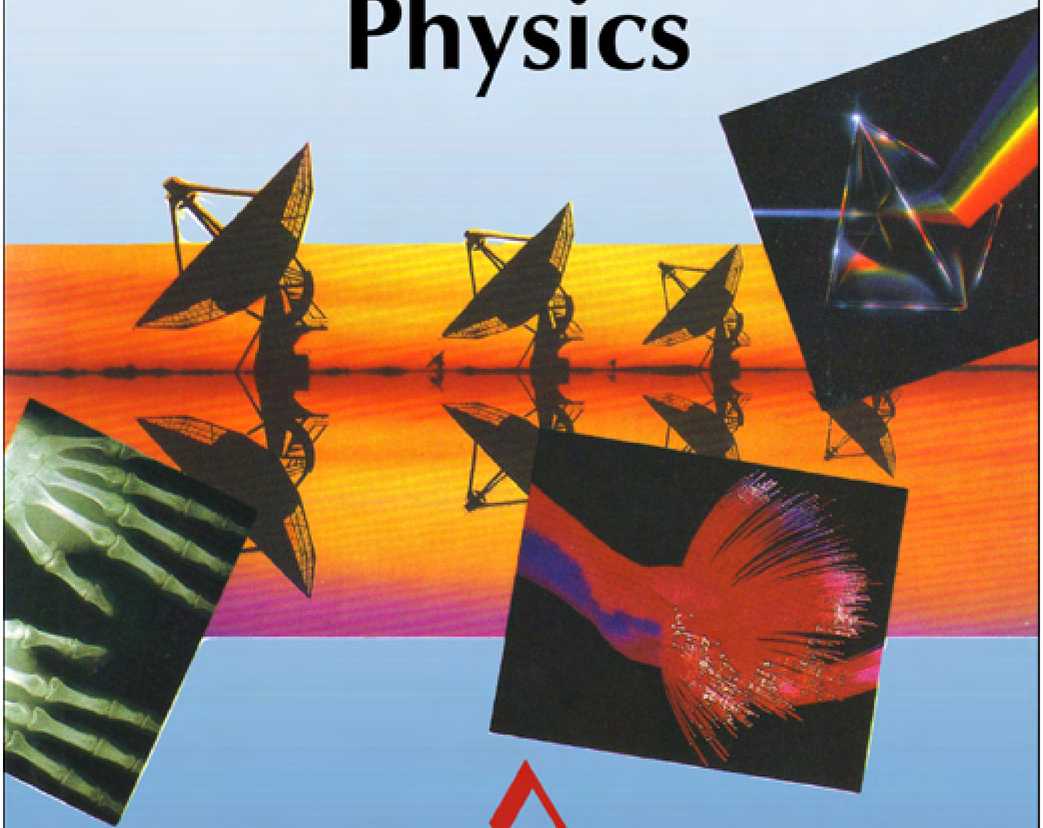
The **HUTCHINSON**

Pocket Dictionary of Physics



Helicon

The Hutchinson Pocket Dictionary of Physics

Preface

The Hutchinson Pocket Dictionary of Physics is a reference book, with entries arranged in A–Z format. To go directly to a particular entry, click on the link in the table of contents. There are also links between entries – click on any underlined word to jump to the related entry.

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A

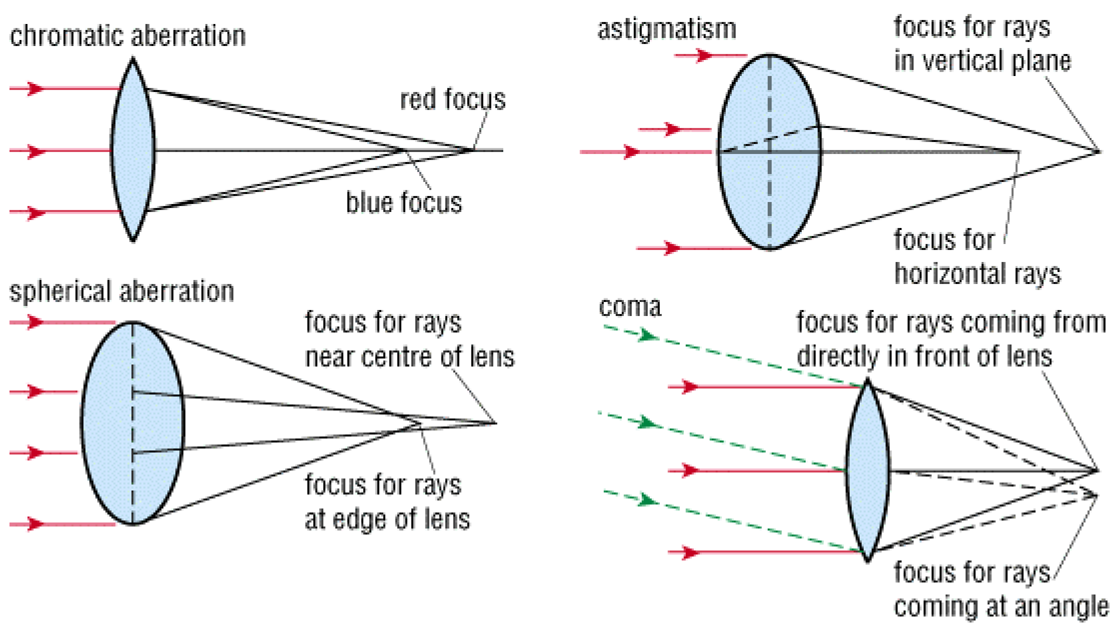
in physics, symbol for ampere, a unit of electrical current.

---

aberration, optical

any of a number of defects that impair the image in an optical instrument. Aberration occurs because of minute variations in lenses and mirrors, and because different parts of the light spectrum are reflected or refracted by varying amounts.

aberration, optical



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The main defects, or aberrations, of optical systems. Chromatic aberration, or coloured fringes around images, arises because light of different colours is focused at different points by a lens, causing a blurred image. Spherical aberration arises because light that passes through the centre of the lens is focused at a different point from light passing through the edge of the lens. Astigmatism arises if a lens has different curvatures in the vertical and horizontal directions. Coma arises because light passing directly through a lens is focused at a different point to light entering the lens from an angle.

---

absolute zero

lowest temperature theoretically possible according to kinetic theory, zero kelvin (0 K), equivalent to -273.15°C/-459.67°F, at which molecules are in their lowest energy state. Although the third law of thermodynamics indicates the impossibility of reaching absolute zero, in practice temperatures of less than a billionth of a degree above absolute zero have been reached. Near absolute zero, the physical properties of some materials change substantially; for example, some metals lose their electrical resistance and become superconducting.

---

absorption

in physics, taking up of matter or energy of one substance by another, such as a liquid by a solid (ink by blotting paper) or a gas by a liquid (ammonia by water). In physics, absorption is the phenomenon by which a substance retains the energy of radiation of particular wavelengths; for example, a piece of blue glass absorbs all visible light except the wavelengths in the blue part of the spectrum; it also refers to the partial loss of energy resulting from light and other electromagnetic waves passing through a medium. In nuclear physics, absorption is the capture by elements, such as boron, of neutrons produced by fission in a reactor.

AC

in physics, abbreviation for alternating current.

---

acceleration

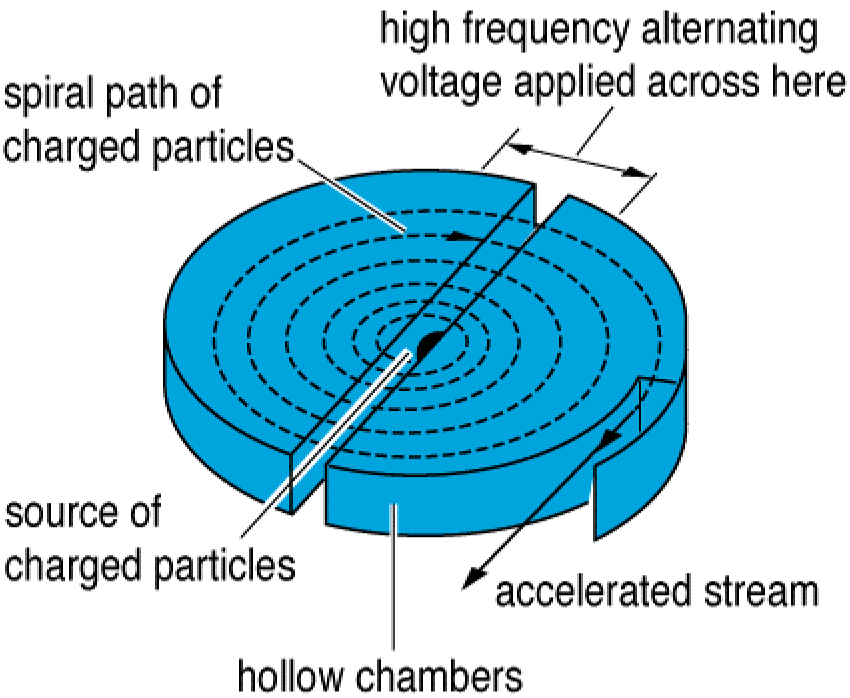
rate of change of the velocity of a moving body. It is usually measured in feet per second per second (ft s^{-2}) or meters per second per second (m s^{-2}). Because velocity is a vector quantity (possessing both magnitude and direction) a body travelling at constant speed may be said to be accelerating if its direction of motion changes. According to Newton's second law of motion, a body will accelerate only if it is acted upon by an unbalanced, or resultant, force. Acceleration due to gravity is the acceleration of a body falling freely under the influence of the Earth's gravitational field; it varies slightly at different latitudes and altitudes. The value adopted internationally for gravitational acceleration is 32.174 ft s^{-2}/9.806 ms^{-2}.

---

accelerator

in physics, a device to bring charged particles (such as protons and electrons) up to high speeds and energies, at which they can be of use in industry, medicine, and pure physics. At low energies, accelerated particles can be used to produce the image on a television screen and (by means of a cathode-ray tube) generate X-rays, destroy tumour cells, or kill bacteria. When high-energy particles collide with other particles, the fragments formed reveal the nature of the fundamental forces.

accelerator



(Image © Research Machines plc)

The cyclotron, an early accelerator, consisted of two D-shaped hollow chambers enclosed in a vacuum. An alternating voltage was applied across the gap between the hollows. Charged particles spiralled outward from the centre, picking up energy and accelerating each time they passed through the gap.

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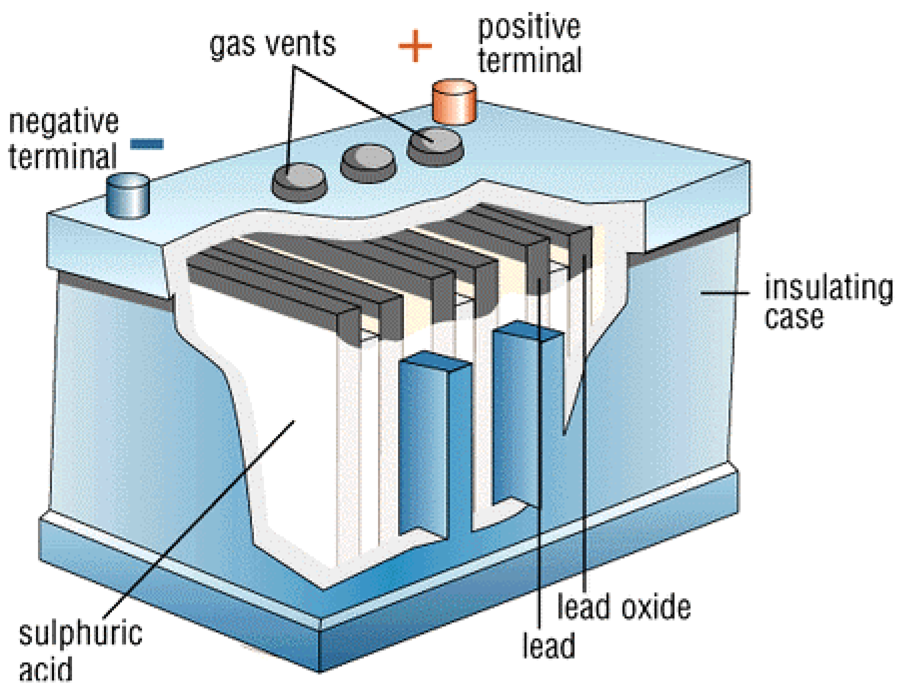
accumulator

in electricity, a storage battery – that is, a group of rechargeable secondary cells. A familiar example is the lead–acid car battery.

accumulator



The lead–acid car battery is a typical example of an accumulator. The battery has a set of grids immersed in a sulphuric acid electrolyte. One set of grids is made of lead (Pb) and acts as the anode and the other set made of lead oxide (PbO_2) acts as the cathode.

---

acoustics

in general, the experimental and theoretical science of sound and its transmission; in particular, that branch of the science that has to do with the phenomena of sound in a particular space such as a room or theatre. In architecture, the sound-reflecting character of an internal space.

---

adiabatic

in biology and physics, describing a process that occurs without loss or gain of heat, especially the expansion or contraction of a gas in which a change takes place in the pressure or volume, although no heat is allowed to enter or leave. Adiabatic processes can be both non-reversible and approximately reversible.

---

adsorption

taking up of a gas or liquid at the surface of another substance, most commonly a solid (for example, activated charcoal adsorbs gases). It involves molecular attraction at the surface, and should be distinguished from absorption (in which a uniform solution results from a gas or liquid being incorporated into the bulk structure of a liquid or solid).

---

aerodynamics

branch of fluid physics that studies the forces exerted by air or other gases in motion. Examples include the airflow around bodies moving at speed through the atmosphere (such as land vehicles, bullets, rockets, and aircraft), the behaviour of gas in engines and furnaces, air conditioning of buildings, the deposition of snow, the operation of air-cushion vehicles (hovercraft), wind loads on buildings and bridges, bird and insect flight, musical wind instruments, and meteorology. For maximum efficiency, the aim is usually to design the shape of an object to produce a streamlined flow, with a minimum of turbulence in the moving air. The behaviour of aerosols or the pollution of the atmosphere by foreign particles are other aspects of aerodynamics.

---

afterimage

persistence of an image on the retina of the eye after the object producing it has been removed. This leads to persistence of vision, a necessary phenomenon for the illusion of continuous movement in films and television. The term is also used for the persistence of sensations other than vision.

---

alpha particle

or *alpha ray*,

positively charged (2+), high-energy particle emitted from the nucleus of a radioactive atom. It is one of the products of the spontaneous disintegration of radioactive elements (see radioactivity) such as radium and thorium, and is identical to the nucleus of a helium atom (^{4}He) – that is, it consists of two protons and two neutrons. The process of emission, **alpha decay**, transforms one element into another, decreasing the atomic number by two and the atomic mass by four. Plutonium-239 (^{239}Pu) is an example of a material that emits alpha particles.

---

alternating current

***AC*,**

electric current that flows for an interval of time in one direction and then in the opposite direction; that is, a current that flows in alternately reversed directions through or around a circuit. Electric energy is usually generated as alternating current in a power station, and alternating currents may be used for both power and lighting.

---

alternator

electricity generator that produces an alternating current.

AM

in physics, abbreviation for amplitude modulation.

---

ammeter

instrument that measures electric current (flow of charge per unit time), usually in amperes, through a conductor. It should not to be confused with a voltmeter, which measures potential difference between two points in a circuit. The ammeter is placed in series (see series circuit) with the component through which current is to be measured, and is constructed with a low internal resistance in order to prevent the reduction of that current as it flows through the instrument itself. A common type is the moving-coil meter, which measures direct current (DC), but can, in the presence of a rectifier (a device which converts alternating current to direct current), measure alternating current (AC) also. Hot-wire, moving-iron, and dynamometer ammeters can be used for both DC and AC.

---

ampere

symbol A,

SI unit of electrical current. Electrical current (a flow of negative charge) is measured in a similar way to water current, in terms of an amount per unit time; one ampere (amp) represents a flow of one coulomb per second, which is about 6.28×10^{18} electrons per second.

---

amplifier

electronic device that increases the strength of a signal, such as a radio signal. The ratio of output signal strength to input signal strength is called the gain of the amplifier. As well as achieving high gain, an amplifier should be free from distortion and able to operate over a range of frequencies. Practical amplifiers are usually complex circuits, although simple amplifiers can be built from single transistors or valves.

---

amplitude modulation

AM,

method by which radio waves are altered for the transmission of broadcasting signals. AM waves are constant in frequency, but the amplitude of the transmitting wave varies in accordance with the signal being broadcast.

---

analogue signal

in electronics, current or voltage that conveys or stores information, and varies continuously in the same way as the information it represents (compare digital signal). Analogue signals are prone to interference and distortion.

---

anemometer

device for measuring wind speed and liquid flow. The most basic form, the **cup-type anemometer**, consists of cups at the ends of arms, which rotate when the wind blows. The speed of rotation indicates the wind speed.

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aneroid barometer

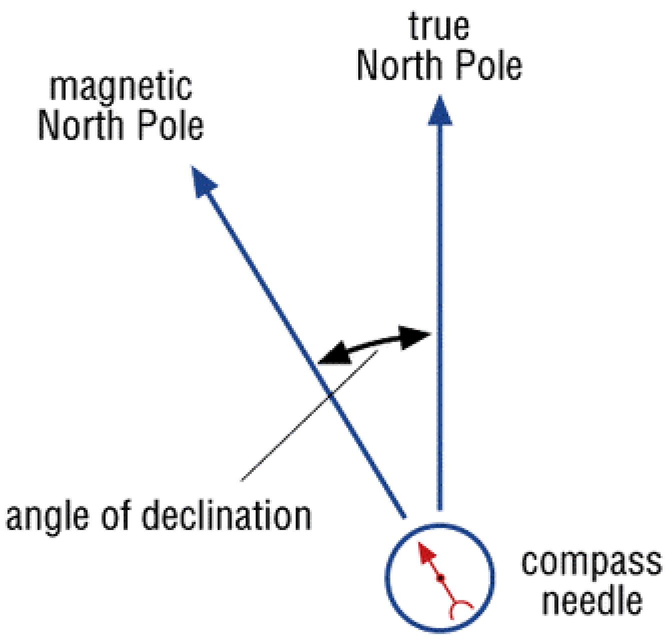
kind of barometer.

---

angle of declination

angle at a particular point on the Earth's surface between the direction of the true or geographic North Pole and the magnetic north pole. The angle of declination has varied over time because of the slow drift in the position of the magnetic north pole.

angle of declination



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The angle of declination is the angle at a particular point on the Earth's surface between the direction of the true or geographic North Pole and the magnetic north pole. The angle of declination has varied over time because of the slow drift in the position of the magnetic north pole.

anion

ion carrying a negative charge. An anion is formed from an atom by the gain of electrons, a process known as **ionic bonding**. Non-metallic elements form anions. During electrolysis, anions in the electrolyte move towards the anode (positive electrode).

annihilation

in nuclear physics, a process in which a particle and its 'mirror image' particle called an antiparticle collide and disappear, with the creation of a burst of energy. The energy created is equivalent to the mass of the colliding particles in accordance with the mass–energy equation. For example, an electron and a positron annihilate to produce a burst of high-energy X-rays. Not all particle–antiparticle interactions result in annihilation; the exception concerns the group called mesons, which belong to the class of particles that are composed of quarks and their antiquarks. See antimatter.

anode

positive electrode of an electrolytic cell, towards which negative particles (anions), usually in solution, are attracted.

---

antimatter

in physics, form of matter in which most of the attributes (such as electrical charge, magnetic moment, and spin) of elementary particles are reversed. These antiparticles can be created in particle accelerators, such as those at CERN in Geneva, Switzerland, and at Fermilab in the USA. In 1996 physicists at CERN created the first atoms of antimatter: nine atoms of antihydrogen survived for 40 nanoseconds (40 billionths of a second).

---

antiparticle

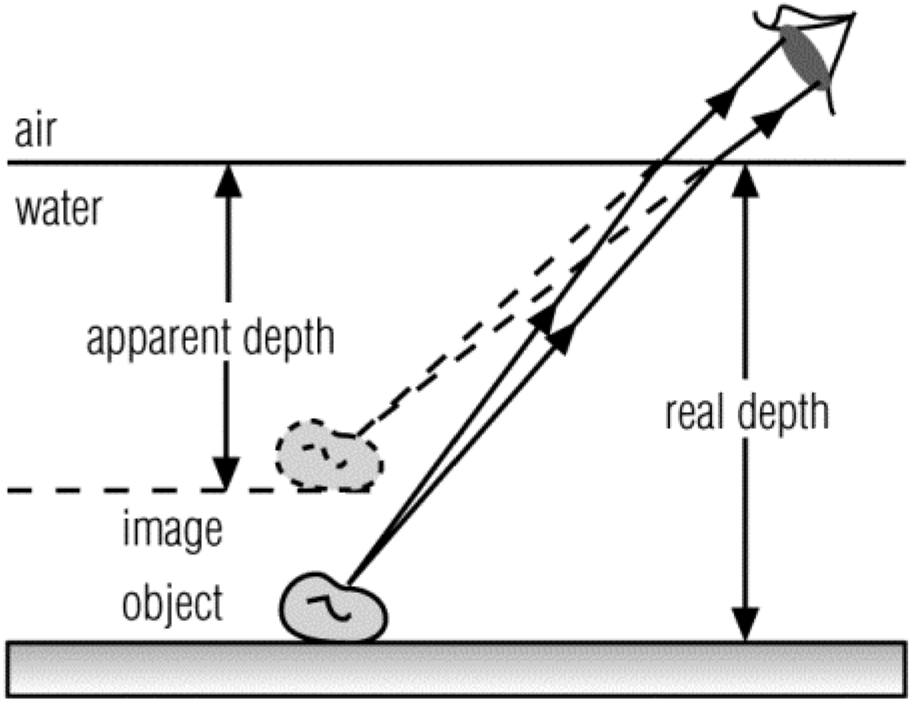
in nuclear physics, a particle corresponding in mass and properties to a given elementary particle but with the opposite electrical charge, magnetic properties, or coupling to other fundamental forces. For example, an electron carries a negative charge whereas its antiparticle, the positron, carries a positive one. When a particle and its antiparticle collide, they destroy each other, in the process called 'annihilation', their total energy being converted to lighter particles and/or photons. A substance consisting entirely of antiparticles is known as antimatter.

---

apparent depth

depth that a transparent material such as water or glass appears to have when viewed from above. This is less than its real depth because of the refraction that takes place when light passes into a less dense medium. The ratio of the real depth to the apparent depth of a transparent material is equal to its refractive index.

apparent depth



(Image © Research Machines plc)

The apparent depth of an object in water when viewed from above. This is less than the object's real depth because of refractive effects: the light wave bends as it passes from the denser water into the less dense air.

Appleton layer

or *F-layer*,

band containing ionized gases in the Earth's upper atmosphere, at a height of 150–1,000 km/94–625 mi, above the E-layer (formerly the Kennelly-Heaviside layer). It acts as a dependable reflector of radio signals as it is not affected by atmospheric conditions, although its ionic composition varies with the sunspot cycle.

Archimedes' principle

in physics, the principle that the weight of the liquid displaced by a floating body is equal to the weight of the body. The principle is often stated in the form: 'an object totally or partially submerged in a fluid displaces a volume of fluid that weighs the same as the apparent loss in weight of the object (which, in turn, equals the upwards force, or upthrust, experienced by that object).' It was discovered by the Greek mathematician Archimedes.

---

astigmatism

aberration occurring in the lens of the eye. It results when the curvature of the lens differs in two perpendicular planes, so that rays in one plane may be in focus while rays in the other are not. With astigmatic eyesight, the vertical and horizontal cannot be in focus at the same time; correction is by the use of a cylindrical lens that reduces the overall focal length of one plane so that both planes are seen in sharp focus.

---

atmosphere

symbol atm; or *standard atmosphere*,

in physics, a unit of pressure equal to 760 mmHg, 1013.25 millibars, or 1.01325×10^5 pascals, or newtons per square metre. The actual pressure exerted by the atmosphere fluctuates around this value, which is assumed to be standard at sea level and 0°C/32°F, and is used when dealing with very high pressures.

---

atmospheric pressure

pressure at any point on the Earth's surface that is due to the weight of the column of air above it; it therefore decreases as altitude increases, because there is less air above. Particles in the air exert a force (pressure) against surfaces; when large numbers of particles press against a surface, the overall effect is known as air pressure. At sea level the average pressure is 101 kilopascals (1,013 millibars, or 760 mm Hg, or 14.7 lb per sq in, or 1 atmosphere). Changes in atmospheric pressure, measured with a barometer, are used in weather forecasting. Areas of relatively high pressure are called anticyclones; areas of low pressure are called depressions.

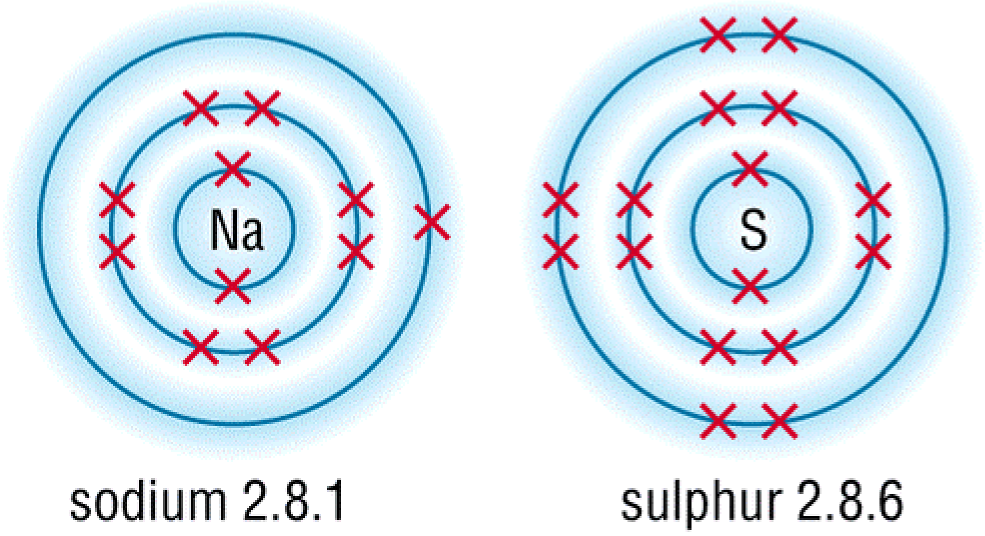
---

atom

(Greek *atomos* 'undivided')

smallest unit of matter that can take part in a chemical reaction, and which cannot be broken down chemically into anything simpler. An atom is made up of protons and neutrons in a central nucleus (except for hydrogen, which has a single proton in its nucleus) surrounded by electrons (see atomic structure). The atoms of the various elements differ in atomic number, relative atomic mass, and chemical behaviour.

atom, electronic structure



The arrangement of electrons in a sodium atom and a sulphur atom. The number of electrons in a neutral atom gives that atom its atomic number: sodium has an atomic number of 11 and sulphur has an atomic number of 16.

---

atomic energy

former name for nuclear energy.

---

atomic mass unit

or *dalton unit*; symbol amu or u,

unit of mass that is used to measure the relative mass of atoms and molecules. It is equal to one-twelfth of the mass of a carbon-12 atom, which is equivalent to the mass of a proton or 1.66×10^{-27} kg. The atomic weight of an atom has no units; thus oxygen-16 has an atomic mass of 16 daltons, but an atomic weight of 16.

