

What is physics?

Why does physics work in SI units?

Physics, science that deals with the structure of matter and the interactions between the fundamental constituents of the observable universe. In the broadest sense, physics (from the Greek *physikos*) is concerned with all aspects of nature on both the macroscopic and submicroscopic levels. Its scope of study encompasses not only the behaviour of objects under the action of given forces but also the nature and origin of gravitational, electromagnetic, and nuclear force fields. Its ultimate objective is the formulation of a few comprehensive principles that bring together and explain all such disparate phenomena.

Physics is the basic physical science. Until rather recent times *physics* and *natural philosophy* were used interchangeably for the science whose aim is the discovery and formulation of the fundamental laws of nature. As the modern sciences developed and became increasingly specialized, physics came to denote that part of physical science not included in astronomy, chemistry, geology, and engineering. Physics plays an important role in all the natural sciences, however, and all such fields have branches in which physical laws and measurements receive special emphasis, bearing such names as astrophysics, geophysics, biophysics, and even psychophysics. Physics can, at base, be defined as the science of matter, motion, and energy. Its laws are typically expressed with economy and precision in the language of mathematics.

Both experiment, the observation of phenomena under conditions that are controlled as precisely as possible, and theory, the formulation of a unified conceptual framework, play essential and complementary roles in the advancement of physics. Physical experiments result in measurements, which are compared with the outcome predicted by theory. A theory that reliably predicts the results of experiments to which it is applicable is said to embody a law of physics. However, a law is always subject to modification, replacement, or restriction to a more limited domain, if a later experiment makes it necessary.

Physics and Natural Law

The ultimate aim of physics is to find a unified set of laws governing matter, motion, and energy at small (microscopic) subatomic distances, at the human (macroscopic) scale of everyday life, and out to the largest distances (e.g., those on the extragalactic scale). This ambitious goal has been realized to a notable extent. Although a completely unified theory of physical phenomena has not yet been achieved (and possibly never will be), a remarkably small set of fundamental physical laws appears able to account for all known

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phenomena. The body of physics developed up to about the turn of the 20th century, known as classical physics, can largely account for the motions of macroscopic objects that move slowly with respect to the speed of light and for such phenomena as heat, sound, electricity, magnetism, and light. The modern developments of relativity and quantum mechanics modify these laws insofar as they apply to higher speeds, very massive objects, and to the tiny elementary constituents of matter, such as electrons, protons, and neutrons.

The scope of physics

The traditionally organized branches or fields of classical and modern physics are delineated below.

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Mechanics

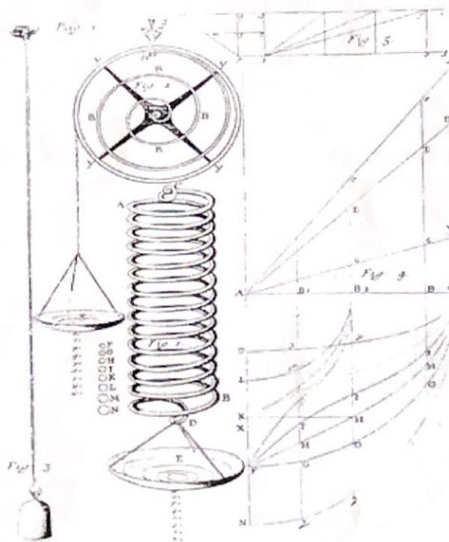


illustration of Robert Hooke's law of elasticity of materials

Illustration of Hooke's law of elasticity of materials, showing the stretching of a spring in proportion to the applied force, from Robert Hooke's *Lectures de Potentia Restitutiva* (1678).[\(more\)](#)

Mechanics is generally taken to mean the study of the motion of objects (or their lack of motion) under the action of given forces. Classical mechanics is sometimes considered

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a branch of applied mathematics. It consists of kinematics, the description of motion, and dynamics, the study of the action of forces in producing either motion or static equilibrium (the latter constituting the science of statics). The 20th-century subjects of quantum mechanics, crucial to treating the structure of matter, subatomic particles, superfluidity, superconductivity, neutron stars, and other major phenomena, and relativistic mechanics, important when speeds approach that of light, are forms of mechanics that will be discussed later in this section.

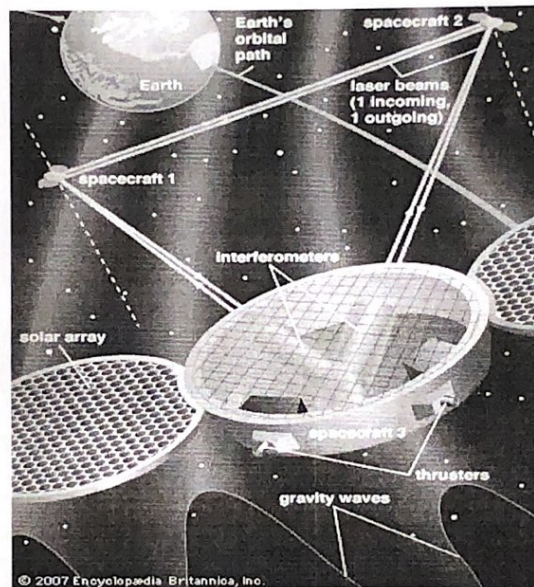
In classical mechanics the laws are initially formulated for point particles in which the dimensions, shapes, and other intrinsic properties of bodies are ignored. Thus in the first approximation even objects as large as Earth and the Sun are treated as pointlike—e.g., in calculating planetary orbital motion. In rigid-body dynamics, the extension of bodies and their mass distributions are considered as well, but they are imagined to be incapable of deformation. The mechanics of deformable solids is elasticity; hydrostatics and hydrodynamics treat, respectively, fluids at rest and in motion.

