**Sound**

Sound, a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium. A purely subjective definition of sound is also possible, as that which is perceived by the ear, but such a definition is not particularly illuminating and is unduly restrictive, for it is useful to speak of sounds that cannot be heard by the human ear, such as those that are produced by dog whistles or by sonar equipment.

The study of sound should begin with the properties of sound waves. There are two basic types of wave, transverse and longitudinal, differentiated by the way in which the wave is propagated. In a transverse wave, such as the wave generated in a stretched rope when one end is wiggled back and forth, the motion that constitutes the wave is perpendicular, or transverse, to the direction (along the rope) in which the wave is moving. An important family of transverse waves is generated by electromagnetic sources such as light or radio, in which the electric and magnetic fields constituting the wave oscillate perpendicular to the direction of propagation.

Sound propagates through air or other mediums as a longitudinal wave, in which the mechanical vibration constituting the wave occurs along the direction of propagation of the wave. A longitudinal wave can be created in a coiled spring by squeezing several of the turns together to form a compression and then releasing them, allowing the compression to travel the length of the spring. Air can be viewed as being composed of layers analogous to such coils, with a sound wave propagating as layers of air “push” and “pull” at one another much like the compression moving down the spring.

A sound wave thus consists of alternating compressions and rarefactions, or regions of high pressure and low pressure, moving at a certain speed. Put another way, it consists of a periodic (that is, oscillating or vibrating) variation of pressure occurring around the equilibrium pressure prevailing at a particular time and place.

A discussion of sound waves and their propagation can begin with an examination of a plane wave of a single frequency passing through the air. A plane wave is a wave that propagates through space as a plane, rather than as a sphere of increasing radius.

**Plasma**

Plasma, in physics, an electrically conducting medium in which there are roughly equal numbers of positively and negatively charged particles, produced when the atoms in a gas become ionized. It is sometimes referred to as the fourth state of matter, distinct from the solid, liquid, and gaseous states.

The negative charge is usually carried by electrons, each of which has one unit of negative charge. The positive charge is typically carried by atoms or molecules that are missing those same electrons. In some rare but interesting cases, electrons missing from one type of atom or molecule become attached to another component, resulting in a plasma containing both positive and negative ions. The most extreme case of this type occurs when small but macroscopic dust particles become charged in a state referred to as a dusty plasma. The uniqueness of the plasma state is due to the importance of electric and magnetic forces that act on a plasma in addition to such forces as gravity that affect all forms of matter. Since these electromagnetic forces can act at large distances, a plasma will act collectively much like a fluid even when the particles seldom collide with one another.

Nearly all the visible matter in the universe exists in the plasma state, occurring predominantly in this form in the Sun and stars and in interplanetary and interstellar space. Auroras, lightning, and welding arcs are also plasmas; plasmas exist in neon and fluorescent tubes, in the crystal structure of metallic solids, and in many other phenomena and objects. The Earth itself is immersed in a tenuous plasma called the solar wind and is surrounded by a dense plasma called the ionosphere.

A plasma may be produced in the laboratory by heating a gas to an extremely high temperature, which causes such vigorous collisions between its atoms and molecules that electrons are ripped free, yielding the requisite electrons and ions. A similar process occurs inside stars. In space the dominant plasma formation process is photoionization, wherein photons from sunlight or starlight are absorbed by an existing gas, causing electrons to be emitted. Since the Sun and stars shine continuously, virtually all the matter becomes ionized in such cases, and the plasma is said to be fully ionized. This need not be the case, however, for a plasma may be only partially ionized. A completely ionized hydrogen plasma, consisting solely of electrons and protons (hydrogen nuclei), is the most elementary plasma.

**Oscillograph**

Oscillograph, instrument for indicating and recording time-varying electrical quantities, such as current and voltage. The two basic forms of the instrument in common use are the electromagnetic oscillograph and the cathode-ray oscillograph; the latter is also known as a cathode-ray oscilloscope (q.v.), which, strictly speaking, is purely an indicating instrument, while the oscillograph can make permanent records.

The operation of an electromagnetic oscillograph, like the operation of a d’Arsonval galvanometer, depends on the interaction of the field of a permanent magnet and a coil of wire through which an electric current is flowing.

Some oscillographs are provided with a pen arm, attached to the coil, that traces an ink record on a moving paper chart. The most common device of this nature is the electrocardiograph, which employs a coil of fine wire with many turns and is used for studying heart action.

