	A

1	2	3	4	5	6	7		8		7	6	5	4	3	2	1	0
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Ni	Co	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Yt	Zr	Nb	Mo	...	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
						→				←							
Cs	Ba	La	Ce	Nd	Pr	...	Sm	Eu	Gd	Tb	...	Er	...	Tu	Yb	...	...
...	...	...	...	Ta	W	...	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	...	...	...
...	Ra	...	Th	...	U	...	...	...	...	...	...	...	...	...	...	...	...

Valence Relations.

Without attempting to open the question "What is valence?" it would seem from the discussion in the previous portion that there is evident, especially in the short periods, some relation, as yet unknown, between the simplest valences and specific gravities. In the long periods, this relation of valence towards hydrogen is obscure; but then the relations

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[1] This does not exclude but rather confirms the possibility of an arrangement whereby at one end of the series potassium and sodium are symmetrically opposed to each other and at the other end bromine and chlorine are so placed—as developed in much detail and with great wealth of illustration in the February number of the *American Chemical Journal* by my colleague, Professor B. K. Emerson.

[2] *Loc. cit.*

[3] *Chem. News*, 1898, 194.

of the oxygen valences become of interest. On the right, in the K...Br period, we have the non-metals in their sequence (Br—Se—As—etc.), the upper valences of which may be 7—6—5—etc., gradually decreasing as the specific gravity rises. On the left, we have the metals (K—Ca—Sc—etc.), the highest valences of which are gradually increasing as the specific gravity increases. This latter tendency may be followed to chromium with a valence of six and manganese with valence seven, so that the next logical step would give to the eighth family a valence of eight, were it not that at this point there is met the tendency from the right towards a valence of zero. The arrows on the chart are intended to indicate these opposing tendencies. From the one side the tendency is to give the iron family a valence of eight and from the other to give a valence of zero so that the resultant might be any valence. Therefore, although it is inexplicable that the elements of this family tend toward a valence of two and three, yet with the two tendencies meeting here, some abnormal valence is to be expected. Again, it is normal that copper, silver and gold should be reckoned univalent; and zinc, cadmium and mercury bivalent; if we take into account the tendency towards decreasing oxygen-valence which began with bromine. This is just as normal as that chromium and manganese should have possible valences of six and seven and that the iron family should have a valence of neither eight nor zero. The univalence of copper and silver is seen to be due to a reason just the opposite of that for the univalence of potassium. Copper is thus seen to mask as a very poor metal ("noble," inert) because it is the last, heaviest of the non-metals in the period. Potassium is a true metal, of low specific gravity, base-forming, active. It is evidently an error to place these two metals in one family as they appear on the Mendeléeff chart.

The Length of the Last Periods.

Beyond the two long periods and beginning with caesium, any arrangement of the elements, in the present state of our knowledge, must surely be tentative. I have chosen the arrangement given because it allows, as Baskerville states, a place for each element that is accurately known; also because it is concise. The length of these last periods has never been indicated by any data. It is my belief that light will be thrown most promptly upon the question of the arrangement of the lower periods by increasing our knowledge of the specific gravities of the pure elements. We can then finish plotting the charts of the periodic curves of specific gravity and position-number (*v.* Part I, Charts IV and VI). It may be that these periods should be much longer, *i. e.*, that the position-numbers should run from one to possibly sixteen; or that the eighth family should in these periods contain (*e. g.*) six rather than three members; or that we should have here a return to short periods of eight members. But this question must wait further knowledge either of the number or of the physical properties—especially the specific gravities—of the rare-earth elements.

Summary.

It has been shown in Part I that, in physical calculations, symmetry is often more surely obtained by neglecting atomic weights and substituting specific gravity, valence or position-number in the place of atomic weight; that a harmonic relation, which has not been previously sufficiently recognized, exists between these three properties in any one period. In Part II there has been proposed an arrangement of the periodic system, slightly different from the usual one but in harmony with the fundamental physical property specific gravity, and more rational especially in regard to the heavy metals of the long series.

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THE DIFFUSION OF OXYGEN IN WATER.

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In a previous investigation[1] it was shown from determinations of the rate of solution of carbon dioxide and oxygen in water or the rate of escape of the gases from water that, if one adopts Nernst's theory for the phenomenon of solution, the ratio between the coefficients of diffusion of the gases mentioned may be calculated to be 1.158. For the coefficient of diffusion of carbon dioxide there are available closely concordant values obtained at 16° by two different observers, *viz.*: 1.36 and 1.41 (per sq. cm. per 24 hours) by Stefan,[2] and 1.37 by Hüfner,[3] who used hydrophane plates. For oxygen, moreover, Hüfner (with hydrophane plates and counter-diffusion of nitrogen) found 1.62 at 16°, and Hagenbach,[4] in water containing 20 per cent. gelatin, obtained the value 7.58 at 14°; but in each case only one determination was made. Hagenbach also states that the gelatin offered greater resistance to the diffusing gas molecules than pure water, which in a 20 per cent. gelatin solution was on an average 1.5 times as great. Consequently the coefficient of diffusion for oxygen in water in Hagenbach's experiment amounts to 11.37 (14°) per square centimeter per 24 hours.[5] If the coefficient of carbon dioxide be taken as 1.38 (16°), the mean of the above three determinations, then the ratio between the coefficients of diffusion for oxygen and carbon dioxide

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[1] Tor Carlson, *Meddel. fran Vet. Akad. Nobelinstitut.*, Vol. II, No. 5, 1911.

[2] *Sitzb. Wien Akad.*, **77**, Abth. II, 37 (1878).

[3] *Wied. Ann.*, **60**, 134 (1897).

[4] *Ibid.*, **65**, 673 (1898).

[5] For the carbon dioxide in a 20 per cent. solution of gelatin Hagenbach obtained the numbers 0.843 and 0.770, giving the mean value 1.21, calculated as above for water.