The three laws of motion set forth by Isaac Newton form the foundation of classical mechanics, together with the recognition that forces are directed quantities (vectors) and combine accordingly. The first law, also called the law of inertia, states that, unless acted upon by an external force, an object at rest remains at rest, or if in motion, it continues to move in a straight line with constant speed. Uniform motion therefore does not require a cause. Accordingly, mechanics concentrates not on motion as such but on the change in the state of motion of an object that results from the net force acting upon it. Newton's second law equates the net force on an object to the rate of change of its momentum, the latter being the product of the mass of a body and its velocity. Newton's third law, that of action and reaction, states that when two particles interact, the forces each exerts on the other are equal in magnitude and opposite in direction. Taken together, these mechanical laws in principle permit the determination of the future motions of a set of particles, providing their state of motion is known at some instant, as well as the forces that act between them and upon them from the outside. From this deterministic character of the laws of classical mechanics, profound (and probably incorrect) philosophical conclusions have been drawn in the past and even applied to human history.

Lying at the most basic level of physics, the laws of mechanics are characterized by certain symmetry properties, as exemplified in the aforementioned symmetry between action and reaction forces. Other symmetries, such as the invariance (i.e., unchanging form) of the laws under reflections and rotations carried out in space, reversal of time, or transformation to a different part of space or to a different epoch of time, are present both in classical mechanics and in relativistic mechanics, and with certain restrictions, also in quantum mechanics. The symmetry properties of the theory can be shown to have as mathematical consequences basic principles known as conservation laws, which assert the constancy in time of the values of certain physical quantities under prescribed conditions. The conserved quantities are the most important ones in physics; included

among them are mass and energy (in relativity theory, mass and energy are equivalent and are conserved together), momentum, angular momentum, and electric charge.

The study of gravitation



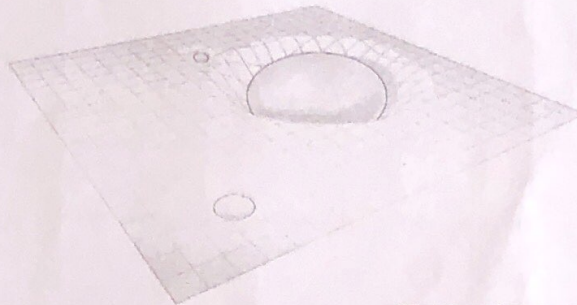
Laser Interferometer Space Antenna (LISA)

Laser Interferometer Space Antenna (LISA), a Beyond Einstein Great Observatory, is scheduled for launch in 2034. Funded by the European Space Agency, LISA will consist of three identical spacecraft that will trail the Earth in its orbit by about 50 million km (30 million miles). The spacecraft will contain thrusters for maneuvering them into an equilateral triangle, with sides of approximately 5 million km (3 million miles), such that the triangle's centre will be located along the Earth's orbit. By measuring the transmission of laser signals between the spacecraft (essentially a giant Michelson interferometer in space), scientists hope to detect and accurately measure gravity waves.(more)

This field of inquiry has in the past been placed within classical mechanics for historical reasons, because both fields were brought to a high state of perfection by Newton and also because of its universal character. Newton's gravitational law states that every material particle in the universe attracts every other one with a force that acts along the line joining them and whose strength is directly proportional to the product of their masses and inversely proportional to the square of their separation. Newton's detailed accounting for the orbits of the planets and the Moon, as well as for such subtle gravitational effects as the tides and the precession of the equinoxes (a slow cyclical change in direction of Earth's axis of rotation), through this fundamental force was the first triumph of classical mechanics. No further principles are required to understand the principal

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aspects of rocketry and space flight (although, of course, a formidable technology is needed to carry them out).



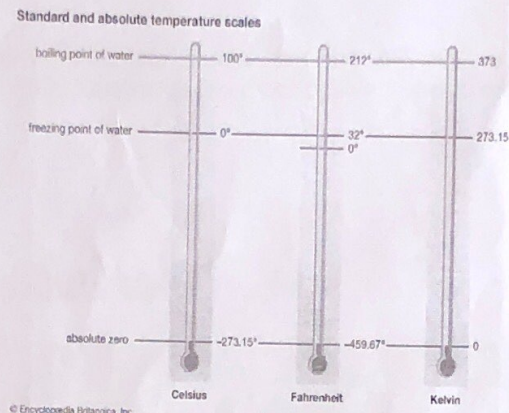
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curved space-time

The four dimensional space-time continuum itself is distorted in the vicinity of any mass, with the amount of distortion depending on the mass and the distance from the mass. Thus, relativity accounts for Newton's inverse square law of gravity through geometry and thereby does away with the need for any mysterious "action at a distance."(more)

The modern theory of gravitation was formulated by Albert Einstein and is called the general theory of relativity. From the long-known equality of the quantity "mass" in Newton's second law of motion and that in his gravitational law, Einstein was struck by the fact that acceleration can locally annul a gravitational force (as occurs in the so-called weightlessness of astronauts in an Earth-orbiting spacecraft) and was led thereby to the concept of curved space-time. Completed in 1915, the theory was valued for many years mainly for its mathematical beauty and for correctly predicting a small number of phenomena, such as the gravitational bending of light around a massive object. Only in recent years, however, has it become a vital subject for both theoretical and experimental research. (Relativistic mechanics refers to Einstein's special theory of relativity, which is not a theory of gravitation.)

The study of heat, thermodynamics, and statistical mechanics



temperature scales

Standard and absolute temperature scales.

Heat is a form of internal energy associated with the random motion of the molecular constituents of matter or with radiation. Temperature is an average of a part of the internal energy present in a body (it does not include the energy of molecular binding or of molecular rotation). The lowest possible energy state of a substance is defined as the absolute zero (-273.15°C , or -459.67°F) of temperature. An isolated body eventually reaches uniform temperature, a state known as thermal equilibrium, as do two or more bodies placed in contact. The formal study of states of matter at (or near) thermal equilibrium is called thermodynamics; it is capable of analyzing a large variety of thermal systems without considering their detailed microstructures.

First law

The first law of thermodynamics is the energy conservation principle of mechanics (i.e., for all changes in an isolated system, the energy remains constant) generalized to include heat.

