**Light**

Light, electromagnetic radiation that can be detected by the human eye. Electromagnetic radiation occurs over an extremely wide range of wavelengths, from gamma rays with wavelengths less than about 1 × 10−11 metre to radio waves measured in metres. Within that broad spectrum the wavelengths visible to humans occupy a very narrow band, from about 700 nanometres (nm; billionths of a metre) for red light down to about 400 nm for violet light. The spectral regions adjacent to the visible band are often referred to as light also, infrared at the one end and ultraviolet at the other. The speed of light in a vacuum is a fundamental physical constant, the currently accepted value of which is exactly 299,792,458 metres per second, or about 186,282 miles per second.

No single answer to the question “What is light?” satisfies the many contexts in which light is experienced, explored, and exploited. The physicist is interested in the physical properties of light, the artist in an aesthetic appreciation of the visual world. Through the sense of sight, light is a primary tool for perceiving the world and communicating within it. Light from the Sun warms the Earth, drives global weather patterns, and initiates the life-sustaining process of photosynthesis. On the grandest scale, light’s interactions with matter have helped shape the structure of the universe. Indeed, light provides a window on the universe, from cosmological to atomic scales. Almost all of the information about the rest of the universe reaches Earth in the form of electromagnetic radiation. By interpreting that radiation, astronomers can glimpse the earliest epochs of the universe, measure the general expansion of the universe, and determine the chemical composition of stars and the interstellar medium. Just as the invention of the telescope dramatically broadened exploration of the universe, so too the invention of the microscope opened the intricate world of the cell. The analysis of the frequencies of light emitted and absorbed by atoms was a principal impetus for the development of quantum mechanics. Atomic and molecular spectroscopies continue to be primary tools for probing the structure of matter, providing ultrasensitive tests of atomic and molecular models and contributing to studies of fundamental photochemical reactions.

**Mechanics**

Mechanics, science concerned with the motion of bodies under the action of forces, including the special case in which a body remains at rest. Of first concern in the problem of motion are the forces that bodies exert on one another. This leads to the study of such topics as gravitation, electricity, and magnetism, according to the nature of the forces involved. Given the forces, one can seek the manner in which bodies move under the action of forces; this is the subject matter of mechanics proper.

Historically, mechanics was among the first of the exact sciences to be developed. Its internal beauty as a mathematical discipline and its early remarkable success in accounting in quantitative detail for the motions of the Moon, the Earth, and other planetary bodies had enormous influence on philosophical thought and provided impetus for the systematic development of science into the 20th century.

Mechanics may be divided into three branches: statics, which deals with forces acting on and in a body at rest; kinematics, which describes the possible motions of a body or system of bodies; and kinetics, which attempts to explain or predict the motion that will occur in a given situation. Alternatively, mechanics may be divided according to the kind of system studied. The simplest mechanical system is the particle, defined as a body so small that its shape and internal structure are of no consequence in the given problem. More complicated is the motion of a system of two or more particles that exert forces on one another and possibly undergo forces exerted by bodies outside of the system.

The principles of mechanics have been applied to three general realms of phenomena. The motions of such celestial bodies as stars, planets, and satellites can be predicted with great accuracy thousands of years before they occur. (The theory of relativity predicts some deviations from the motion according to classical, or Newtonian, mechanics; however, these are so small as to be observable only with very accurate techniques, except in problems involving all or a large portion of the detectable universe.) As the second realm, ordinary objects on Earth down to microscopic size (moving at speeds much lower than that of light) are properly described by classical mechanics without significant corrections.

**Gravity**

*Gravity*, also called gravitation, in mechanics, the universal force of attraction acting between all matter. It is by far the weakest known force in nature and thus plays no role in determining the internal properties of everyday matter. On the other hand, through its long reach and universal action, it controls the trajectories of bodies in the solar system and elsewhere in the universe and the structures and evolution of stars, galaxies, and the whole cosmos. On Earth all bodies have a weight, or downward force of gravity, proportional to their mass, which Earth’s mass exerts on them. Gravity is measured by the acceleration that it gives to freely falling objects. At Earth’s surface the acceleration of gravity is about 9.8 metres (32 feet) per second per second. Thus, for every second an object is in free fall, its speed increases by about 9.8 metres per second. At the surface of the Moon the acceleration of a freely falling body is about 1.6 metres per second per second.

