HISTORICAL DEVELOPMENT *of the* CONCEPTION *of* CHEMICAL ELEMENTS

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L'habitude d'une opinion produit souvent une conviction complète de sa justesse; elle en cache les parties faibles et rend l'homme incapable, d'apprécier les preuves contraires.—J. J. Berrelius. "Théorie des proportions chimiques," Deuxième édition, 1835, page 35.

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ELEMENTS are ultimate component parts which constitute a given object. To obtain a knowledge of them the original object must be decomposed by analysis: the ultimate undecomposable products of analysis are the immediate component parts, objective elements, which in turn serve for the deduction of abstract elements. Analytical methods are being continually perfected in every science. Thus it may happen that at a certain moment of time the existing elements are decomposed into new ones, and these may give rise to new abstract elements.

The object of chemistry is the investigation of natural and artificial bodies and of substances composing them. Their ultimate component parts are chemical elements (1) which must be chemically undecomposable into simpler substances and (2) which must be immediate component parts of a given substance. Now the investigation of substances produced by nature and art, from matter, occupied the attention of philosophers from the very earliest times. Thus the history of the development of the conception "chemical element" covers more than two millennia, and in this short summary I can touch only upon some of the principal facts.

I. It seems that a very old conception of the constitution of matter is contained in the atomic theory. This postulated that indivisible atoms of matter moving in a vacuum were the elements of all bodies of nature.

Another conception was brought forward, perhaps somewhat later, being developed chiefly by Aristotle (IV century B.C.), who denied the existence of a vacuum and taught that all bodies are composed of qualities: hot-cold, wet-dry, perceptible to our senses and embodied in the four elements, fire (dry and hot), air (wet and hot), water (wet and cold), earth (cold and dry). These Aristotelian elements were almost universally accepted up to the second half of the XVIII century A.D. But chemists early adopted other elemental qualities. These were sulfur (quality of combustibility) and mercury (quality of volatility), mentioned already by the early Greek chemists, more fully described by Djabir ibn Hayan (end of VIII century A.D.), and salt (quality of incombustibility, as evidenced by a residue left after calcination), introduced by Paracelsus (beginning of XVI century). In the early years of the XVIII century sulfur coëxisted with phlogiston: this element-quality is characteristic of the XVIII century, being used for the explanation of all chemical phenomena known at the time. The theory of phlogiston allowed one (for the first time in the history of chemistry) to systematize chemical knowledge from one point of view.

Under the influence of new ideas brought forward by R. Boyle and described in section II, and of the gradual extension of quantitative methods of work, philosophers began to regard the elemental qualities as substances. Jung in 1730 was the first to hold phlogiston to be a weightless substance conferring to its compounds a loss of weight. Others began to regard the Aristotelian qualities, fire, water, air, earth, as substances of the same name, and this point of view became universal during the last decades of the XVIII century. It was these elemental substances that were overthrown by Lavoisier who showed that air, water, earths were compounded bodies, that the substance phlogiston was a product of imagination. He introduced instead the elements of Boyle, the simple or uncompounded bodies. But this chemical revolution was not brought to a logical conclusion by Lavoisier, inasmuch as he left among the new elements two substances without weight—light and heat (caloric). This was doubtless due to the influence of physics, where immaterial fluids were used to explain such phenomena as light, heat, electricity, etc. In the first decades of the XIX century we find in textbooks of chemistry these more modern elemental qualities. Light was discarded in the early forties from chemistries, caloric in the fifties, and the electrical fluids in the early sixties. But physicists retained the electrical fluids up to the end of the XIX century. Thus some of the elemental qualities persisted, in a modern dress, almost up to our times.

II. In 1661 R. Boyle gave a new definition of a chemical element in the following words (Sceptical Chymist): "I now mean by elements . . . certain primitive and simple, or perfectly unmingled bodies, which not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved." He indicated also chemical analysis as the means of deciding if a body was simple or "mixt." During the XVIII century, as stated above, the elements of Boyle began to find recognition by chemists, and were definitely introduced by Lavoisier in the years 1787–89.

Lavoisier gives several definitions of a chemical element:

(*a*) An element is every simple substance undecomposed by chemical analysis and giving in chemical reactions products always having a greater weight than itself. This is the element of R. Boyle.

(*b*) An element is the "base" of a gas or of another body. These "bases" (or "principles," another name employed by Lavoisier) are undecomposable substances which cannot be directly observed, as we know them only in compounds with caloric or with other bases. Thus the base oxygen is contained in the gas oxygen combined with caloric, and in different oxides combined with other "bases." The "base" carbon forms different simple bodies (diamond, charcoal) and compounds, such as carbonic acid gas.