Second law

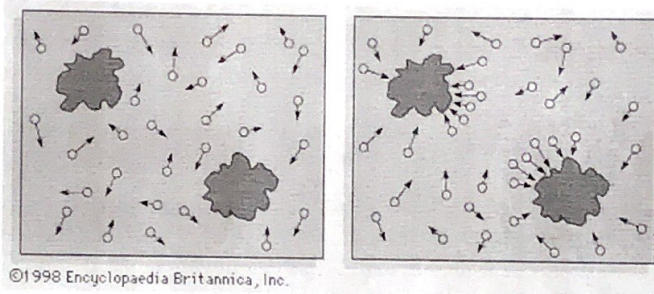
The second law of thermodynamics asserts that heat will not flow from a place of lower temperature to one where it is higher without the intervention of an external device (e.g., a refrigerator). The concept of entropy involves the measurement of the state of disorder

of the particles making up a system. For example, if tossing a coin many times results in a random-appearing sequence of heads and tails, the result has a higher entropy than if heads and tails tend to appear in clusters. Another formulation of the second law is that the entropy of an isolated system never decreases with time.

Third law

The third law of thermodynamics states that the entropy at the absolute zero of temperature is zero, corresponding to the most ordered possible state.

Statistical mechanics



Brownian particle

(Left) Random motion of a Brownian particle and (right) random discrepancy between the molecular pressures on different surfaces of the particle that cause motion.(more)

The science of statistical mechanics derives bulk properties of systems from the mechanical properties of their molecular constituents, assuming molecular chaos and applying the laws of probability. Regarding each possible configuration of the particles as equally likely, the chaotic state (the state of maximum entropy) is so enormously more likely than ordered states that an isolated system will evolve to it, as stated in the second law of thermodynamics. Such reasoning, placed in mathematically precise form, is typical of statistical mechanics, which is capable of deriving the laws of thermodynamics but goes beyond them in describing fluctuations (i.e., temporary departures) from the thermodynamic laws that describe only average behaviour. An example of a fluctuation phenomenon is the random motion of small particles suspended in a fluid, known as Brownian motion.

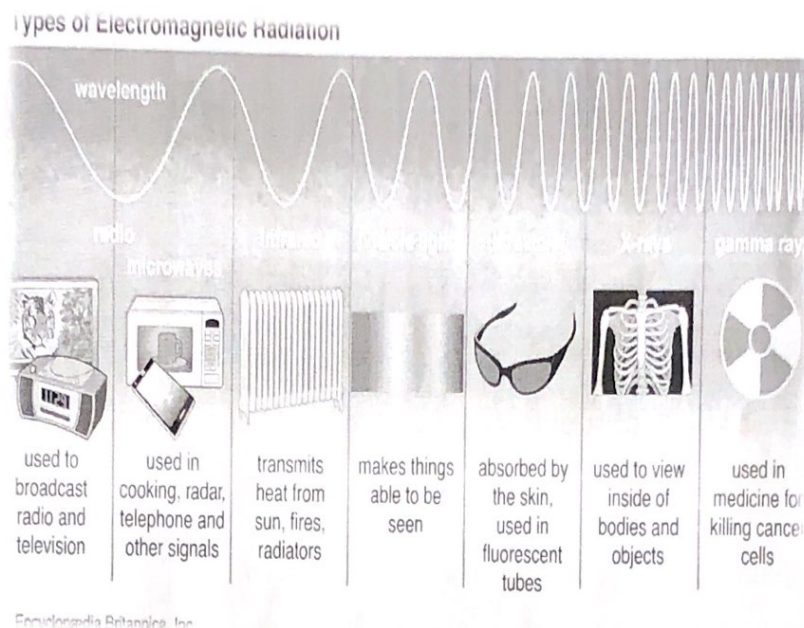
Quantum statistical mechanics plays a major role in many other modern fields of science, as, for example, in plasma physics (the study of fully ionized gases), in solid-state

physics, and in the study of stellar structure. From a microscopic point of view the laws of thermodynamics imply that, whereas the total quantity of energy of any isolated system is constant, what might be called the quality of this energy is degraded as the system moves inexorably, through the operation of the laws of chance, to states of increasing disorder until it finally reaches the state of maximum disorder (maximum entropy), in which all parts of the system are at the same temperature, and none of the state's energy may be usefully employed. When applied to the universe as a whole, considered as an isolated system, this ultimate chaotic condition has been called the "heat death."

The study of electricity and magnetism

Although conceived of as distinct phenomena until the 19th century, electricity and magnetism are now known to be components of the unified field of electromagnetism. Particles with electric charge interact by an electric force, while charged particles in motion produce and respond to magnetic forces as well. Many subatomic particles, including the electrically charged electron and proton and the electrically neutral neutron, behave like elementary magnets. On the other hand, in spite of systematic searches undertaken, no magnetic monopoles, which would be the magnetic analogues of electric charges, have ever been found.

The field concept plays a central role in the classical formulation of electromagnetism, as well as in many other areas of classical and contemporary physics. Einstein's gravitational field, for example, replaces Newton's concept of gravitational action at a distance. The field describing the electric force between a pair of charged particles works in the following manner: each particle creates an electric field in the space surrounding it, and so also at the position occupied by the other particle; each particle responds to the force exerted upon it by the electric field at its own position.



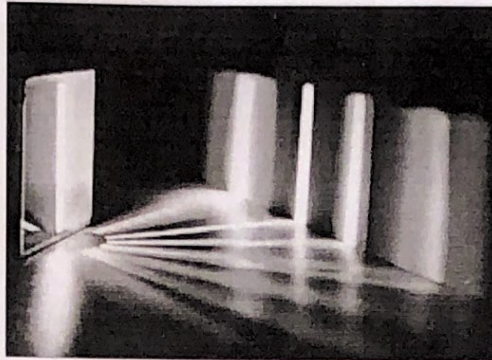
Types Of Electromagnetic Radiation

Radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays are all types of electromagnetic radiation. Radio waves have the longest wavelength, and gamma rays have the shortest wavelength.(more)

Classical electromagnetism is summarized by the laws of action of electric and magnetic fields upon electric charges and upon magnets and by four remarkable equations formulated in the latter part of the 19th century by the Scottish physicist James Clerk Maxwell. The latter equations describe the manner in which electric charges and currents produce electric and magnetic fields, as well as the manner in which changing magnetic fields produce electric fields, and vice versa. From these relations Maxwell inferred the existence of electromagnetic waves—associated electric and magnetic fields in space, detached from the charges that created them, traveling at the speed of light, and endowed with such “mechanical” properties as energy, momentum, and angular momentum. The light to which the human eye is sensitive is but one small segment of an electromagnetic spectrum that extends from long-wavelength radio waves to short-wavelength gamma rays and includes X-rays, microwaves, and infrared (or heat) radiation.