The light-beam oscillograph has much less weight to move than does the pen-writing instrument and so responds satisfactorily to higher frequencies, about 500 Hz, or cycles per second, compared with 100 Hz for the pen assembly. It uses a coil to which a small mirror is attached. A beam of light is reflected from the mirror onto a photographic film moving at a constant speed. The cathode-ray oscillograph makes use of a sharply focused electron beam to display the relationship between variable quantities on a luminescent screen similar to that used in a television. It may be either a three- or a four-dimensional recording device, the latter being very versatile. Recording is by transfer of energy to a light-sensitive record, using either an optical-lens system or a fibre-optic faceplate. It can be employed at frequencies in the megahertz range.

*Cathode-ray oscilloscope*, electronic-display device containing a cathode-ray tube (CRT) that generates an electron beam that is used to produce visible patterns, or graphs, on a phosphorescent screen. The graphs plot the relationships between two or more variables, with the horizontal axis normally being a function of time and the vertical axis usually a function of the voltage generated by the input signal to the oscilloscope. Because almost any physical phenomenon can be converted into a corresponding electric voltage through the use of a transducer, the oscilloscope is a versatile tool in all forms of physical investigation.

**Mass**

Mass, in physics, quantitative measure of inertia, a fundamental property of all matter. It is, in effect, the resistance that a body of matter offers to a change in its speed or position upon the application of a force. The greater the mass of a body, the smaller the change produced by an applied force. By international agreement the standard unit of mass, with which the masses of all other objects are compared, is a platinum-iridium cylinder of one kilogram. This unit is commonly called the International Prototype Kilogram and is kept at the International Bureau of Weights and Measures in Sèvres, France. In countries that continue to favour the English system of measurement over the International System of Units (SI), the unit of mass is the slug, a mass whose weight at sea level is 32.17 pounds.

Weight, though related to mass, nonetheless differs from the latter. Weight essentially constitutes the force exerted on matter by the gravitational attraction of the Earth, and so it varies from place to place. In contrast, mass remains constant regardless of its location under ordinary circumstances. A satellite launched into space, for example, weighs increasingly less the further it travels away from the Earth. Its mass, however, stays the same.

According to the principle of conservation of mass, the mass of an object or collection of objects never changes, no matter how the constituent parts rearrange themselves. If a body split into pieces, the mass divides with the pieces, so that the sum of the masses of the individual pieces is equal to the original mass. Or, if particles are joined together, the mass of the composite is equal to the sum of the masses of the constituent particles. However, this principle is not always correct.

With the advent of the special theory of relativity by Einstein in 1905, the notion of mass underwent a radical revision. Mass lost its absoluteness. The mass of an object was seen to be equivalent to energy, to be interconvertible with energy, and to increase significantly at exceedingly high speeds near that of light (about 3 × 108 metres per second, or 186,000 miles per second). The total energy of an object was understood to comprise its rest mass as well as its increase of mass caused by high speed. The rest mass of an atomic nucleus was discovered to be measurably smaller than the sum of the rest masses of its constituent neutrons and protons. Mass was no longer considered constant, or unchangeable.

**Magnetic field**

Magnetic field, region in the neighbourhood of a magnet, electric current, or changing electric field, in which magnetic forces are observable. Magnetic fields such as that of the Earth cause magnetic compass needles and other permanent magnets to line up in the direction of the field. Magnetic fields force moving electrically charged particles in a circular or helical path. This force – exerted on electric currents in wires in a magnetic field – underlies the operation of electric motors.

Around a permanent magnet or a wire carrying a steady electric current in one direction, the magnetic field is stationary and referred to as a magnetostatic field. At any given point its magnitude and direction remain the same. Around an alternating current or a fluctuating direct current, the magnetic field is continuously changing its magnitude and direction.

Magnetic fields may be represented by continuous lines of force or magnetic flux that emerge from north-seeking magnetic poles and enter south-seeking magnetic poles. The density of the lines indicates the magnitude of the magnetic field. At the poles of a magnet, for example, where the magnetic field is strong, the field lines are crowded together, or more dense. Farther away, where the magnetic field is weak, they fan out, becoming less dense. A uniform magnetic field is represented by equally spaced parallel straight lines. The direction of the flux is the direction in which the north-seeking pole of a small magnet points. The lines of flux are continuous, forming closed loops. For a bar magnet, they emerge from the north-seeking pole, fan out and around, enter the magnet at the south-seeking pole, and continue through the magnet to the north pole, where they again emerge. The SI unit for magnetic flux is the weber. The number of webers is a measure of the total number of field lines that cross a given area.

Magnetic fields may be represented mathematically by quantities called vectors that have direction as well as magnitude. Two different vectors are in use to represent a magnetic field: one called magnetic flux density, or magnetic induction, is symbolized by B; the other, called the magnetic field strength, or magnetic field intensity, is symbolized by H. The magnetic field H might be thought of as the magnetic field produced by the flow of current in wires and the magnetic field B as the total magnetic field including also the contribution made by the magnetic properties of the materials in the field.

