# The Genesis of a Law of Nature

## from *The Periodic Law of the Chemical Elements*

Before one of the oldest and most powerful of (scientific societies) I am about to take the liberty of passing in review the 20 years' life of a generalization which is known under the name of the Periodic Law. It was in March, 1869, that I ventured to lay before the then youthful Russian Chemical Society the ideas upon the same subject which I had expressed in my just written *Principles of Chemistry.*

Without entering into details, I will give the conclusions I then arrived at in the very words I used:

1. The elements, if arranged according to their atomic weights, exhibit an evident *periodicity* of properties.
2. Elements which are similar as regards their chemical properties have atomic weights which are either of nearly the same value (*e.g.* platinum, iridium, osmium) or which increase regularly (*e.g.* potassium, rubidium, caesium).
3. The arrangement of the elements, or of groups of elements, in the order of their atomic weights, corresponds to their so-called *valencies* as well as, to some extent, to their distinctive chemical properties—as is apparent, among other series, in that of lithium, beryllium, barium, carbon, nitrogen, oxygen, and iron.
4. The elements which are the most widely diffused have small atomic weights.
5. The *magnitude* of the atomic weight determines the character of the element, just as the magnitude of the molecule determines the character of a compound.
6. We must expect the discovery of many yet *unknown* elements—

for example, elements analogous to aluminium and silicon, whose atomic weight would be between 65 and 75.

7. The atomic weight of an element may sometimes be amended by a knowledge of those of the contiguous elements. Thus, the atomic weight of tellurium must lie between 123 and 126, and cannot be 128.

8. Certain characteristic properties of the elements can be foretold from their atomic weights.

The aim of this communication will be fully attained if I succeed in drawing the attention of investigators to those relations which exist between the atomic weights of dissimilar elements, which, as far as I know, have hitherto been almost completely neglected. I believe that the solution of some of the most important problems of our science lies in researches of this kind.

To-day, twenty years after the above conclusions were formulated, they may still be considered as expressing the essence of the now well-known periodic law.

Reverting to the epoch terminating with the sixties, it is proper to indicate three series of data without the knowledge of which the periodic law could not have been discovered, and which rendered its appearance natural and intelligible.

In the first place, it was at that time that the numerical value of atomic weights became definitely known. Ten years earlier such knowledge did not exist, as may be gathered from the fact that in 1860 chemists from all parts of the world met at Karlsruhe in order to come to some agreement, if not with respect to views relating to atoms, at any rate as regards their definite representation. Many of those present probably remember how vain were the hopes of coming to an understanding, and how much ground was gained at that congress by the followers of the unitary theory so brilliantly represented by Cannizzaro. I vividly remember the impression produced by his speeches, which admitted of no compromise, and seemed to advocate truth itself, based on the conceptions of Avogadro, Gerhardt, and Regnault, which at that time were far from being generally recognized. And though no understanding could be arrived at, yet the objects of the meeting were attained, for the ideas of Cannizzaro proved, after a few years, to be the only ones which could stand criticism, and which represented an atom as—"the smallest portion of an element which enters into a molecule of its compound." Only such real atomic weights—not conventional ones—could afford a basis for generalization. It is sufficient, by way of example, to indicate the following cases in which the relation is seen at once and is perfectly clear:

| | | |
|---|---|---|
| K = 39 | Rb = 85 | Cs = 133 |
| Ca = 40 | Sr = 87 | Ba = 137 |

whereas with the equivalents then in use—

| | | |
|---|---|---|
| K = 39 | Rb = 85 | Cs = 133 |
| Ca = 20 | Sr = 43.5 | Ba = 68.5 |

the consecutiveness of change in atomic weights, which with the true values is so evident, completely disappears.

Secondly, it had become evident during the period 1860–70, and even during the preceding decade, that the relations between the atomic weights of analogous elements were governed by some general and simple laws. Cooke, Cremers, Gladstone, Gmelin, Lenssen, Pettenkofer, and especially Dumas, had already established many facts bearing on that view. Thus Dumas compared the following groups of analogous elements with organic radicals:

| | Diff. | | Diff. | | Diff. | | Diff. |
|---|---|---|---|---|---|---|---|
| Li = 7 | 16 | Mg = 12 | 8 | P = 31 | 44 | O = 8 | 8 |
| Na = 23 | 16 | Ca = 20 | $3 \times 8$ | As = 75 | 44 | S = 16 | $3 \times 8$ |
| K = 39 | | Sr = 44 | $3 \times 8$ | Sb = 119 | $2 \times 44$ | Se = 40 | $3 \times 8$ |
| | | Ba = 68 | | Bi = 207 | | Te = 64 | |