---

atomic number

or *proton number*; symbol *Z*,

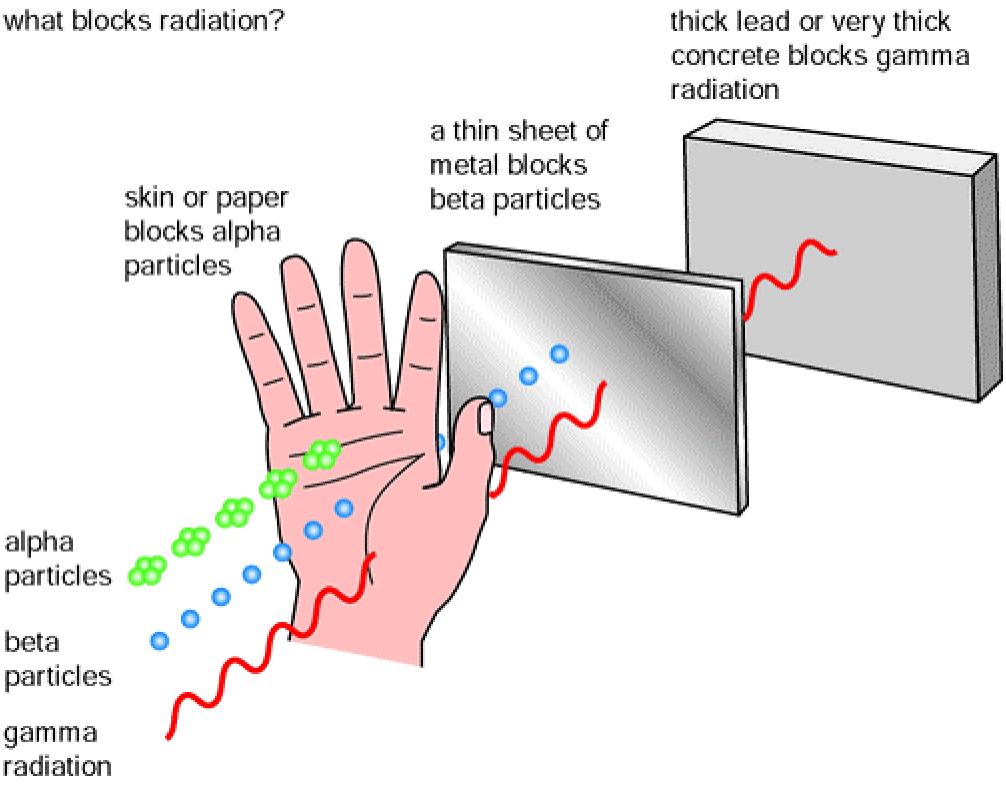
number of protons in the nucleus of an atom. It is equal to the positive charge on the nucleus. In a neutral atom, it is also equal to the number of electrons surrounding the nucleus. The chemical elements are arranged in the periodic table of the elements according to their atomic number. Nuclear notation is used to label an atom according to the composition of its nucleus.

---

atomic radiation

energy given out by disintegrating atoms during radioactive decay, whether natural or synthesized. The energy may be in the form of fast-moving particles, known as alpha particles and beta particles, or in the form of high-energy electromagnetic waves known as gamma radiation. Overlong exposure to atomic radiation can lead to radiation sickness.

atomic radiation



(Image © Research Machines plc)

Atomic radiation may be in the form of alpha particles, beta particles, or gamma radiation. Alpha particles are fast-moving and consist of two protons and two neutrons. Because they have a relatively large mass, alpha particles have a range of up to 10 cm in air and can be stopped by skin or thin paper. Beta particles are electrons created and then instantly ejected from a radioactive atom. They have a greater range in air than alpha particles and can be stopped by a thin sheet of metal, such as aluminium. Gamma radiation is high-frequency, high-energy electromagnetic radiation. It is very penetrating and can only be blocked by thick lead or very thick concrete.

---

atomic structure

internal structure of an atom.

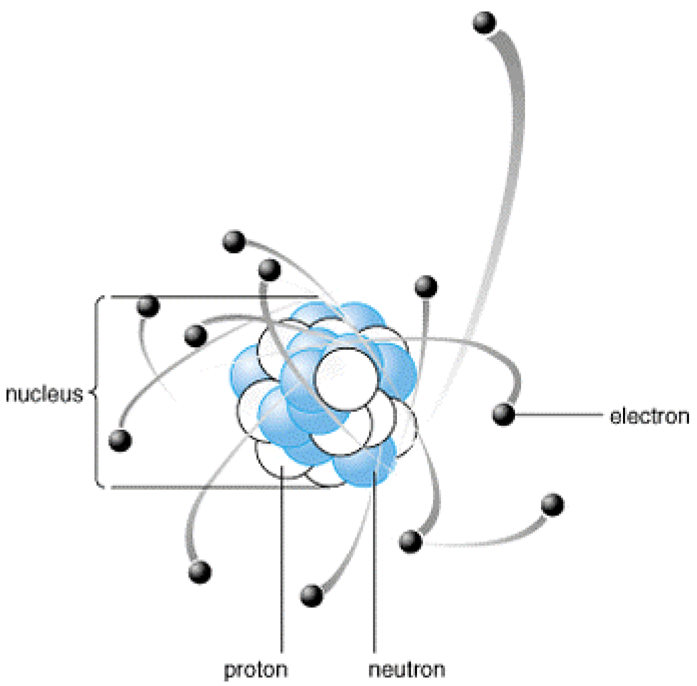
the nucleus

The core of the atom is the **nucleus**, a dense body only one ten-thousandth the diameter of the atom itself. The simplest nucleus, that of hydrogen, comprises a single stable positively charged particle, the **proton**. Nuclei of other elements contain more protons and additional particles, called **neutrons**, of about the same mass as the proton but with no electrical charge. Each element has its own characteristic nucleus with a unique number of protons, the atomic number. The number of neutrons may vary. Where atoms of a single element have different numbers of neutrons, they are called isotopes. Although some isotopes tend to be unstable and exhibit radioactivity, all those of a single element have identical chemical properties.

electrons

The nucleus is surrounded by a number of moving **electrons**, each of which has a negative charge equal to the positive charge on a proton, but which has a mass of only 1/1,836 times as much. In a neutral atom, the nucleus is surrounded by the same number of electrons as it contains protons. According to quantum theory, the position of an electron is uncertain; it may be found at any point. However, it is more likely to be found in some places than others. The region of space in which an electron is most likely to be found is called an atomic orbital. The chemical properties of an element are determined by the ease with which its atoms can gain or lose electrons.

atomic structure



(Image © Research Machines plc)

The structure of a sodium atom. The nucleus is composed of 11 protons and 12 neutrons. Eleven electrons orbit the nucleus in 3 orbits: 2 in the inner orbit, 8 in the middle, and 1 in the outer.

---

atomic weight

or *atomic mass*,

mass of an atom. It depends on the number of protons and neutrons in the atom, the electrons having negligible mass. It is calculated relative to one-twelfth the mass of an atom of carbon-12. If more than one isotope of the element is present, the atomic weight is calculated by taking an average that takes account of the relative proportions of each isotope, resulting in values that are not whole numbers.

---

background radiation

radiation that is always present in the environment. By far the greater proportion (87%) of it is emitted from natural sources. Alpha particles, beta particles, and gamma radiation are emitted by the traces of radioactive minerals that occur naturally in the environment and even in the human body (for example, by breathing in ^{14}C). Radioactive gases such as radon and thoron are found in soil and may seep upwards into buildings. Radiation from space (cosmic radiation) also contributes to the background level.

---

ballistics

study of the motion and impact of projectiles such as bullets, bombs, and missiles. For projectiles from a gun, relevant exterior factors include temperature, barometric pressure, and wind strength; and for nuclear missiles these extend to such factors as the speed at which the Earth turns.

---

barograph

device for recording variations in atmospheric pressure. A pen, governed by the movements of an aneroid barometer, makes a continuous line on a paper strip on a cylinder that rotates over a day or week to create a **barogram**, or permanent record of variations in atmospheric pressure.

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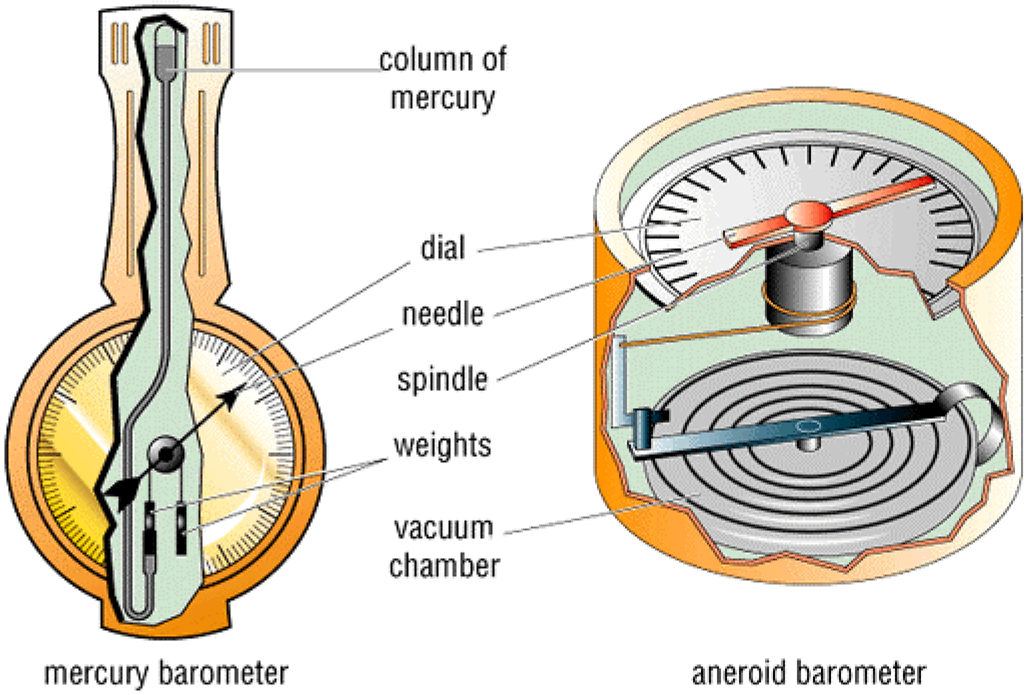
barometer

instrument that measures atmospheric pressure as an indication of weather. Most often used are the mercury barometer and the aneroid barometer.

barometer



(Image © Research Machines plc)

The mercury barometer (left) and the aneroid barometer (right). In the mercury barometer, the weight of the column of mercury is balanced by the pressure of the atmosphere on the lower end. A change in height of the column indicates a change in atmospheric pressure. In the aneroid barometer, any change of atmospheric pressure causes the metal box which contains the vacuum to be squeezed or to expand slightly. The movements of the box sides are transferred to a pointer and scale via a chain of levers.

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baryon

in nuclear physics, a heavy subatomic particle made up of three indivisible elementary particles called quarks. The baryons form a subclass of the hadrons and comprise the nucleons (protons and neutrons) and hyperons.

---

beat frequency

in musical acoustics, fluctuation produced when two notes of nearly equal pitch or frequency are heard together. Beats result from the interference between the sound waves of the notes. The frequency of the beats equals the difference in frequency of the notes.

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becquerel

symbol Bq,

SI unit of radioactivity, equal to one radioactive disintegration (change in the nucleus of an atom when a particle or ray is given off) per second.

---

beta decay

the spontaneous alteration of the nucleus of a radioactive atom, which transmutes the atom from one atomic number to another through the emission of either an electron (beta-minus decay) or a positron (beta-plus decay). In the more commonly occurring of the two, beta-minus decay, the atomic number increases by one (through the decay of a neutron, which converts to a proton emitting an electron and an antineutrino); in the less commonly occurring beta-plus decay, the atomic number decreases by one (the proton converts to a neutron, emitting a positron and a neutrino). The symbol used for the electron in beta-minus decay is β^-; the symbol for the positron in beta-plus decay is β^+.

---

beta particle

or *beta ray*,

electron ejected with great velocity from a radioactive atom that is undergoing spontaneous disintegration. Beta particles are created in the nucleus on disintegration, beta decay, when a neutron converts to a proton (the atomic number increases by one while the atomic mass stays the same) by emitting an electron. The mass lost in the change is converted into kinetic energy of the beta particle. Strontium-90 (^{90}Sr) is an example of a material that emits beta particles.

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binding energy

in physics, the amount of energy needed to break the nucleus of an atom into the neutrons and protons of which it is made.

---

boiling point

for any given liquid, the temperature at which the application of heat raises the temperature of the liquid no further, but converts it into vapour.

Boltzmann constant

symbol *k*,

in physics, the constant that relates the kinetic energy (energy of motion) of a gas atom or molecule to temperature. Its value is 1.38066×10^{-23} joules per kelvin. It is equal to the gas constant *R*, divided by Avogadro's number.

---

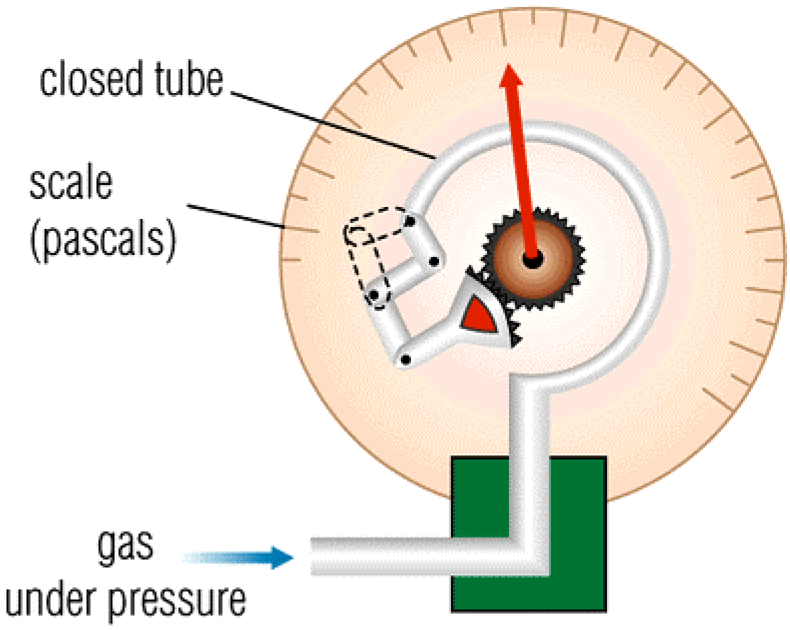
boson

in physics, an elementary particle whose spin can only take values that are whole numbers or zero. Bosons may be classified as gauge bosons (carriers of the four fundamental forces) or mesons. All elementary particles are either bosons or fermions.

Bourdon gauge

instrument for measuring pressure, patented by French watchmaker Eugène Bourdon in 1849. The gauge contains a C-shaped tube, closed at one end. When the pressure inside the tube increases, the tube uncurls slightly causing a small movement at its closed end. A system of levers and gears magnifies this movement and turns a pointer, which indicates the pressure on a circular scale. Bourdon gauges are often fitted to cylinders of compressed gas used in industry and hospitals.

Bourdon gauge



The most common form of Bourdon gauge is the C-shaped tube. However, in high-pressure gauges spiral tubes are used; the spiral rotates as pressure increases and the tip screws forwards.

Boyle's law

law stating that the volume of a given mass of gas at a constant temperature is inversely proportional to its pressure. For example, if the pressure on a gas doubles, its volume will be reduced by a half, and vice versa. The law was discovered in 1662 by Irish physicist and chemist Robert Boyle. See also gas laws.

Bq

in physics, symbol for becquerel, the SI unit of radioactivity (equal to the average number of disintegrations per second in a given time).

---

breeder reactor

or *fast breeder*,

alternative name for fast reactor, a type of nuclear reactor.

---

breeding

in nuclear physics, a process in a reactor in which more fissionable material is produced than is consumed in running the reactor.

---

bubble chamber

in physics, a device for observing the nature and movement of atomic particles, and their interaction with radiation. It is a vessel filled with a superheated liquid through which ionizing particles move and collide. The paths of these particles are shown by strings of bubbles, which can be photographed and studied. By using a pressurized liquid medium instead of a gas, it overcomes drawbacks inherent in the earlier cloud chamber. It was invented by US physicist Donald Glaser in 1952. See particle detector.

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buckminsterfullerene

form of carbon, made up of molecules (buckyballs) consisting of 60 carbon atoms arranged in 12 pentagons and 20 hexagons to form a perfect sphere. It was named after the US architect and engineer Richard Buckminster Fuller because of its structural similarity to the geodesic dome that he designed. See fullerene.

---

buckyballs

popular name for molecules of buckminsterfullerene.

---

buoyancy

lifting effect of a fluid on a body wholly or partly immersed in it. This was studied by Archimedes in the 3rd century BC.

C

in physics, symbol for coulomb, the SI unit of electrical charge.

---

calorific value

amount of heat generated by a given mass of fuel when it is completely burned. It is measured in joules per kilogram. Calorific values are measured experimentally with a bomb calorimeter.

---

capacitance, electrical

property of a capacitor that determines how much charge can be stored in it for a given potential difference between its terminals. It is equal to the ratio of the electrical charge stored to the potential difference. The SI unit of capacitance is the farad, but most capacitors have much smaller capacitances, and the microfarad (a millionth of a farad) is the commonly used practical unit.

---

capacitor

or *condenser*,

device for storing electric charge, used in electronic circuits; it consists of two or more metal plates separated by an insulating layer called a dielectric (see capacitance).

---

capillarity

spontaneous movement of liquids up or down narrow tubes, or capillaries. The movement is due to unbalanced molecular attraction at the boundary between the liquid and the tube. If liquid molecules near the boundary are more strongly attracted to molecules in the material of the tube than to other nearby liquid molecules, the liquid will rise in the tube. If liquid molecules are less attracted to the material of the tube than to other liquid molecules, the liquid will fall.

---

carburation

any process involving chemical combination with carbon, especially the mixing or charging of a gas, such as air, with volatile compounds of carbon (petrol, kerosene, or fuel oil) in order to increase potential heat energy during combustion. Carburation applies to combustion in the cylinders of reciprocating petrol engines of the types used in aircraft, road vehicles, or marine vessels. The device by which the liquid fuel is atomized and mixed with air is called a **carburettor**.

Carnot cycle

series of changes in the physical condition of a gas in a reversible heat engine, necessarily in the following order: (1) isothermal expansion (without change of temperature), (2) adiabatic expansion (without change of heat content), (3) isothermal compression, and (4) adiabatic compression.

---

cathode

in chemistry, the negative electrode of an electrolytic cell, towards which positive particles (cations), usually in solution, are attracted. A cathode is given its negative charge by connecting it to the negative side of an external electrical supply.

---

cathode

in electronics, the part of an electronic device in which electrons are generated. In a thermionic valve, electrons are produced by the heating effect of an applied current; in a photocell, they are produced by the interaction of light and a semiconducting material. The cathode is kept at a negative potential relative to the device's other electrodes (anodes) in order to ensure that the liberated electrons stream away from the cathode and towards the anodes.

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cathode ray

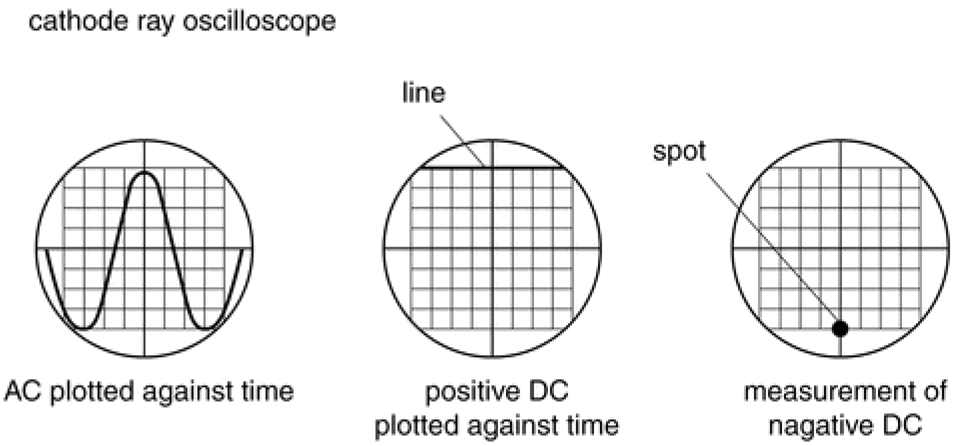
stream of fast-moving electrons that travel from a cathode (negative electrode) towards an anode (positive electrode) in a vacuum tube. They carry a negative charge and can be deflected by electric and magnetic fields. Cathode rays focused into fine beams of fast electrons are used in cathode-ray tubes, the electrons'kinetic energy being converted into light energy as they collide with the tube's fluorescent screen.

cathode-ray oscilloscope

CRO,

instrument used to measure electrical potentials or voltages that vary over time and to display the waveforms of electrical oscillations or signals. Readings are displayed graphically on the screen of a cathode-ray tube.

cathode-ray oscilloscope



(Image © Research Machines plc)

The cathode-ray oscilloscope (CRO) is used to measure voltage and its changes over time. This is how the CRO screen would appear measuring AC and DC current.

cathode-ray tube

CRT,

vacuum tube in which a beam of electrons is produced and focused onto a fluorescent screen. The electrons' kinetic energy is converted into light energy as they collide with the screen. It is an essential component of television receivers, computer visual display units, and oscilloscopes.

cation

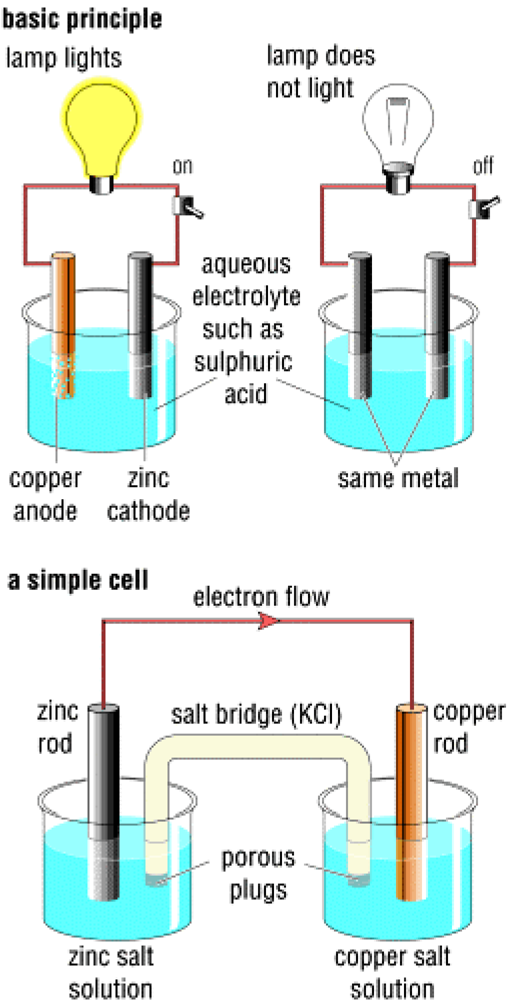
ion carrying a positive charge. During electrolysis, cations in the electrolyte move to the cathode (negative electrode). Cations are formed from atoms by loss of electrons during ionic bonding. Metals form cations.

cell, electrical

or *voltaic cell* or *galvanic cell*,

device in which chemical energy is converted into electrical energy; the popular name is 'battery', but this strictly refers to a collection of cells in one unit. The reactive chemicals of a **primary cell** cannot be replenished, whereas **secondary cells** – such as storage batteries – are rechargeable: their chemical reactions can be reversed and the original condition restored by applying an electric current. It is dangerous to attempt to recharge a primary cell.

cell, electrical



(Image © Research Machines plc)

When electrical energy is produced from chemical energy using two metals acting as electrodes in a aqueous solution, it is sometimes known as a galvanic cell or voltaic cell. Here the two metals copper (+) and zinc (-) are immersed in dilute sulphuric acid, which acts as an electrolyte. If a light bulb is connected between the two, an electric current will flow with bubbles of gas being deposited on the electrodes in a process known as polarization.

---

centre of mass

point in or near an object at which the whole mass of the object may be considered to be concentrated. A symmetrical homogeneous object such as a sphere or cube has its centre of mass at its geometrical centre; a hollow object (such as a cup) may have its centre of mass in space inside the hollow.

---

centrifugal force

in physics, apparent force arising for an observer moving with a rotating system. For an object of mass *m* moving with a velocity *v* in a circle of radius *r*, the centrifugal force *F* equals mv^2/r (outwards).

---

centripetal force

force that acts radially inwards on an object moving in a curved path. For example, with a weight whirled in a circle at the end of a length of string, the centripetal force is the tension in the string. For an object of mass *m* moving with a velocity *v* in a circle of radius *r*, the centripetal force *F* equals mv^2/r (inwards). The reaction to this force is the centrifugal force.

CERN

particle physics research organization founded in 1954 as a cooperative enterprise among European governments. It has laboratories at Meyrin, near Geneva, Switzerland. It houses the world's largest particle accelerator, the Large Electron Positron Collider (LEP), operational 1989–2000, with which notable advances were made in particle physics.

---

chain reaction

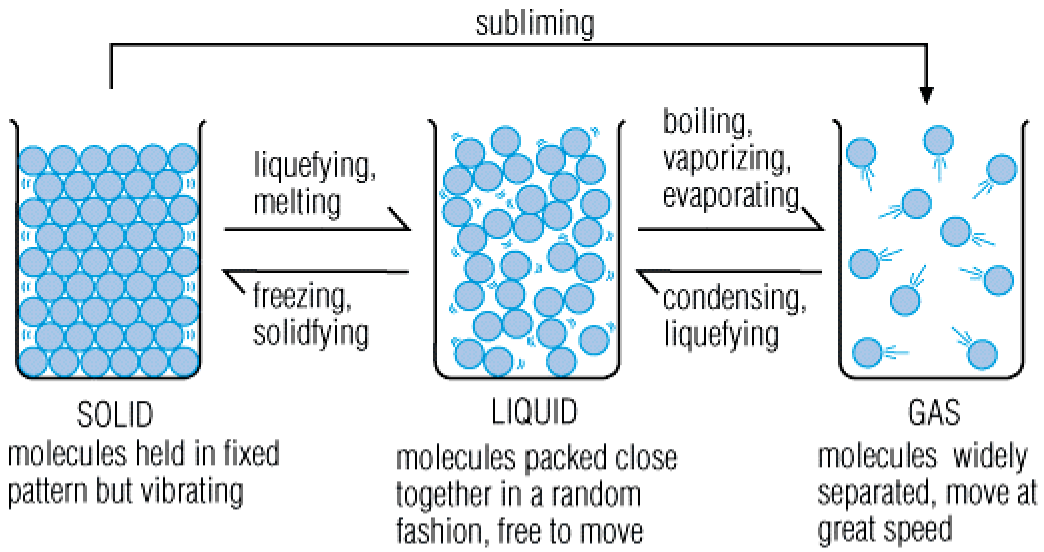
in nuclear physics, a fission reaction that is maintained because neutrons released by the splitting of some atomic nuclei themselves go on to split others, releasing even more neutrons. Such a reaction can be controlled (as in a nuclear reactor) by using moderators to absorb excess neutrons. Uncontrolled, a chain reaction produces a nuclear explosion (as in an atom bomb).

---

change of state

in science, change in the physical state (solid, liquid, or gas) of a material. For instance, melting, boiling, and evaporation and their opposites, solidification and condensation, are changes of state. The former set of changes are brought about by heating or decreased pressure; the latter by cooling or increased pressure.

change of state



The state (solid, liquid, or gas) of a substance is not fixed but varies with changes in temperature and pressure.

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charge

see electric charge.

Charles's law

law stating that the volume of a given mass of gas at constant pressure is directly proportional to its absolute temperature (temperature in kelvin). It was discovered by French physicist Jacques Charles in 1787, and independently by French chemist Joseph Gay-Lussac in 1802.

---

charm

in physics, a property possessed by one type of quark (very small particles found inside protons and neutrons), called the charm quark. The effects of charm are only seen in experiments with particle accelerators.

---

choke coil

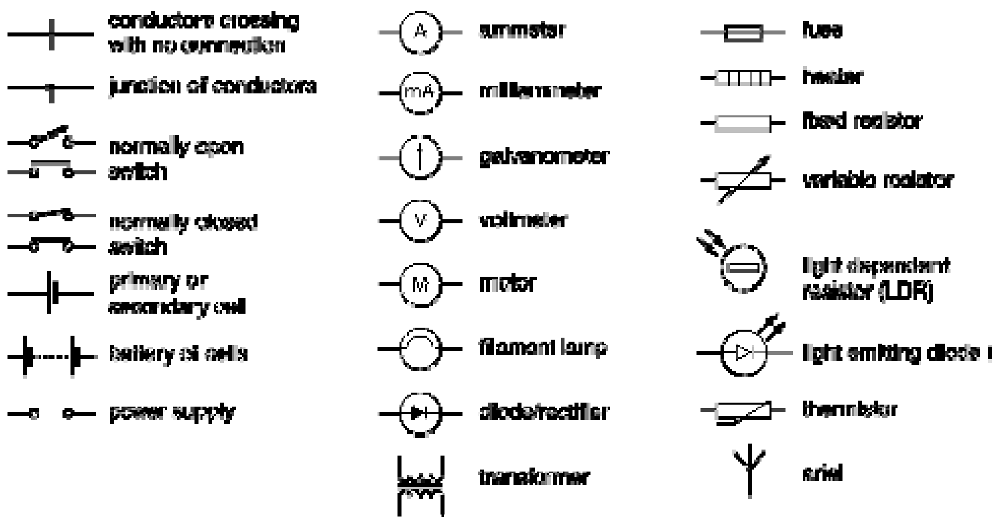
in physics, a coil employed to limit or suppress alternating current without stopping direct current, particularly the type used as a 'starter' in the circuit of fluorescent lighting.

---

circuit

in physics or electrical engineering, an arrangement of electrical components connected by a conducting material through which a current can flow. There are two basic circuits, series and parallel. In a series circuit, the components are connected end to end so that the current flows through all components one after the other. In a parallel circuit, components are connected side by side so that part of the current passes through each component. A circuit diagram shows in graphical form how components are connected together, using standard symbols for the components. If the circuit is unbroken, it is a closed circuit and current flows. If the circuit is broken, it becomes an open circuit and no current flows.