Optics

طاهر عبد الباقى



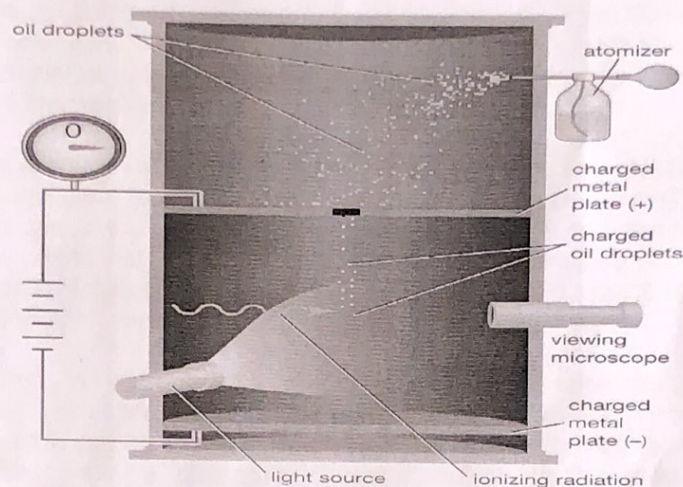
Diffraction grating

Spectrum of white light by a diffraction grating. With a prism, the red end of the spectrum is more compressed than the violet end.(more)

توضيح
Because light consists of electromagnetic waves, the propagation of light can be regarded as merely a branch of electromagnetism. However, it is usually dealt with as a separate subject called optics: the part that deals with the tracing of light rays is known as geometrical optics, while the part that treats the distinctive wave phenomena of light is called physical optics. More recently, there has developed a new and vital branch, quantum optics, which is concerned with the theory and application of the laser, a device that produces an intense coherent beam of unidirectional radiation useful for many applications.

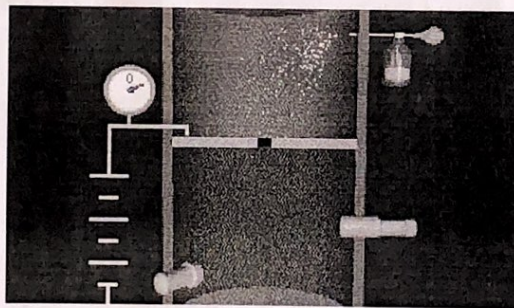
The formation of images by lenses, microscopes, telescopes, and other optical devices is described by ray optics, which assumes that the passage of light can be represented by straight lines, that is, rays. The subtler effects attributable to the wave property of visible light, however, require the explanations of physical optics. One basic wave effect is interference, whereby two waves present in a region of space combine at certain points to yield an enhanced resultant effect (e.g., the crests of the component waves adding together); at the other extreme, the two waves can annul each other, the crests of one wave filling in the troughs of the other. Another wave effect is diffraction, which causes light to spread into regions of the geometric shadow and causes the image produced by any optical device to be fuzzy to a degree dependent on the wavelength of the light. Optical instruments such as the interferometer and the diffraction grating can be used for measuring the wavelength of light precisely (about 500 micrometres) and for measuring distances to a small fraction of that length.

Atomic and chemical physics



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Millikan oil-drop experiment



See how physicist Robert Millikan devised a method for measuring the electric charge of single electrons

Millikan oil-drop experiment.
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One of the great achievements of the 20th century was the establishment of the validity of the atomic hypothesis, first proposed in ancient times, that matter is made up of relatively few kinds of small, identical parts—namely, atoms. However, unlike the

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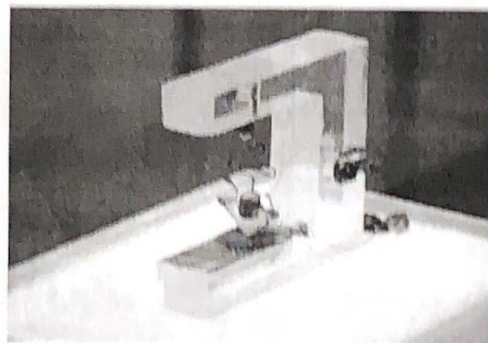
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indivisible atom of Democritus and other ancients, the atom, as it is conceived today, can be separated into constituent electrons and nucleus. Atoms combine to form molecules, whose structure is studied by chemistry and physical chemistry; they also form other types of compounds, such as crystals, studied in the field of condensed-matter physics. Such disciplines study the most important attributes of matter (not excluding biologic matter) that are encountered in normal experience—namely, those that depend almost entirely on the outer parts of the electronic structure of atoms. Only the mass of the atomic nucleus and its charge, which is equal to the total charge of the electrons in the neutral atom, affect the chemical and physical properties of matter.

Although there are some analogies between the solar system and the atom due to the fact that the strengths of gravitational and electrostatic forces both fall off as the inverse square of the distance, the classical forms of electromagnetism and mechanics fail when applied to tiny, rapidly moving atomic constituents. Atomic structure is comprehensible only on the basis of quantum mechanics, and its finer details require as well the use of quantum electrodynamics (QED).

Atomic properties are inferred mostly by the use of indirect experiments. Of greatest importance has been spectroscopy, which is concerned with the measurement and interpretation of the electromagnetic radiations either emitted or absorbed by materials. These radiations have a distinctive character, which quantum mechanics relates quantitatively to the structures that produce and absorb them. It is truly remarkable that these structures are in principle, and often in practice, amenable to precise calculation in terms of a few basic physical constants: the mass and charge of the electron, the speed of light, and Planck's constant (approximately $6.62606957 \times 10^{-34}$ joule-second), the fundamental constant of the quantum theory named for the German physicist Max Planck.