**Nanotechnology**

Nanotechnology, the manipulation and manufacture of materials and devices on the scale of atoms or small groups of atoms. The “nanoscale” is typically measured in nanometres, or billionths of a metre, and materials built at this scale often exhibit distinctive physical and chemical properties due to quantum mechanical effects. Although usable devices this small may be decades away (see microelectromechanical system), techniques for working at the nanoscale have become essential to electronic engineering, and nanoengineered materials have begun to appear in consumer products. For example, billions of microscopic “nanowhiskers,” each about 10 nanometres in length, have been molecularly hooked onto natural and synthetic fibres to impart stain resistance to clothing and other fabrics; zinc oxide nanocrystals have been used to create invisible sunscreens that block ultraviolet light; and silver nanocrystals have been embedded in bandages to kill bacteria and prevent infection.

Possibilities for the future are numerous. Nanotechnology may make it possible to manufacture lighter, stronger, and programmable materials that require less energy to produce than conventional materials, that produce less waste than with conventional manufacturing, and that promise greater fuel efficiency in land transportation, ships, aircraft, and space vehicles. Nanocoatings for both opaque and translucent surfaces may render them resistant to corrosion, scratches, and radiation. Nanoscale electronic, magnetic, and mechanical devices and systems with unprecedented levels of information processing may be fabricated, as may chemical, photochemical, and biological sensors for protection, health care, manufacturing, and the environment; new photoelectric materials that will enable the manufacture of cost-efficient solar-energy panels.

At the same time, significant challenges must be overcome for the benefits of nanotechnology to be realized. Scientists must learn how to manipulate and characterize individual atoms and small groups of atoms reliably. New and improved tools are needed to control the properties and structure of materials at the nanoscale. Next, new tools and approaches are needed for assembling atoms and molecules into nanoscale systems and for the further assembly of small systems into more-complex objects. Furthermore, nanotechnology products must provide not only improved performance but also lower cost.

**Atom**

Atom, smallest unit into which matter can be divided without the release of electrically charged particles. It also is the smallest unit of matter that has the characteristic properties of a chemical element. As such, the atom is the basic building block of chemistry.

Most of the atom is empty space. The rest consists of a positively charged nucleus of protons and neutrons surrounded by a cloud of negatively charged electrons. The nucleus is small and dense compared with the electrons, which are the lightest charged particles in nature. Electrons are attracted to any positive charge by their electric force; in an atom, electric forces bind the electrons to the nucleus.

Because of the nature of quantum mechanics, no single image has been entirely satisfactory at visualizing the atom’s various characteristics, which thus forces physicists to use complementary pictures of the atom to explain different properties. In some respects, the electrons in an atom behave like particles orbiting the nucleus. In others, the electrons behave like waves frozen in position around the nucleus. Such wave patterns, called orbitals, describe the distribution of individual electrons. The behaviour of an atom is strongly influenced by these orbital properties, and its chemical properties are determined by orbital groupings known as shells.

This article opens with a broad overview of the fundamental properties of the atom and its constituent particles and forces. Following this overview is a historical survey of the most influential concepts about the atom that have been formulated through the centuries. For additional information pertaining to nuclear structure and elementary particles, see subatomic particles.

All atoms are roughly the same size, whether they have 3 or 90 electrons. Approximately 50 million atoms of solid matter lined up in a row would measure 1 cm (0.4 inch). A convenient unit of length for measuring atomic sizes is the angstrom (Å), defined as 10−10 metre. The radius of an atom measures 1–2 Å. Compared with the overall size of the atom, the nucleus is even more minute. It is in the same proportion to the atom as a marble is to a football field. In volume the nucleus takes up only 10−14 metres of the space in the atom—i.e., 1 part in 100,000. A convenient unit of length for measuring nuclear sizes is the femtometre (fm), which equals 10−15 metre.

**Principles of physical science**

Physical science, like all the natural sciences, is concerned with describing and relating to one another those experiences of the surrounding world that are shared by different observers and whose description can be agreed upon. One of its principal fields, physics, deals with the most general properties of matter, such as the behaviour of bodies under the influence of forces, and with the origins of those forces. In the discussion of this question, the mass and shape of a body are the only properties that play a significant role, its composition often being irrelevant. Physics, however, does not focus solely on the gross mechanical behaviour of bodies but shares with chemistry the goal of understanding how the arrangement of individual atoms into molecules and larger assemblies confers particular properties. Moreover, the atom itself may be analyzed into its more basic constituents and their interactions.

