Periodic Table

The periodic table is a classification and tabulation of the chemical elements in the order of their atomic numbers that permits systematic explanation and prediction of many of the elements' chemical and physical properties.

DEVELOPMENT OF THE PERIODIC TABLE

As the 19th century began, chemistry had progressed to the point of defining an element as a substance that could not be decomposed into a simpler substance by any known means. The number of substances thus defined increased rapidly, but there was no way of telling how many remained to be discovered, or where they might be expected to be discovered. As the number increased, however, it became evident that certain groups of elements could be classified into families with similar chemical properties. Thus, the reactions of lithium, sodium, and potassium resembled each other closely, as did those of chlorine, bromine, and iodine.

The actual discovery of the periodic law came in the years between 1868 and 1870 and was made almost simultaneously by Lothar MEYER in Germany and Dmitry Ivanovich MENDELEYEV in Russia. Meyer arranged the 57 elements known to him in the order of their atomic weights, leaving blank spaces where the properties of the elements seemed to indicate that one was missing. He was particularly concerned with the physical properties of the elements, such as their atomic volumes, and he saw that similar values for these recurred periodically after every seventh element in his table. (Had the inert gases been known then, the recurrence would have been after every eighth element.) Meyer drew up his first table in 1868 but did not publish it until 1870.

At the same time Mendeleyev, who was engaged in writing a chemistry textbook that later became world-famous, reached a conclusion similar to that of Meyer but based instead largely on the chemical properties of the elements. He also left blank spaces where elements were obviously missing, and he went well beyond Meyer in his published tables (1869 to 1870). In several cases the atomic weights of elements, as they had been determined at the time, indicated misplacement of the position of the elements in these tables; Mendeleyev did not hesitate to say that these atomic weights were incorrect. Even more boldly, he predicted in detail what the chemical and physical properties of the missing elements would be when they were found. Using the Sanskrit word for the numeral one, eka, he prefixed the names of known elements that were situated above missing ones in his table. Thus he described the properties of what he called ekaaluminum, ekaboron, and ekasilicon. Mendeleyev's predictions were soon confirmed. New atomic weight determinations corrected the values he had questioned, and the discovery of the actual elements gallium, scandium, and germanium showed that these had almost exactly the properties that he had indicated for them.

ARRANGEMENT OF THE PERIODIC TABLE

From that time on, the periodic table--as it began to be called-- assumed the basic form that, in spite of some modifications, it has retained ever since. Hydrogen, which was recognized as an anomalous element, is placed by itself at the beginning of the chart. The elements that follow are arranged horizontally until an element is reached that has the properties of one in the previous period. This is placed below the analog, and a new horizontal period is begun.
The chart so designed can be read either horizontally or vertically. If horizontally, the elements are arranged in a series not only by atomic weight, but also by VALENCE. Beginning with the monovalent alkali metals the positive valence increases to three. Carbon, with its nonpolar valence of four, occupies a central position, followed by nitrogen, oxygen, and fluorine, with valences of -3, -2, and -1, respectively.

Originally there were seven vertical columns below each element in the first period, designated by the Roman numerals I to VII. Further down the table appeared the so-called transition elements iron, cobalt, and nickel. Because the properties of these transition elements set them apart, another column, VIII, was designated for them.
When the table is read vertically, each column comprises a family of elements having similar properties. In this form the table was able to meet the needs of inorganic chemists for the organization of what had previously been a mass of uncoordinated facts. Even though the table as an empirical construction fit the observed facts very well, however, no theoretical reasons for its existence could be given.

The first serious challenge to the neat organization occurred in 1894, when argon was discovered. No similar unreactive gases were then known. To fit the substance into the table, Mendeleyev proposed adding a new vertical column, designated the zero column, to the table. Since the gas formed no compounds, it had no valence and so could take its place before the elements of column I. This, of course, implied that other similar inert gases must also exist. With the table as a guide, the other members of the inert-gas family, helium, neon, krypton, and xenon, were quickly found (1895-98). They fit exactly into the proper positions in the table as required by their atomic weights, except that argon had to be interchanged with potassium. Since there was no doubt as to the proper relationships among the gases, the argon-potassium discrepancy was disregarded for the time being.

