Topic Page: Physics

Definition: **physics** from *Dictionary of Energy*

the study of mass and energy and the interactions that they are observed to have throughout the universe, including such subfields as mechanics, astrophysics, nuclear physics, particle physics, and quantum mechanics.

Summary Article: **physics**
From *The Columbia Encyclopedia*

branch of science traditionally defined as the study of matter, energy, and the relation between them; it was called natural philosophy until the late 19th cent. and is still known by this name at a few universities. Physics is in some senses the oldest and most basic pure science; its discoveries find applications throughout the natural sciences, since matter and energy are the basic constituents of the natural world. The other sciences are generally more limited in their scope and may be considered branches that have split off from physics to become sciences in their own right. Physics today may be divided loosely into classical physics and modern physics.

Classical Physics

Classical physics includes the traditional branches and topics that were recognized and fairly well developed before the beginning of the 20th cent.—mechanics, sound, light, heat, and electricity and magnetism. Mechanics is concerned with bodies acted on by forces and bodies in motion and may be divided into statics (study of the forces on a body or bodies at rest), kinematics (study of motion without regard to its causes), and dynamics (study of motion and the forces that affect it); mechanics may also be divided into solid mechanics and fluid mechanics, the latter including such branches as hydrostatics, hydrodynamics, aerodynamics, and pneumatics. Acoustics, the study of sound, is often considered a branch of mechanics because sound is due to the motions of the particles of air or other medium through which sound waves can travel and thus can be explained in terms of the laws of mechanics. Among the important modern branches of acoustics is ultrasonics, the study of sound waves of very high frequency, beyond the range of human hearing. Optics, the study of light, is concerned not only with visible light but also with infrared and ultraviolet radiation, which exhibit all of the phenomena of visible light except visibility, e.g., reflection, refraction, interference, diffraction, dispersion (see spectrum), and polarization of light. Heat is a form of energy, the internal energy possessed by the particles of which a substance is composed; thermodynamics deals with the relationships between heat and other forms of energy. Electricity and magnetism have been studied as a single branch of physics since the intimate connection between them was discovered in the early 19th cent.; an electric current gives rise to a magnetic field and a changing magnetic field induces an electric current. Electrostatics deals with electric charges at rest, electrodynamics with moving charges, and magnetostatics with magnetic poles at rest.

Modern Physics

Most of classical physics is concerned with matter and energy on the normal scale of observation; by contrast, much of modern physics is concerned with the behavior of matter and energy under extreme conditions or on the very large or very small scale. For example, atomic and nuclear physics studies matter on the smallest scale at which chemical elements can be identified. The physics of elementary particles is on an even smaller scale, being concerned with the most basic units of matter; this branch of physics is also known as high-energy physics because of the extremely high energies necessary to produce many types of particles in large particle accelerators. On this scale, ordinary, commonsense notions of space, time, matter, and energy are no longer valid.

The two chief theories of modern physics present a different picture of the concepts of space, time, and matter from that presented by classical physics. The quantum theory is concerned with the discrete, rather than continuous, nature of many phenomena at the atomic and subatomic level, and with the complementary aspects of particles and waves in the description of such phenomena. The theory of relativity is concerned with the description of phenomena that take place in a frame of reference that is in motion with respect to an observer; the special theory of relativity is concerned with relative uniform motion in a straight line and the general theory of relativity with accelerated motion and its connection with gravitation. Both the quantum theory and the theory of relativity find applications in all areas of modern physics.

Evolution of Physics

Greek Contributions

The earliest history of physics is interrelated with that of the other sciences. A number of contributions were made during the period of Greek civilization, dating from Thales and the early Ionian natural philosophers in the Greek colonies of Asia Minor (6th and 5th cent. B.C.). Democritus (c.460–370 B.C.) proposed an atomic theory of matter and extended it to other phenomena as well, but the dominant theories of matter held that it was formed of a few basic elements, usually earth, air, fire, and water. In the school founded by Pythagoras of Samos the principal concept was that of number; it was applied to all aspects of the universe, from planetary orbits to the lengths of strings used to sound musical notes.

The most important philosophy of the Greek period was produced by two men at Athens, Plato (427–347 B.C.) and his student Aristotle (384–322 B.C.); Aristotle in particular had a critical influence on the development of science in general and physics in particular. The Greek approach to physics was largely geometrical and reached its peak with Archimedes (287–212 B.C.), who studied a wide range of problems and anticipated the methods of the calculus. Another important scientist of the early Hellenistic period, centered in Alexandria, Egypt, was the astronomer Aristarchus (c.310–220 B.C.), who proposed a heliocentric, or sun-centered, system of the universe. However, just as the earlier atomic theory had not become generally accepted, so too the astronomical system that eventually prevailed was the geocentric system proposed by Hipparchus (190–120 B.C.) and developed in detail by Ptolemy (A.D. 85–A.D. 165).