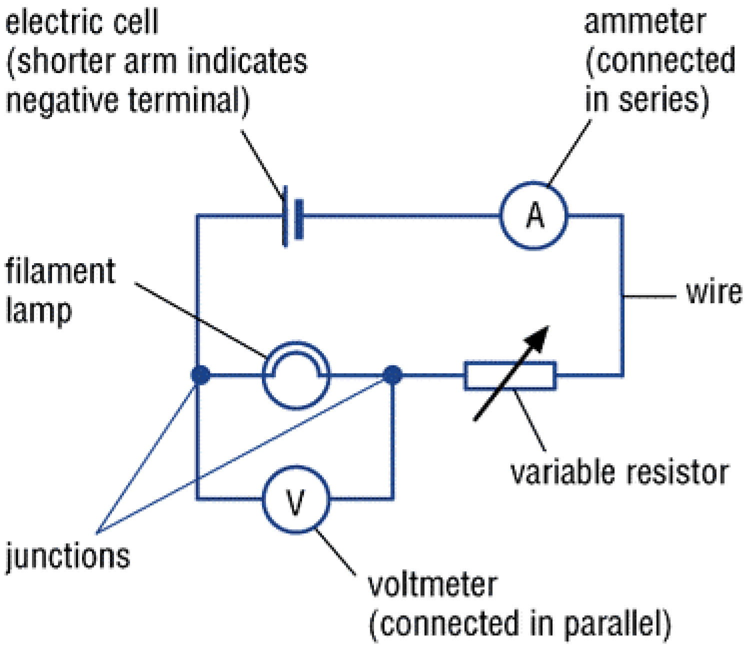
circuit



(Image © Research Machines plc)

Electrical symbols commonly used in circuit diagrams.

circuit diagram



(Image © Research Machines plc)

A circuit diagram shows in graphical form how the components of an electric circuit are connected together. Each component is represented by an internationally recognized symbol, and the connecting wires are shown by straight lines. A dot indicates where wires join.

cloud chamber

apparatus, now obsolete, for tracking ionized particles. It consists of a vessel fitted with a piston and filled with air or other gas, saturated with water vapour. When the volume of the vessel is suddenly expanded by moving the piston outwards, the vapour cools and a cloud of tiny droplets forms on any nuclei, dust, or ions present. As fast-moving ionizing particles collide with the air or gas molecules, they show as visible tracks.

cold fusion

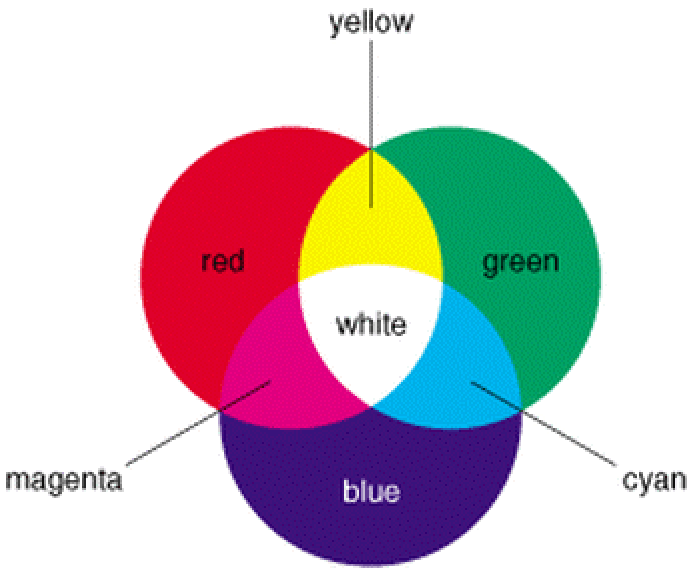
in nuclear physics, the fusion of atomic nuclei at room temperature. If cold fusion were possible it would provide a limitless, cheap, and pollution-free source of energy, and it has therefore been the subject of research around the world.

colour

in physics, quality or wavelength of light emitted or reflected from an object. Visible white light consists of electromagnetic radiation of various wavelengths, and if a beam is refracted through a prism, it can be spread out into the visible spectrum (that can be detected by the human eye), in which the various colours correspond to different wavelengths. From long to short wavelengths (from about 700 to 400 nanometres) the colours are red, orange, yellow, green, blue, indigo, and violet.

The colour of grass is green because grass absorbs all the colours from the spectrum and only transmits or reflects the wavelength corresponding to green. A sheet of white paper reflects all the colours of the spectrum from its surface; black objects absorb all the colours of the spectrum.

colour



The mixing of the primary (red, blue, and green) coloured beams of light. All the colours mixed together produce white.

---

concave lens

lens that possesses at least one surface that curves inwards. It is a diverging lens, spreading out those light rays that have been refracted through it. A concave lens is thinner at its centre than at its edges, and is used to correct short-sightedness (myopia).

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condenser

in electronic circuits, a former name for a capacitor.

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conduction, electrical

flow of charged particles through a material giving rise to electric current. Conduction in metals involves the flow of negatively charged free electrons. Conduction in gases and some liquids involves the flow of ions that carry positive charges in one direction and negative charges in the other. Conduction in a semiconductor such as silicon involves the flow of electrons and positive holes.

---

conduction, heat

flow of heat energy through a material without the movement of any part of the material itself (compare conduction, electrical). Heat energy is present in all materials in the form of the kinetic energy of their constituent vibrating particles, and may be conducted from one particle to the next in the form of this vibration.

---

convection current

current caused by the expansion of a liquid, solid, or gas as its temperature rises. The expanded material, being less dense, rises, while colder, denser material sinks. Material of neutral buoyancy moves laterally. Convection currents arise in the atmosphere above warm land masses or seas, giving rise to sea breezes and land breezes, respectively. In some heating systems, convection currents are used to carry hot water upwards in pipes.

---

convex lens

lens that possesses at least one surface that curves outwards. It causes light to deviate inward, bringing the rays of light to a focus, and is thus called a converging lens. A convex lens is thicker at its centre than at its edges, and is used to correct long-sightedness (hypermetropism).

---

cosmic radiation

streams of high-energy particles and elctromagnetic radiation from outer space, consisting of electrons, protons, alpha particles, light nuclei, and gamma rays, which collide with atomic nuclei in the Earth's atmosphere and produce secondary nuclear particles (chiefly mesons, such as pions and muons) that shower the Earth. Space shuttles carry dosimeter instruments to measure the levels of cosmic radiation.

---

coulomb

symbol C,

SI unit of electrical charge. One coulomb is the amount of charge transferred by a current of one ampere in one second. The unit is named after French scientist Charles Augustin de Coulomb.

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critical mass

in nuclear physics, the minimum mass of fissile material that can undergo a continuous chain reaction. Below this mass, too many neutrons escape from the surface for a chain reaction to carry on; above the critical mass, the reaction may accelerate into a nuclear explosion.

---

cryogenics

science of very low temperatures (approaching absolute zero), including the production of very low temperatures and the exploitation of special properties associated with them, such as the disappearance of electrical resistance (superconductivity).

---

current, electric

see electric current.

---

cycle

in physics, a sequence of changes that moves a system away from, and then back to, its original state. An example is a vibration that moves a particle first in one direction and then in the opposite direction, with the particle returning to its original position at the end of the vibration.

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decay, radioactive

see radioactive decay.

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decibel

symbol dB,

unit of measure used originally to compare sound intensities and subsequently electrical or electronic power outputs; now also used to compare voltages. A whisper has a sound intensity of 20 dB; 140 dB (a jet aircraft taking off nearby) is the threshold of pain.

---

density

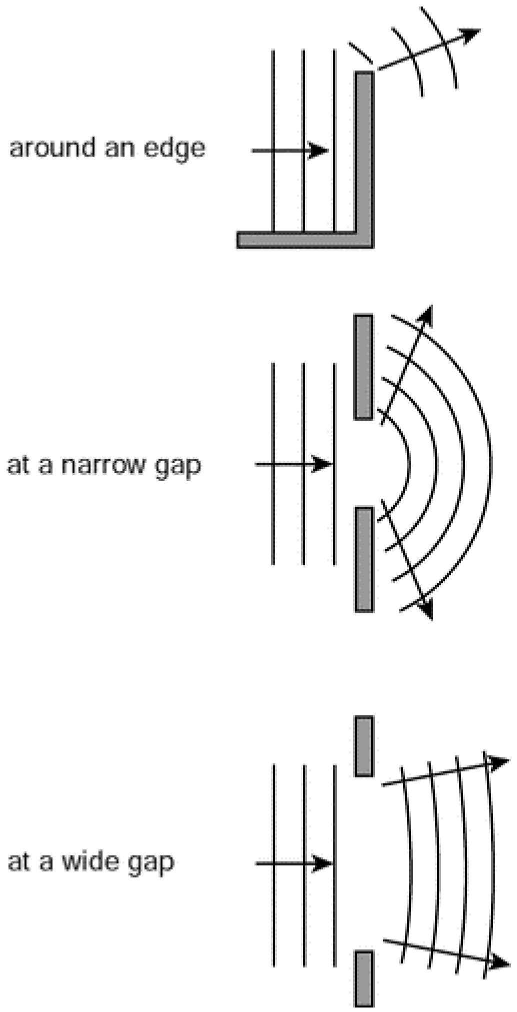
measure of the compactness of a substance; it is equal to its mass per unit volume and is measured, for example, in kg per cubic metre or lb per cubic foot. Density is a scalar quantity. The average density D of a mass m occupying a volume V is given by the formula: $D = m/V$. Relative density is the ratio of the density of a substance to that of water at 4°C/39.2°F.

---

diffraction

the spreading out of waves when they pass through a small gap or around a small object, resulting in some change in the direction of the waves. In order for this effect to be observed, the size of the object or gap must be comparable to or smaller than the wavelength of the waves. Diffraction occurs with all forms of progressive waves – electromagnetic, sound, and water waves – and explains such phenomena as the ability of long-wave radio waves to bend around hills more easily than short-wave radio waves.

diffraction



(Image © Research Machines plc)

When waves pass around a barrier or through a gap, they spread out. The effect, known as diffraction, will be more pronounced at a narrow gap than at a wider gap.

dimension

in science, any directly measurable physical quantity such as mass (M), length (L), and time (T), and the derived units obtainable by multiplication or division from such quantities. For example, acceleration (the rate of change of velocity) has dimensions (LT^{-2}), and is expressed in such units as km s^{-2}. A quantity that is a ratio, such as relative density or humidity, is dimensionless.

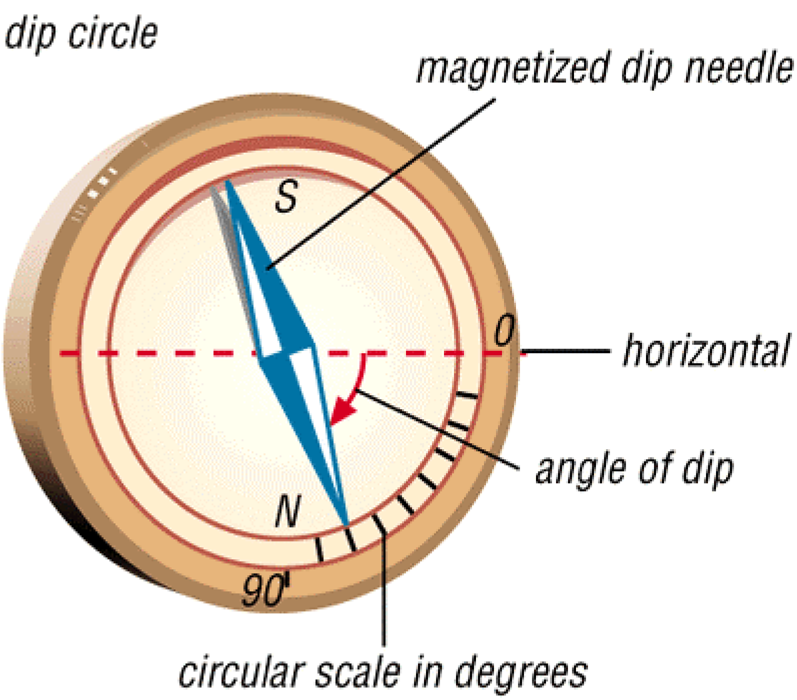
dioptre

optical unit in which the power of a lens is expressed as the reciprocal of its focal length in metres. The usual convention is that convergent lenses are positive and divergent lenses negative. Short-sighted people need lenses of power about -0.7 dioptre; a typical value for long sight is about +1.5 dioptre.

dip, magnetic

angle at a particular point on the Earth's surface between the direction of the Earth's magnetic field and the horizontal. It is measured using a **dip circle**, which has a magnetized needle suspended so that it can turn freely in the vertical plane of the magnetic field. In the northern hemisphere the needle dips below the horizontal, pointing along the line of the magnetic field towards its north pole. At the magnetic north and south poles, the needle dips vertically and the angle of dip is 90°. See also angle of declination.

dip



(Image © Research Machines plc)

A dip circle is used to measure the angle between the direction of the Earth's magnetic field and the horizontal at any point on the Earth's surface.

dipole

uneven distribution of magnetic or electrical characteristics within a molecule or substance so that it behaves as though it possesses two equal but opposite poles or charges, a finite distance apart.

dipole, magnetic

see magnetic dipole.

direct current

***DC*,**

electric current where the electrons (negative charge) flow in one direction, and that does not reverse its flow as alternating current does. The electricity produced by a battery is direct current. Electromagnets and electric trains use direct current.

dispersion

in physics, a particular property of refraction in which the angle and velocity of waves passing through a dispersive medium depends upon their frequency. When visible white light passes through a prism it is split into a spectrum (see electromagnetic waves). This occurs because each component frequency of light, which corresponds to a colour, is refracted by a slightly different angle, and so the light is split into its component frequencies (colours). A rainbow is formed when sunlight is dispersed by raindrops.

distance ratio

in a machine, the distance moved by the input force, or effort, divided by the distance moved by the output force, or load. The ratio indicates the movement magnification achieved, and is equivalent to the machine's velocity ratio.

domain

in physics, small area in a magnetic material that behaves like a tiny magnet. The magnetism of the material is due to the movement of electrons in the atoms of the domain. In an unmagnetized sample of material, the domains point in random directions, or form closed loops, so that there is no overall magnetization of the sample. In a magnetized sample, the domains are aligned so that their magnetic effects combine to produce a strong overall magnetism.

Doppler effect

change in the observed frequency (or wavelength) of waves due to relative motion between the wave source and the observer. The Doppler effect is responsible for the perceived change in pitch of a siren as it approaches and then recedes, and for the red shift of light from distant galaxies. It is named after the Austrian physicist Christian Doppler.

dynamics

or *kinetics*,

in mechanics, the mathematical and physical study of the behaviour of bodies under the action of forces that produce changes of motion in them.

dynamo

former name for a generator.

echo

repetition of a sound wave, or of a radar or sonar signal, by reflection from a hard surface such as a wall or building. By accurately measuring the time taken for an echo to return to the transmitter, and by knowing the speed of a radar signal (the speed of light) or a sonar signal (the speed of sound in water), it is possible to calculate the range of the object causing the echo (echolocation).

eddy current

electric current induced, in accordance with Faraday's laws of electromagnetic induction, in a conductor located in a changing magnetic field. Eddy currents can cause much wasted energy in the cores of transformers and other electrical machines.

efficiency

in physics, a general term indicating the degree to which a process or device can convert energy from one form to another without loss, or how effectively energy is used, and wasted energy, such as heat and sound, minimized. It is normally expressed as a fraction or a percentage, where 100% indicates conversion with no loss. The efficiency of a machine, for example, is the ratio of the energy output to the energy input; in practice it is always less than 100% because of frictional heat losses.

elasticity

in physics, the ability of a solid to recover its shape once deforming forces are removed. An elastic material obeys Hooke's law, which states that its deformation is proportional to the applied stress up to a certain point, called the **elastic limit**;

beyond this point additional stresses will deform it permanently. Elastic materials include metals and rubber; however, all materials have some degree of elasticity.

E-layer

formerly *Kennelly-Heaviside layer*,

lower regions (90–120 km/56–75 mi) of the ionosphere, which reflect radio waves, allowing their reception around the surface of the Earth. The E-layer approaches the Earth by day and recedes from it at night.

---

electric charge

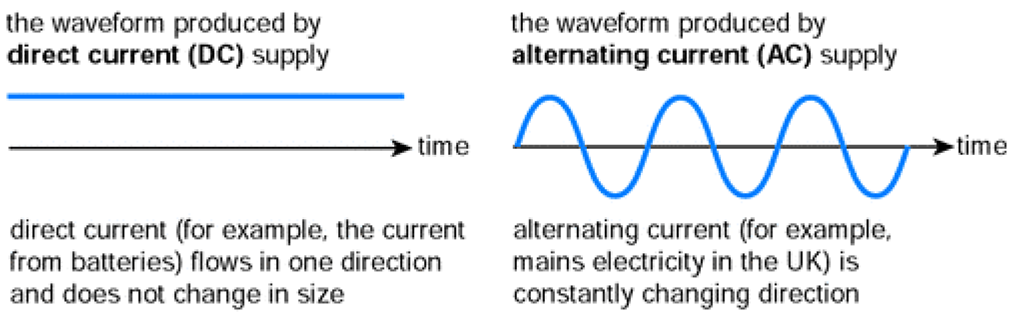
property of some bodies that causes them to exert forces on each other. Two bodies both with positive or both with negative charges repel each other, whereas bodies with opposite or 'unlike' charges attract each other. Electrons possess a negative charge, and protons an equal positive charge. The SI unit of electric charge is the coulomb (symbol C).

---

electric current

flow of electrically charged particles through a conducting circuit due to the presence of a potential difference. The current at any point in a circuit is the amount of charge flowing per second; its SI unit is the ampere (coulomb per second).

electric current



(Image © Research Machines plc)

The patterns produced by a direct current and an alternating current on the screen of an oscilloscope.

---

electric field

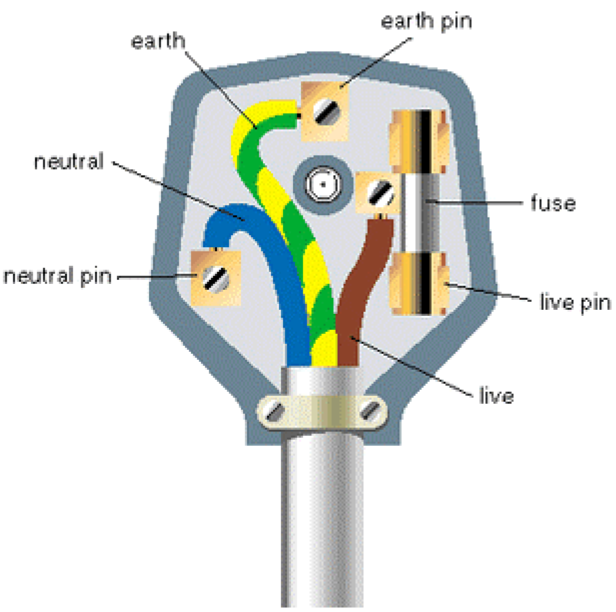
in physics, a region in which a particle possessing electric charge experiences a force owing to the presence of another electric charge. The strength of an electric field, *E*, is measured in volts per metre (V m^{-1}). It is a type of electromagnetic field.

electricity

all phenomena caused by electric charge. There are two types of electricity: static and current. Electric charge is caused by an excess or deficit of electrons in a substance, and an electric current is the movement of charge through a material. Materials having equal numbers of positive and negative charges are termed neutral, as the charges balance out. Substances may be electrical conductors, such as metals, which allow the passage of electricity through them readily, or insulators, such as rubber, which are extremely poor conductors. Substances with relatively poor conductivities that increase with a rise in temperature or when light falls on the material are known as semiconductors. Electric currents also flow through the nerves of organisms. For example, the optic nerve in humans carries electric signals from the eye to the brain. Electricity cannot be seen, but the effects it produces can be clearly seen; for example, a flash of lightning, or the small sparks produced by rubbing a nylon garment.

plug, three-pin

electrical plug



(Image © Research Machines plc)

The wiring in an electrical plug. The colours of the wires are used universally to represent the same things: earth is green and yellow, live is brown, and neutral is blue.

electrode

any terminal by which an electric current passes in or out of a conducting substance; for example, the anode or cathode in an electrolytic cell. The anode is the positive electrode and the cathode is the negative electrode.

---

electrodynamics

branch of physics dealing with electric charges, electric currents, and associated forces. Quantum electrodynamics (QED) studies the interaction between charged particles and their emission and absorption of electromagnetic radiation. This subject combines quantum theory and relativity theory, making accurate predictions about subatomic processes involving charged particles such as electrons and protons.

---

electromagnet

coil of wire wound around a soft iron core that acts as a magnet when an electric current flows through the wire. Electromagnets have many uses: in switches, electric bells, solenoids, and metal-lifting cranes.

---

electromagnetic field

in physics, region in which a particle with an electric charge experiences a force. If it does so only when moving, it is in a pure **magnetic field**; if it does so when stationary, it is in an **electric field**. Both can be present simultaneously. For example, a light wave consists of an electric field and a magnetic field travelling simultaneously at right angles to each other.

---

electromagnetic force

one of the four fundamental forces of nature, the other three being the gravitational force (gravity), the weak nuclear force, and the strong nuclear force. The particle that is the carrier for the electromagnetic force is the photon.

---

electromagnetic induction

in electronics, the production of an electromotive force (emf) in a circuit by a change of magnetic flux through the circuit or by relative motion of the circuit and the magnetic flux. As a magnet is moved in and out of a coil of wire in a closed circuit an induced current will be produced. All dynamos and generators produce electricity using this effect. When magnetic tape is driven past the playback head (a small coil) of a tape recorder, the moving magnetic field induces an emf in the head, which is then amplified to reproduce the recorded sounds.

---

electromagnetic spectrum

complete range, over all wavelengths and frequencies, of electromagnetic waves. These include (in order of decreasing wavelength) radio and television waves, microwaves, infrared radiation, visible light, ultraviolet light, X-rays, and gamma radiation.

---

electromagnetic waves

oscillating electric and magnetic fields travelling together through space at a speed of nearly 300,000 kps/186,000 mps. Visible light is composed of electromagnetic waves. The **electromagnetic spectrum** is a family of waves that includes radio waves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. All electromagnetic waves are transverse waves. They can be reflected, refracted, diffracted, and polarized.

---

electromotive force

***EMF*,**

in physics, the greatest potential difference that can be generated by a source of current. This is always greater than the measured potential difference generated, due to the resistance of the wires and components, in the circuit.

---

electron

negatively-charged particle with negligible mass. Electrons form the outer portion of all atoms, orbiting the nucleus in groupings called shells. The first shell can hold up to two electrons; the second and third shells can hold up to eight electrons each. The electron arrangement of an element is called its **electronic configuration**; for example, the electronic configuration of the sodium atom is $Na_{(2,8,1)}$. In a neutral atom the number of electrons is equal to the number of protons in the nucleus. This electron structure is responsible for the chemical properties of the atom (see atomic structure). Electrons are a member of the class of elementary particles known as leptons.

---

electron gun

series of electrodes, including a cathode for producing an electron beam. It plays an essential role in many electronic devices, including cathode-ray tubes (television tubes) and electron microscopes.

---

electrons, delocalized

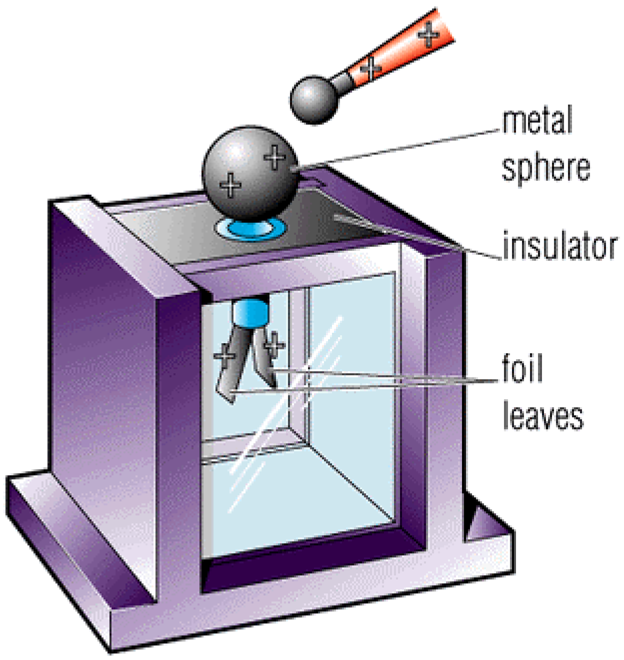
electrons that are not associated with individual atoms or identifiable chemical bonds, but are shared collectively by all the constituent atoms or ions of some chemical substances (such as metals, graphite, and aromatic compounds).

---

electroscope

apparatus for detecting electric charge. The simple gold-leaf electroscope consists of a vertical conducting (metal) rod ending in a pair of rectangular pieces of gold foil, mounted inside and insulated from an earthed metal case or glass jar. An electric charge applied to the end of the metal rod makes the gold leaves diverge, because they each receive a similar charge (positive or negative) via the rod and so repel each other.

electroscope



The electroscope is a simple means of detecting electric charge. The metal foil leaves diverge when a charge is applied to the metal sphere.

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electrostatics

study of stationary electric charges and their fields (not currents). See static electricity.

---

element

substance that cannot be split chemically into simpler substances. The atoms of a particular element all have the same number of protons in their nuclei (their proton or atomic number). Elements are classified in the periodic table of the elements. Of the known elements, 92 are known to occur naturally on Earth (those with atomic numbers 1–92). Those elements with atomic numbers above 96 do not occur in nature and must be synthesized in particle accelerators. Of the elements, 81 are stable; all the others, which include atomic numbers 43, 61, and from 84 up, are radioactive.

---

elementary particle

or *fundamental particle*,

any of those particles that combine to form atoms and all matter, the most familiar being the electron, proton, and neutron. More than 200 particles have now been identified by physicists, categorized into several classes as characterized by their mass, electric charge, spin, magnetic moment, and interaction. Although many particles were thought to be nondivisible and permanent, now most are known to be combinations of a small number of basic particles.

---

energy

capacity for doing work. This work may be as simple as reading a book, using a computer, or driving a car. Without energy no activity is possible. Energy can exist in many different forms. For example, potential energy (PE) is energy deriving from position; thus a stretched spring has elastic PE, and an object raised to a height above the Earth's surface, or the water in an elevated reservoir, has gravitational PE. Moving bodies possess kinetic energy (KE). Energy can be converted from one form to another, but the total quantity in a system stays the same (in accordance with the conservation of energy principle). Energy cannot be created or destroyed. For example, as an apple falls it loses gravitational PE but gains KE. Although energy is never lost, after a number of conversions it tends to finish up as the kinetic energy of random motion of molecules (of the air, for example) at relatively low temperatures. This is 'degraded' energy that is difficult to convert back to other forms.

---

engine

device for converting stored energy into useful work or movement. Most engines use a fuel as their energy store. The fuel is burnt to produce heat energy – hence the name 'heat engine' – which is then converted into movement. Heat engines can be classified according to the fuel they use (petrol engine or diesel engine), or according to whether the fuel is burnt inside (internal combustion engine) or outside (steam engine) the engine, or according to whether they produce a reciprocating or a rotary motion (turbine or Wankel engine).

---

entropy

in thermodynamics, a parameter representing the state of disorder of a system at the atomic, ionic, or molecular level; the greater the disorder, the higher the entropy. Thus the fast-moving disordered molecules of water vapour have higher entropy than those of more ordered liquid water, which in turn have more entropy than the molecules in solid crystalline ice.

---

equilibrium

in physics, an unchanging condition in which an undisturbed system can remain indefinitely in a state of balance. In a **static equilibrium**, such as an object resting on the floor, there is no motion. In a **dynamic equilibrium**, in contrast, a steady state is maintained by constant, though opposing, changes. For example, in a sealed bottle half-full of water, the constancy of the water level is a result of molecules evaporating from the surface and condensing on to it at the same rate.

---

evaporation

process in which a liquid turns to a vapour without its temperature reaching boiling point. Evaporation is the change of state that occurs when a liquid turns into a gas. In a liquid the particles are close together, with forces holding them together, yet able to move about. Some particles in a liquid have more energy than others. Even when a liquid is below its boiling point, some particles have enough energy to escape and form a gas. Evaporation is greater when temperatures and wind speeds are high, and the air is dry. It is why puddles dry up in the sun, and clothes dry faster in dry, windy weather.

---

expansion

in physics, the increase in size of a constant mass of substance caused by, for example, increasing its temperature (thermal expansion) or its internal pressure. The **expansivity**, or coefficient of thermal expansion, of a material is its expansion (per unit volume, area, or length) per degree rise in temperature.