PERIODICITY AND ATOMIC THEORY

The next major step was to explain the positions of the elements in the table. This was accomplished by physicists rather than chemists. At the end of the 19th and the beginning of the 20th century great progress was made in elucidating the structure of the ATOM itself. The resulting picture of the arrangement of nuclei and electrons in the atom, which had previously been considered to be indivisible, was the key to understanding the periodic table.

The most direct application of the new atomic theories came from the work of Henry G. J. MOSELEY in 1913. Moseley bombarded a number of different target metals with a stream of electrons and observed that X rays were produced. The frequency of these X rays varied with the metal used and the shift in frequency varied in a characteristic manner from element to element. The shift could be expressed mathematically by a unit number, which Moseley called the ATOMIC NUMBER. The order of these numbers was exactly the same as the order of elements in the periodic table, except that the discrepancies for argon and potassium, iodine and tellurium, and cobalt and nickel disappeared and each element took its proper place in the order of elements. It was quickly realized that the atomic number represented the positive charge of the atomic nucleus, and that this charge increased by one as the elements advanced along the table. The atomic number was thus a more fundamental value than the ATOMIC WEIGHT.

In fact, it was found that the atomic weight was not a unique value for each element. Studies of radioactive elements and their end products had turned up samples of certain elements, lead in particular, that came from different locations and had different atomic weights, yet showed identical chemical properties. These were named ISOTOPES by Frederick SODDY, and in 1919, Francis William ASTON showed by means of his mass spectrograph that most elements are mixtures of isotopes. The atomic weights determined by chemical analysis, then, are actually the average of the atomic weights of all the isotopes with the same atomic number. In the case of the anomalously placed elements, atomic weight did not put each element in its proper position as indicated by its atomic number.

The concept of the atomic number also indicated exactly where missing elements occurred in the periodic table, and the chemical properties of each missing element as shown by the table itself indicated where those elements should be sought in nature. Using these criteria as guides, hafnium and rhenium were soon discovered, though all attempts to discover elements 43 (an analog of rhenium), 61 (a rare earth), 85 (a halogen), and 87 (an alkali) remained unsuccessful. With these exceptions, the table from hydrogen, atomic number 1, to uranium, 92, was complete, and no more elements could be expected, although it was not known why the table stopped at uranium.

As the structure of the atom became clearer, so did the theoretical explanation for the periodic table. Atomic structure was based on the picture proposed by Niels BOHR in 1913. The atomic number was identified with the number of protons--positively charged particles--present in the nucleus of each atom. Balancing this was an equal number of negatively charged electrons orbiting the nucleus in a series of shells designated by the letters K, L, M, and so on. The innermost shell, K, held either one electron, corresponding to hydrogen, or two, corresponding to the inert gas helium. When the K shell was complete, a new shell, L, began to form, building up the next eight elements to the next inert gas, neon, atomic number 10. Thus the ELECTRON CONFIGURATION of the inert gases represented a stable situation that the other elements tended to approach by gain or loss of electrons in chemical reactions. The periodicity of the table was due to the repeating trend toward formation of the stable configuration, and the outer shells could contain 18 or even 32 electrons.

This permitted the chemists once more to take part in the development of the periodic theory, basing their ideas on chemical properties such as valence and compound formation. Gilbert

LEWIS and Irving LANGMUIR between 1916 and 1920 pointed out that the chemical properties of an element are determined by the number of electrons in the outermost shell. The inert gases do not normally form compounds, because their outermost shells are filled. Other elements tend to form the ideal number to attain this maximum, either by losing electrons, leaving a positive charge on the atom, or by gaining electrons to form a negatively charged atom. Atoms of opposite charges could then neutralize each other in joining to form a compound.