Preservation of Learning

With the passing of the Greek civilization and the Roman civilization that followed it, Greek learning passed into the hands of the Muslim world that spread its influence from the E Mediterranean eastward into Asia, where it picked up contributions from the Chinese (papermaking, gunpowder) and the Hindus (the place-value decimal number system with a zero), and westward as far as Spain, where Islamic culture flourished in Córdoba, Toledo, and other cities. Little specific advance was made in physics during this period, but the preservation and study of Greek science by the Muslim world made possible the revival of learning in the West beginning in the 12th and 13th cent.

The Scientific Revolution

The first areas of physics to receive close attention were mechanics and the study of planetary motions. Modern mechanics dates from the work of Galileo and Simon Stevin in the late 16th and early 17th cent. The great breakthrough in astronomy was made by Nicolaus Copernicus, who proposed (1543) the heliocentric model of the solar system that was later modified by Johannes Kepler (using observations by Tycho Brahe) into the description of planetary motions that is still accepted today. Galileo gave his support to this new system and applied his discoveries in mechanics to its explanation.

The full explanation of both celestial and terrestrial motions was not given until 1687, when Isaac Newton published his *Principia* [Mathematical Principles of Natural Philosophy]. This work, the most important document of the Scientific Revolution of the 16th and 17th cent., contained Newton's famous three laws of motion and showed how the principle of universal gravitation could be used to explain the behavior not only of falling bodies on the earth but also planets and other celestial bodies in the heavens. To arrive at his results, Newton invented one form of an entirely new branch of mathematics, the calculus (also invented independently by G. W. Leibniz), which was to become an essential tool in much of the later development in most branches of physics.

Other branches of physics also received attention during this period. William Gilbert, court physician to Queen Elizabeth I, published (1600) an important work on magnetism, describing how the earth itself behaves like a giant magnet. Robert Boyle (1627–91) studied the behavior of gases enclosed in a chamber and formulated the gas law named for him; he also contributed to physiology and to the founding of modern chemistry.

Newton himself discovered the separation of white light into a spectrum of colors and published an important work on optics, in which he proposed the theory that light is composed of tiny particles, or corpuscles. This corpuscular theory was related to the mechanistic philosophy presented early in the 17th cent. by René Descartes, according to which the universe functioned like a mechanical system describable in terms of mathematics. A rival theory of light, explaining its behavior in terms of Waves, was presented in 1690 by Christian Huygens, but the belief in the mechanistic philosophy together with the great weight of Newton's reputation was such that the wave theory gained relatively little support until the 19th cent.

Development of Mechanics and Thermodynamics

During the 18th cent. the mechanics founded by Newton was developed by several scientists and received brilliant exposition in the *Analytical Mechanics* (1788) of J. L. Lagrange and the *Celestial Mechanics* (1799–1825) of P. S. Laplace. Daniel Bernoulli made important mathematical studies (1738) of the behavior of gases, anticipating the kinetic theory of gases developed more than a century later, and has been referred to as the first mathematical physicist.

The accepted theory of heat in the 18th cent. viewed heat as a kind of fluid, called caloric; although this theory was later shown to be erroneous, a number of scientists adhering to it nevertheless made important discoveries useful in developing the modern theory, including Joseph Black (1728–99) and Henry Cavendish (1731–1810). Opposed to this caloric theory, which had been developed mainly by the chemists, was the less accepted theory dating from Newton's time that heat is due to the motions of the particles of a substance. This mechanical theory gained support in 1798 from the cannon-boring experiments of Count Rumford (Benjamin Thompson), who found a direct relationship between heat and mechanical energy.

In the 19th cent. this connection was established quantitatively by J. R. Mayer and J. P. Joule, who measured the mechanical equivalent of heat in the 1840s. This experimental work and the theoretical work of Sadi Carnot, published in 1824 but not widely known until later, together provided a basis for the formulation of the first two laws of thermodynamics in the 1850s by William Thomson (later Lord Kelvin) and R. J. E. Clausius. The first law is a form of the law of conservation of energy, stated earlier by J. R. von Mayer and Hermann Helmholtz on the basis of biological considerations; the second law describes the tendency of energy to be converted from more useful to less useful forms.

The atomic theory of matter had been proposed again in the early 19th cent. by the chemist John Dalton and became one of the hypotheses of the kinetic-molecular theory of gases developed by Clausius and James Clerk Maxwell to explain the laws of thermodynamics. The kinetic theory in turn led to the statistical mechanics of Ludwig Boltzmann and J. W. Gibbs.

Advances in Electricity, Magnetism, and Thermodynamics

The study of electricity and magnetism also came into its own during the 18th and 19th cents. C. A. Coulomb had discovered the inverse-square laws of electrostatics and magnetostatics in the late 18th cent. and Alessandro Volta had invented the electric battery, so that electric currents could also be studied. In 1820, H. C. Oersted found that a current-carrying conductor gives rise to a magnetic force surrounding it, and in 1831 Michael Faraday (and independently Joseph Henry) discovered the reverse effect, the production of an electric potential or current through magnetism (see induction); these two discoveries are the basis of the electric motor and the electric generator, respectively.