(*c*) "If we understand by elements simple and indivisible molecules of bodies, it is probable that we do not know them."

III. The same three points of view on the nature of elements were current during the XIX century. We will consider them under the same headings.

(*a*) Very many scientists, even up to the present day, hold the elements to be simple substances. It is enough to examine such recently published fundamental works as the latest edition of F. Ephraim's "Inorganic Chemistry," or the "Physico-chemical Tables" of Landolt-Börnstein (issued in October, 1935), to see that under the heading "properties of chemical elements" the properties of simple substances are described. These authors evidently do not take into account the existence of allotropic modifications, discovered by Lavoisier for carbon and described in the XIX and the XX centuries in great numbers. Such modifications having identical chemical properties and different physical ones show that they are composed by the same element, but that they themselves are *not* chemical elements. Indeed the simple bodies, or simple substances, as they are being called nowadays, have only one of the two characteristics of a chemical element: they are chemically undecomposable, but they are not contained as such in compound substances. This was the opinion of Lavoisier, stated by some before him. It is accepted today by practically all chemists.

(*b*) During the last century the chemical elements begin to be identified with the "bases" or "principles" of Lavoisier. Thus already A. Fourcroy in his "Système des connaissances chimiques" (1801) points out that a principle cannot be separated as such, but it can be measured, weighed, combined; it is partly an abstract entity. I will retain the old word "principle" in order to distinguish the two different conceptions—that of principle and that of simple substance (F. Paneth in 1931 proposed for principle the name "primary substance," Grundstoff).

There is no question as to principles being true chemical elements, since they are chemically undecomposable immediate component parts of simple and compound bodies, thus completely satisfying the definition of a chemical element. They possess chemical properties, but few physical ones, the chief (from the chemist's point of view) being their weight. Almost every chemist, even today, confuses the principles and the simple substances, designating both these different things by the same term "chemical element." The question as to the nature of chemical element was discussed at the first International Chemical Congress in 1860. No resolutions were passed, but the majority of the members seemed to consider the principle as chemical element. Since that date the leading chemists, as, for instance, D. I. Mendeléeff, draw the distinction between simple substances and principles and hold only these last to be chemical elements. Thus the periodic system of Mendeléeff is a system of principles, not of simple substances.

(*c*) Lavoisier's remark about elements being simple and indivisible molecules of bodies is the keynote to the amazing developments which this point of view received in the XIX century. These developments were primarily the result of several important quantitative facts established by Lavoisier and his successors: (1) two principles can sometimes form *several* distinct compounds with each other; (2) in such compounds, if the weight of one principle is taken as constant, the weights of the second principle are proportionate to simple numbers (W. Higgins, 1789; J. Dalton, 1803, and seq.); (3) the composition of a chemically pure substance is constant (J. Proust, C. Berthollet, 1803). These facts were explained by W. Higgins in 1789, by J. Dalton in 1808, by the assumption that *atoms of simple bodies combine with each other*. All atoms of a given simple body were held to be identical as regards dimensions and weights, this last remaining without change during chemical interactions. Atoms of different simple bodies were thought to differ by weight and dimensions.

Thus W. Higgins and J. Dalton brought together the conception of chemical element-simple substance of Boyle [(*a*) of Lavoisier] with that of abstract atoms. They postulated the existence of as many kinds of atoms, differing by weight and chemical properties, as there were simple bodies.

Further developments of this doctrine were due to the introduction of the conception of *chemical molecule* as the smallest quantity of a substance having all the chemical properties of this substance, and composed of atoms. Proposed by A. Avogadro (1811) and A. Ampère (1814) in order to explain the work of J. Gay-Lussac, who studied the chemical properties of gases, it was developed by M. Gaudin (1831), Ch. Gerhardt, and Aug. Laurent (soon after 1840). The molecular theory was definitely adopted on the recommendation of S. Cannizzaro in the historical first International Chemical Congress of 1860. Henceforth, all substances are considered by chemists to consist of molecules, not of atoms as such; an atom is the smallest quantity of an element (principle) in the molecules of its compounds. This Congress marks the date when *atoms were brought into relation with principles*, not with simple substances, as heretofore. Chemistry from 1860 onward is a science of molecules and of atoms, accepted by chemists "as if they existed." The amazing progress of organic chemistry, dating from the early sixties of last century, is due not only to the synthetic methods discovered by M. Berthelot, but in a great measure to the introduction of molecules.