F

in physics, symbol for farad, the SI unit of capacitance equal to that of a capacitor with a potential difference of 1 volt between plates carrying a charge of 1 coulomb.

---

fallout

harmful radioactive material released into the atmosphere in the debris of a nuclear explosion and descending to the surface of the Earth. Such material can enter the food chain, cause radiation sickness, and last for hundreds of thousands of years (see half-life).

---

farad

symbol F,

SI unit of electrical capacitance (how much electric charge a capacitor can store for a given voltage). One farad is a capacitance of one coulomb per volt. For practical purposes the microfarad (one millionth of a farad, symbol μF) is more commonly used.

Faraday's laws

three laws of electromagnetic induction, and two laws of electrolysis, all proposed originally by English physicist Michael Faraday. The laws of induction are: (1) a changing magnetic field induces an electromagnetic force in a conductor; (2) the electromagnetic force is proportional to the rate of change of the field; and (3) the direction of the induced electromagnetic force depends on the orientation of the field. The laws of electrolysis are: (1) the amount of chemical change during electrolysis is proportional to the charge passing through the liquid; and (2) the amount of chemical change produced in a substance by a given amount of electricity is proportional to the electrochemical equivalent of that substance.

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farsightedness

alternative name for hypermetropia, a vision defect.

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fast breeder

or *breeder reactor*,

alternative name for fast reactor, a type of nuclear reactor.

fast reactor

or *fast breeder reactor*,

nuclear reactor that makes use of fast neutrons to bring about fission. Unlike other reactors used by the nuclear-power industry, it has little or no moderator, to slow down neutrons. The reactor core is surrounded by a 'blanket' of uranium carbide. During operation, some of this uranium is converted into plutonium, which can be extracted and later used as fuel.

Fermat's principle

in physics, the principle that a ray of light, or other radiation, moves between two points along the path that takes the minimum time. The principle is named after French mathematician Pierre de Fermat, who used it to deduce the laws of reflection and refraction.

fermion

in physics, a subatomic particle whose spin can only take values that are half-odd-integers, such as 1/2 or 3/2. Fermions may be classified as leptons, such as the electron, and hadrons, such as the proton, neutron, mesons, and so on. All elementary particles are either fermions or bosons.

ferromagnetism

form of magnetism that can be acquired in an external magnetic field and usually retained in its absence, so that ferromagnetic materials are used to make permanent magnets. A ferromagnetic material may therefore be said to have a high magnetic permeability and susceptibility (which depends upon temperature). Examples are iron, cobalt, nickel, and their alloys.

fibre optics

branch of physics dealing with the transmission of light and images through glass or plastic fibres known as optical fibres. Such fibres are now commonly used in both communications technology and medicine.

field

in physics, region of space in which an object exerts a force on a separate object because of certain properties they both possess. For example, there is a force of attraction between any two objects that have mass when one is within the gravitational field of the other.

---

filter

in electronics, a circuit that transmits a signal of some frequencies better than others. A low-pass filter transmits signals of low frequency and also direct current; a high-pass filter transmits high-frequency signals; a band-pass filter transmits signals in a band of frequencies.

---

filter

in optics, a device that absorbs some parts of the visible spectrum and transmits others. A beam of white light can be made into a beam of coloured light by placing a transparent colour filter in the path of the beam. For example, a green filter will absorb or block all colours of the spectrum except green, which it allows to pass through. A yellow filter absorbs only light at the blue and violet end of the spectrum, transmitting red, orange, green, and yellow light.

---

fission

in physics, the splitting of a heavy atomic nucleus into two or more major fragments. It is accompanied by the emission of two or three neutrons and the release of large amounts of nuclear energy.

---

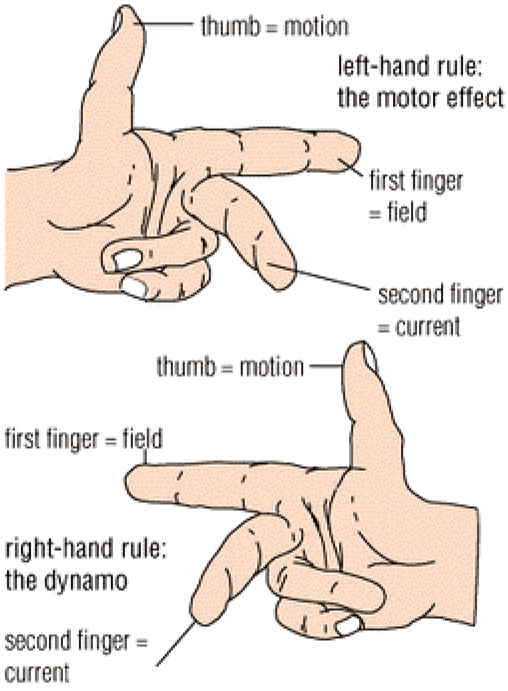
fixed point

temperature that can be accurately reproduced and used as the basis of a temperature scale. In the Celsius scale, the fixed points are the temperature of melting ice, defined to be 0°C (32°F), and the temperature of boiling water (at standard atmospheric pressure), defined to be 100°C (212°F).

Fleming's rules

memory aids used to recall the relative directions of the magnetic field, current, and motion in an electric generator or motor, using one's fingers. The three directions are represented by the thu*m*b (for *m*otion), *f*orefinger (for *f*ield), and se*c*ond finger (for conventional *c*urrent), all held at right angles to each other. The right hand is used for generators and the left for motors. The rules were devised by the English physicist John Fleming.

Fleming's rules



(Image © Research Machines plc)

Fleming's rules give the direction of the magnetic field, motion, and current in electrical machines. The left hand is used for motors, and the right hand for generators and dynamos.

---

flotation, law of

law stating that a floating object displaces its own weight of the fluid in which it floats. See Archimedes principle.

---

fluid mechanics

study of the behaviour of fluids (liquids and gases) in motion. Fluid mechanics is important in the study of the weather, the design of aircraft and road vehicles, and in industries, such as the chemical industry, which deal with flowing liquids or gases.

---

fluorescence

short-lived luminescence (a glow not caused by high temperature). Phosphorescence lasts a little longer.

FM

in physics, abbreviation for frequency modulation, or the variation of the frequency of a carrier wave in accordance with the signal to be transmitted. Used in radio, FM is constant in amplitude and has much better signal-to-noise ratio than AM (amplitude modulation). It was invented by the US electronic engineer Edwin Armstrong.

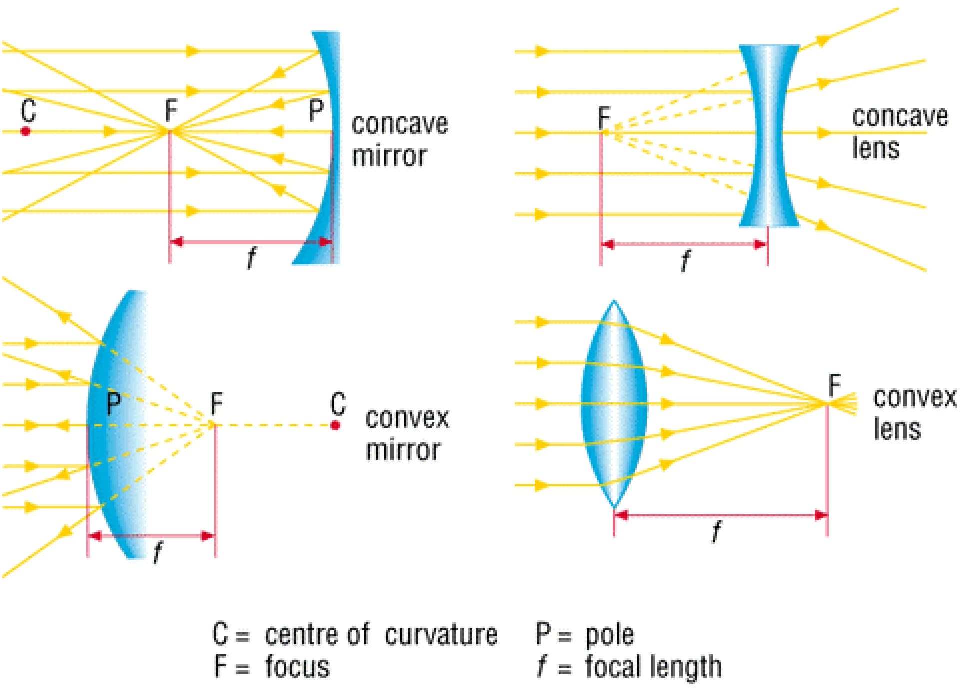
---

focal length

or *focal distance*,

distance from the centre of a lens or curved mirror to the focal point. For a concave mirror or convex lens, it is the distance at which rays of light parallel to the principal axis of the mirror or lens are brought to a focus (for a mirror, this is half the radius of curvature). For a convex mirror or concave lens, it is the distance from the centre to the point from which rays of light originally parallel to the principal axis of the mirror or lens diverge after being reflected or refracted.

focal length



(Image © Research Machines plc)

The distance from the pole (P), or optical centre, of a lens or spherical mirror to its principal focus (F). The focal length of a spherical mirror is equal to half the radius of curvature (f = CP/2). The focal length of a lens is inversely proportional to the power of that lens (the greater the power the shorter the focal length).

---

focus

or *focal point*,

in optics, the point at which light rays converge, or from which they appear to diverge. Other electromagnetic rays, such as microwaves, and sound waves may also be brought together at a focus. Rays parallel to the principal axis of a lens or mirror are converged at, or appear to diverge from, the principal focus.

---

force

any influence that tends to change the state of rest of a body its uniform motion in a straight line. The action of an unbalanced or resultant force results in the acceleration of a body in the direction of action of the force, or it may, if the body is unable to move freely, result in its deformation (see Hooke's law). A force is a push or a pull on an object. A force will cause an object to move if it is stationary, change direction, slow down, or speed up. Force is a vector quantity, possessing both magnitude and direction; its SI unit is the newton.

---

force ratio

magnification of a force by a machine; see mechanical advantage.

---

forces, fundamental

in physics, four fundamental interactions currently known to be at work in the physical universe. There are two long-range forces: the **gravitational force**, or **gravity**, which keeps the planets in orbit around the Sun and acts between all particles that have mass; and the **electromagnetic force**, which stops solids from falling apart and acts between all particles with electric charge. There are two very short-range forces, which operate over distances comparable with the size of the atomic nucleus: the **weak nuclear force**, responsible for the reactions that fuel the Sun and for the emission of beta particles by some particles; and the **strong nuclear force**, which binds together the protons and neutrons in the nuclei of atoms. The relative strengths of the four forces are: strong, 1; electromagnetic, 10^{-2}; weak, 10^{-6}; gravitational, 10^{-40}.

---

freezing

change of state from liquid to solid, as when water becomes ice. For a given substance, freezing occurs at a definite temperature, known as the **freezing point**, that is invariable under similar conditions of pressure, and the temperature remains at this point until all the liquid is frozen; the freezing point and melting point of the substance are the same temperature. By measuring the temperature of a liquid against time as it cools a cooling curve can be plotted; on the cooling curve the temperature levels out at the freezing point.

---

freezing point, depression of

lowering of a solution's freezing point below that of the pure solvent; it depends on the number of molecules of solute dissolved in it. For a single solvent, such as pure water, all solute substances in the same molar concentration produce the same lowering of freezing point. The depression d produced by the presence of a solute of molar concentration C is given by the equation $d = KC$, where K is a constant (called the cryoscopic constant) for the solvent concerned.

---

frequency

in physics, number of periodic oscillations, vibrations, or waves occurring per unit of time. The SI unit of frequency is the hertz (Hz), one hertz being equivalent to one cycle per second. Frequency is related to wavelength and velocity by the equation: $f = v/\lambda$ where f is frequency, v is velocity, and λ is wavelength. Frequency is the reciprocal of the period T: $f = 1/T$

---

frequency modulation

see FM.

---

friction

in physics, the force that opposes the movement of two bodies in contact as they move relative to each other. The **coefficient of friction** is the ratio of the force required to achieve this relative motion to the force pressing the two bodies together.

---

fuel

any source of heat or energy, embracing the entire range of materials that burn in air (combustibles). A fuel is a substance that gives out energy when it burns. A **nuclear fuel** is any material that produces energy by nuclear fission in a nuclear reactor. Fossil fuels are formed from the fossilized remains of plants and animals.

---

fuel cell

cell converting chemical energy directly to electrical energy. It works on the same principle as a battery but is continually fed with fuel, usually hydrogen and oxygen. Fuel cells are silent and reliable (they have no moving parts) but expensive to produce. They are an example of a renewable energy source.

---

fullerene

form of carbon, discovered in 1985, based on closed cages of carbon atoms. The molecules of the most symmetrical of the fullerenes are called buckminsterfullerenes (or buckyballs). They are perfect spheres made up of 60 carbon atoms linked together in 12 pentagons and 20 hexagons fitted together like those of a spherical football. Other fullerenes with 28, 32, 50, 70, and 76 carbon atoms, have also been identified.

---

fundamental constant

physical quantity that is constant in all circumstances throughout the whole universe. Examples are the electric charge of an electron, the speed of light, Planck's constant, and the gravitational constant.

---

fundamental forces

see forces, fundamental.

---

fundamental particle

another term for **elementary particle**.

---

fusion

in physics, the fusing of the nuclei of light elements, such as hydrogen, into those of a heavier element, such as helium. The resultant loss in their combined mass is converted into energy. Stars and thermonuclear weapons are powered by nuclear fusion.

---

gain

in electronics, the ratio of the amplitude of the output signal produced by an amplifier to that of the input signal. In a voltage amplifier the voltage gain is the ratio of the output voltage to the input voltage; in an inverting operational amplifier (op-amp) it is equal to the ratio of the resistance of the feedback resistor to that of the input resistor.

---

gamma radiation

very high-frequency, high-energy electromagnetic radiation, similar in nature to X-rays but of shorter wavelength, emitted by the nuclei of radioactive substances during decay or by the interactions of high-energy electrons with matter. Cosmic gamma rays have been identified as coming from pulsars, radio galaxies, and quasars, although they cannot penetrate the Earth's atmosphere.

---

gas

form of matter, such as air, in which the molecules move randomly in otherwise empty space, filling any size or shape of container into which the gas is put.

---

gas laws

physical laws concerning the behaviour of gases. They include Boyle's law and Charles's law, which are concerned with the relationships between the pressure (P), temperature (T), and volume (V) of an ideal (hypothetical) gas. These two laws can be combined to give the **general** or **universal gas law**, which may be expressed as: PV/T = constant.

---

gauge boson

or *field particle*,

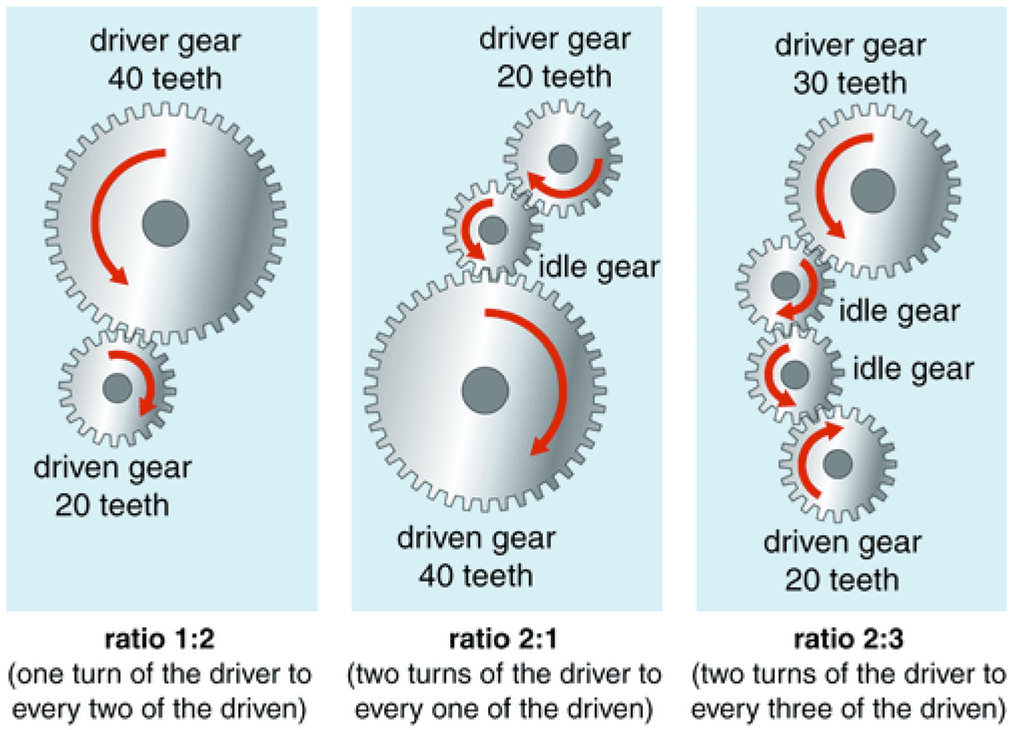
any of the particles that carry the four fundamental forces of nature (see forces, fundamental). Gauge bosons are elementary particles that cannot be subdivided, and include the photon, the graviton, the gluons, and the W^+, W^-, and Z particles.

---

gear

toothed wheel that transmits the turning movement of one shaft to another shaft. Gear wheels may be used in pairs, or in threes if both shafts are to turn in the same direction. The gear ratio – the ratio of the number of teeth on the two wheels – determines the torque ratio, the turning force on the output shaft compared with the turning force on the input shaft. The ratio of the angular velocities of the shafts is the inverse of the gear ratio.

gear



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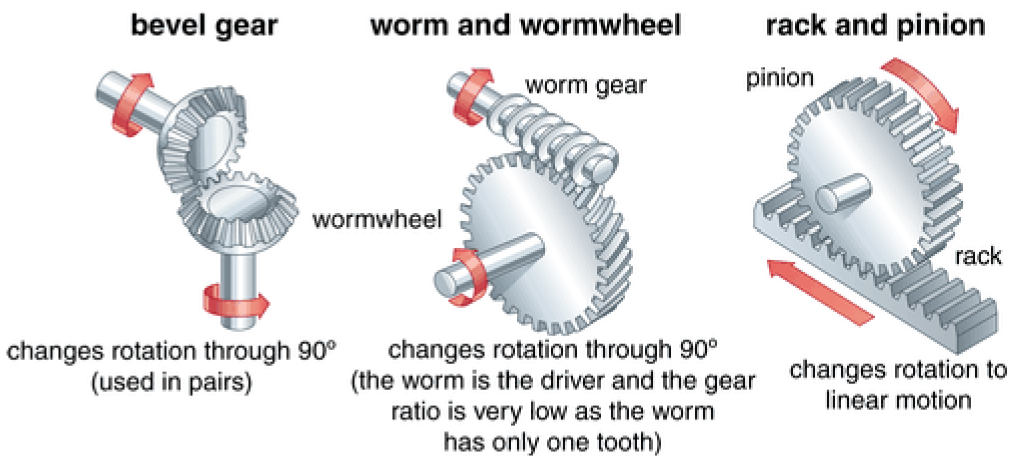
Gear ratio is calculated by dividing the number of teeth on the driver gear by the number of teeth on the driven gear (gear ratio = driver/driven); the idler gears are ignored. Idler gears change the direction of rotation but do not affect speed. A high driven to driver ratio (middle) is a speed-reducing ratio.

gear



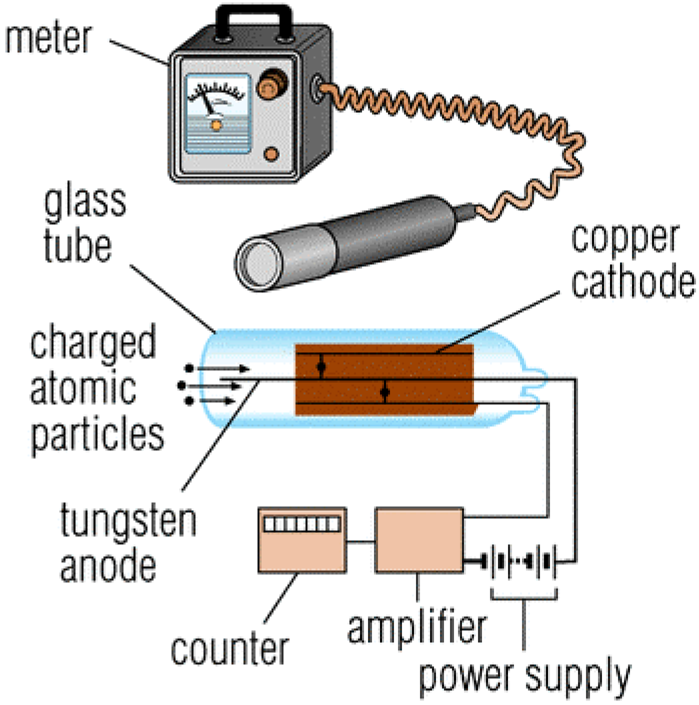
(Image © Research Machines plc)

Different gears are used to perform different engineering functions depending on the change in direction of motion that is needed. Rack and pinion gears are the commonest gears and are used in car steering mechanisms.

Geiger counter

any of a number of devices used for detecting nuclear radiation and measuring its intensity by counting the number of ionizing particles produced (see radioactivity). It detects the momentary current that passes between electrodes (anode and cathode) in a suitable gas (such as argon) when radiation causes the ionization of the gas. The electrodes are connected to electronic devices that enable the number of particles passing to be measured. The increased frequency of measured particles indicates the intensity of radiation. The device is named after the German physicist Hans Geiger.

Geiger counter



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A Geiger–Müller counter detects and measures ionizing radiation (alpha particles, beta particles, and gamma rays) emitted by radioactive materials. Any incoming radiation creates ions (charged particles) within the counter, which are attracted to the anode and cathode to create a measurable electric current.

---

generator

machine that produces electrical energy from mechanical energy, as opposed to an electric motor, which does the opposite. A simple generator (known as a dynamo in the UK) consists of a wire-wound coil (armature) that is rotated between the poles of a permanent magnet. As the coil rotates it cuts across the magnetic field lines and a current is generated. A dynamo on a bicycle is an example of a simple generator.

---

gluon

in physics, a gauge boson that carries the strong nuclear force, responsible for binding quarks together to form the strongly interacting subatomic particles known as hadrons. There are eight kinds of gluon.

---

grand unified theory

in physics, sought-for theory that would combine the theory of the strong nuclear force (called quantum chromodynamics) with the theory of the weak nuclear and electromagnetic forces (see forces, fundamental). The search for the grand unified theory is part of a larger programme seeking a unified field theory, which would combine all the forces of nature (including gravity) within one framework.

---

gravitational field

region around a body in which other bodies experience a force due to its gravitational attraction. The gravitational field of a massive object such as the Earth is very strong and easily recognized as the force of gravity, whereas that of an object of much smaller mass is very weak and difficult to detect. Gravitational fields produce only attractive forces.

---

gravitational force

or *gravity*,

one of the four fundamental forces of nature, the other three being the electromagnetic force, the weak nuclear force, and the strong nuclear force. The gravitational force is the weakest of the four forces, but acts over great distances. The particle that is postulated as the carrier of the gravitational force is the graviton.

---

gravitational lensing

bending of light by a gravitational field, predicted by German-born US physicist Albert Einstein's general theory of relativity. The effect was first detected in 1917, when the light from stars was found to bend as it passed the totally eclipsed Sun. More remarkable is the splitting of light from distant quasars into two or more images by intervening galaxies. In 1979 the first double image of a quasar produced by gravitational lensing was discovered and a quadruple image of another quasar was later found.

---

graviton

in physics, the gauge boson that is the postulated carrier of the gravitational force.

---

gravity

force of attraction that arises between objects by virtue of their masses. The larger the mass of an object the more strongly it attracts other objects. On Earth, gravity causes objects to have weight; it accelerates objects (at 9.806 metres per second per second/32.174 ft per second per second) towards the centre of the Earth, the ground preventing them falling further.

---

ground

an electrical connection between an appliance and the ground, which becomes part of the circuit. In the event of a fault in an electrical appliance (for example, involving connection between the live part of the circuit and the outer casing) the current flows to ground, causing no harm to the user.

---

gyroscope

mechanical instrument, used as a stabilizing device and consisting, in its simplest form, of a heavy wheel mounted on an axis fixed in a ring that can be rotated about another axis, which is also fixed in a ring capable of rotation about a third axis. Applications of the gyroscope principle include the gyrocompass, the gyropilot for automatic steering, and gyro-directed torpedoes.

---

hadron

in physics, a subatomic particle that experiences the strong nuclear force. Each is made up of two or three indivisible particles called quarks. The hadrons are grouped into the baryons (protons, neutrons, and hyperons), consisting of three quarks, and the mesons, consisting of two quarks.

---

half-life

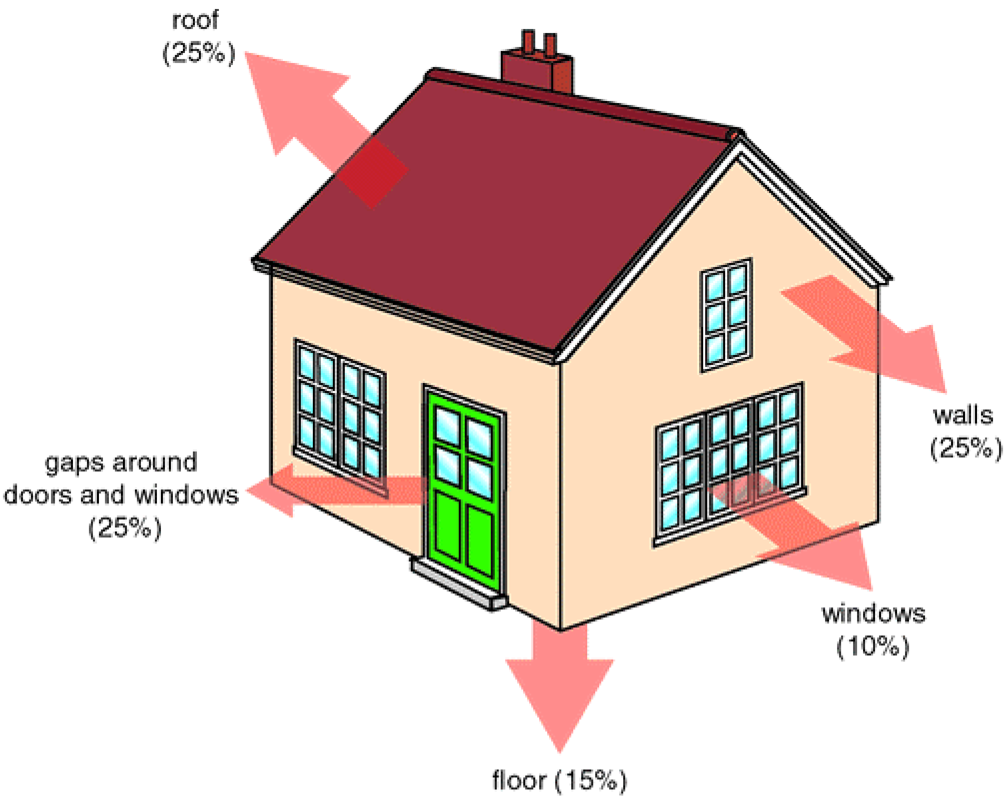
during radioactive decay, the time in which the activity of a radioactive source decays to half its original value (the time taken for half the atoms to decay). In theory, the decay process is never complete and there is always some residual radioactivity. For this reason, the half-life of a radioactive isotope is measured, rather than the total decay time. It may vary from millionths of a second to billions of years.

---

heat

form of energy possessed by a substance by virtue of the vibrational movement (kinetic energy) of its molecules or atoms. Heat energy is transferred by conduction, convection, and radiation. It always flows from a region of higher temperature (heat intensity) to one of lower temperature. Its effect on a substance may be simply to raise its temperature, or to cause it to expand, melt (if a solid), vaporize (if a liquid), or increase its pressure (if a confined gas).

heat



The ways in which heat energy is lost from an ordinary house. Insulation methods, such as fitting double glazing and draught excluders, can help to reduce heat losses.

---

heat capacity

in physics, the quantity of heat required to raise the temperature of an object by one degree. The **specific heat capacity** of a substance is the heat capacity per unit of mass, measured in joules per kilogram per kelvin (J kg^{-1} K^{-1}).

Higgs boson

or *Higgs particle*,

postulated elementary particle whose existence would explain why particles have mass. The current theory of elementary particles, called the standard model, cannot explain how mass arises. To overcome this difficulty, Peter Higgs of the University of Edinburgh, Scotland, and Thomas Kibble of Imperial College, London, England, proposed in 1964 a new particle that binds to other particles and gives them their mass.