The works of Isaac Newton and Albert Einstein dominate the development of gravitational theory. Newton’s classical theory of gravitational force held sway from his Principia, published in 1687, until Einstein’s work in the early 20th century. Newton’s theory is sufficient even today for all but the most precise applications. Einstein’s theory of general relativity predicts only minute quantitative differences from the Newtonian theory except in a few special cases. The major significance of Einstein’s theory is its radical conceptual departure from classical theory and its implications for further growth in physical thought.

The launch of space vehicles and developments of research from them have led to great improvements in measurements of gravity around Earth, other planets, and the Moon and in experiments on the nature of gravitation.

*Zero gravity* (weightlessness) is a condition experienced while in free-fall, in which the effect of gravity is canceled by the inertial (e.g., centrifugal) force resulting from orbital flight. The term zero gravity is often used to describe such a condition. Excluding spaceflight, true weightlessness can be experienced only briefly, as in an airplane following a ballistic (i.e., parabolic) path.

**S-matrix and String Theory in quantum physics**

*S-matrix*, also called scattering matrix, in quantum mechanics, array of mathematical quantities that predicts the probabilities of all possible outcomes of a given experimental situation. For instance, two particles in collision may alter in speed and direction or even change into entirely new particles: the S-matrix for the collision gives the likelihood of each possibility. Complete knowledge of the S-matrix for all processes would amount to complete understanding of all physical laws.

An S-matrix is expressed in terms of observable quantities, and its application circumvents the discussion, common in modern physics, of the unobservable phenomena that are supposed to occur in the mysterious interval between the time that free particles enter their region of interaction and the time that they emerge. In its pure form, the mathematical pursuit of S-matrix theory has produced important results, but the method is so general that it must be augmented by a great amount of additional physics to deal with the details of experimental fact.

*String theory*, in particle physics, a theory that attempts to merge quantum mechanics with Albert Einstein’s general theory of relativity. The name string theory comes from the modeling of subatomic particles as tiny one-dimensional “stringlike” entities rather than the more conventional approach in which they are modeled as zero-dimensional point particles. The theory envisions that a string undergoing a particular mode of vibration corresponds to a particle with definite properties such as mass and charge. In the 1980s, physicists realized that string theory had the potential to incorporate all four of nature’s forces – gravity, electromagnetism, strong force, and weak force – and all types of matter in a single quantum mechanical framework, suggesting that it might be the long-sought unified field theory. While string theory is still a vibrant area of research that is undergoing rapid development, it remains primarily a mathematical construct because it has yet to make contact with experimental observations.

**Neutron optics**

Neutron optics, branch of physics dealing with the theory and applications of the wave behaviour of neutrons, the electrically neutral subatomic particles that are present in all atomic nuclei except those of ordinary hydrogen. Neutron optics involves studying the interactions of matter with a beam of free neutrons, much as spectroscopy represents the interaction of matter with electromagnetic radiation. There are two major sources of free neutrons for neutron-beam production: (1) the neutrons emitted in fission reactions at nuclear reactors and (2) the neutrons released in particle-accelerator collisions of proton beams with targets of heavy atoms, such as tantalum. When a neutron beam is directed onto a sample of matter, the neutrons can be reflected, scattered, or diffracted, depending on the composition and structure of the sample and on the properties of the neutron beam. All three of these processes have been exploited in the development of analytic methods, with important applications in physics, chemistry, biology, and materials science. Among the diverse achievements in the field of neutron optics, neutron-scattering studies have yielded insight into the fundamental nature of magnetism, probed the detailed structure of proteins embedded in cell membranes, and provided a tool for examining stress and strain in jet engines.

In contrast to fast neutrons, which act more exclusively as particles when they strike materials, slow, or “thermal,” neutrons have longer wavelengths—about 10−10 metre, comparable in scale to the distance between atoms in crystals—and thus exhibit wavelike behaviour in their interactions with matter. Slow neutrons scattered by the atoms in a solid undergo mutual interference (similar to the behaviour of X-rays and light) to form diffraction patterns from which details of crystal structure and magnetic properties of solids can be deduced. The American physicist Clifford G. Shull and the Canadian physicist Bertram N. Brockhouse shared the 1994 Nobel Prize for Physics for their development of the complementary techniques and applications of neutron diffraction (elastic scattering) and neutron spectroscopy (inelastic scattering).