IV. The very beginning of the XX century brought forward proofs of the real existence of molecules and of atoms, and such proofs have repeatedly been advanced since that epoch. X-ray analysis (1912–1914) has shown that crystals are formed by atoms and ions: consequently principles, as component parts of all bodies, are contained in them in the form of atoms and ions. Atoms and ions are best characterized by their atomic numbers, first introduced by Rydberg in 1897. The atomic numbers, as shown by H. Moseley (1913), are easily calculated from the wave-lengths of the lines of X-ray spectra of the principles. It was he who established the total number of elements (principles) up to uranium inclusive (92), and who pointed out the number of rare earths' elements.

The physical significance of the atomic number was demonstrated by E. Rutherford and J. Chadwick (1919–1920): this constant is the value of the positive electric charge of the atomic nucleus, as was supposed by H. Moseley, and indicates the number of the planetary electrons of the atom. The atomic number is the same for all atoms and ions of a given principle.

The study of mass spectra of elements, begun by F. Aston in 1920, giving the mass of each individual atom, has brought to light an utterly unexpected fact: there are many principles, each of which has atoms of different mass. Every separate kind of atoms having identical masses and atomic numbers constitutes one isotope (F. Soddy, 1913). Several isotopes having the same atomic number and identical chemical properties form an element-pleiad (K. Fajans, 1913). On the other hand it is observed in some instances that different elements have atoms of identical mass, but of different atomic numbers: these kinds of atoms are called isobares. Isobares exhibit unlike chemical properties. Thus, the number of different kinds of atoms was found to be much greater than ninety-two.

Atoms and ions, being chemically undecomposable and forming all substances, are, according to definition, elements. At the present time some three hundred different kinds of atoms are known. Each of them can produce several ions, so that the total number of these elements, different atoms and ions, approximates one thousand. It is easy, however, to systematize them: ions are directly connected with atoms, being, in fact, formed from atoms by addition or by elimination of electrons, and having acquired in consequence an electrical charge. Thus, only atoms have to be classified by means of their atomic numbers. Each group of atoms and their ions having the same atomic number form one aggregation. Each such aggregation is *one chemical element*, which can be defined thus: *a chemical element is a principle, all atoms and ions of which have the same atomic number.* This definition is based on the resolutions passed by the International Union in 1923. Chemical elements can be divided into homogeneous (all atoms are of an identical mass), and heterogeneous (having several kinds of atoms differring by their mass, *i. e.*, consisting of several isotopes), as I have called the "simple" and "complex" elements of the International Union (the ultimate component parts of course cannot be "complex" by the very nature of things).

The chemical atomic weight of an element, *i. e.*, the value of its equivalent mutiplied by the valency, expresses the mean weight of an enormous number of atoms of a given principle. The physical atomic weight is calculated from the mass of atom of each isotope and from the relative abundance of these isotopes. At the present time these two atomic weights practically coincide for all chemical elements (principles), where both can be determined.

Atoms and ions are themselves built up of protons, neutrons, electrons, etc.; of course, these are also elements, but not chemical ones: the chemical analysis does not go beyond atoms and ions. These constituent parts of atoms and ions, determined by physical analysis, may be called ultrachemical elements.

MIDWEST REGIONAL MEETING OF THE A. C. S.

The Midwest Regional Meeting of the American Chemical Society will convene in Omaha, Nebraska, on Thursday, April 29, Friday, April 30, and the forenoon of Saturday, May 1, 1937. All meetings will be held in conveniently located and air-conditioned rooms on the mezzanine floor of the Hotel Paxton in downtown Omaha.

Divisional groups have been organized as follows:

1. Dr. Frank B. Dains, University of Kansas, chairman of the chemical education and history of chemistry group. Secretary, Dr. Arthur W. Davidson, University of Kansas, Lawrence, Kansas.
2. Dr. M. J. Blish, University of Nebraska, chairman of the agricultural and food chemistry group, Experiment Station, University of Nebraska. Secretary, Dr. G. F. Stewart, Omaha Cold Storage Company, Omaha. This group is organizing a symposium on "Eggs."
3. Dr. Edward Bartow, University of Iowa, chairman of the industrial chemistry group. Secretary, Dr. L. B. Parsons, Cudahy Packing Company, South Omaha, Nebraska.
4. Dr. Cliff S. Hamilton, University of Nebraska, chairman of the organic chemistry group. Secretary, Dr. Mary L. Morse, Duchesne College, Omaha.
5. Dr. L. F. Yntema, University of St. Louis, chairman of the physical and inorganic group. Secretary, Dr. E. Roger Washburn, University of Nebraska.

Titles are invited and should reach the respective group secretaries not later than March 13.