Hooke's law

law stating that the deformation of a body is proportional to the magnitude of the deforming force, provided that the body's elastic limit (see elasticity) is not exceeded. If the elastic limit is not reached, the body will return to its original size once the force is removed. The law was discovered by English physicist Robert Hooke in 1676.

---

humidity

quantity of water vapour in a given volume of the atmosphere (absolute humidity), or the ratio of the amount of water vapour in the atmosphere to the saturation value at the same temperature (relative humidity). At dew point the relative humidity is 100% and the air is said to be saturated. Condensation (the conversion of vapour to liquid) may then occur. Relative humidity is measured by various types of hygrometer.

---

hydrodynamics

science of nonviscous liquids (for example water, alcohol, ether) in motion.

---

hydrometer

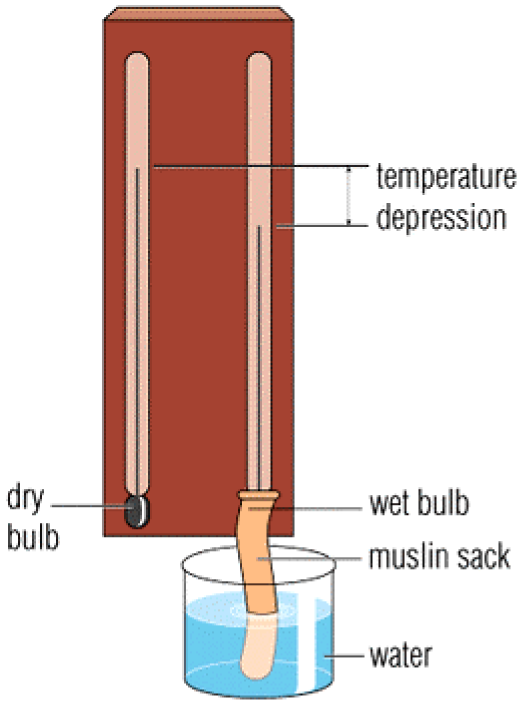
instrument used to measure the relative density of liquids (the density compared with that of water). A hydrometer consists of a thin glass tube ending in a sphere that leads into a smaller sphere, the latter being weighted so that the hydrometer floats upright, sinking deeper into less dense liquids than into denser liquids. Hydrometers are used in brewing and to test the strength of acid in car batteries.

---

hygrometer

any instrument for measuring the humidity, or water vapour content, of a gas (usually air). A wet and dry bulb hygrometer consists of two vertical thermometers, with one of the bulbs covered in absorbent cloth dipped into water. As the water evaporates, the bulb cools, producing a temperature difference between the two thermometers. The amount of evaporation, and hence cooling of the wet bulb, depends on the relative humidity of the air.

hygrometer



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The most common hygrometer, or instrument for measuring the humidity of a gas, is the wet and dry bulb hygrometer. The wet bulb records a lower temperature because water evaporates from the muslin, taking heat from the wet bulb. The degree of evaporation and hence cooling depends upon the humidity of the surrounding air or other gas.

---

hypercharge

in physics, a property of certain elementary particles, analogous to electric charge, that accounts for the absence of some expected behaviour (such as certain decays).

---

hypermetropia

or *farsightedness*,

defect of vision in which a person is able to focus on objects in the distance, but not on close objects. It is caused by the failure of the lens to return to its normal rounded shape, or by the eyeball being too short, with the result that the image is focused on a point behind the retina. Hypermetropia is corrected by wearing eyeglasses fitted with converging lenses, each of which acts like a magnifying glass.

Hz

in physics, the symbol for hertz.

IC

abbreviation for integrated circuit.

---

image

picture or appearance of a real object, formed by light that passes through a lens or is reflected from a mirror. If rays of light actually pass through an image, it is called a **real image**. Real images, such as those produced by a camera or projector lens, can be projected onto a screen. An image that cannot be projected onto a screen, such as that seen in a flat mirror, is known as a **virtual image**.

---

impedance

symbol *Z*,

total opposition of a circuit to the passage of alternating electric current. It includes the resistance R and the reactance X (caused by capacitance or inductance); the impedance can then be found using the equation $Z^2 = R^2 + X^2$.

---

incandescence

emission of light from a substance in consequence of its high temperature. The colour of the emitted light from liquids or solids depends on their temperature, and for solids generally the higher the temperature the whiter the light. Gases may become incandescent through ionizing radiation, as in the glowing vacuum discharge tube.

---

indeterminacy principle

alternative name for uncertainty principle.

---

inductance

in physics, phenomenon in which a changing current in a circuit builds up a magnetic field which induces an electromotive force either in the same circuit and opposing the current (self-inductance) or in another circuit (mutual inductance). The SI unit of inductance is the henry (symbol H).

---

induction coil

type of electrical transformer, similar to an ignition coil, that produces an intermittent high-voltage alternating current from a low-voltage direct current supply.

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inductor

device included in an electrical circuit because of its inductance.

---

inertia

in physics, the tendency of an object to remain in a state of rest or uniform motion until an external force is applied, as described by Isaac Newton's first law of motion (see Newton's laws of motion).

---

infrared radiation

***i.r.*,**

electromagnetic radiation of wavelength between about 700 nanometres and 1 millimetre – that is, between the limit of the red end of the visible spectrum and the shortest microwaves. All bodies above the absolute zero of temperature absorb and radiate infrared radiation. Infrared radiation is used in medical photography and treatment, and in industry, astronomy, and criminology.

---

insulator

any poor conductor of heat, sound, or electricity. Most substances lacking free (mobile) electrons, such as non-metals, are electrical or thermal insulators that resist the flow of electricity or heat through them. Plastics and rubber are good insulators. Usually, devices of glass or porcelain, called insulators, are used for insulating and supporting overhead wires.

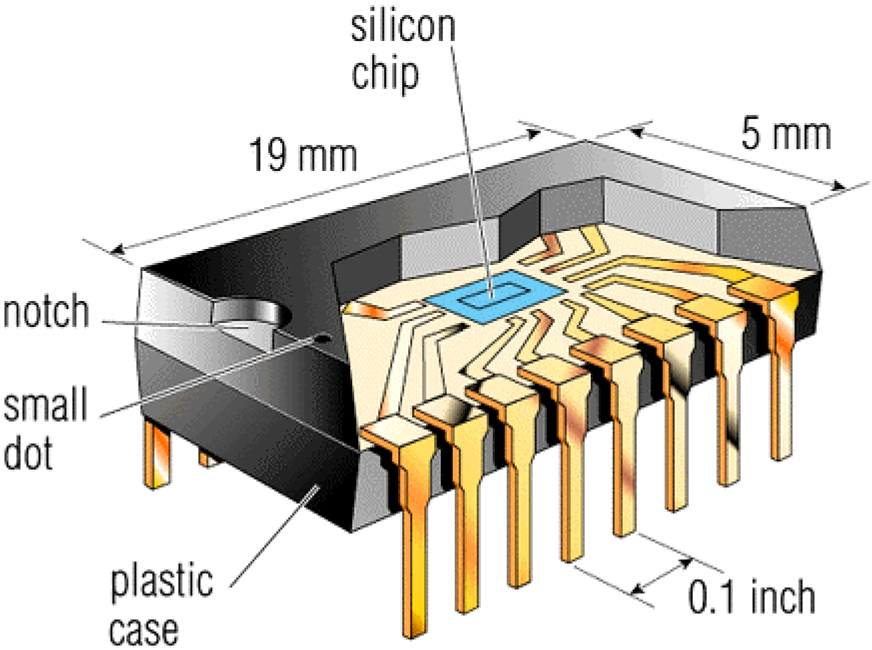
---

integrated circuit

***IC*; or *silicon chip*,**

miniaturized electronic circuit produced on a single crystal, or chip, of a semiconducting material – usually silicon. It may contain many millions of components and yet measure only 5 mm/0.2 in square and 1 mm/0.04 in thick. The IC is encapsulated within a plastic or ceramic case, and linked via gold wires to metal pins with which it is connected to a printed circuit board and the other components that make up such electronic devices as computers and calculators.

integrated circuit



An integrated circuit (IC), or silicon chip.

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intensity

in physics, power (or energy per second) per unit area carried by a form of radiation or wave motion. It is an indication of the concentration of energy present and, if measured at varying distances from the source, of the effect of distance on this. For example, the intensity of light is a measure of its brightness, and may be shown to diminish with distance from its source in accordance with the inverse square law (its intensity is inversely proportional to the square of the distance).

---

interference

in physics, the phenomenon of two or more wave motions interacting and combining to produce a resultant wave of larger or smaller amplitude (depending on whether the combining waves are in or out of phase with each other).

intermolecular force

or *van der Waals' force*,

force of attraction between molecules. Intermolecular forces are relatively weak; hence simple molecular compounds are gases, liquids, or low-melting-point solids.

inverse square law

statement that the magnitude of an effect (usually a force) at a point is inversely proportional to the square of the distance between that point and the object exerting the force.

ion

atom, or group of atoms, that is either positively charged (cation) or negatively charged (anion), as a result of the loss or gain of electrons during chemical reactions or exposure to certain forms of radiation. In solution or in the molten state, ionic compounds such as salts, acids, alkalis, and metal oxides conduct electricity. These compounds are known as electrolytes.

ionizing radiation

radiation that removes electrons from atoms during its passage, thereby leaving ions in its path. Alpha and beta particles are far more ionizing in their effect than are neutrons or gamma radiation.

ion plating

method of applying corrosion-resistant metal coatings. The article is placed in argon gas, together with some coating metal, which vaporizes on heating and becomes ionized (acquires charged atoms) as it diffuses through the gas to form the coating. It has important applications in the aerospace industry.

isotope

one of two or more atoms that have the same atomic number (same number of protons), but which contain a different number of neutrons, thus differing in their relative atomic mass. They may be stable or radioactive (as a radioisotope), naturally occurring, or synthesized. For example, hydrogen has the isotopes ^{2}H (deuterium) and ^3H (tritium). The term was coined by English chemist Frederick Soddy, a pioneer researcher in atomic disintegration.

J

in physics, the symbol for **joule**, the SI unit of energy.

---

joule

symbol J,

SI unit of work and energy (such as potential energy, kinetic energy, or electrical energy).

Kelvin scale

temperature scale used by scientists. It begins at absolute zero (-273.15°C) and increases in kelvins, the same degree intervals as the Celsius scale; that is, 0°C is the same as 273.15 K and 100°C is 373.15 K. It is named after the Irish physicist William Thomson, 1st Baron Kelvin.

Kennelly-Heaviside layer

former term for the E-layer of the ionosphere.

---

kinetic energy

the energy of a body resulting from motion.

---

kinetics

alternative name for dynamics. It is distinguished from **kinematics**, which deals with motion without reference to force or mass.

---

kinetic theory

theory describing the physical properties of matter in terms of the behaviour – principally movement – of its component atoms or molecules. It states that all matter is made up of very small particles that are in constant motion, and can be used to explain the properties of solids, liquids, and gases, as well as changes of state. In a solid, the particles are arranged close together in a regular pattern and vibrate on the spot. In a liquid, the particles are still close together but in an irregular arrangement, and the particles are moving a little faster and are able to slide past one another. In a gas, the particles are far apart and moving rapidly, bouncing off the walls of their container. The temperature of a substance is dependent on the velocity of movement of its constituent particles, increased temperature being accompanied by increased movement.

Large Electron Positron Collider

***LEP*,**

world's largest particle accelerator, in operation 1989–2000 at the CERN laboratories near Geneva in Switzerland. It occupies a tunnel 3.8 m/12.5 ft wide and 27 km/16.7 mi long, which is buried 180 m/590 ft underground and forms a ring consisting of eight curved and eight straight sections. In June 1996, LEP resumed operation after a £210 million upgrade. The upgraded machine, known as LEP2, generated collision energy of 161 gigaelectron volts.

---

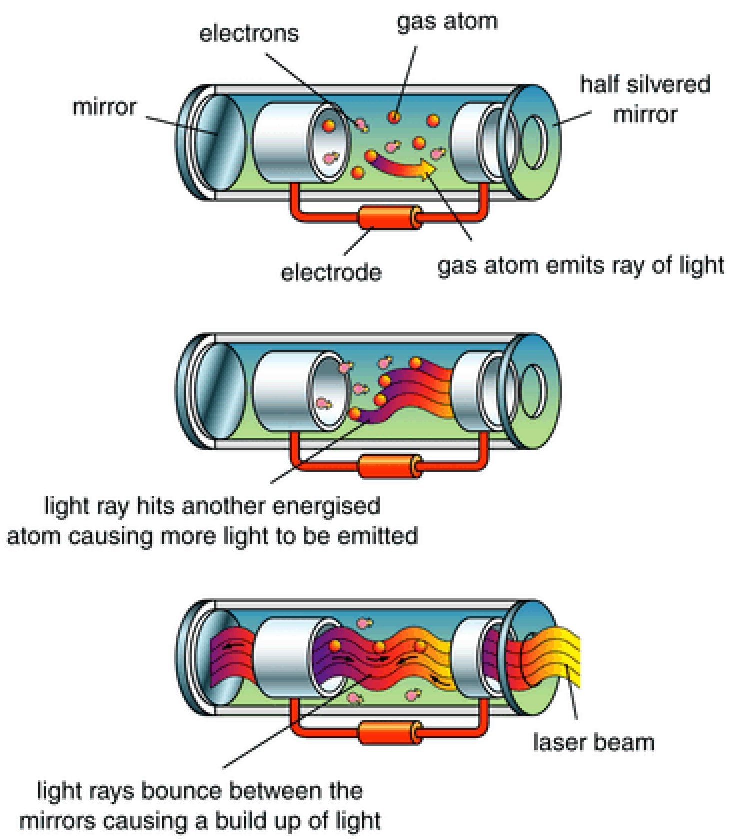
laser

acronym for *light amplification by stimulated emission of radiation*,

device for producing a narrow beam of light, capable of travelling over vast distances without dispersion, and of being focused to give enormous power densities (10^8 watts per cm^2 for high-energy lasers). The laser operates on a principle similar to that of the maser (a high-frequency microwave amplifier or oscillator). The uses of lasers include communications (a laser beam can carry much more information than can radio waves), cutting, drilling, welding, satellite tracking, medical and biological research, and surgery. Sound wave vibrations from the window glass of a room can be picked up by a reflected laser beam. Lasers are also used as entertainment in theatres, concerts, and light shows.

laser

laser



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In a gas laser, electrons moving between the electrodes pass energy to gas atoms. An energized atom emits a ray of light. The ray hits another energized atom causing it to emit a further light ray. The rays bounce between mirrors at each end causing a build-up of light. Eventually it becomes strong enough to pass through the half-silvered mirror at one end, producing a laser beam.

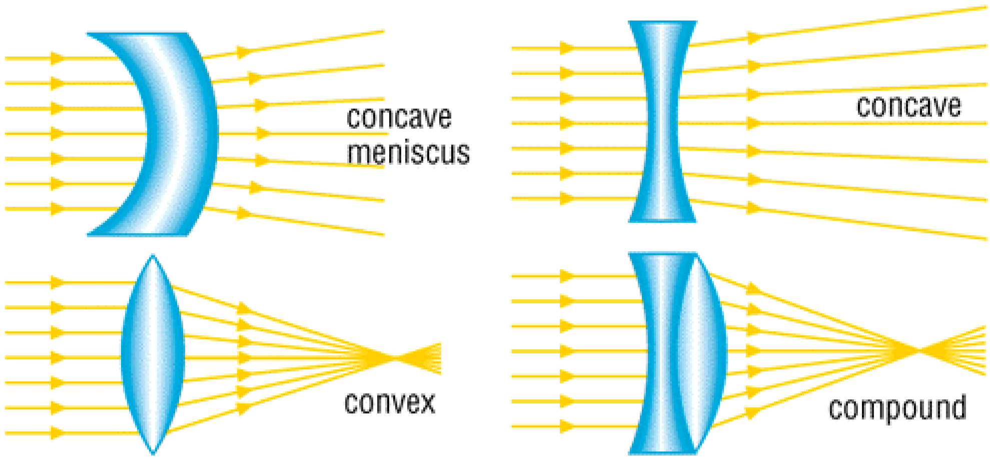
latent heat

in physics, the heat absorbed or released by a substance as it changes state (for example, from solid to liquid) at constant temperature and pressure.

lens

in optics, a piece of a transparent material, such as glass, with two polished surfaces – one concave or convex, and the other plane, concave, or convex – that modifies rays of light. A convex lens brings rays of light together; a concave lens makes the rays diverge. Lenses are essential to spectacles, microscopes, telescopes, cameras, and almost all optical instruments.

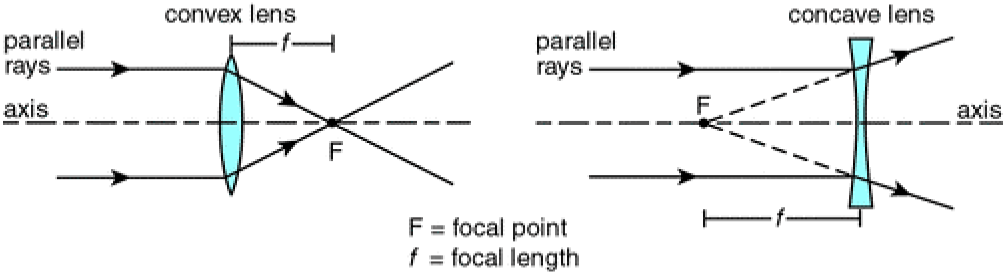
lens



(Image © Research Machines plc)

The passage of light through lenses. The concave lenses diverges a beam of light from a distant source. The convex and compound lenses focus light from a distant source to a point. The distance between the focus and the lens is called the focal length. The shorter the focus, the more powerful the lens.

lens



(Image © Research Machines plc)

A convex (or converging) lens causes light rays to refract inwards. A concave (or diverging lens) causes light rays to refract outwards. Convex lenses are used to correct long-sightedness and concave lenses to correct short-sightedness.

---

lens, gravitational

see gravitational lensing.

Lenz's law

in physics, a law stating that the direction of an electromagnetically induced current (generated by moving a magnet near a wire or a wire in a magnetic field) will be such as to oppose the motion producing it. It is named after the Russian physicist Heinrich Friedrich Lenz, who announced it in 1833.

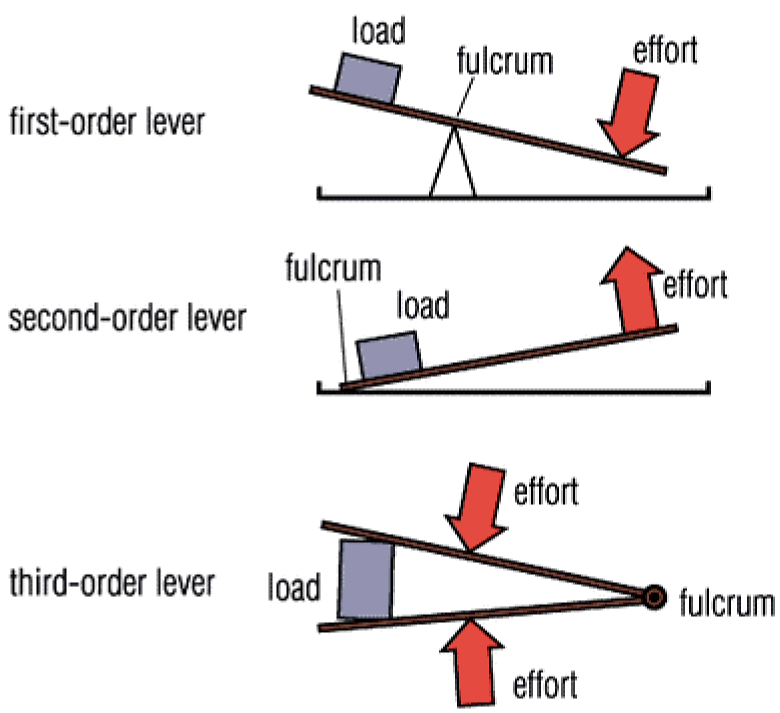
lepton

any of a class of elementary particles that are not affected by the strong nuclear force. The leptons comprise the electron, muon, and tau, and their neutrinos (the electron neutrino, muon neutrino, and tau neutrino), as well as their six antiparticles.

lever

simple machine consisting of a rigid rod pivoted at a fixed point called the fulcrum, used for shifting or raising a heavy load or applying force. Levers are classified into orders according to where the effort is applied, and the load-moving force developed, in relation to the position of the fulcrum.

lever



Types of lever. Practical applications of the first-order lever include the crowbar, seesaw, and scissors. The wheelbarrow is a second-order lever; tweezers or tongs are third-order levers.

---

light

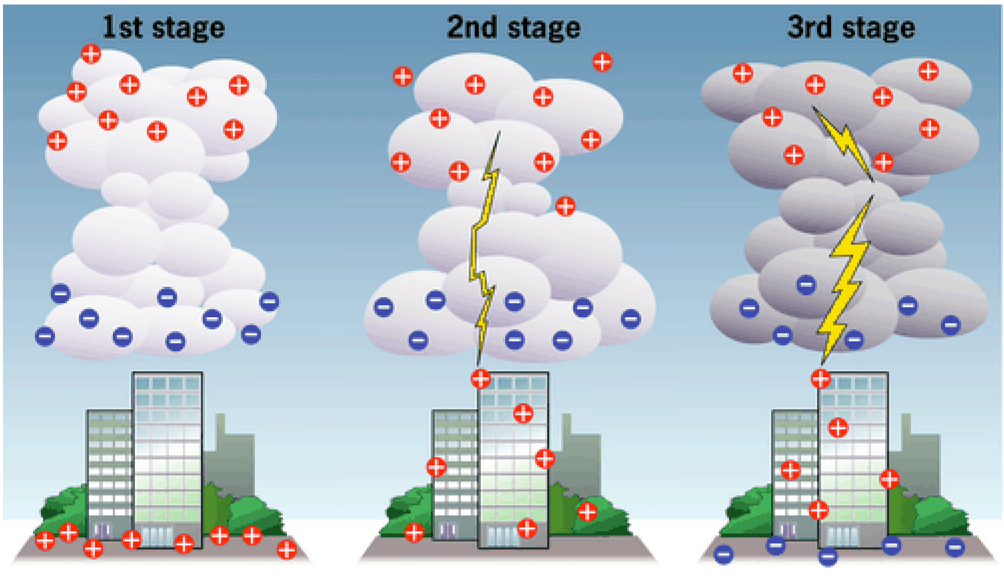
electromagnetic waves (made up of electric and magnetic components) in the visible range, having a wavelength from about 400 nanometres in the extreme violet to about 700 nanometres in the extreme red. Light is considered to exhibit particle and wave properties, and the fundamental particle, or quantum, of light is called the photon. A light wave comprises two transverse waves of electric and magnetic fields travelling at right angles to each other, and as such is a form of electromagnetic radiation. The speed of light (and of all electromagnetic radiation) in a vacuum is approximately 300,000 km/186,000 mi per second, and is a universal constant denoted by *c*.

---

lightning

high-voltage electrical discharge between two rainclouds or between a cloud and the Earth, caused by the build-up of electrical charges. Air in the path of lightning ionizes (becomes a conductor), and expands; the accompanying noise is heard as thunder. Currents of 20,000 amperes and temperatures of 30,000°C/54,000°F are common. Lightning causes nitrogen oxides to form in the atmosphere and approximately 25% of atmospheric nitrogen oxides are formed in this way.

lightning



(Image © Research Machines plc)

The build-up of electrical charge during a thunderstorm that causes lightning. Negative charge builds up at the bottom of a cloud; positive charges rise from the ground and also within the cloud, moving to the top of it. A conducting channel forms through the cloud and a giant spark jumps between opposite charges causing lightning to strike within the cloud and from cloud to ground.

---

lightning conductor

device that protects a tall building from lightning strike, by providing an easier path for current to flow to earth than through the building. It consists of a thick copper strip of very low resistance connected to the ground below. A good connection to the ground is essential and is made by burying a large metal plate deep in the damp earth. In the event of a direct lightning strike, the current in the conductor may be so great as to melt or even vaporize the metal, but the damage to the building will nevertheless be limited.

---

linear accelerator

or *linac*,

see accelerator.

---

liquefied petroleum gas

***LPG*,**

liquid form of butane, propane, or pentane, produced by the distillation of petroleum during oil refining. At room temperature these substances are gases, although they can be easily liquefied and stored under pressure in metal containers. They are used for heating and cooking where other fuels are not available: camping stoves and cigarette lighters, for instance, often use liquefied butane as fuel.

---

liquid

state of matter between a solid and a gas. A liquid forms a level surface and assumes the shape of its container. The way that liquids behave can be explained by the kinetic theory of matter and particle theory. Its atoms do not occupy fixed positions as in a crystalline solid, nor do they have total freedom of movement as in a gas. Unlike a gas, a liquid is difficult to compress since pressure applied at one point is equally transmitted throughout (Pascal's principle). Hydraulics makes use of this property.

---

loudness

subjective judgement of the level or power of sound reaching the ear. The human ear cannot give an absolute value to the loudness of a single sound, but can only make comparisons between two different sounds. The precise measure of the power of a sound wave at a particular point is called its intensity. Accurate comparisons of sound levels may be made using sound-level meters, which are calibrated in units called decibels.

---

luminescence

emission of light from a body when its atoms are excited by means other than raising its temperature. Short-lived luminescence is called fluorescence; longer-lived luminescence is called phosphorescence.

MA

abbreviation for mechanical advantage.

---

machine

in mechanics, device that allows a small force (the effort) to overcome a larger one (the load). There are three basic machines: the inclined plane (ramp), the lever, and the wheel and axle. All other machines are combinations of these three basic types. Simple machines derived from the inclined plane include the wedge, the gear, and the screw; the spanner is derived from the lever; the pulley from the wheel.

Mach number

ratio of the speed of a body to the speed of sound in the medium through which the body travels. In the Earth's atmosphere, Mach 1 is reached when a body (such as an aircraft or spacecraft) 'passes the sound barrier', at a velocity of 331 m/1,087 ft per second (1,192 kph/740 mph) at sea level. A space shuttle reaches Mach 15 (about 17,700 kph/11,000 mph an hour) 6.5 minutes after launch.

---

magnet

any object that forms a magnetic field (displays magnetism), either permanently or temporarily through induction, causing it to attract materials such as iron, cobalt, nickel, and alloys of these. It always has two magnetic poles, called north and south.

---

magnetic compass

device for determining the direction of the horizontal component of the Earth's magnetic field. It consists of a magnetized needle (a small bar magnet) with its north-seeking pole clearly indicated, pivoted so that it can turn freely in a plane parallel to the surface of the Earth (in a horizontal circle). The needle aligns itself with the lines of force of the Earth's magnetic field, turning so that its north-seeking pole points towards the Earth's magnetic north pole.

---

magnetic dipole

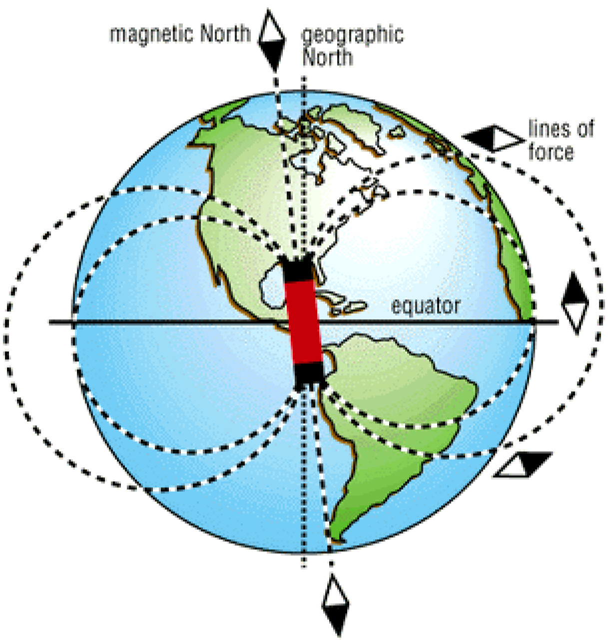
the pair of north and south magnetic poles, separated by a short distance, that makes up all magnets. Individual magnets are often called 'magnetic dipoles'. Single magnetic poles, or monopoles, have never been observed despite being searched for. See also magnetic domain.