*Distribution of the Elements*

| Group | I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|---|
| Series | | | | | | | | |
| 1 | Hydrogen | 1 | — | | — | | — | |
| 2 | Lithium | 7 | Beryllium | 9 | Boron | 11 | Carbon | 12 |
| 3 | Sodium | 23 | Magnesium | 24 | Aluminum | 27 | Silicon | 28 |
| 4 | Potassium | 39 | Calcium | 40 | Scandium | 44 | Titanium | 48 |
| 5 | Copper | 63 | Zinc | 65 | Gallium | 70 | Germanium | 72 |
| 6 | Rubidium | 85 | Strontium | 87 | Yttrium | 89 | Zirconium | 91 |
| 7 | Silver | 108 | Cadmium | 112 | Indium | 113 | Tin | 118 |
| 8 | Caesium | 133 | Barium | 137 | Lanthanum | 138 | Cerium | 140 |
| 9 | — | | — | | — | | — | |
| 10 | — | | — | | Ytterbium | 173 | — | |
| 11 | Gold | 198 | Mercury | 200 | Thallium | 204 | Lead | 206 |
| 12 | — | | — | | — | | Thorium | 232 |

and pointed out some really striking relationships, such as the following:

$$
\begin{aligned}
F &= 19 \\
Cl &= 35.5 = 19 + 16.5 \\
Br &= 80 = 19 + (2 \times 16.5) + 28 \\
I &= 127 = (2 \times 19) + (2 \times 16.5) + (2 \times 28).
\end{aligned}
$$

A. Strecker, in his work *Theorien und Experimente zur Bestimmung der Atomgewichte der Elemente* (Braunschweig, 1859), after summarizing the data relating to the subject, and pointing out the remarkable series of equivalents—Cr = 26.2 Mn = 27.6 Fe = 28 Ni = 29 Co = 30 Cu = 31.7 Zn = 32.5

remarks that: "It is hardly probable that all the above-mentioned relations between the atomic weights (or equivalents) of chemically analogous elements are merely accidental. We must, however, leave to the future the discovery of the *law* of the relations which appear in these figures."

In such attempts at arrangement and in such views are to be recognized the real forerunners of the periodic law; the ground was prepared for it between 1860 and 1870, and that it was not expressed in a determinate form before the end of the decade may, I suppose, be ascribed to the fact that only analogous elements had been compared. The idea of seeking for a relation between the atomic weights of all elements was foreign to the ideas then current, so that neither the *vis tellurique* [telluric screw] of De Chancourtois, nor the *law of octaves* of Newlands, could secure anybody's attention. And yet both De Chancourtois and Newlands, like Dumas and Strecker, more than Lenssen and Petten-

*in Groups and Series*

| V | | VI | | VII | | VIII | | |
|---|---|---|---|---|---|---|---|---|
| — | | — | | — | | — | | |
| Nitrogen | 14 | Oxygen | 16 | Fluorine | 19 | | | |
| Phosphorus | 31 | Sulphur | 32 | Chlorine | 35 | | | |
| Vanadium | 51 | Chromium | 52 | Manganese | 55 | Iron 56 | Cobalt 58 | Nickel 59 |
| Arsenic | 75 | Selenium | 79 | Bromine | 80 | | | |
| Niobium | 94 | Molybdenum | 96 | — | | Ruthenium 103 | Rhodium 104 | Palladium 106 |
| Antimony | 120 | Tellurium | 125 | Iodine | 127 | | | |
| Didymium ? | | — | | — | | — | — | — |
| — | | — | | — | | | | |
| Tantalum | 182 | Tungsten | 185 | — | | Osmium 191 | Iridium 193 | Platinum 196 |
| Bismuth | 208 | — | | — | | | | |
| — | | Uranium | 240 | — | | | | |

kofer, had made an approach to the periodic law and had discovered its germs. The solution of the problem advanced but slowly, because the facts, and not the law, stood foremost in all attempts; and the law could not awaken a general interest so long as elements, having no apparent connection with each other, were included in the same octave, as for example:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1st octave of Newlands | H | F | Cl | Co and Ni | Br | Pd | I | Pt & Ir |
| 7th ditto ........... | O | S | Fe | Se | Rh & Ru | Te | Au | Os or Th |

Analogies of the above order seemed quite accidental, and the more so as the octave contained occasionally ten elements instead of eight, and when two such elements as Ba and V, Co and Ni, or Rh and Ru, occupied one place in the octave. Nevertheless, the fruit was ripening, and I now see clearly that Strecker, De Chancourtois, and Newlands stood foremost in the way towards the discovery of the periodic law, and that they merely wanted the boldness necessary to place the whole question at such a height that its reflection on the facts could be clearly seen.

A third circumstance which revealed the periodicity of chemical elements was the accumulation, by the end of the sixties, of new information respecting the rare elements, disclosing their many-sided relations to the other elements and to each other. The researches of Marignac on niobium, and those of Roscoe on vanadium, were of special moment. The striking analogies between vanadium and phosphorus on the one hand, and between vanadium and chromium on the other, which became so apparent in the investigations connected with that element, naturally induced the comparison of $V = 51$ with $Cr = 52$, $Nb = 94$ with $Mo = 96$, and $Ta = 192$ with $W = 194$; while, on the other hand, $P = 31$ could be compared with $S = 32$, $As = 75$ with $Se = 79$, and $Sb = 120$ with $Te = 125$. From such approximations there remained but one step to the discovery of the law of periodicity.

The law of periodicity was thus a direct outcome of the stock of generalizations and established facts which had accumulated by the end of the decade 1860–1870: it is the embodiment of those data in a more or less systematic expression.

---

*The foregoing is a selection from the Faraday Lecture delivered before the Fellows of the Chemical Society at the Royal Institution, June 4, 1889.*