Condensed-matter physics



transistor

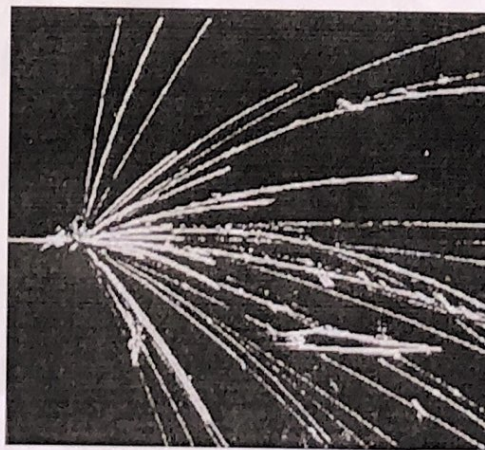
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The first transistor, invented by American physicists John Bardeen, Walter H. Brattain, and William B. Shockley.(more)

This field, which treats the thermal, elastic, electrical, magnetic, and optical properties of solid and liquid substances, grew at an explosive rate in the second half of the 20th century and scored numerous important scientific and technical achievements, including the transistor. Among solid materials, the greatest theoretical advances have been in the study of crystalline materials whose simple repetitive geometric arrays of atoms are multiple-particle systems that allow treatment by quantum mechanics. Because the atoms in a solid are coordinated with each other over large distances, the theory must go beyond that appropriate for atoms and molecules. Thus conductors, such as metals, contain some so-called free electrons, or valence electrons, which are responsible for the electrical and most of the thermal conductivity of the material and which belong collectively to the whole solid rather than to individual atoms. Semiconductors and insulators, either crystalline or amorphous, are other materials studied in this field of physics.

Other aspects of condensed matter involve the properties of the ordinary liquid state, of liquid crystals, and, at temperatures near absolute zero, of the so-called quantum liquids. The latter exhibit a property known as superfluidity (completely frictionless flow), which is an example of macroscopic quantum phenomena. Such phenomena are also exemplified by superconductivity (completely resistance-less flow of electricity), a low-temperature property of certain metallic and ceramic materials. Besides their significance to technology, macroscopic liquid and solid quantum states are important in astrophysical theories of stellar structure in, for example, neutron stars.

Nuclear physics



particle tracks from the collision of an accelerated nucleus

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Particle tracks from the collision of an accelerated nucleus of a niobium atom with another niobium nucleus. The single line on the left is the track of the incoming projectile nucleus, and the other tracks are fragments from the collision.(more)

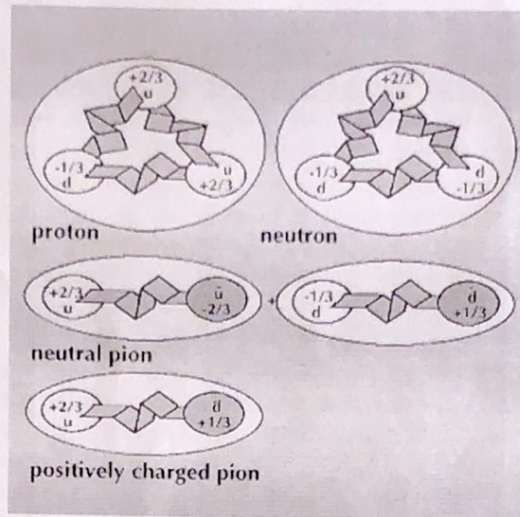
This branch of physics deals with the structure of the atomic nucleus and the radiation from unstable nuclei. About 10,000 times smaller than the atom, the constituent particles of the nucleus, protons and neutrons, attract one another so strongly by the nuclear forces that nuclear energies are approximately 1,000,000 times larger than typical atomic energies. Quantum theory is needed for understanding nuclear structure.

Like excited atoms, unstable radioactive nuclei (either naturally occurring or artificially produced) can emit electromagnetic radiation. The energetic nuclear photons are called gamma rays. Radioactive nuclei also emit other particles: negative and positive electrons (beta rays), accompanied by neutrinos, and helium nuclei (alpha rays).

A principal research tool of nuclear physics involves the use of beams of particles (e.g., protons or electrons) directed as projectiles against nuclear targets. Recoiling particles and any resultant nuclear fragments are detected, and their directions and energies are analyzed to reveal details of nuclear structure and to learn more about the strong force. A much weaker nuclear force, the so-called weak interaction, is responsible for the emission of beta rays. Nuclear collision experiments use beams of higher-energy particles, including those of unstable particles called mesons produced by primary nuclear collisions in accelerators dubbed meson factories. Exchange of mesons between protons and neutrons is directly responsible for the strong force. (For the mechanism underlying mesons, *see below* Fundamental forces and fields.)

In radioactivity and in collisions leading to nuclear breakup, the chemical identity of the nuclear target is altered whenever there is a change in the nuclear charge. In fission and fusion nuclear reactions in which unstable nuclei are, respectively, split into smaller nuclei or amalgamated into larger ones, the energy release far exceeds that of any chemical reaction.

Particle physics



protons, neutrons, pions, and other hadrons

Very simplified illustrations of protons, neutrons, pions, and other hadrons show that they are made of quarks (yellow spheres) and antiquarks (green spheres), which are bound together by gluons (bent ribbons). (more)

One of the most significant branches of contemporary physics is the study of the fundamental subatomic constituents of matter, the elementary particles. This field, also called high-energy physics, emerged in the 1930s out of the developing experimental areas of nuclear and cosmic-ray physics. Initially investigators studied cosmic rays, the very-high-energy extraterrestrial radiations that fall upon Earth and interact in the atmosphere (see *below* The methodology of physics). However, after World War II, scientists gradually began using high-energy particle accelerators to provide subatomic particles for study. Quantum field theory, a generalization of QED to other types of force fields, is essential for the analysis of high-energy physics. Subatomic particles cannot be visualized as tiny analogues of ordinary material objects such as billiard balls, for they have properties that appear contradictory from the classical viewpoint. That is to say, while they possess charge, spin, mass, magnetism, and other complex characteristics, they are nonetheless regarded as pointlike.