---

magnetic field

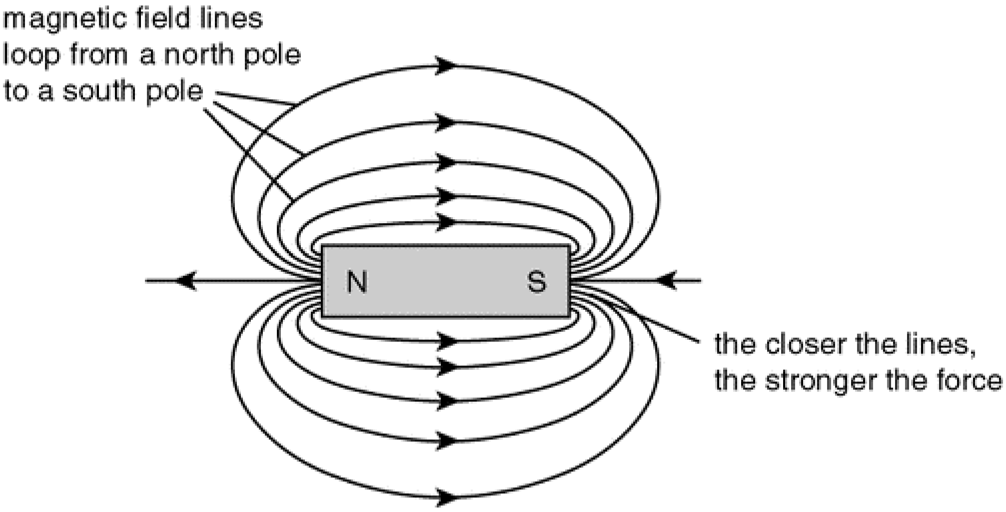
region around a permanent magnet, or around a conductor carrying an electric current, in which a force acts on a moving charge or on a magnet placed in the field. The force cannot be seen; only the effects it produces are visible. The field can be represented by lines of force parallel at each point to the direction of a small compass needle placed on them at that point. These invisible lines of force are called the magnetic field or the flux lines. A magnetic field's magnitude is given by the magnetic flux density (the number of flux lines per unit area), expressed in teslas.

magnetic field



The Earth's magnetic field is similar to that of a bar magnet with poles near, but not exactly at, the geographic poles. Compass needles align themselves with the magnetic field, which is horizontal near the equator and vertical at the magnetic poles.

magnetic field



(Image © Research Machines plc)

A magnet is an object that forms a magnetic field. It has a north pole and a south pole. As iron is a magnetic material, iron filings shaken around a magnet will form along the lines of force and produce the pattern of the magnetic field.

---

magnetic flux

measurement of the strength of the magnetic field around electric currents and magnets. Its SI unit is the weber; one weber per square metre is equal to one tesla.

---

magnetic material

one of a number of substances that are strongly attracted by magnets and can be magnetized. These include iron, nickel, and cobalt, and all those alloys that contain a proportion of these metals. Nonmagnetic materials are not attracted by magnets. These materials include paper, plastic, and rubber.

---

magnetic pole

region of a magnet in which its magnetic properties are strongest. Every magnet has two poles, called north and south. The north (or north-seeking) pole is so named because a freely-suspended magnet will turn so that this pole points towards the Earth's magnetic north pole. The north pole of one magnet will be attracted to the south pole of another, but will be repelled by its north pole. So unlike poles attract, like poles repel.

---

magnetism

phenomena associated with magnetic fields. Magnetic fields are produced by moving charged particles. In electromagnets, electrons flow through a coil of wire connected to a battery; in permanent magnets, spinning electrons within the atoms generate the field.

---

magnetron

thermionic valve (electron tube) for generating very high-frequency oscillations, used in radar and to produce microwaves in a microwave oven. The flow of electrons from the tube's cathode to one or more anodes is controlled by an applied magnetic field.

---

maser

acronym for *microwave amplification by stimulated emission of radiation*,

in physics, a high-frequency microwave amplifier or oscillator in which the signal to be amplified is used to stimulate excited atoms into emitting energy at the same frequency. Atoms or molecules are raised to a higher energy level and then allowed to lose this energy by radiation emitted at a precise frequency. The principle has been extended to other parts of the electromagnetic spectrum as, for example, in the laser.

---

mass

in physics, quantity of matter in a body as measured by its inertia, including all the particles of which the body is made up. Mass determines the acceleration produced in a body by a given force acting on it, the acceleration being inversely proportional to the mass of the body. The mass also determines the force exerted on a body by gravity on Earth, although this attraction varies slightly from place to place (the mass itself will remain the same). In the SI system, the base unit of mass is the kilogram.

---

mass–energy equation

German-born US physicist Albert Einstein's equation $E = mc^2$, denoting the equivalence of mass and energy. In SI units, E is the energy in joules, m is the mass in kilograms, and c, the speed of light in a vacuum, is in metres per second.

mass spectrograph

or *mass spectrometer*,

in physics, an apparatus for analysing chemical composition. Positive ions (charged particles) of a substance are separated by an electromagnetic system, designed to focus particles of equal mass to a point where they can be detected. This permits accurate measurement of the relative concentrations of the various ionic masses present, particularly isotopes.

---

matter

in physics, anything that has mass. All matter is made up of atoms, which in turn are made up of elementary particles; it ordinarily exists in one of three physical states: solid, liquid, or gas.

---

mean free path

in physics, the average distance travelled by a particle, atom, or molecule between successive collisions. It is of importance in the kinetic theory of gases.

---

mechanical advantage

***MA*,**

in physics, the ratio by which the load moved by a machine is greater than the effort applied to that machine. In equation terms: MA = load/effort.

---

mechanical equivalent of heat

in physics, a constant factor relating the calorie (the *c*.g.s. unit of heat) to the joule (the unit of mechanical energy), equal to 4.1868 joules per calorie. It is redundant in the SI system of units, which measures heat and all forms of energy in joules.

---

mechanics

branch of physics dealing with the motions of bodies and the forces causing these motions, and also with the forces acting on bodies in equilibrium. It is usually divided into dynamics and statics.

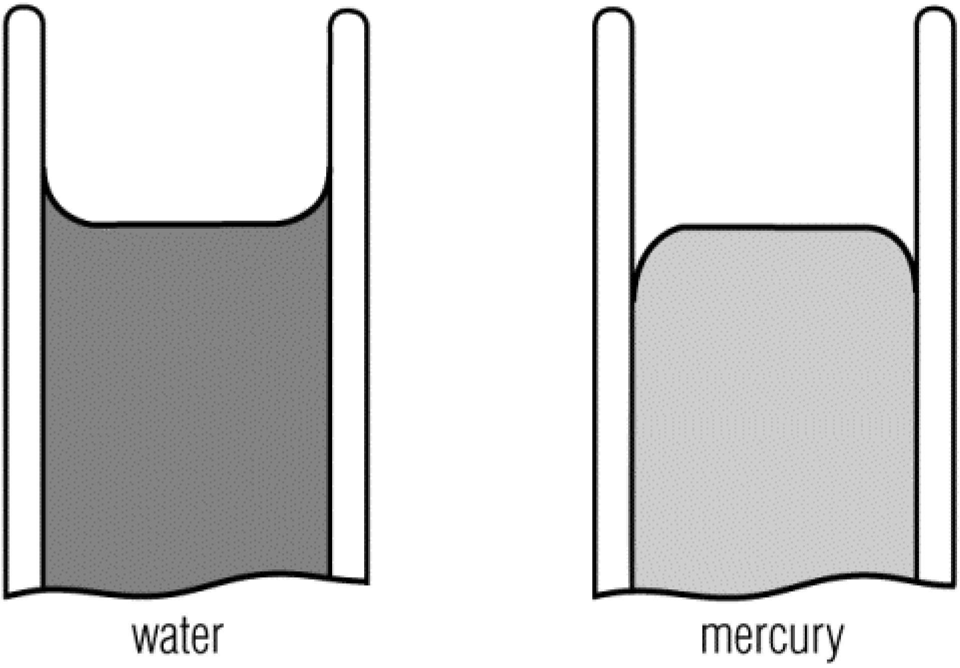
melting point

temperature at which a substance melts, or changes from solid to liquid form. A pure substance under standard conditions of pressure (usually one atmosphere) has a definite melting point. If heat is supplied to a solid at its melting point, the temperature does not change until the melting process is complete. The melting point of ice is 0°C or 32°F.

meniscus

in physics, the curved shape of the surface of a liquid in a thin tube, caused by the cohesive effects of surface tension (capillary action). When the walls of the container are made wet by the liquid, the meniscus is concave, but with highly viscous liquids (such as mercury) the meniscus is convex. Also, a meniscus lens is a concavo-convex or convexo-concave lens.

meniscus



Comparison of the appearance of the meniscus in water and in mercury. When a liquid is placed in a thin tube, surface tension causes its surface to curve. A liquid, such as water, that wets the walls of the container has a concave meniscus, but a liquid that does not wet the walls, such as mercury, has a convex meniscus.

meson

in physics, a group of unstable subatomic particles made up of a quark and an antiquark. It is found in cosmic radiation, and is emitted by nuclei under bombardment by very high-energy particles.

---

minute

unit of time consisting of 60 seconds; also a unit of angle equal to one sixtieth of a degree.

---

mirage

illusion seen in hot weather of water on the horizon, or of distant objects being enlarged. The effect is caused by the refraction, or bending, of light.

---

moderator

in a nuclear reactor, a material such as graphite or heavy water used to reduce the speed of high-energy neutrons. Neutrons produced by nuclear fission are fast-moving and must be slowed to initiate further fission so that nuclear energy continues to be released at a controlled rate.

---

modulation

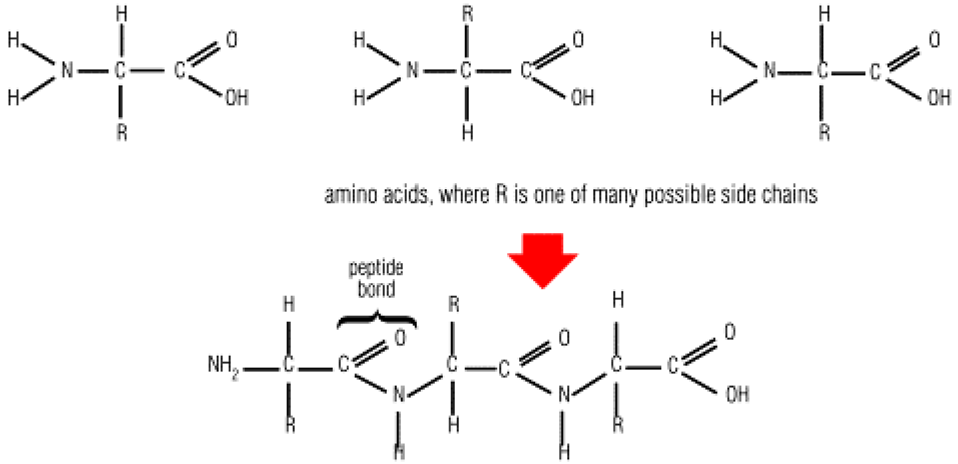
in radio transmission, the variation of frequency, or amplitude, of a radio carrier wave, in accordance with the audio characteristics of the speaking voice, music, or other signal being transmitted.

---

molecule

smallest configuration of an element or compound that can exist independently. One molecule is made up of a group of atoms held together by covalent or ionic bonds. Several non-metal elements exist as molecules. For example, hydrogen atoms, at room temperature, do not exist independently. They are bonded in pairs to form hydrogen molecules. A molecule of a compound consists of two or more different atoms bonded together. For example, carbon dioxide is made up of molecules, each containing one carbon and two oxygen atoms bonded together. The molecular formula is made up of the chemical symbols representing each element in the molecule and numbers showing how many atoms of each element are present. For example, the formula for hydrogen is H_2, and for carbon dioxide is CO_2. Molecules vary in size and complexity from the hydrogen molecule to the large macromolecules of proteins. In general, elements and compounds with molecular structures have similar properties. They have low melting and boiling points, so that many molecular substances are gases or liquids at room temperatures. They are usually insoluble in water and do not conduct electricity even when melted.

protein



peptide – this is one made of just three amino acid units. Proteins consist of very large numbers of amino acid units in long chains, folded up in specific ways

A protein molecule is a long chain of amino acids linked by peptide bonds. The properties of a protein are determined by the order, or sequence, of amino acids in its molecule, and by the three-dimensional structure of the molecular chain. The chain folds and twists, often forming a spiral shape.

---

moment of a force

in physics, measure of the turning effect, or torque, produced by a force acting on a body. It is equal to the product of the force and the perpendicular distance from its line of action to the point, or pivot, about which the body will turn. The turning force around the pivot is called the moment. Its unit is the newton metre.

---

moment of inertia

in physics, the sum of all the point masses of a rotating object multiplied by the squares of their respective distances from the axis of rotation.

---

momentum

product of the mass of a body and its velocity. If the mass of a body is *m* kilograms and its velocity is *v* m s^{-1}, then its momentum is given by: momentum = *mv*. Its unit is the kilogram metre-per-second (kg m s^{-1}) or the newton second. The momentum of a body does not change unless a resultant or unbalanced force acts on that body (see Newton's laws of motion).

---

motor effect

tendency of a wire carrying an electric current in a magnetic field to move. The direction of the movement is given by the left-hand rule (see Fleming's rules). This effect is used in the electric motor. It also explains why streams of electrons produced, for instance, in a television tube can be directed by electromagnets.

---

muon

elementary particle similar to the electron except for its mass which is 207 times greater than that of the electron. It has a half-life of 2 millionths of a second, decaying into electrons and neutrinos. The muon was originally thought to be a meson but is now classified as a lepton. See also tau.

---

natural frequency

frequency at which a mechanical system will vibrate freely. A pendulum, for example, always oscillates at the same frequency when set in motion. More complicated systems, such as bridges, also vibrate with a fixed natural frequency. If a varying force with a frequency equal to the natural frequency is applied to such an object the vibrations can become violent, a phenomenon known as resonance.

---

neural network

artificial network of processors that attempts to mimic the structure of nerve cells (neurons) in the human brain. Neural networks may be electronic, optical, or simulated by computer software.

---

neutrino

in physics, any of three uncharged elementary particles (and their antiparticles) of the lepton class, having a mass that is very small (possibly zero). The most familiar type, the antiparticle of the electron neutrino, is emitted in the beta decay of a nucleus. The other two are the muon and tau neutrinos.

---

neutron

one of the three main subatomic particles, the others being the proton and the electron. Neutrons have about the same mass as protons but no electric charge, and occur in the nuclei of all atoms except hydrogen. They contribute to the mass of atoms but do not affect their chemistry.

---

neutron bomb

or *enhanced radiation weapon*,

small hydrogen bomb for battlefield use that kills by radiation, with minimal damage to buildings and other structures.

---

newton

symbol N,

SI unit of force. A newton is defined as the amount of force needed to move an object of 1 kg so that it accelerates at 1 metre per second per second. It is also used as a unit of weight. The weight of a medium size (100 g/3 oz) apple is one newton.

Newton's laws of motion

in physics, three laws that form the basis of Newtonian mechanics, describing the motion of objects. (1) Unless acted upon by an unbalanced force, a body at rest stays at rest, and a moving body continues moving at the same speed in the same straight line. (2) An unbalanced force applied to a body gives it an acceleration proportional to the force (and in the direction of the force) and inversely proportional to the mass of the body. (3) When a body A exerts a force on a body B, B exerts an equal and opposite force on A; that is, to every action there is an equal and opposite reaction.

---

node

in physics, a position in a standing wave pattern at which there is no vibration. Points at which there is maximum vibration are called **antinodes**. Stretched strings, for example, can show nodes when they vibrate. Guitarists can produce special effects (harmonics) by touching a sounding string lightly to produce a node.

---

noise

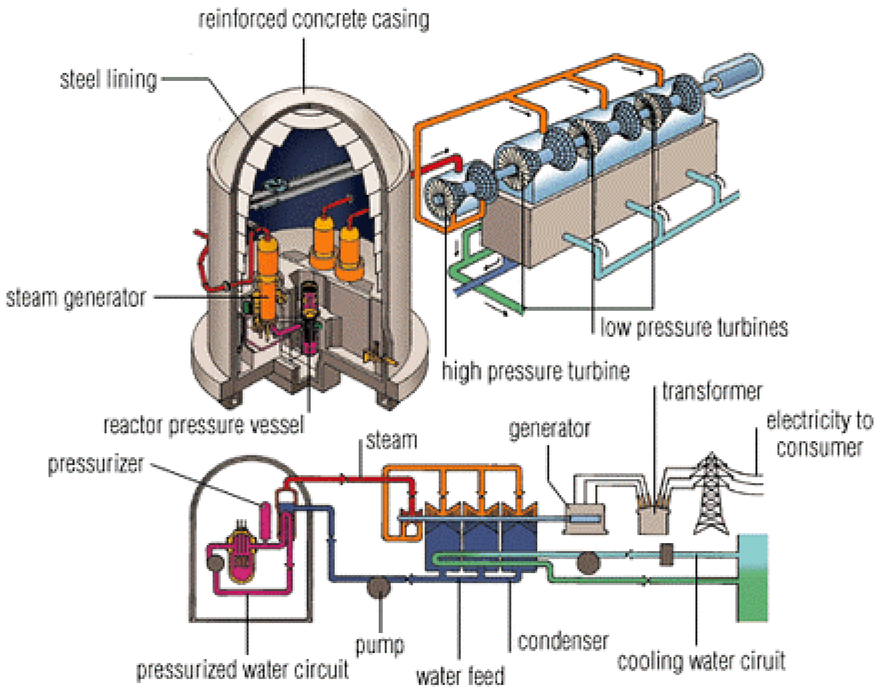
unwanted sound. Permanent, incurable loss of hearing can be caused by prolonged exposure to high noise levels (above 85 decibels). Over 55 decibels on a daily outdoor basis is regarded as an unacceptable level. In scientific and engineering terms, a noise is any random, unpredictable signal.

nuclear energy

or *atomic energy*,

energy released from the inner core, or nucleus, of the atom. Energy produced by nuclear fission (the splitting of certain atomic nuclei) has been harnessed since the 1950s to generate electricity, and research continues into the possible controlled use of nuclear fusion (the fusing, or combining, of atomic nuclei).

nuclear energy



(Image © Research Machines plc)

A pressurized water nuclear power station. Water at high pressure is circulated around the reactor vessel where it is heated. The hot water is pumped to the steam generator where it boils in a separate circuit; the steam drives the turbines coupled to the electricity generator. This is the most widely used type of reactor. More than 20 countries have pressurized water reactors.

nuclear fusion

process whereby two atomic nuclei are fused, with the release of a large amount of energy. Very high temperatures and pressures are required for the process. Under these conditions the atoms involved are stripped of all their electrons so that the remaining particles, which together make up a **plasma**, can come close together at very high speeds and overcome the mutual repulsion of the positive charges on the atomic nuclei. At very close range the strong nuclear force will come into play, fusing the particles to form a larger nucleus. As fusion is accompanied by the release of large amounts of energy, the process might one day be harnessed to form the basis of commercial energy production. Methods of achieving controlled fusion are therefore the subject of research around the world.

nuclear physics

study of the properties of the nucleus of the atom, including the structure of nuclei; nuclear forces; the interactions between particles and nuclei; and the study of radioactive decay. The study of elementary particles is particle physics.

nucleon

in particle physics, either a proton or a neutron, when present in the atomic nucleus. **Nucleon number** is an alternative name for the mass number of an atom.

nucleus

plural *nuclei*,

in physics, the positively-charged central part of an atom, which constitutes almost all its mass. Except for hydrogen nuclei, which have only one proton, nuclei are composed of both protons and neutrons. Surrounding the nucleus are electrons, of equal and opposite charge to that of the protons, thus giving the atom a neutral charge. Nuclei that are unstable may undergo radioactive decay or nuclear fission. In all stars, including our Sun, small nuclei join together to make more stable, larger nuclei. This process is called nuclear fusion.

nuclide

in physics, a species of atomic nucleus characterized by the number of protons (Z) and the number of neutrons (N). Nuclides with identical proton number but differing neutron number are called isotopes.

ohm

symbol Ω,

SI unit of electrical resistance (the property of a conductor that restricts the flow of electrons through it).

Ohm's law

law that states that, for many materials over a wide range of conditions, the current flowing in a conductor maintained at constant temperature is directly proportional to the potential difference (voltage) between its ends. The law was discovered by German physicist Georg Ohm in 1827. He found that if the voltage across a conducting material is changed, the current flow through the material is changed proportionally (for example, if the voltage is doubled then the current also doubles).

---

operational amplifier

or *op-amp*,

processor that amplifies the difference between two incoming electrical signals. It is a current gain device. Operational amplifiers have two inputs, an inverting input (-) and a noninverting input (+). The input signal from a sensor or switch, often as part of a potential divider, is compared with a similar signal at the other input. This then decides the type of output. If a positive signal is applied to the noninverting input, the output will be positive. If the input is negative, the output will be negative. If a positive signal is given to the inverting input, the output will be negative. A negative input will give a positive output. If the signals at the two inputs are the same, the output will be zero. Feedback loops are attached from the output to the input in order to control the amplification of the output.

---

optics

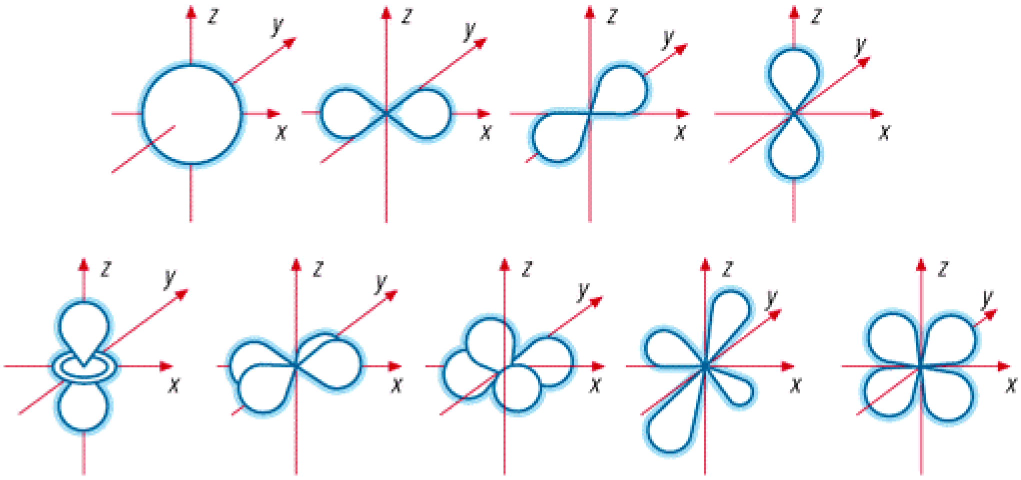
branch of physics that deals with the study of light and vision – for example, shadows and mirror images, lenses, microscopes, telescopes, and cameras. On striking a surface, light rays are reflected or refracted with some absorption of energy, and the study of this is known as geometrical optics.

---

orbital, atomic

region around the nucleus of an atom (or, in a molecule, around several nuclei) in which an electron is likely to be found. According to quantum theory, the position of an electron is uncertain; it may be found at any point. However, it is more likely to be found in some places than in others, and this pattern of probabilities makes up the orbital.

orbital, atomic



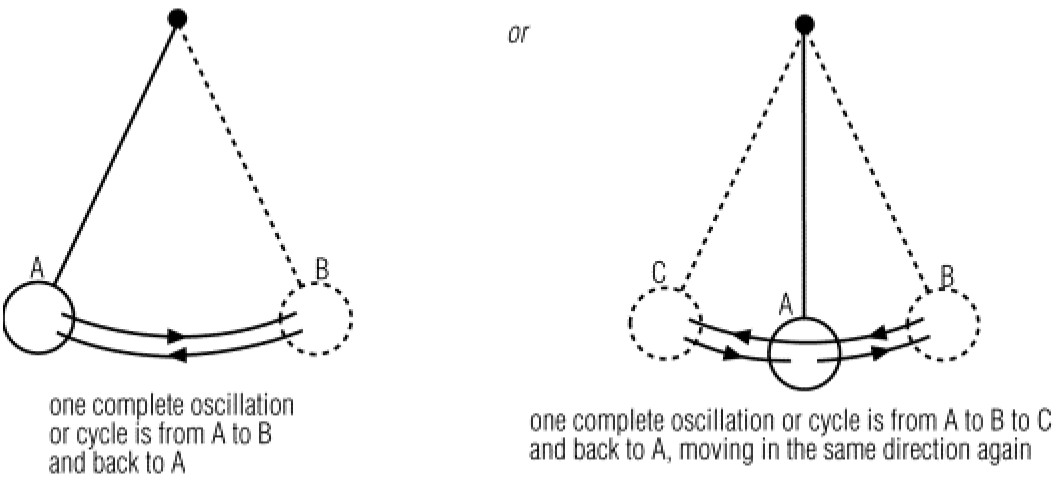
(Image © Research Machines plc)

The shapes of atomic orbitals. An atomic orbital is a picture of the 'electron cloud' that surrounds the nucleus of an atom. There are four basic shapes for atomic orbitals: spherical, dumbbell, clover-leaf, and complex (shown at bottom left).

oscillation

one complete to-and-fro movement of a vibrating object or system. For any particular vibration, the time for one oscillation is called its period and the number of oscillations in one second is called its frequency. The maximum displacement of the vibrating object from its rest position is called the amplitude of the oscillation.

oscillation



(Image © Research Machines plc)

Alternate ways of defining the oscillation (one complete swing) of a pendulum.

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oscillator

any device producing a desired oscillation (vibration). There are many types of oscillator for different purposes, involving various arrangements of thermionic valves or components such as transistors, inductors, capacitors, and resistors.

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oscillograph

instrument for displaying or recording rapidly changing oscillations, electrical or mechanical.

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oscilloscope

another name for cathode-ray oscilloscope.

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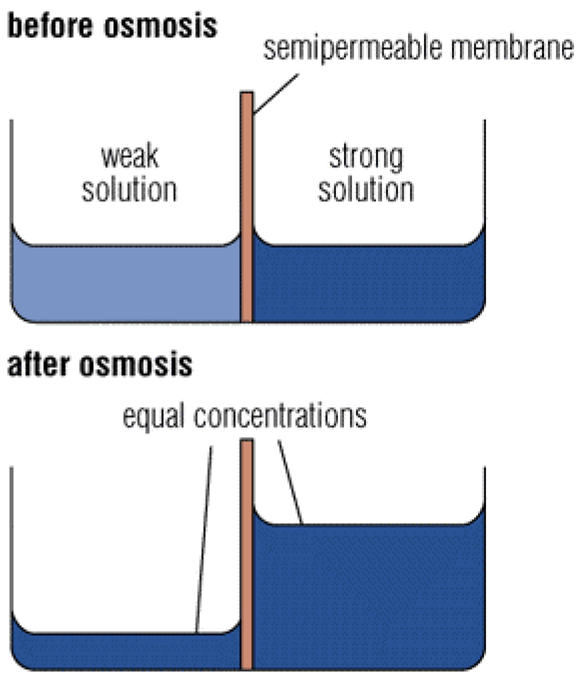
osmosis

movement of water through a partially (selectively) permeable membrane separating solutions of different concentrations. Water passes by diffusion from a **weak solution** (high water concentration) to a **strong solution** (low water concentration) until the two concentrations are equal. A membrane is partially permeable if it lets water through but not the molecules or ions dissolved in the water (the solute; for example, sugar molecules). Many cell membranes behave in this way, and osmosis is a vital mechanism in the transport of fluids in living organisms. One example is in the transport of water from soil (weak solution) into the roots of plants (stronger solution of cell sap) via the root hair cells. Another is the uptake of water by the epithelium lining the gut in animals. There are also membranes that humans can manufacture that are partially permeable.

osmosis



(Image © Research Machines plc)

Apparatus for demostrating osmosis. In 1877 German physicist Wilhelm Pfeffer used a similar apparatus to make the first ever measurement of osmotic pressure and show that osmotic pressure varies according to temperature and the strength of the solute (dissolved substance).

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overtone

note that has a frequency or pitch that is a multiple of the fundamental frequency, the sounding body's natural frequency. Each sound source produces a unique set of overtones, which gives the source its quality or timbre.