Faraday invented the concept of the field of force to explain these phenomena and Maxwell, from c.1856, developed these ideas mathematically in his theory of electromagnetic radiation. He showed that electric and magnetic fields are propagated outward from their source at a speed equal to that of light and that light is one of several kinds of electromagnetic radiation, differing only in frequency and wavelength from the others. Experimental confirmation of Maxwell's theory was provided by Heinrich Hertz, who generated and detected electric waves in 1886 and verified their properties, at the same time foreshadowing their application in radio, television, and other devices. The wave theory of light had been revived in 1801 by Thomas Young and received strong experimental support from the work of A. J. Fresnel and others; the theory was widely accepted by the time of Maxwell's work on the electromagnetic field, and afterward the study of light and that of electricity and magnetism were closely related.

Birth of Modern Physics

By the late 19th cent. most of classical physics was complete, and optimistic physicists turned their attention to what they considered minor details in the complete elucidation of their subject. Several problems, however, provided the cracks that eventually led to the shattering of this optimism and the birth of modern physics. On the experimental side, the discoveries of X rays by Wilhelm Roentgen (1895), radioactivity by A. H. Becquerel (1896), the electron by J. J. Thomson (1897), and new radioactive elements by Marie and Pierre Curie raised questions about the supposedly indestructible atom and the nature of matter. Ernest Rutherford identified and named two types of radioactivity and in 1911 interpreted experimental evidence as showing that the atom consists of a dense, positively charged nucleus surrounded by negatively charged electrons. Classical theory, however, predicted that this structure should be unstable. Classical theory had also failed to explain successfully two other experimental results that appeared in the late 19th cent. One of these was the demonstration by A. A.

Michelson and E. W. Morley that there did not seem to be a preferred frame of reference, at rest with respect to the hypothetical luminiferous ether, for describing electromagnetic phenomena.

Relativity and Quantum Mechanics

In 1905, Albert Einstein showed that the result of the Michelson-Morley experiment could be interpreted by assuming the equivalence of all inertial (unaccelerated) frames of reference and the constancy of the speed of light in all frames; Einstein's special theory of relativity eliminated the need for the ether and implied, among other things, that mass and energy are equivalent and that the speed of light is the limiting speed for all bodies having mass. Hermann Minkowski provided (1908) a mathematical formulation of the theory in which space and time were united in a four-dimensional geometry of space-time. Einstein extended his theory to accelerated frames of reference in his general theory (1916), showing the connection between acceleration and gravitation. Newton's mechanics was interpreted as a special case of Einstein's, valid as an approximation for small speeds compared to that of light.

Although relativity resolved the electromagnetic phenomena conflict demonstrated by Michelson and Morley, a second theoretical problem was the explanation of the distribution of electromagnetic radiation emitted by a blackbody; experiment showed that at shorter wavelengths, toward the ultraviolet end of the spectrum, the energy approached zero, but classical theory predicted it should become infinite. This glaring discrepancy, known as the ultraviolet catastrophe, was solved by Max Planck's quantum theory (1900). In 1905, Einstein used the quantum theory to explain the photoelectric effect, and in 1913 Niels Bohr again used it to explain the stability of Rutherford's nuclear atom. In the 1920s the theory was extensively developed by Louis de Broglie, Werner Heisenberg, Wolfgang Pauli, Erwin Schrödinger, P. A. M. Dirac, and others; the new quantum mechanics became an indispensable tool in the investigation and explanation of phenomena at the atomic level.

Particles, Energy, and Contemporary Physics

Dirac's theory, which combined quantum mechanics with the theory of relativity, also predicted the existence of antiparticles. During the 1930s the first antiparticles were discovered, as well as other particles. Among those contributing to this new area of physics were James Chadwick, C. D. Anderson, E. O. Lawrence, J. D. Cockcroft, E. T. S. Walton, Enrico Fermi, and Hideki Yukawa.

The discovery of nuclear fission by Otto Hahn and Fritz Strassmann (1938) and its explanation by Lise Meitner and Otto Frisch provided a means for the large-scale conversion of mass into energy, in accordance with the theory of relativity, and triggered as well the massive governmental involvement in physics that is one of the fundamental facts of contemporary science. The growth of physics since the 1930s has been so great that it is impossible in a survey article to name even its most important individual contributors.

Among the areas where fundamental discoveries have been made more recently are solid-state physics, plasma physics, and cryogenics, or low-temperature physics. Out of solid-state physics, for example, have come many of the developments in electronics (e.g., the transistor and microcircuitry) that have revolutionized much of modern technology. Another development is the maser and laser (in principle the same device), with applications ranging from communication and controlled nuclear fusion experiments to atomic clocks and other measurement standards.

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