**Semiconductor materials**

Solid-state materials are commonly grouped into three classes: insulators, semiconductors, and conductors. (At low temperatures some conductors, semiconductors, and insulators may become superconductors.) The figure shows the conductivities σ (and the corresponding resistivities ρ = 1/σ) that are associated with some important materials in each of the three classes. Insulators, such as fused quartz and glass, have very low conductivities, on the order of 10−18 to 10−10 siemens per centimetre; and conductors, such as aluminum, have high conductivities, typically from 104 to 106 siemens per centimetre. The conductivities of semiconductors are between these extremes and are generally sensitive to temperature, illumination, magnetic fields, and minute amounts of impurity atoms. For example, the addition of about 10 atoms of boron (known as a dopant) per million atoms of silicon can increase its electrical conductivity a thousandfold (partially accounting for the wide variability shown in the preceding figure).

The study of semiconductor materials began in the early 19th century. The elemental semiconductors are those composed of single species of atoms, such as silicon (Si), germanium (Ge), and tin (Sn) in column IV and selenium (Se) and tellurium (Te) in column VI of the periodic table. There are, however, numerous compound semiconductors, which are composed of two or more elements. Gallium arsenide (GaAs), for example, is a binary III-V compound, which is a combination of gallium (Ga) from column III and arsenic (As) from column V. Ternary compounds can be formed by elements from three different columns – for instance, mercury indium telluride (HgIn2Te4), a II-III-VI compound. They also can be formed by elements from two columns, such as aluminum gallium arsenide (AlxGa1 − xAs), which is a ternary III-V compound, where both Al and Ga are from column III and the subscript x is related to the composition of the two elements from 100 percent Al (x = 1) to 100 percent Ga (x = 0). Pure silicon is the most important material for integrated circuit applications, and III-V binary and ternary compounds are most significant for light emission.

Prior to the invention of the bipolar transistor in 1947, semiconductors were used only as two-terminal devices, such as rectifiers and photodiodes.

**Molecular beam**

Molecular beam, any stream or ray of molecules moving in the same general direction, usually in a vacuum – i.e., inside an evacuated chamber. In this context the word molecule includes atoms as a special case. Most commonly, the molecules comprising the beam are at a low density; that is, they are far enough apart to move independently of each other. Because of the one-directional motion of the atoms or molecules, their properties can be studied in experiments that involve deflecting the beam in electric and magnetic fields or directing the beam onto a target. The target may be a solid, a gas, or a second beam of atoms or molecules.

*Applications*

Deflections of beams in electric and magnetic fields can give information about the structure and properties (such as rotation and spin) of the molecules, or atoms, in the beam. In more sophisticated experiments, two beams are allowed to intersect, producing scattering interactions or collisions between molecules in pairs, one from each beam. Scattering can demonstrate such properties of these pairs as the potential energy of their interaction as it varies with the distance of separation, their chemical reactivity, and the probability that they will exchange internal energy on collision.

The first experiment with molecular beams, in 1911, confirmed a postulate of kinetic theory that molecules of a gas at a very low pressure travel in straight lines until they hit the walls of their container. At higher pressures, molecules have a shorter free path because they collide with each other before arriving at the wall. The first extensive experiments with molecular beams were made in Germany between 1920 and 1933. The use of beams to study chemical reactions and the transfer of energy between colliding molecules increased rapidly after 1955.

*Production*

A molecular beam is produced by allowing gas to enter a vacuum chamber through a small hole or slit in a box containing vapour of the molecules that are to make up the beam. The vapour often comes from evaporation of a liquid sample in the box, called an oven, that can be heated to a suitable temperature. At low pressures of vapour in the box, when the free path of the molecules is greater than the width of the exit hole, the molecules will effuse through the hole; at higher pressures they will flow through the hole as fluids do under pressure, forming a jet.

**Relativity And Quantum Mechanics**

In 1905 Einstein unified space and time (see space-time) with his special theory of relativity, showing that motion through space affects the passage of time. In 1915 Einstein further unified space, time, and gravitation with his general theory of relativity, showing that warps and curves in space and time are responsible for the force of gravity. These were monumental achievements, but Einstein dreamed of an even grander unification. He envisioned one powerful framework that would account for space, time, and all of nature’s forces – something he called a unified theory. For the last three decades of his life, Einstein relentlessly pursued this vision. Although from time to time rumours spread that he had succeeded, closer scrutiny always dashed such hopes. Most of Einstein’s contemporaries considered the search for a unified theory to be a hopeless, if not misguided, quest.