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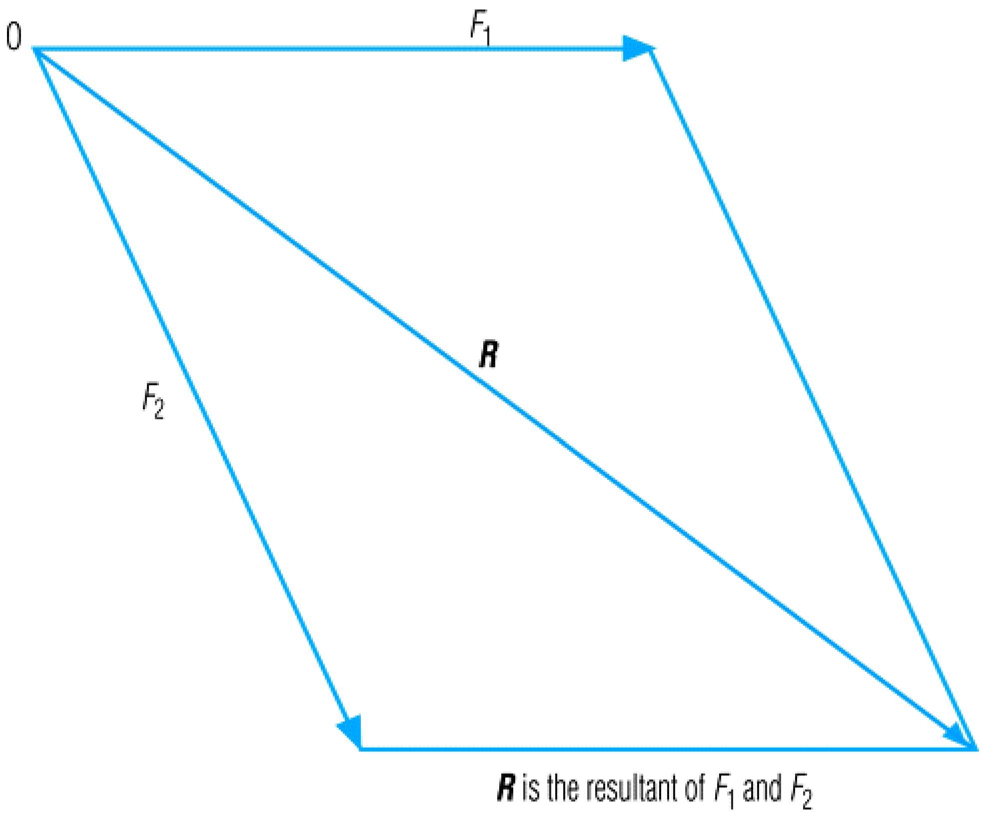
parallelogram of forces

in physics and applied mathematics, a method of calculating the resultant (combined effect) of two different forces acting together on an object. Because a force has both magnitude and direction it is a vector quantity and can be represented by a straight line. A second force acting at the same point in a different direction can be represented by another line drawn at an angle to the first. By completing the parallelogram (of which the two lines are sides) a diagonal may be drawn from the original angle to the opposite corner to represent the resultant force vector.

parallelogram of forces



(Image © Research Machines plc)

The diagram shows how the parallelogram of forces can be used to calculate the resultant (combined effect) of two different forces acting together on an object. The two forces are represented by two lines drawn at an angle to each other. By completing the parallelogram (of which the two lines are sides), a diagonal may be drawn from the original angle to the opposite corner to represent the resultant force vector.

particle detector

one of a number of instruments designed to detect subatomic particles and track their paths; they include the cloud chamber, bubble chamber, spark chamber, and multiwire chamber.

particle physics

the study of the properties of elementary particles and of fundamental interactions (see forces, fundamental).

particle, subatomic

see subatomic particle.

Peltier effect

in physics, a change in temperature at the junction of two different metals produced when an electric current flows through them. The extent of the change depends on what the conducting metals are, and the nature of change (rise or fall in temperature) depends on the direction of current flow. It is the reverse of the Seebeck effect. It is named after the French physicist Jean Charles Peltier (1785–1845) who discovered it in 1834.

---

pendulum

weight (called a 'bob') swinging at the end of a rod or cord. The regularity of a pendulum's swing was used in making the first really accurate clocks in the 17th century. Pendulums can be used for measuring the acceleration due to gravity (an important constant in physics).

---

periscope

optical instrument designed for observation from a concealed position such as from a submerged submarine. In its basic form it consists of a tube with parallel mirrors at each end, inclined at 45° to its axis. The periscope attained prominence in naval and military operations of World War I.

---

perpetual motion

idea that a machine can be designed and constructed in such a way that, once started, it will do work indefinitely without requiring any further input of energy (motive power). Such a device would contradict at least one of the two laws of thermodynamics that state that (1) energy can neither be created nor destroyed (the law of conservation of energy) and (2) heat cannot by itself flow from a cooler to a hotter object. As a result, all practical (real) machines require a continuous supply of energy, and no heat engine is able to convert all the heat into useful work.

---

phase

in physics, a stage in an oscillatory motion, such as a wave motion: two waves are in phase when their peaks and their troughs coincide. Otherwise, there is a **phase**

difference, which has consequences in interference phenomena and alternating current electricity.

---

photocell

or *photoelectric cell*,

device for measuring or detecting light or other electromagnetic radiation, since its electrical state is altered by the effect of light. In a **photoemissive** cell, the radiation causes electrons to be emitted and a current to flow (photoelectric effect); a **photovoltaic** cell causes an electromotive force to be generated in the presence of light across the boundary of two substances. A **photoconductive** cell, which contains a semiconductor, increases its conductivity when exposed to electromagnetic radiation.

---

photoelectric cell

alternative name for photocell.

---

photon

in physics, the elementary particle or 'package' (quantum) of energy in which light and other forms of electromagnetic radiation are emitted. The photon has both particle and wave properties; it has no charge, is considered massless but possesses momentum and energy. It is one of the gauge bosons, and is the carrier of the electromagnetic force, one of the fundamental forces of nature.

---

physics

branch of science concerned with the laws that govern the structure of the universe, and the investigation of the properties of matter and energy and their interactions. Before the 19th century, physics was known as **natural philosophy**.

---

piezoelectric effect

property of some crystals (for example, quartz) to develop an electromotive force or voltage across opposite faces when subjected to tension or compression, and, conversely, to expand or contract in size when subjected to an electromotive force. Piezoelectric crystal oscillators are used as frequency standards (for example, replacing balance wheels in watches), and for producing ultrasound. Crystalline quartz is a good example of a piezoelectric material.

pion

or *pi meson*,

in physics, a subatomic particle with a neutral form (mass 135 MeV) and a charged form (mass 139 MeV). The charged pion decays into muons and neutrinos and the neutral form decays into gamma-ray photons. They belong to the hadron class of elementary particles.

---

pitch

in mechanics, the distance between the adjacent threads of a screw or bolt. When a screw is turned through one full turn it moves a distance equal to the pitch of its thread. A screw thread is a simple type of machine, acting like a rolled-up inclined plane, or ramp (as may be illustrated by rolling a long paper triangle around a pencil). A screw has a mechanical advantage greater than one.

Planck's constant

symbol *h*,

fundamental constant that relates the energy (E) of one quantum of electromagnetic radiation (a 'packet' of energy; see quantum theory) to the frequency (f) of its radiation by $E = hf$. Its value is 6.6262×10^{-34} joule seconds.

---

plasma

in physics, ionized gas produced at extremely high temperatures, as in the Sun and other stars. It contains positive and negative charges in equal numbers. It is a good electrical conductor. In thermonuclear reactions the plasma produced is confined through the use of magnetic fields.

---

polarized light

light in which the electromagnetic vibrations take place in one particular plane. In ordinary (unpolarized) light, the electric fields vibrate in all planes perpendicular to the direction of propagation. After reflection from a polished surface or transmission through certain materials (such as Polaroid), the electric fields are confined to one direction, and the light is said to be **linearly polarized**. In **circularly polarized** and **elliptically polarized** light, the electric fields are confined to one direction, but the direction rotates as the light propagates. Polarized light is used to test the strength of sugar solutions and to measure stresses in transparent materials.

positron

antiparticle of the electron; an elementary particle having the same mass as an electron but exhibiting a positive charge. The positron was discovered in 1932 by US physicist Carl Anderson at the California Institute of Technology, USA, its existence having been predicted by the British physicist Paul Dirac in 1928.

---

positron emission tomography

***PET*,**

imaging technique that enables doctors to observe the metabolic activity of the human body by following the progress of a radioactive chemical that has been inhaled or injected, detecting gamma radiation given out when positrons emitted by the chemical are annihilated. The technique has been used to study a wide range of conditions, including schizophrenia, Alzheimer's disease, and Parkinson's disease.

---

potential difference

***PD*,**

difference in the electrical potential (see potential, electric) of two points, being equal to the electrical energy converted by a unit electric charge moving from one point to the other. Electrons flow in a conducting material towards the part that is relatively more positive (fewer negative charges). The SI unit of potential difference is the volt (V). The potential difference between two points in a circuit is commonly referred to as voltage (and can be measured with a voltmeter). See also Ohm's law.

---

potential, electric

energy required to bring a unit electric charge from infinity to the point at which potential is defined. The SI unit of potential is the volt (V). Positive electric charges will flow 'downhill' from a region of high potential to a region of low potential.

---

potential energy

***PE*,**

energy possessed by an object by virtue of its relative position or state (for example, as in a compressed spring or a muscle). It can be thought of as 'stored' energy. An object that has been raised up has energy stored due to its height. It is described as having gravitational potential energy.

power

in optics, a measure of the amount by which a lens will deviate light rays. A powerful converging lens will converge parallel rays strongly, bringing them to a focus at a short distance from the lens. The unit of power is the **dioptre**, which is equal to the reciprocal of focal length in metres. By convention, the power of a converging (or convex) lens is positive and that of a diverging (or concave) lens negative.

power

in physics, the rate of doing work or transferring energy from one form to another. It is measured in watts (joules per second) or other units of work per unit time.

pressure

in a fluid, the force exerted normally (at right angles) on the surface of a body immersed in the fluid. The SI unit of pressure is the pascal (Pa), equal to a pressure of one newton per square metre. In the atmosphere, the pressure declines with increasing height from about 100 kPa at sea level to zero where the atmosphere fades into space. Pressure is commonly measured with a barometer, manometer, or Bourdon gauge. Other common units of pressure are the bar and the torr.

proportion

relation of a part to the whole (usually expressed as a fraction or percentage). In mathematics two variable quantities x and y are proportional if, for all values of x, $y = kx$, where k is a constant. This means that if x increases, y increases in a linear fashion.

proton

(Greek 'first')

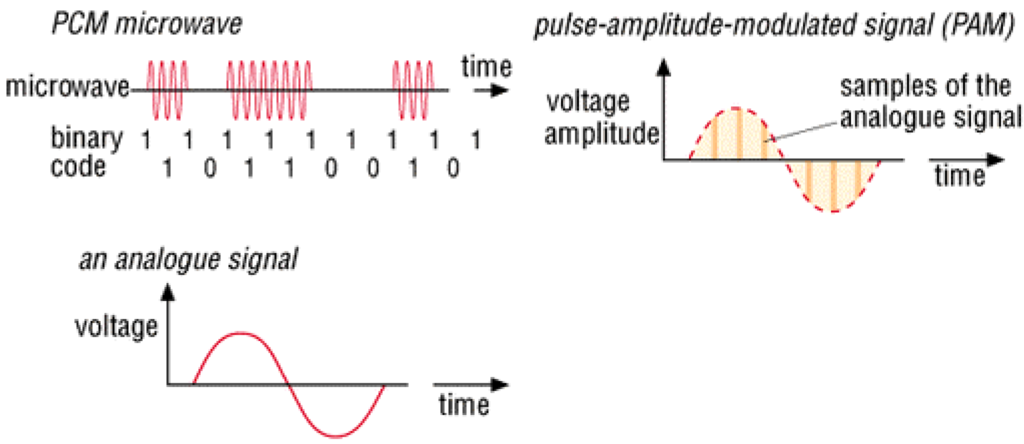
in physics, a positively charged elementary particle, a constituent of the nucleus of all atoms. It belongs to the baryon group of hadrons and is composed of two up quarks and one down quark. A proton is extremely long-lived, with a lifespan of at least 10^{32} years. It carries a unit positive charge equal to the negative charge of an electron. Its mass is almost 1,836 times that of an electron, or 1.673×10^{-24} g. The number of protons in the atom of an element is equal to the atomic number of that element.

pulse-code modulation

***PCM*,**

in physics, a form of digital modulation in which microwaves or light waves (the carrier waves) are switched on and off in pulses of varying length according to a binary code. It is a relatively simple matter to transmit data that are already in binary code, such as those used by computer, by these means. However, if an analogue audio signal is to be transmitted, it must first be converted to a **pulse-amplitude modulated** signal (PAM) by regular sampling of its amplitude. The value of the amplitude is then converted into a binary code for transmission on the carrier wave.

pulse-code modulation



(Image © Research Machines plc)

The amplitude, duration, and timing of a series of pulses are controlled in pulse-code modulation, which is relatively simple for digital data already in binary code. Analogue signals need to be converted into a recognizable binary code (a pulse-amplitude modulated signal) by regular sampling of its amplitude. Morse code is a very simple example of pulse-code modulation.

---

pyrometer

any instrument used for measuring high temperatures by means of the thermal radiation emitted by a hot object. In a **radiation pyrometer** the emitted radiation is detected by a sensor such as a thermocouple. In an **optical pyrometer** the colour of an electrically heated filament is matched visually to that of the emitted radiation. Pyrometers are especially useful for measuring the temperature of distant, moving, or inaccessible objects.

quantum chromodynamics

***QCD*,**

in physics, a theory describing the interactions of quarks, the elementary particles that make up all hadrons (subatomic particles such as protons and neutrons). In quantum chromodynamics, quarks are considered to interact by exchanging particles called gluons, which carry the strong nuclear force, and whose role is to 'glue' quarks together.

quantum electrodynamics

***QED*,**

in physics, a theory describing the interaction of charged subatomic particles within electric and magnetic fields. It combines quantum theory and relativity, and considers charged particles to interact by the exchange of photons. QED is remarkable for the accuracy of its predictions; for example, it has been used to calculate the value of some physical quantities to an accuracy of ten decimal places, a feat equivalent to calculating the distance between New York and Los Angeles to within the thickness of a hair. The theory was developed by US physicists Richard Feynman and Julian Schwinger and by Japanese physicist Sin-Itiro Tomonaga in 1948.

quantum mechanics

branch of physics dealing with the interaction of matter and radiation, the structure of the atom, the motion of atomic particles, and with related phenomena (see quantum theory).

quantum number

in physics, one of a set of four numbers that uniquely characterize an electron and its state in an atom. The **principal quantum number** n defines the electron's main energy level. The **orbital quantum number** l relates to its angular momentum. The **magnetic quantum number** m describes the energies of electrons in a magnetic field. The **spin quantum number** m_s gives the spin direction of the electron.

quantum theory

or *quantum mechanics*,

in physics, the theory that energy does not have a continuous range of values, but is, instead, absorbed or radiated discontinuously, in multiples of definite, indivisible units called quanta. Just as earlier theory showed how light, generally seen as a wave motion, could also in some ways be seen as composed of discrete particles (photons), quantum theory shows how atomic particles such as electrons may also be seen as having wavelike properties. Quantum theory is the basis of particle physics, modern theoretical chemistry, and the solid-state physics that describes the behaviour of the silicon chips used in computers.

---

quark

in physics, the elementary particle that is the fundamental constituent of all hadrons (subatomic particles that experience the strong nuclear force and divided into baryons, such as neutrons and protons, and mesons). Quarks have electric charges that are fractions of the electronic charge (+2/3 or -1/3 of the electronic charge). There are six types, or 'flavours': up, down, top, bottom, strange, and charmed, each of which has three varieties, or 'colours': red, green, and blue (visual colour is not meant, although the analogy is useful in many ways). To each quark there is an antiparticle, called an antiquark. See quantum chromodynamics (QCD).

---

radar

acronym for *radio direction and ranging*,

device for locating objects in space, direction finding, and navigation by means of transmitted and reflected high-frequency radio waves.

---

radiation

emission of radiant energy as particles or waves – for example, heat, light, alpha particles, and beta particles (see electromagnetic waves and radioactivity). See also atomic radiation.

---

radiation sickness

sickness resulting from exposure to radiation, including X-rays, gamma rays, neutrons, and other nuclear radiation, as from weapons and fallout. Such radiation ionizes atoms in the body and causes nausea, vomiting, diarrhoea, and other symptoms. The body cells themselves may be damaged even by very small doses, causing leukaemia and other cancers.

---

radiation units

units of measurement for radioactivity and radiation doses. In SI units, the activity of a radioactive source is measured in becquerels (symbol Bq), where one becquerel is equal to one nuclear disintegration per second (an older unit is the curie). The exposure is measured in coulombs per kilogram ($C\ kg^{-1}$); the amount of ionizing radiation (X-rays or gamma rays) that produces one coulomb of charge in one kilogram of dry air (replacing the roentgen). The absorbed dose of ionizing radiation is measured in grays (symbol Gy) where one gray is equal to one joule of energy being imparted to one kilogram of matter (the rad is the previously used unit). The dose equivalent, which is a measure of the effects of radiation on living organisms, is the absorbed dose multiplied by a suitable factor that depends upon the type of radiation. It is measured in sieverts (symbol Sv), where one sievert is a dose equivalent of one joule per kilogram (an older unit is the rem).

---

radioactive decay

process of disintegration undergone by the nuclei of radioactive elements, such as radium and various isotopes of uranium and the transuranic elements, in order to produce a more stable nucleus. The three most common forms of radioactive decay are alpha, beta, and gamma decay.

---

radioactivity

spontaneous change of the nuclei of atoms, accompanied by the emission of radiation. Such atoms are called radioactive. It is the property exhibited by the radioactive isotopes of stable elements and all isotopes of radioactive elements, and can be either natural or induced. See radioactive decay.

---

radio frequencies and wavelengths

see electromagnetic waves.

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radioisotope

or *radioactive isotope*,

naturally occurring or synthetic radioactive form of an element. Most radioisotopes are made by bombarding a stable element with neutrons in the core of a nuclear reactor (see fission). The radiations given off by radioisotopes are easy to detect (hence their use as tracers), can in some instances penetrate substantial thicknesses of materials, and have profound effects (such as genetic mutation) on living matter.

---

radio wave

electromagnetic wave possessing a long wavelength (ranging from about 10^{-3} to 10^{4} m) and a low frequency (from about 10^{5} to 10^{11} Hz) that travels at the speed of light. Included in the radio wave part of the spectrum are: microwaves, used for both communications and for cooking; ultra high- and very high-frequency waves, used for television and FM (frequency modulation) radio communications; and short, medium, and long waves, used for AM (amplitude modulation) radio communications. Radio waves that are used for communications have all been modulated (see modulation) to carry information. Certain astronomical objects emit radio waves, which may be detected and studied using radio telescopes.

---

rainbow

arch in the sky displaying the colours of the spectrum formed by the refraction and reflection of the Sun's rays through rain or mist. Its cause was discovered by Theodoric of Freiburg in the 14th century.

---

recording

any of a variety of techniques used to capture, store, and reproduce music, speech, and other information carried by sound waves. A microphone first converts the sound waves into an electrical signal that varies in proportion to the loudness of the sound. The signal can be stored in digital or analogue form, or on magnetic tape.

---

rectifier

device for obtaining one-directional current (DC) from an alternating source of supply (AC). (The process is necessary because almost all electrical power is generated, transmitted, and supplied as alternating current, but many devices, from television sets to electric motors, require direct current.) Types include plate rectifiers, thermionic diodes, and semiconductor diodes.

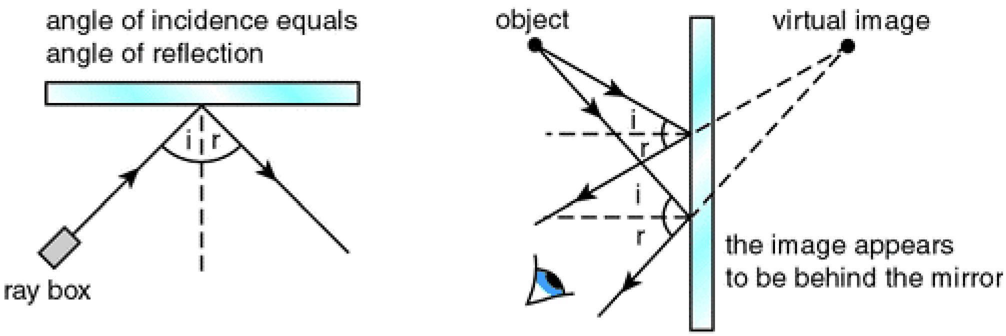
---

reflection

throwing back or deflection of waves, such as light or sound waves, when they hit a surface. Reflection occurs whenever light falls on an object. The **law of reflection** states that the angle of incidence (the angle between the ray and a perpendicular line drawn to the surface) is equal to the angle of reflection (the angle between the reflected ray and a perpendicular to the surface).

Looking at an image on the surface of the water in a lake is an example of light rays reflecting towards the observer. Reflection of light takes place from all materials. Some materials absorb a small amount of light and reflect most of it back; for example, a shiny, silvery surface. Other materials absorb most of the light and reflect only a small amount back; for example, a dark, dull surface. Reflected light gives objects their visible texture and colour.

reflection



(Image © Research Machines plc)

Light rays reflected from a regular (plane) mirror. The angle of incidence is the angle between the ray and a perpendicular line drawn to the surface and the angle of reflection is the angle between the reflected ray and a perpendicular to the surface. The image of an object in a plane mirror is described as virtual or imaginary because it appears to be the position from which the rays are formed.

---

refraction

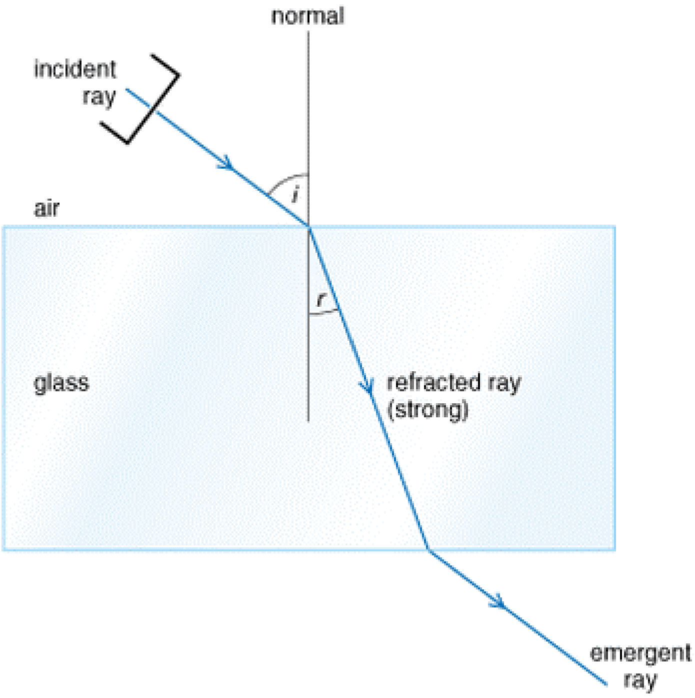
bending of a wave when it passes from one medium into another. It is the effect of the different speeds of wave propagation in two substances that have different densities. For example, when light passes from air (less dense) into glass (more dense) it slows down (from 300 million to 200 million metres per second) and is refracted. The amount of refraction depends on the densities of the media, the angle at which the wave strikes the surface of the second medium, and the amount of bending and change of velocity corresponding to the wave's frequency (dispersion). Refraction occurs with all types of progressive waves – electromagnetic waves, sound waves, and water waves – and differs from reflection, which involves no change in velocity.

refraction

(Image © Research Machines plc)

Refraction is the bending of a light beam when it passes from one transparent medium to another. This is why a spoon appears bent when standing in a glass of water and pools of water appear shallower than they really are. The quantity sin *i*/sin *r* has a constant value, for each material, called the refractive index.

refraction



(Image © Research Machines plc)

The refraction of light through glass. When the light ray strikes the glass (a denser medium than the air) it is bent towards the normal. When it leaves the glass and re-enters the less dense medium it is bent away from the normal.

---

regelation

phenomenon in which water refreezes to ice after it has been melted by pressure at a temperature below the freezing point of water. Pressure makes an ice skate, for example, form a film of water that freezes once again after the skater has passed.

---

relative density

density (at 20°C/68°F) of a solid or liquid relative to (divided by) the maximum density of water (at 4°C/39.2°F). The relative density of a gas is its density divided by the density of hydrogen (or sometimes dry air) at the same temperature and pressure.

---

relative humidity

concentration of water vapour in the air. It is expressed as the ratio of the partial pressure of the water vapour to its saturated vapour pressure at the same temperature. The higher the temperature, the higher the saturated vapour pressure.

---

relativity

in physics, theory of the relative rather than absolute character of mass, time, and space, and their interdependence, as developed by German-born US physicist Albert Einstein in two phases:

special theory of relativity (1905)

Starting with the premises that (1) the laws of nature are the same for all observers in unaccelerated motion and (2) the speed of light is independent of the motion of its source, Einstein arrived at some rather unexpected consequences. Intuitively familiar concepts, like mass, length, and time, had to be modified. For example, an object moving rapidly past the observer will appear to be both shorter and more massive than when it is at rest (that is, at rest relative to the observer), and a clock moving rapidly past the observer will appear to be running slower than when it is at rest. These predictions of relativity theory seem to be foreign to everyday experience merely because the changes are quite negligible at speeds less than about 1,500 kps/930 mps and only become appreciable at speeds approaching the speed of light.

general theory of relativity (1915)

The geometrical properties of space-time were to be conceived as modified locally by the presence of a body with mass. A planet's orbit around the Sun (as observed in three-dimensional space) arises from its natural trajectory in modified space-time. Einstein's general theory accounts for a peculiarity in the behaviour of the motion of the perihelion of the orbit of the planet Mercury that cannot be explained in Newton's theory. The new theory also said that light rays should bend when they pass by a massive object. The predicted bending of starlight was observed during the eclipse of the Sun in 1919. A third corroboration is found in the shift towards the red in the spectra of the Sun and, in particular, of stars of great density – white dwarfs such as the companion of Sirius.

---

rem

acronym for *roentgen equivalent man*,

unit of radiation dose equivalent.

---

resistance

in physics, that property of a conductor that restricts the flow of electricity through it, associated with the conversion of electrical energy to heat; also the magnitude of this property.

---

resistivity

in physics, a measure of the ability of a material to resist the flow of an electric current. It is numerically equal to the resistance of a sample of unit length and unit cross-sectional area, and its unit is the ohm metre (symbol Ωm). A good conductor has a low resistivity (1.7×10^{-8} Ωm for copper); an insulator has a very high resistivity (10^{15} Ωm for polyethane).

---

resistor

in physics, any component in an electrical circuit used to introduce resistance to a current by restricting the flow of electrons. Resistors are often made from wire-wound coils (higher resistance) or pieces of carbon (lower resistance). Rheostats and potentiometers are variable resistors.

---

resonance

rapid amplification of a vibration when the vibrating object is subject to a force varying at its natural frequency. In a trombone, for example, the length of the air column in the instrument is adjusted until it resonates with the note being sounded. Resonance effects are also produced by many electrical circuits. Tuning a radio, for example, is done by adjusting the natural frequency of the receiver circuit until it coincides with the frequency of the radio waves falling on the aerial.

---

rest mass

in physics, the mass of a body when its velocity is zero or considerably below that of light. According to the theory of relativity, at very high velocities, there is a relativistic effect that increases the mass of the particle.

---

reverberation

in acoustics, the multiple reflections, or echoes, of sounds inside a building that merge and persist a short time (up to a few seconds) before fading away. At each reflection some of the sound energy is absorbed, causing the amplitude of the sound wave and the intensity of the sound to reduce a little.

---

rheostat

variable resistor, usually consisting of a high-resistance wire-wound coil with a sliding contact. It is used to vary electrical resistance without interrupting the current (for example, when dimming lights). The circular type, which can be used, for example, as the volume control of an amplifier, is also known as a potentiometer.

---

ring circuit

household electrical circuit in which appliances are connected in series to form a ring with each end of the ring connected to the power supply. It superseded the radial circuit.

---

ripple tank

in physics, shallow water-filled tray used to demonstrate various properties of waves, such as reflection, refraction, diffraction, and interference.

S

in physics, symbol for siemens, the SI unit of electrical conductance, equal to a conductance of 1 ohm^{-1}.

St Elmo's fire

bluish, flamelike electrical discharge that sometimes occurs above ships' masts and other pointed objects or about aircraft in stormy weather. Although of high voltage, it is of low current and therefore harmless. St Elmo (or St Erasmus) is the patron saint of sailors.

---

saturated solution

in physics and chemistry, a solution obtained when a solvent (liquid) can dissolve no more of a solute (usually a solid) at a particular temperature. Normally, a slight fall in temperature causes some of the solute to crystallize out of solution. If this does not happen the phenomenon is called supercooling, and the solution is said to be **supersaturated**.

---

scalar quantity

in mathematics and science, a quantity that has magnitude but no direction, as distinct from a vector quantity, which has a direction as well as a magnitude. Temperature, mass, volume, and speed are scalar quantities.

---

secondary emission

emission of electrons from the surface of certain substances when they are struck by high-speed electrons or other particles from an external source. It can be detected with a photomultiplier.

Seebeck effect

generation of a voltage in a circuit containing two different metals, or semiconductors, by keeping the junctions between them at different temperatures. Discovered by the German physicist Thomas Seebeck (1770–1831), it is also called the thermoelectric effect, and is the basis of the thermocouple. It is the opposite of the Peltier effect (in which current flow causes a temperature difference between the junctions of different metals).

---

self-inductance

or *self-induction*,

in physics, the creation of an electromotive force opposing the current. See inductance.