During the latter half of the 20th century, a coherent picture evolved of the underlying strata of matter involving two types of subatomic particles: fermions (baryons and leptons), which have odd half-integral angular momentum (spin $1/2$, $3/2$) and make up ordinary matter; and bosons (gluons, mesons, and photons), which have integral spins and mediate the fundamental forces of physics.

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Leptons (e.g., electrons, muons, taus), gluons, and photons are believed to be truly fundamental particles. Baryons (e.g., neutrons, protons) and mesons (e.g., pions, kaons), collectively known as hadrons, are believed to be formed from indivisible elements known as quarks, which have never been isolated.

Quarks come in six types, or "flavours," and have matching antiparticles, known as antiquarks. Quarks have charges that are either positive two-thirds or negative one-third of the electron's charge, while antiquarks have the opposite charges. Like quarks, each lepton has an antiparticle with properties that mirror those of its partner (the antiparticle of the negatively charged electron is the positive electron, or positron; that of the neutrino is the antineutrino). In addition to their electric and magnetic properties, quarks participate in both the strong force (which binds them together) and the weak force (which underlies certain forms of radioactivity), while leptons take part in only the weak force.

Baryons, such as neutrons and protons, are formed by combining three quarks—thus baryons have a charge of -1 , 0 , or 1 . Mesons, which are the particles that mediate the strong force inside the atomic nucleus, are composed of one quark and one antiquark; all known mesons have a charge of -2 , -1 , 0 , 1 , or 2 . Most of the possible quark combinations, or hadrons, have very short lifetimes, and many of them have never been seen, though additional ones have been observed with each new generation of more powerful particle accelerators.

The quantum fields through which quarks and leptons interact with each other and with themselves consist of particle-like objects called quanta (from which quantum mechanics derives its name). The first known quanta were those of the electromagnetic field; they are also called photons because light consists of them. A modern unified theory of weak and electromagnetic interactions, known as the electroweak theory, proposes that the weak force involves the exchange of particles about 100 times as massive as protons. These massive quanta have been observed—namely, two charged particles, W^+ and W^- , and a neutral one, W^0 .

In the theory of the strong force known as quantum chromodynamics (QCD), eight quanta, called gluons, bind quarks to form baryons and also bind quarks to antiquarks to form mesons, the force itself being dubbed the "colour force." (This unusual use of the term colour is a somewhat forced analogue of ordinary colour mixing.) Quarks are said to come in three colours—red, blue, and green. (The opposites of these imaginary colours, minus-red, minus-blue, and minus-green, are ascribed to antiquarks.) Only certain colour combinations, namely colour-neutral, or "white" (i.e., equal mixtures of the above colours cancel out one another, resulting in no net colour), are conjectured to exist in nature in an observable form. The gluons and quarks themselves, being coloured, are permanently confined (deeply bound within the particles of which they are a part), while the colour-neutral composites such as protons can be directly observed. One consequence of colour confinement is that the observable particles are either electrically neutral or have charges

that are integral multiples of the charge of the electron. A number of specific predictions of QCD have been experimentally tested and found correct.

Quantum mechanics

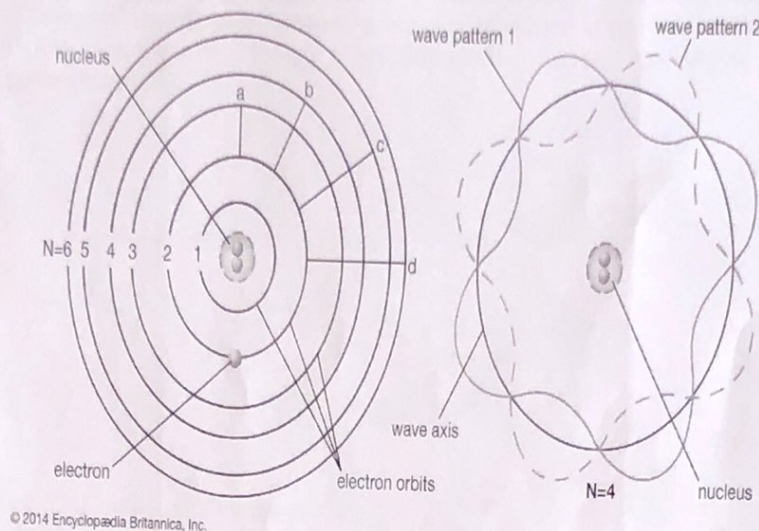
Brian Greene explains how the revolutionary idea of quantum mechanics is that reality evolves through a game of chance described by probabilities. This video is an episode in his *Daily Equation* series.(more)

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Although the various branches of physics differ in their experimental methods and theoretical approaches, certain general principles apply to all of them. The forefront of contemporary advances in physics lies in the submicroscopic regime, whether it be in atomic, nuclear, condensed-matter, plasma, or particle physics, or in quantum optics, or even in the study of stellar structure. All are based upon quantum theory (i.e., quantum mechanics and quantum field theory) and relativity, which together form the theoretical foundations of modern physics. Many physical quantities whose classical counterparts vary continuously over a range of possible values are in quantum theory constrained to have discontinuous, or discrete, values. Furthermore, the intrinsically deterministic character of values in classical physics is replaced in quantum theory by intrinsic uncertainty.

According to quantum theory, electromagnetic radiation does not always consist of continuous waves; instead it must be viewed under some circumstances as a collection of particle-like photons, the energy and momentum of each being directly proportional to its frequency (or inversely proportional to its wavelength, the photons still possessing some wavelike characteristics). Conversely, electrons and other objects that appear as particles in classical physics are endowed by quantum theory with wavelike properties as well, such a particle's quantum wavelength being inversely proportional to its momentum. In both instances, the proportionality constant is the characteristic quantum of action (action being defined as energy \times time)—that is to say, Planck's constant divided by 2π , or \hbar .

