Kémia angolul

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Évkezdési gondolatok:

Előszóban:

A kémiaórákon olykor számolunk is. A számolások során pedig gyakran használunk nevezetes állandókat. De valójában melyek a nevezetes állandók? Mióta ismertek és hogyan határozták meg őket? Ehhez a betekintés Barry N. Taylor 1971-es cikkét használjuk, amely az Encyclopaedia Britannica 15. kiadásában jelent meg. A lefordítandó feladatban a kémiai szempontból fontos alapvető fizikai állandókra szorítkozunk. De fontos tudatosítanunk magunkban, hogy a kémia és fizikai közötti határvonal a valóságban messze nem olyan egyértelmű, mint az órarend láttatja.

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Fundamental Physical Constants

Introduction to the constants for non-experts

Throughout all of the formulations of the basic theories of physics and their application to the real world, there appear again and again certain fundamental invariant quantities. These quantities, called the fundamental physical constants, and which have specific and universally used symbols, are of such importance that they must be known to as high an accuracy as is possible. They include the velocity of light in vacuum (c); the charge of the electron, the absolute value of which is the fundamental unit of electric charge (e); the mass of the electron (m_e); Planck's constant (h). These will all be considered in detail below.

There are, of course, many other important quantities that can be measured with high accuracy -- the density of a particular piece of silver, for example, or the lattice spacing (the distance between the planes of atoms) of a particular crystal of silicon, or the distance from the Earth to the Sun. These quantities, however, are generally not considered to be fundamental constants. First, they are not universal invariants because they are too specific, too closely associated with the particular properties of the material or system upon which the measurements are carried out. Second, such quantities lack universality because they do not consistently appear in the basic theoretical equations of physics upon which the entire science rests, nor are they properties of the fundamental particles of physics of which all matter is constituted.

It is important to know the numerical values of the fundamental constants with high accuracy for at least two reasons. First, the quantitative predictions of the basic theories of physics depend on the numerical values of the constants that appear in the theories. An accurate knowledge of their values is therefore essential if man hopes to achieve an accurate quantitative description of the physical universe. Second, and more important, the careful study of the numerical values of these constants, as determined from various experiments in the different fields of physics, can in turn test the overall consistency and correctness of the basic theories of physics themselves.

Definition, importance, and accuracy

The constants named above, five among many, were listed because they exemplify the different origins of fundamental constants. The velocity of light (c) and Planck's constant (h) are examples of quantities that occur naturally in the mathematical formulation of certain fundamental physical theories, the former in James Clerk Maxwell's theory of electric and magnetic fields and Albert Einstein's theories of relativity, and the latter in the theory of atomic particles, or quantum theory. For example, in Einstein's theories of relativity, mass and energy are equivalent, the energy (E) being directly proportional to the mass (m), with the constant of proportionality being the velocity of light squared (c^2) -- i.e., the famous equation $E = m \cdot c^2$. In this equation, E and m are variables and c is invariant, a constant of the equation. In quantum theory, the energy (E) and frequency, symbolized by the Greek letter ν (nu), of a photon (a single quantum unit of electromagnetic energy such as light or heat radiation) are related by $E = h\nu$. Here, Planck's constant (h) is the constant of proportionality.

The elementary charge (*e*) and the electron mass are examples of constants that characterize the basic, or elementary, particles that constitute matter, such as the electron, alpha particle, proton, neutron, muon, and pion. Additionally, they are examples of constants that are used as standard units

of measurement. The charge and mass of atomic and elementary particles may be expressed in terms of the elementary charge (*e*) and the electron mass (m_e); the charge of an alpha particle, the nucleus of the helium atom, is given as 2*e*, whereas the mass of the muon is given as 206.77 m_e.

[...]

The accuracy with which many of the fundamental constants can be currently measured is a few parts in a million. By accuracy is meant the relative size of the uncertainty that must be assigned to the numerical value of any quantity to indicate how far from the true value it may be because of limitations in experiment or theory. This uncertainty is a quantitative estimate of the extent of the doubts associated with the value. The most commonly used uncertainty, the standard deviation, symbolized by the Greek letter sigma, is such that there is about a 68 percent chance that the true value lies within plus or minus sigma. Furthermore, there is a 95 percent chance that the true value lies between plus and minus two standard deviations and a 99.7 percent chance that it lies between plus and minus 3 standard deviations. [...]

In practice, an uncertainty of one part per million (abbreviated ppm) is rather respectable. It corresponds to determining the length of a United States football field (100 yards, or about 91 meters) to within the thickness of two of these pages (one page is about 0.0022 inch or 0.056 millimeter thick). There are several quantities that have been measured with uncertainties approaching one part in 1 000 000 000 000 (one in 10^{12}); this uncertainty corresponds to determining the distance from New York to San Francisco to within one-tenth the thickness of a piece of paper.