The idea of a regularly increasing number of electrons as the atomic number increased implied that each shell was built up until it was complete before the next shell could be started. This idea could be modified to account for the rare earth elements, which showed an increasing number of electrons in regular order from lanthanum to lutecium but relatively little difference in chemical properties. It is now assumed that before the outermost shell is complete, a new shell somehow begins to form and becomes, in turn, the outermost shell. Meanwhile, the incomplete shell continues to be filled, while the chemical properties determined by the outer shell remain very similar.

Thus, another anomaly of the table can be explained without having to change the table itself.

RADIOACTIVITY

The final vindication of the periodic table came from the study of radioactive elements, which led to the creation of the TRANSURANIUM ELEMENTS. Almost as soon as radioactive elements were discovered it was recognized that they decayed at definite rates, giving rise to new elements while emitting rays of three kinds--alpha, beta, and gamma. The gamma rays were soon identified as X rays that do not change the nature of the element concerned. The alpha rays, however, were found to be helium ions with an atomic weight of four and a double negative charge, while the beta rays were electrons whose slight mass did not alter the atomic weight of the elements from which they came.

The loss of these particles from the nucleus altered the atomic number of the element, thus producing a new element. In 1911 and 1913, Soddy showed that loss of an alpha particle moved an element two places to the left in the table, while loss of an electron moved it one place to the right. A decay series of elements is formed by a continued chain of such transformations. Three such series were recognized that started from isotopes of uranium, actinium, and thorium. A plutonium series was later recognized. Obviously a number of isotopes could be formed, and in most cases the end product was a nonradioactive lead isotope. Had the large number of isotopes involved in these events been discovered early they would have been inexplicable, but the concept of atomic numbers made it possible to understand what had happened.

Artificial Transmutation

Once the idea of the interconversion of elements had been accepted, it became apparent that artificial changes might be produced if some sort of charged particle could be introduced into an atomic nucleus. Elements so produced could be expected to be too unstable to be found in nature, since they would decay too rapidly. In the 1930s Frederick and Irene JOLIOT-CURIE actually produced artificial transmutations by bombarding metal targets with alpha rays. The cyclotron, developed by Ernest LAWRENCE, supplied a much more powerful source of particles with which to bombard targets of various elements and permitted Emilio SEGRE to find the missing element 43, the first artificially produced element. It was named technetium from the Greek word for "artificial." Artificial production of elements completed the periodic table with the creation of promethium, element 61; astatine, element 85; and francium, element 87. All these elements were radioactive and decayed rapidly, which explained why they had not been found by ordinary chemical methods. All fit exactly into their places in the table.

Much more exciting to chemists was the possibility of creating new elements heavier than uranium. In 1940, Edwin M. MCMILLAN was able to produce element 93, which he called neptunium, the first element beyond uranium, just as Neptune was the first planet beyond Uranus. At this point the work on the production of new elements apparently stopped, but it actually continued very actively in secret because the research was connected with the manufacture of the atomic bomb. Glenn Seaborg, McMillan's colleague, continued the latter's work, and large quantities of element 94, plutonium, were synthesized. The results of all this work were finally published in 1946, and open work on the transuranium elements continued actively. Elements as high as 109 have been prepared, and the possibility exists of SUPERHEAVY ELEMENTS far beyond the known table.

As the number of synthetic elements increased it became evident that the new transuraniums were forming a new series analogous to the rare earths in which added electrons were filling the shell below the valence shell. To indicate this, Seaborg suggested that the known rare earths that began with lanthanum in the table should be called LANTHANIDE SERIES, while the new series beginning with actinium be called the ACTINIDE SERIES. This suggestion has since been accepted.
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***Bibliography**:*

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See also: ELEMENT; ELEMENT 107; ELEMENT 109