Models of atomic structure



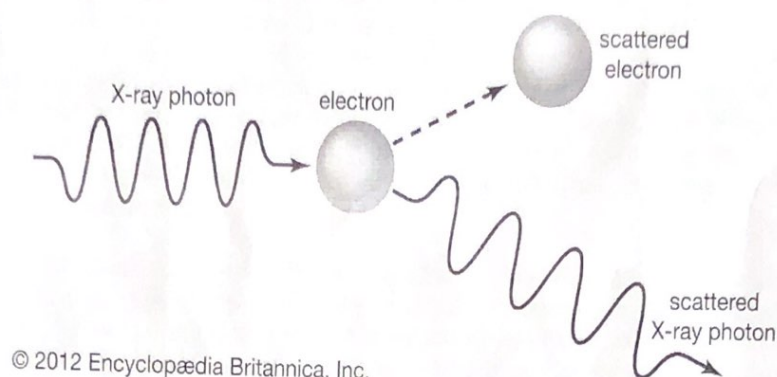
Bohr theory

The Bohr theory sees an electron (left) as a point mass occupying certain energy levels. Wave mechanics sees an electron as a wave washing back and forth in the atom in certain patterns only. The wave patterns and energy levels correspond exactly. (more)

In principle, all of atomic and molecular physics, including the structure of atoms and their dynamics, the periodic table of elements and their chemical behaviour, as well as the spectroscopic, electrical, and other physical properties of atoms, molecules, and condensed matter, can be accounted for by quantum mechanics. Roughly speaking, the electrons in the atom must fit around the nucleus as some sort of standing wave (as given by the Schrödinger equation) analogous to the waves on a plucked violin or guitar string. As the fit determines the wavelength of the quantum wave, it necessarily determines its energy state. Consequently, atomic systems are restricted to certain discrete, or quantized, energies. When an atom undergoes a discontinuous transition, or quantum jump, its energy changes abruptly by a sharply defined amount, and a photon of that energy is emitted when the energy of the atom decreases, or is absorbed in the opposite case.

Although atomic energies can be sharply defined, the positions of the electrons within the atom cannot be, quantum mechanics giving only the probability for the electrons to have certain locations. This is a consequence of the feature that distinguishes quantum theory from all other approaches to physics, the uncertainty principle of the German physicist Werner Heisenberg. This principle holds that measuring a particle's position with increasing precision necessarily increases the uncertainty as to the particle's momentum,

and conversely. The ultimate degree of uncertainty is controlled by the magnitude of Planck's constant, which is so small as to have no apparent effects except in the world of microstructures. In the latter case, however, because both a particle's position and its velocity or momentum must be known precisely at some instant in order to predict its future history, quantum theory precludes such certain prediction and thus escapes determinism.



Compton effect

When a beam of X-rays is aimed at a target material, some of the beam is deflected, and the scattered X-rays have a greater wavelength than the original beam. The physicist Arthur Holly Compton concluded that this phenomenon could only be explained if the X-rays were understood to be made up of discrete bundles or particles, now called photons, that lost some of their energy in the collisions with electrons in the target material and then scattered at lower energy.(more)

The complementary wave and particle aspects, or wave-particle duality, of electromagnetic radiation and of material particles furnish another illustration of the uncertainty principle. When an electron exhibits wavelike behaviour, as in the phenomenon of electron diffraction, this excludes its exhibiting particle-like behaviour in the same observation. Similarly, when electromagnetic radiation in the form of photons interacts with matter, as in the Compton effect in which X-ray photons collide with electrons, the result resembles a particle-like collision and the wave nature of electromagnetic radiation is precluded. The principle of complementarity, asserted by the Danish physicist Niels Bohr, who pioneered the theory of atomic structure, states that the physical world presents itself in the form of various complementary pictures, no one of which is by itself complete, all of these pictures being essential for our total understanding. Thus both wave and particle pictures are needed for understanding either the electron or the photon.

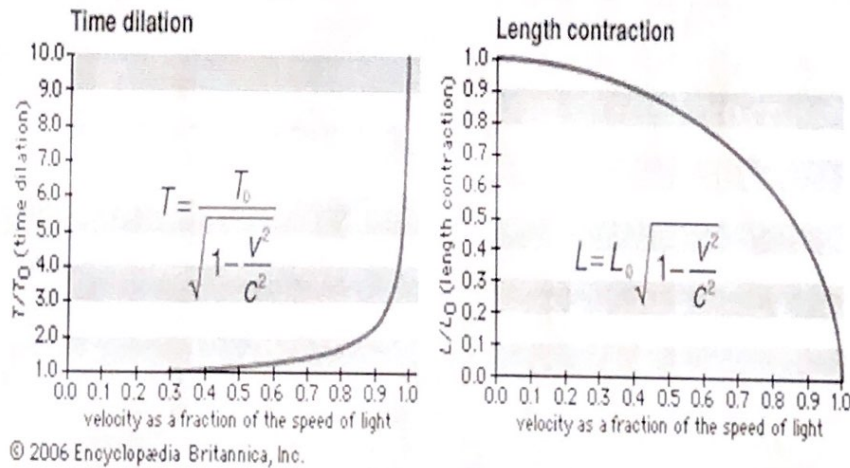
Although it deals with probabilities and uncertainties, the quantum theory has been spectacularly successful in explaining otherwise inaccessible atomic phenomena and in thus far meeting every experimental test. Its predictions, especially those of QED, are the

most precise and the best checked of any in physics; some of them have been tested and found accurate to better than one part per billion.

Relativistic mechanics

In classical physics, space is conceived as having the absolute character of an empty stage in which events in nature unfold as time flows onward independently; events occurring simultaneously for one observer are presumed to be simultaneous for any other; mass is taken as impossible to create or destroy; and a particle given sufficient energy acquires a velocity that can increase without limit. The special theory of relativity, developed principally by Albert Einstein in 1905 and now so adequately confirmed by experiment as to have the status of physical law, shows that all these, as well as other apparently obvious assumptions, are false.

Specific and unusual relativistic effects flow directly from Einstein's two basic postulates, which are formulated in terms of so-called inertial reference frames. These are reference systems that move in such a way that in them Isaac Newton's first law, the law of inertia, is valid. The set of inertial frames consists of all those that move with constant velocity with respect to each other (accelerating frames therefore being excluded). Einstein's postulates are: (1) All observers, whatever their state of motion relative to a light source, measure the same speed for light; and (2) The laws of physics are the same in all inertial frames.



length contraction and time dilation

General physics cores

1st class - inv. Sci. Dep.