1900-1920

The fundamental-constants field has advanced so rapidly since mid 20th century that nearly all of the measurements carried out before World War II may be considered historical (if not the method, at least the result). Indeed, few measurements of constants existed before about the turn of the 20th century, because not until then did the modern era of physics begin. Relativity, atomic physics, and quantum theory all emerged after 1900. Two of the more important historical measurements made before about 1920 are:

The elementary charge (*e*)

One of the earlier experiments to measure a fundamental constant to high accuracy, as well as an example of how the accurate determination of a fundamental constant using different methods can lead to an improved understanding of a particular physical phenomenon, was the measurement of the fundamental unit of charge (*e*) by Robert A. Millikan, a physicist in the United States. From about 1907 to 1917 he carried out his now-famous oil drop experiment to determine *e*. In this method, the displacement of small, charged oil drops (the charge on the drop is usually just a few *e*) moving in air between two horizontal and parallel metal plates (with and without an applied known voltage) is followed as a function of time. The value of the fundamental constant *e* is then calculated from many observations on different drops and knowledge of other relevant quantities, especially the viscosity (resistance to flow) of the air. Millikan's final value, reported in 1917, was: $(4.774 \pm 0.002) \times 10^{-10}$ esu (esu being the electrostatic unit, one of the units of charge in the centimeter-gram-second [cgs] system of units; this cgs-esu system was in wide use before the general adoption of the SI system).

That this value was significantly in error became clear in the 1930s with the development of a new but indirect method for obtaining the value of *e*. The technique consisted of separately measuring *N*, the Avogadro constant (the number of atoms or molecules contained in a mole, which was defined as a mass in grams equal to the atomic or molecular weight of a substance), and *F*, the Faraday constant (the amount of charge that must pass through a solution to electrolytically deposit a mole of a singly charged, or monovalent element contained in the solution). These two quantities are related by the simple equation that states that the

Faraday constant is equal to the Avogadro constant times unit of charge, or $F = Ne$. It therefore follows that $e = F/N$, so that the constant e can readily be obtained if the two constants, Faraday and Avogadro, are known.

The Avogadro constant (N) was determined by measuring the density, molecular weight, and crystal lattice spacing of a particular crystal species such as rock salt, using x-ray techniques. The Faraday (F) was determined by measuring the mass of material (e.g., silver) electrolytically deposited onto an electrode when a known current flowing for a known time was allowed to pass through a solution containing the material. The indirect value of the elementary charge (e) deduced in this way was $(4.8021 \pm 0.0009) \times 10^{-10}$ esu, significantly different from the Millikan value. The major source of this disturbing discrepancy was traced in the latter part of the 1930s to the use by Millikan of an incorrect value for the viscosity of air. Millikan had taken a value that was almost entirely based on a measurement by one of his students; but it was later shown that the student had made a rather subtle experimental error. When Millikan's data were reevaluated with a correctly determined value for the viscosity of air, the value of e obtained agreed with the indirect value calculated from the Faraday and the Avogadro constant.

[...]

Ratio of Planck's constant (h) to the elementary charge (e), h/e

The very first precision determination of the ratio h/e used the photoelectric effect: when light of a particular wavelength is allowed to impinge upon a metal surface, electrons are emitted from the surface. If a retarding voltage, or potential, is applied to the metal so that the electrons are just prevented from leaving the surface, then a unique relationship can be shown to exist between the wavelength of the light, the voltage, and the ratio h/e. Millikan, using sodium and lithium, first reported a result from this method in 1916.

A second method to determine the h/e ratio is the so-called short wavelength limit of the continuous x-ray spectrum. In this technique, a beam of electrons is accelerated through a known voltage and is allowed to strike a metal target. The maximum-energy x-ray (that is, the one having the highest frequency or shortest wavelength) is emitted when all of the electrical potential energy of an electron in the beam is converted to a single x-ray photon. By measuring the voltage and the wavelength of the emitted x-ray, the ratio h/e can be determined. The first precision measurement of this type was reported in 1921

1920-1940

Ratio of the electron charge ($-e$) to the electron mass (m_e), $-e/m_\mathrm{e}$

Numerous direct measurements of this quantity were carried out over the period 1897 to 1938. The experiments usually involved the deflection of beams of free electrons by electric and magnetic fields. Many of the experiments required the measurement of the velocity of the electrons combined with a simultaneous determination of the voltage used to initially impart kinetic energy (i.e., velocity) to the electrons. Often the electron velocity was determined by a null deflection method in which the magnitudes of crossed electric and magnetic fields, through which the electron beam traveled, were so adjusted that the electric and magnetic deflecting forces just balanced each other. An English physicist, Joseph John Thomson, was the first to use this technique in 1897.

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