In contrast, the primary concern of theoretical physicists from the 1920s onward was quantum mechanics – the emerging framework for describing atomic and subatomic processes. Particles at these scales have such tiny masses that gravity is essentially irrelevant in their interactions, and so for decades quantum mechanical calculations generally ignored general relativistic effects. Instead, by the late 1960s the focus was on a different force – the strong force, which binds together the protons and neutrons within atomic nuclei. Gabriele Veneziano, a young theorist working at the European Organization for Nuclear Research (CERN), contributed a key breakthrough in 1968 with his realization that a 200-year-old formula, the Euler beta function, was capable of explaining much of the data on the strong force then being collected at various particle accelerators around the world. A few years later, three physicists – Leonard Susskind of Stanford University, Holger Nielsen of the Niels Bohr Institute, and Yoichiro Nambu of the University of Chicago – significantly amplified Veneziano’s insight by showing that the mathematics underlying his proposal described the vibrational motion of minuscule filaments of energy that resemble tiny strands of string, inspiring the name string theory. Roughly speaking, the theory suggested that the strong force amounted to strings tethering together particles attached to the strings’ endpoints.

**Transistors**

Transistor is a semiconductor device for amplifying, controlling, and generating electrical signals. Transistors are the active components of integrated circuits, or “microchips,” which often contain billions of these minuscule devices etched into their shiny surfaces. Deeply embedded in almost everything electronic, transistors have become the nerve cells of the Information Age.

There are typically three electrical leads in a transistor, called the emitter, the collector, and the base – or, in modern switching applications, the source, the drain, and the gate. An electrical signal applied to the base (or gate) influences the semiconductor material’s ability to conduct electrical current, which flows between the emitter (or source) and collector (or drain) in most applications. A voltage source such as a battery drives the current, while the rate of current flow through the transistor at any given moment is governed by an input signal at the gate – much as a faucet valve is used to regulate the flow of water through a garden hose.

The first commercial applications for transistors were for hearing aids and “pocket” radios during the 1950s. With their small size and low power consumption, transistors were desirable substitutes for the vacuum tubes (known as “valves” in Great Britain) then used to amplify weak electrical signals and produce audible sounds. Transistors also began to replace vacuum tubes in the oscillator circuits used to generate radio signals, especially after specialized structures were developed to handle the higher frequencies and power levels involved. Low-frequency, high-power applications, such as power-supply inverters that convert alternating current (AC) into direct current (DC), have also been transistorized.

*Development of Transistors*

The transistor was invented in 1947–48 by three American physicists, John Bardeen, Walter H. Brattain, and William B. Shockley, at the American Telephone and Telegraph Company’s Bell Laboratories. The transistor proved to be a viable alternative to the electron tube and, by the late 1950s, supplanted the latter in many applications. Its small size, low heat generation, high reliability, and low power consumption made possible a breakthrough in the miniaturization of complex circuitry. During the 1960s and ’70s, transistors were incorporated into integrated circuits, in which a multitude of components (e.g., diodes, resistors, and capacitors) are formed on a single “chip” of semiconductor material.

**Vacuum technology**

Vacuum technology, all processes and physical measurements carried out under conditions of below-normal atmospheric pressure. A process or physical measurement is generally performed in a vacuum for one of the following reasons: (1) to remove the constituents of the atmosphere that could cause a physical or chemical reaction during the process (e.g., vacuum melting of reactive metals such as titanium); (2) to disturb an equilibrium condition that exists at normal room conditions, such as the removal of occluded or dissolved gas or volatile liquid from the bulk of material (e.g., degassing of oils, freeze-drying) or desorption of gas from surfaces (e.g., the cleanup of microwave tubes and linear accelerators during manufacture); (3) to extend the distance that a particle must travel before it collides with another, thereby helping the particles in a process to move without collision between source and target (examples of uses are in vacuum coating, particle accelerators, television picture tubes); (4) to reduce the number of molecular impacts per second, thus reducing chances of contamination of surfaces prepared in vacuum (useful in clean-surface studies).

For any vacuum process a limiting parameter for the maximum permissible pressure can be defined. It can be the number of molecules per unit volume (reasons 1 and 2), the mean free path (reason 3), or the time required to form a monolayer (reason 4).

The first major use of vacuum technology in industry occurred about 1900 in the manufacture of electric light bulbs. Other devices requiring a vacuum for their operation followed, such as the various types of electron tube. Furthermore, it was discovered that certain processes carried out in a vacuum achieved either superior results or ends actually unattainable under normal atmospheric conditions. Such developments included the “blooming” of lens surfaces to increase the light transmission, the preparation of blood plasma for blood banks, and the production of reactive metals such as titanium. The advent of nuclear energy in the 1950s provided impetus for the development of vacuum equipment on a large scale. Increasing applications for vacuum processes were steadily discovered, as in space simulation and microelectronics.