As an object approaches the speed of light, an observer sees the object become shorter and its time interval become longer, relative to the length and time interval when the object is at rest.(more)

The first postulate, the constancy of the speed of light, is an experimental fact from which follow the distinctive relativistic phenomena of space contraction (or Lorentz-FitzGerald contraction), time dilation, and the relativity of simultaneity: as measured by an observer assumed to be at rest, an object in motion is contracted along the direction of its motion, and moving clocks run slow; two spatially separated events that are simultaneous for a stationary observer occur sequentially for a moving observer. As a consequence, space intervals in three-dimensional space are related to time intervals, thus forming so-called four-dimensional space-time.

The second postulate is called the principle of relativity. It is equally valid in classical mechanics (but not in classical electrodynamics until Einstein reinterpreted it). This postulate implies, for example, that table tennis played on a train moving with constant velocity is just like table tennis played with the train at rest, the states of rest and motion being physically indistinguishable. In relativity theory, mechanical quantities such as momentum and energy have forms that are different from their classical counterparts but give the same values for speeds that are small compared to the speed of light, the maximum permissible speed in nature (about 300,000 kilometres per second, or 186,000 miles per second). According to relativity, mass and energy are equivalent and interchangeable quantities, the equivalence being expressed by Einstein's famous mass-energy equation $E = mc^2$, where m is an object's mass and c is the speed of light.

The general theory of relativity is Einstein's theory of gravitation, which uses the principle of the equivalence of gravitation and locally accelerating frames of reference. Einstein's theory has special mathematical beauty; it generalizes the "flat" space-time concept of special relativity to one of curvature. It forms the background of all modern cosmological theories. In contrast to some vulgarized popular notions of it, which confuse it with moral and other forms of relativism, Einstein's theory does not argue that "all is relative." On the contrary, it is largely a theory based upon those physical attributes that do not change, or, in the language of the theory, that are invariant.

Conservation laws and symmetry

Since the early period of modern physics, there have been conservation laws, which state that certain physical quantities, such as the total electric charge of an isolated system of bodies, do not change in the course of time. In the 20th century it has been proved mathematically that such laws follow from the symmetry properties of nature, as expressed in the laws of physics. The conservation of mass-energy of an isolated system, for example, follows from the assumption that the laws of physics may depend upon time intervals but not upon the specific time at which the laws are applied. The symmetries and the conservation laws that follow from them are regarded by modern physicists as being even more fundamental than the laws themselves, since they are able to limit the possible forms of laws that may be proposed in the future.

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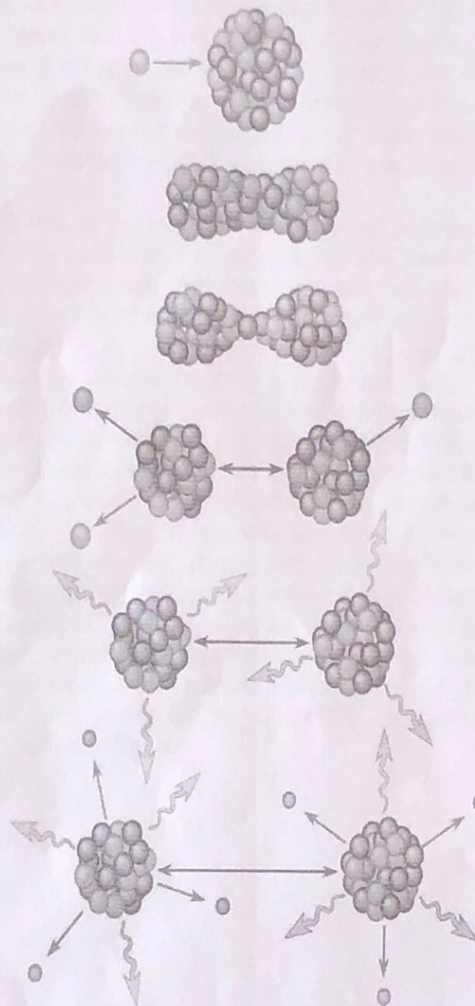
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Conservation laws are valid in classical, relativistic, and quantum theory for mass-energy, momentum, angular momentum, and electric charge. (In nonrelativistic physics, mass and energy are separately conserved.) Momentum, a directed quantity equal to the mass of a body multiplied by its velocity or to the total mass of two or more bodies multiplied by the velocity of their centre of mass, is conserved when, and only when, no external force acts. Similarly angular momentum, which is related to spinning motions, is conserved in a system upon which no net turning force, called torque, acts. External forces and torques break the symmetry conditions from which the respective conservation laws follow.

In quantum theory, and especially in the theory of elementary particles, there are additional symmetries and conservation laws, some exact and others only approximately valid, which play no significant role in classical physics. Among these are the conservation of so-called quantum numbers related to left-right reflection symmetry of space (called parity) and to the reversal symmetry of motion (called time reversal). These quantum numbers are conserved in all processes other than the weak force.

Other symmetry properties not obviously related to space and time (and referred to as internal symmetries) characterize the different families of elementary particles and, by extension, their composites. Quarks, for example, have a property called baryon number, as do protons, neutrons, nuclei, and unstable quark composites. All of these except the quarks are known as baryons. A failure of baryon-number conservation would exhibit itself, for instance, by a proton decaying into lighter non-baryonic particles. Indeed, intensive search for such proton decay has been conducted, but so far it has been fruitless. Similar symmetries and conservation laws hold for an analogously defined lepton number, and they also appear, as does the law of baryon conservation, to hold absolutely.

Fundamental forces and fields



The neutron strikes the nucleus and is absorbed.

The absorbed neutron causes the nucleus to undergo deformation.

In about 10^{-14} second, one of the deformations is so drastic that the nucleus cannot recover.

The nucleus fissions, releasing an average of two to three neutrons.

In about 10^{-12} second, the fission fragments lose their kinetic energy and come to rest, emitting a number of gamma rays. Now the fragments are called fission products.

The fission products lose their excess energy by radioactive decay, emitting particles over a lengthy time period (seconds to years).

● Neutrons ● Protons ● Beta particles ~~~~ Gamma rays

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fission