The present opinion, rather generally held by physicists, is that these fundamental particles and forces, treated quantitatively by the methods of quantum mechanics, can reveal in detail the behaviour of all material objects. This is not to say that everything can be deduced mathematically from a small number of fundamental principles, since the complexity of real things defeats the power of mathematics or of the largest computers. Nevertheless, whenever it has been found possible to calculate the relationship between an observed property of a body and its deeper structure, no evidence has ever emerged to suggest that the more complex objects, even living organisms, require that special new principles be invoked, at least so long as only matter, and not mind, is in question. The physical scientist thus has two very different roles to play: on the one hand, he has to reveal the most basic constituents and the laws that govern them; and, on the other, he must discover techniques for elucidating the peculiar features that arise from complexity of structure without having recourse each time to the fundamentals.

This modern view of a unified science, embracing fundamental particles, everyday phenomena, and the vastness of the Cosmos, is a synthesis of originally independent disciplines, many of which grew out of useful arts.

**Electric current**

Electric current, any movement of electric charge carriers, such as subatomic charged particles (e.g., electrons having negative charge, protons having positive charge), ions (atoms that have lost or gained one or more electrons), or holes (electron deficiencies that may be thought of as positive particles).

Electric current in a wire, where the charge carriers are electrons, is a measure of the quantity of charge passing any point of the wire per unit of time. In alternating current the motion of the electric charges is periodically reversed; in direct current it is not. In many contexts the direction of the current in electric circuits is taken as the direction of positive charge flow, the direction opposite to the actual electron drift. When so defined the current is called conventional current.

Current is usually denoted by the symbol I. Ohm’s law relates the current flowing through a conductor to the voltage V and resistance R; that is, V = IR. An alternative statement of Ohm’s law is I = V/R.

Current in gases and liquids generally consists of a flow of positive ions in one direction together with a flow of negative ions in the opposite direction. To treat the overall effect of the current, its direction is usually taken to be that of the positive charge carrier. A current of negative charge moving in the opposite direction is equivalent to a positive charge of the same magnitude moving in the conventional direction and must be included as a contribution to the total current. Current in semiconductors consists of the motion of holes in the conventional direction and electrons in the opposite direction.

Currents of many other kinds exist, such as beams of protons, positrons, or charged pions and muons in particle accelerators.

Electric current generates an accompanying magnetic field, as in electromagnets. When an electric current flows in an external magnetic field, it experiences a magnetic force, as in electric motors. The heat loss, or energy dissipated, by electric current in a conductor is proportional to the square of the current.

*Alternating current* flow of electric charge that periodically reverses. It starts, say, from zero, grows to a maximum, decreases to zero, reverses, reaches a maximum in the opposite direction, returns again to the original value, and repeats this cycle indefinitely.

**Lasers**

Laser, a device that stimulates atoms or molecules to emit light at particular wavelengths and amplifies that light, typically producing a very narrow beam of radiation. The emission generally covers an extremely limited range of visible, infrared, or ultraviolet wavelengths. Many different types of lasers have been developed, with highly varied characteristics. Laser is an acronym for “light amplification by the stimulated emission of radiation.”

The laser is an outgrowth of a suggestion made by Albert Einstein in 1916 that under the proper circumstances atoms could release excess energy as light –either spontaneously or when stimulated by light. German physicist Rudolf Walther Ladenburg first observed stimulated emission in 1928, although at the time it seemed to have no practical use.

In 1951 Charles H. Townes, then at Columbia University in New York City, thought of a way to generate stimulated emission at microwave frequencies. At the end of 1953, he demonstrated a working device that focused “excited” (see below Energy levels and stimulated emissions) ammonia molecules in a resonant microwave cavity, where they emitted a pure microwave frequency. Townes named the device a maser, for “microwave amplification by the stimulated emission of radiation.” Aleksandr Mikhaylovich Prokhorov and Nikolay Gennadiyevich Basov of the P.N. Lebedev Physical Institute in Moscow independently described the theory of maser operation. For their work all three shared the 1964 Nobel Prize for Physics.

An intense burst of maser research followed in the mid-1950s, but masers found only a limited range of applications as low-noise microwave amplifiers and atomic clocks. In 1957 Townes proposed to his brother-in-law and former postdoctoral student at Columbia University, Arthur L. Schawlow (then at Bell Laboratories), that they try to extend maser action to the much shorter wavelengths of infrared or visible light. Townes also had discussions with a graduate student at Columbia University, Gordon Gould, who quickly developed his own laser ideas. Townes and Schawlow published their ideas for an “optical maser” in a seminal paper in the December 15, 1958, issue of Physical Review. Meanwhile, Gould coined the word laser and wrote a patent application.