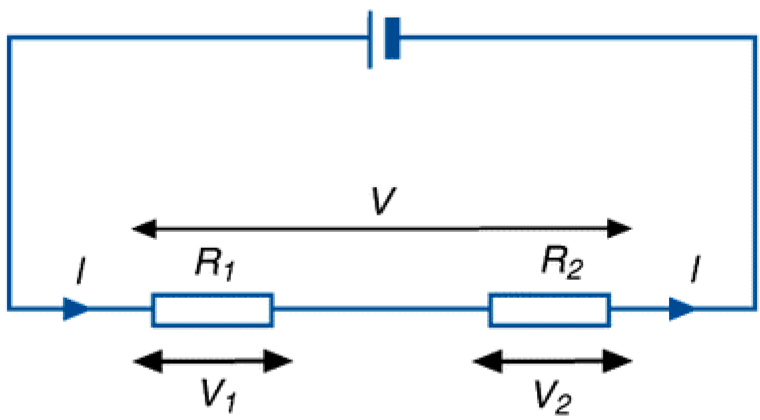
semiconductor

material with electrical conductivity intermediate between metals and insulators and used in a wide range of electronic devices. Certain crystalline materials, most notably silicon and germanium, have a small number of free electrons that have escaped from the bonds between the atoms. The atoms from which they have escaped possess vacancies, called holes, which are similarly able to move from atom to atom and can be regarded as positive charges. Current can be carried by both electrons (negative carriers) and holes (positive carriers). Such materials are known as **intrinsic semiconductors**.

series circuit

electrical circuit in which the components are connected end to end, so that the current flows through them all one after the other.

series circuit



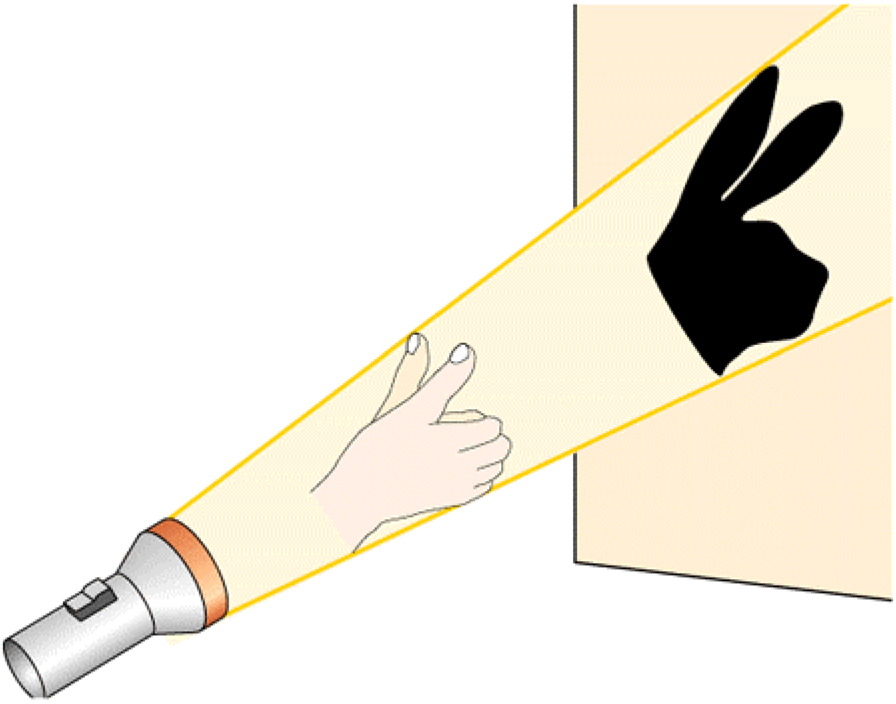
(Image © Research Machines plc)

In a series circuit, the components, R_1 and R_2, of the circuit are connected end to end, so that the current passes through each component one after the other, without division or branching into parallel circuits.

shadow

area of darkness behind an opaque object that cannot be reached by some or all of the light coming from a light source in front. Its presence may be explained in terms of light rays travelling in straight lines and being unable to bend around obstacles. The light in front of the object is blocked. A point source of light produces an umbra, a completely black shadow with sharp edges. An extended source of light produces both a central umbra and a penumbra, a region of semidarkness with blurred edges where darkness gives way to light.

shadow



(Image © Research Machines plc)

Shadows are created as light travels in straight lines and so cannot bend around objects, and is therefore blocked.

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short circuit

unintended direct connection between two points in an electrical circuit. Resistance is proportional to the length of wire through which current flows. By bypassing the rest of the circuit, the short circuit has low resistance and a large current flows through it. This may cause the circuit to overheat dangerously.

---

siemens

symbol S,

SI unit of electrical conductance, the reciprocal of the resistance of an electrical circuit. One siemens equals one ampere per volt. It was formerly called the mho or reciprocal ohm.

---

sievert

symbol Sv,

SI unit of radiation dose equivalent. It replaces the rem (1 Sv equals 100 rem). Some types of radiation do more damage than others for the same absorbed dose – for example, an absorbed dose of alpha radiation causes 20 times as much biological damage as the same dose of beta radiation. The equivalent dose in sieverts is equal to the absorbed dose of radiation in grays multiplied by the relative biological effectiveness. Humans can absorb up to 0.25 Sv without immediate ill effects; 1 Sv may produce radiation sickness; and more than 8 Sv causes death.

---

sine wave

or *sine curve*,

in physics, graph demonstrating properties that vary sinusoidally. It is obtained by plotting values of angles against the values of their sines. Examples include simple harmonic motion, such as the way alternating current (AC) electricity varies with time.

SI units

French *Système International d'Unités*,

standard system of scientific units used by scientists worldwide. Originally proposed in 1960, it replaces the m.k.s., *c*.g.s., and f.p.s. systems. It is based on seven basic units: the metre (m) for length, kilogram (kg) for mass, second (s) for time, ampere (A) for electrical current, kelvin (K) for temperature, mole (mol) for amount of substance, and candela (cd) for luminosity.

Snel's law of refraction

in optics, the rule that when a ray of light passes from one medium to another, the sine of the angle of incidence divided by the sine of the angle of refraction is equal to the ratio of the indices of refraction in the two media. For a ray passing from medium 1 to medium 2: $n_2/n_1 = \sin i/\sin r$ where n_1 and n_2 are the refractive indices of the two media. The law was devised by the Dutch physicist, Willebrord Snel.

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solar radiation

radiation given off by the Sun, consisting mainly of visible light, ultraviolet radiation, and infrared radiation, although the whole spectrum of electromagnetic waves is present, from radio waves to X-rays. High-energy charged particles, such as electrons, are also emitted, especially from solar flares. When these reach the Earth, they cause magnetic storms (disruptions of the Earth's magnetic field), which interfere with radio communications.

---

solenoid

coil of wire, usually cylindrical, in which a magnetic field is created by passing an electric current through it (see electromagnet). This field can be used to temporarily magnetize, and so move, an iron rod placed on its axis. Mechanical valves attached to the rod can be operated by switching the current on or off, so converting electrical energy into mechanical energy. Solenoids are used to relay energy from the battery of a car to the starter motor by means of the ignition switch.

---

solid

in physics, a state of matter that holds its own shape (as opposed to a liquid, which takes up the shape of its container, or a gas, which totally fills its container). According to the kinetic theory of matter, the atoms or molecules in a solid are packed closely together in a regular arrangement, and are not free to move but merely vibrate about fixed positions, such as those in crystal lattices.

---

solubility

measure of the amount of solute (usually a solid or gas) that will dissolve in a given amount of solvent (usually a liquid) at a particular temperature. Solubility may be expressed as grams of solute per 100 grams of solvent or, for a gas, in parts per million (ppm) of solvent.

---

sonar

acronym for SOund Navigation And Ranging,

method of locating underwater objects by the reflection of ultrasonic waves. The time taken for an acoustic beam to travel to the object and back to the source enables the distance to be found since the velocity of sound in water is known. Sonar devices, or **echo sounders**, were developed in 1920, and are the commonest means of underwater navigation.

---

sound

physiological sensation received by the ear, originating in a vibration causing sound waves. The sound waves are pressure variations in the air and travel in every direction, spreading out as an expanding sphere. Sound energy cannot travel in a vacuum.

---

space-time

in physics, combination of space and time used in the theory of relativity. When developing relativity, Albert Einstein showed that time was in many respects like an extra dimension (or direction) to space. Space and time can thus be considered as entwined into a single entity, rather than two separate things.

---

spark chamber

electronic device for recording tracks of charged subatomic particles, decay products, and rays. In combination with a stack of condenser plates, a spark chamber enables the point where an interaction has taken place to be located, to within a cubic centimetre. At its simplest, it consists of two smooth threadlike electrodes that are positioned 1–2 cm/0.5–1 in apart, the space between being filled with a mixture of neon and helium gas. Sparks jump through the gas along the ionized path created by the radiation. See particle detector.

---

specific gravity

alternative term for relative density.

---

specific heat capacity

quantity of heat required to raise unit mass (1 kg) of a substance by one kelvin (1 K). The unit of specific heat capacity in the SI system is the joule per kilogram per kelvin (J kg^{-1} K^{-1}).

---

specific latent heat

heat that changes the physical state of a unit mass (one kilogram) of a substance without causing any temperature change.

---

spectroscopy

study of spectra (see spectrum) associated with atoms or molecules in the solid, liquid, or gaseous phase. Spectroscopy can be used to identify unknown compounds and is an invaluable tool in science, medicine, and industry (for example, in checking the purity of drugs).

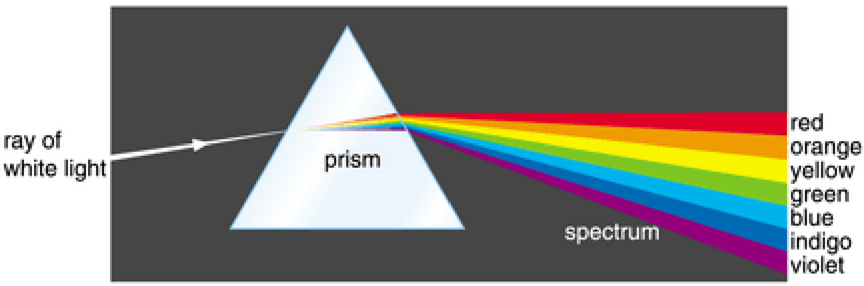
---

spectrum

plural *spectra*,

in physics, the pattern of frequencies or wavelengths obtained when electromagnetic radiations are separated into their constituent parts. Visible light is part of the electromagnetic spectrum and most sources emit waves over a range of wavelengths that can be broken up or 'dispersed'; white light can be separated (for example, using a triangular prism) into red, orange, yellow, green, blue, indigo, and violet. The visible spectrum was first studied by English physicist Isaac Newton, who showed in 1666 how white light could be broken up into different colours.

spectrum



(Image © Research Machines plc)

A prism (a triangular block of transparent material such as plastic, glass, or silica) is used to split a ray of white light into its spectral colours.

---

speed

rate at which an object moves, or how fast an object moves. The average speed v of an object may be calculated by dividing the distance s it has travelled by the time t taken to do so, and may be expressed as:

$v = s/t$

The usual units of speed are metres per second or kilometres per hour.

---

speed of light

speed at which light and other electromagnetic waves travel in a vacuum. Its value is 299,792,458 m per second/186,282 mi per second but for most calculations 3×10^8 m s^{-1} (300 million metres per second) suffices. In glass the speed of light is two-thirds of its speed in air, about 200 million metres per second. The speed of light is the highest speed possible, according to the theory of relativity, and its value is independent of the motion of its source and of the observer. It is impossible to accelerate any material body to this speed because it would require an infinite amount of energy.

---

speed of sound

speed at which sound travels through a medium, such as air or water. In air at a temperature of 0°C/32°F, the speed of sound is 331 m/1,087 ft per second. At higher temperatures, the speed of sound is greater; at 18°C/64°F it is 342 m/1,123 ft per second. It is also affected by the humidity of the air. It is greater in liquids and solids; for example, in water it is about 1,440 m/4,724 ft per second, depending on the temperature.

---

spin

in physics, the intrinsic angular momentum of a subatomic particle, nucleus, atom, or molecule, which continues to exist even when the particle comes to rest. A particle in a specific energy state has a particular spin, just as it has a particular electric charge and mass. According to quantum theory, this is restricted to discrete and indivisible values, specified by a spin quantum number. Because of its spin, a charged particle acts as a small magnet and is affected by magnetic fields.

---

standard form

or *scientific notation*,

method of writing numbers often used by scientists, particularly for very large or very small numbers. The numbers are written with one digit before the decimal point and multiplied by a power of 10. The number of digits given after the decimal point depends on the accuracy required. For example, the speed of light is 2.9979×10^8 m/1.8628×10^5 mi per second.

---

standard model

in physics, modern theory of elementary particles and their interactions. According to the standard model, elementary particles are classified as leptons (light particles, such as electrons), hadrons (particles, such as neutrons and protons, that are formed from quarks), and gauge bosons. Leptons and hadrons interact by exchanging gauge bosons, each of which is responsible for a different fundamental force: photons mediate the electromagnetic force, which affects all charged particles; gluons mediate the strong nuclear force, which affects quarks; gravitons mediate the force of gravity; and the intermediate vector bosons mediate the weak nuclear force. See also forces, fundamental, quantum electrodynamics, and quantum chromodynamics.

---

standing wave

in physics, a wave in which the positions of nodes (positions of zero vibration) and antinodes (positions of maximum vibration) do not move. Standing waves result when two similar waves travel in opposite directions through the same space.

---

states of matter

forms (solid, liquid, or gas) in which material can exist. Whether a material is solid, liquid, or gaseous depends on its temperature and pressure. The transition between states takes place at definite temperatures, called the melting point and boiling point.

---

static electricity

electric charge that is stationary, usually acquired by a body by means of electrostatic induction or friction. Rubbing different materials can produce static electricity, as seen in the sparks produced on combing one's hair or removing a nylon shirt. The frictional force causes electrons to move out of their orbits. The electrons are then transferred to another material. The material that gains electrons becomes negatively charged and the material that loses electrons becomes positively charged. In some processes static electricity is useful, as in paint spraying where the parts to be sprayed are charged with electricity of opposite polarity to that on the paint droplets, and in xerography.

---

statics

branch of mechanics concerned with the behaviour of bodies at rest and forces in equilibrium, and distinguished from dynamics.

Stefan–Boltzmann constant

in physics, a constant relating the energy emitted by a black body (a hypothetical body that absorbs or emits all the energy falling on it) to its temperature. Its value is 5.6697×10^{-8} W m^{-2} K^{-4}.

Stefan–Boltzmann law

in physics, a law that relates the energy, *E*, radiated away from a perfect emitter (a black body), to the temperature, *T*, of that body. It has the form $E = \sigma T^4$, where *E* is the energy radiated per unit area per second, *T* is the temperature, and çis the **Stefan–Boltzmann constant**. Its value is 5.6697×10^{-8} W m^{-2} K^{-4}. The law was derived by the Austrian physicists Josef Stefan and Ludwig Boltzmann.

---

stress and strain

in the science of materials, measures of the deforming force applied to a body (stress) and of the resulting change in its shape (strain). For a perfectly elastic material, stress is proportional to strain (Hooke's law).

---

stroboscope

instrument for studying continuous periodic motion by using light flashing at the same frequency as that of the motion; for example, rotating machinery can be optically 'stopped' by illuminating it with a stroboscope flashing at the exact rate of rotation.

---

strong nuclear force

one of the four fundamental forces of nature, the other three being the gravitational force or gravity, the electromagnetic force, and the weak nuclear force. The strong nuclear force was first described by the Japanese physicist Hideki Yukawa in 1935. It is the strongest of all the forces, acts only over very small distances within the nucleus of the atom (10^{-13} cm), and is responsible for binding together quarks to form hadrons, and for binding together protons and neutrons in the atomic nucleus. The particle that is the carrier of the strong nuclear force is the gluon, of which there are eight kinds, each with zero mass and zero charge.

---

subatomic particle

any of the subdivisions of the atom, including those elementary particles that combine to form all matter. See also particle physics.

---

superconductivity

increase in electrical conductivity at low temperatures. The resistance of some metals and metallic compounds decreases uniformly with decreasing temperature until at a critical temperature (the superconducting point), within a few degrees of absolute zero (0 K/-273.15°C/-459.67°F), the resistance suddenly falls to zero. The phenomenon was discovered by Dutch scientist Heike Kamerlingh Onnes in 1911.

---

supercooling

cooling of a liquid below its freezing point without freezing taking place; or the cooling of a saturated solution without crystallization taking place, to form a supersaturated solution. In both cases supercooling is possible because of the lack of solid particles around which crystals can form. Crystallization rapidly follows the introduction of a small crystal (seed) or agitation of the supercooled solution.

---

superfluid

fluid that flows without viscosity or friction and has a very high thermal conductivity. Liquid helium at temperatures below 2 K (-271°C/-456°F) is a superfluid: it shows unexpected behaviour. For instance, it flows uphill in apparent defiance of gravity and, if placed in a container, will flow up the sides and escape.

---

supersonic speed

speed greater than that at which sound travels, measured in Mach numbers. In dry air at 0°C/32°F, sound travels at about 1,170 kph/727 mph, but decreases its speed with altitude until, at 12,000 m/39,000 ft, it is only 1,060 kph/658 mph.

Superstring Theory

in physics and astronomy, the theory that attempts to link the four fundamental forces. It postulates that each force emerged separately during the expansion of the very early universe from the Big Bang. It also postulates viewing matter as tiny vibrating strings instead of particles within a universe of more than the currently known four dimensions. Continuing research pursues a model based on a ten-dimensional universe, present at singularity. At the Big Bang, the ten dimensions split into two components, with four dimensions expanded into the current observable universe while the other six dimensions contracted to a point in space.

---

supersymmetry

in physics, a theory that relates the two classes of elementary particle, the fermions and the bosons. According to supersymmetry, each fermion particle has a boson partner particle, and vice versa. It has not been possible to marry up all the known fermions with the known bosons, and so the theory postulates the existence of other, as yet undiscovered fermions, such as the photinos (partners of the photons), gluinos (partners of the gluons), and gravitinos (partners of the gravitons). Using these ideas, it has become possible to develop a theory of gravity – called **supergravity** – that extends Einstein's work and considers the gravitational, nuclear, and electromagnetic forces to be manifestations of an underlying superforce. Supersymmetry has been incorporated into the superstring theory, and appears to be a crucial ingredient in the 'theory of everything' sought by scientists.

---

surface tension

property that causes the surface of a liquid to behave as if it were covered with a weak elastic skin; this is why a needle can float on water. It is caused by the exposed surface's tendency to contract to the smallest possible area because of cohesive forces between molecules at the surface. Allied phenomena include the formation of droplets, the concave profile of a meniscus, and the capillary action by which water soaks into a sponge.

Sv

in physics, symbol for sievert, the SI unit of dose equivalent of ionizing radiation, equal to the dose in grays multiplied by a factor that depends mainly on the type of radiation and its effects.

---

symmetry

exact likeness in shape about a given line (axis), point, or plane. A figure has symmetry if one half can be rotated and/or reflected onto the other. (Symmetry preserves length, angle, but not necessarily orientation.) In a wider sense, symmetry exists if a change in the system leaves the essential features of the system unchanged; for example, reversing the sign of electric charges does not change the electrical behaviour of an arrangement of charges.

---

synchrotron

particle accelerator in which particles move, at increasing speed, around a hollow ring. The particles are guided around the ring by electromagnets, and accelerated by electric fields at points around the ring. Synchrotrons come in a wide range of sizes, the smallest being about 1 m/3.3 ft across while the largest is 27 km/17 mi across. The Tevatron synchrotron at Fermilab is some 6 km/4 mi in circumference and accelerates protons and antiprotons to 1 TeV.

tape recording, magnetic

method of recording electric signals on a layer of iron oxide, or other magnetic material, coating a thin plastic tape. The electrical signals from the microphone are fed to the electromagnetic recording head, which magnetizes the tape in accordance with the frequency and amplitude of the original signal. The impulses may be audio (for sound recording), video (for television), or data (for computer). For playback, the tape is passed over the same, or another, head to convert magnetic into electrical signals, which are then amplified for reproduction. Tapes are easily demagnetized (erased) for reuse, and come in cassette, cartridge, or reel form.

tau

elementary particle with the same electric charge as the electron but a mass nearly double that of a proton. It has a lifetime of around 3×10^{-13} seconds and belongs to the lepton family of particles – those which interact via the electromagnetic, weak nuclear, and gravitational forces, but not the strong nuclear force.

temperature

measure of how hot an object is. It is temperature difference that determines whether heat transfer will take place between two objects and in which direction it will flow, that is from warmer object to cooler object. The temperature of an object is a measure of the average kinetic energy possessed by the atoms or molecules of which it is composed. The SI unit of temperature is the kelvin (symbol K) used with the Kelvin scale. Other measures of temperature in common use are the Celsius scale and the Fahrenheit scale. The Kelvin scale starts at absolute zero (0 K = -273°C). The Celsius scale starts at the freezing point of water (0°C = 273 K). 1 K is the same temperature interval as 1°C.

terminal voltage

potential difference (pd) or voltage across the terminals of a power supply, such as a battery of cells. When the supply is not connected in circuit its terminal voltage is the same as its electromotive force (emf); however, as soon as it begins to supply current to a circuit its terminal voltage falls because some electric potential energy is lost in driving current against the supply's own internal resistance. As the current flowing in the circuit is increased the terminal voltage of the supply falls.

theory

in science, a set of ideas, concepts, principles, or methods used to explain a wide set of observed facts. Among the major theories of science are relativity, quantum theory, evolution, and plate tectonics.

---

thermal conductivity

ability of a substance to conduct heat. Good thermal conductors, like good electrical conductors, are generally materials with many free electrons, such as metals. A poor conductor, called an insulator, has low conductivity.

---

thermal reactor

nuclear reactor in which the neutrons released by fission of uranium-235 nuclei are slowed down in order to increase their chances of being captured by other uranium-235 nuclei, and so induce further fission. The material (commonly graphite or heavy water) responsible for doing so is called a **moderator**. When the fast newly emitted neutrons collide with the nuclei of the moderator's atoms, some of their kinetic energy is lost and their speed is reduced. Those that have been slowed down to a speed that matches the thermal (heat) energy of the surrounding material are called **thermal neutrons**, and it is these that are most likely to induce fission and ensure the continuation of the chain reaction. See nuclear energy.

---

thermodynamics

branch of physics dealing with the transformation of heat into and from other forms of energy. It is the basis of the study of the efficient working of engines, such as the steam and internal combustion engines. The three laws of thermodynamics are: (1) energy can be neither created nor destroyed, heat and mechanical work being mutually convertible; (2) it is impossible for an unaided self-acting machine to convey heat from one body to another at a higher temperature; and (3) it is impossible by any procedure, no matter how idealized, to reduce any system to the absolute zero of temperature (0 K/-273.15°C/-459.67°F) in a finite number of operations. Put into mathematical form, these laws have widespread applications in physics and chemistry.

---

thermography

photographic recording of heat patterns. It is used medically as an imaging technique to identify 'hot spots' in the body – for example, tumours, where cells are more active than usual. Thermography was developed in the 1970s and 1980s by the military to assist night vision by detecting the body heat of an enemy or the hot engine of a tank. It uses detectors sensitive to infrared (heat) radiation.

---

thermoluminescence

***TL*,**

release, in the form of a light pulse, of stored nuclear energy in a mineral substance when heated to perhaps 500°C/930° F. The energy originates from the radioactive decay of uranium and thorium, and is absorbed by crystalline inclusions within the mineral matrix, such as quartz and feldspar. The release of TL from these crystalline substances is used in archaeology to date pottery, and by geologists in studying terrestrial rocks and meteorites.

---

thermopile

instrument for measuring radiant heat, consisting of a number of thermocouples connected in series with alternate junctions exposed to the radiation. The current generated (measured by an ammeter) is proportional to the radiation falling on the device.

---

thyristor

type of rectifier, an electronic device that conducts electricity in one direction only. The thyristor is composed of layers of semiconductor material sandwiched between two electrodes called the anode and cathode. The current can be switched on by using a third electrode called the gate.

---

tidal energy

energy derived from the tides. The tides mainly gain their potential energy from the gravitational forces acting between the Earth and the Moon. If water is trapped at a high level during high tide, perhaps by means of a barrage across an estuary, it may then be gradually released and its associated gravitational potential energy exploited to drive turbines and generate electricity. Several schemes have been proposed for the Bristol Channel, in southwestern England, but environmental concerns as well as construction costs have so far prevented any decision from being taken.

---

torque

turning effect of force on an object. A turbine produces a torque that turns an electricity generator in a power station. Torque is measured by multiplying the force by its perpendicular distance from the turning point.

---

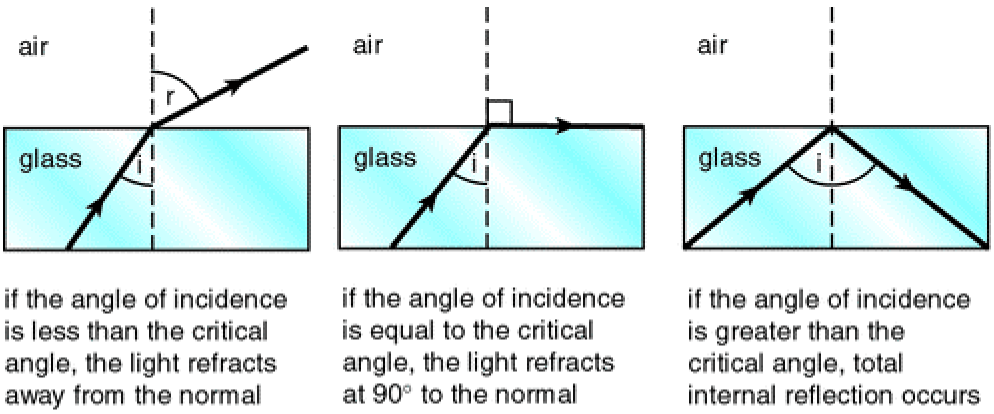
torsion

in physics, the state of strain set up in a twisted material; for example, when a thread, wire, or rod is twisted, the torsion set up in the material tends to return the material to its original state. The **torsion balance**, a sensitive device for measuring small gravitational or magnetic forces, or electric charges, balances these against the restoring force set up by them in a torsion suspension.

total internal reflection

complete reflection of a beam of light that occurs from the surface of an optically 'less dense' material. For example, a beam from an underwater light source can be reflected from the surface of the water, rather than escaping through the surface. Total internal reflection can only happen if a light beam hits a surface at an angle greater than the critical angle for that particular pair of materials.

total internal reflection



(Image © Research Machines plc)

Total internal reflection occurs at the boundary of two transparent substances when a) the incident ray is in the substance with the higher refractive index and b) the angle of incidence exceeds a particular angle known as the critical angle. The critical angle for glass is 42° and for water, about 48°.

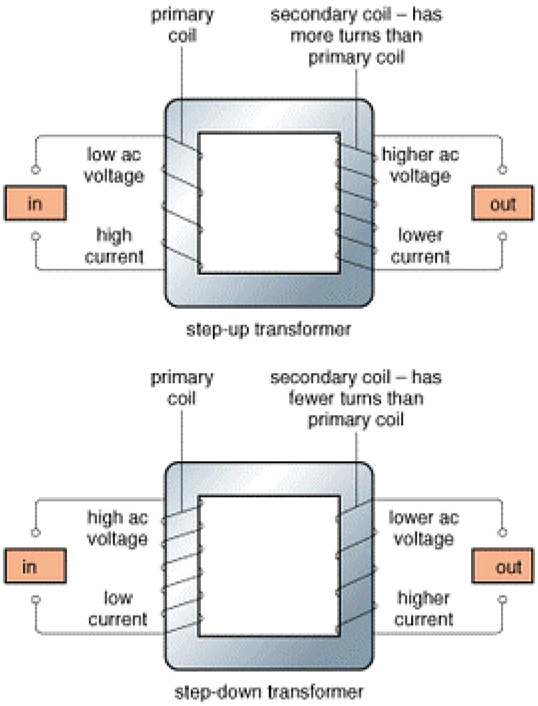
transducer

device that converts one form of energy into another. For example, a thermistor is a transducer that converts heat into an electrical voltage, and an electric motor is a transducer that converts an electrical voltage into mechanical energy. Transducers are important components in many types of sensor, converting the physical quantity to be measured into a proportional voltage signal.

transformer

device in which, by electromagnetic induction, an alternating current (AC) of one voltage is transformed to another voltage, without change of frequency. Transformers are widely used in electrical apparatus of all kinds, and in particular in power transmission where high voltages and low currents are utilized.

transformer



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A step-up transformer increases voltage and has more turns on the secondary coil than on the primary. A step-down transformer decreases voltage and has more turns on the primary coil than on the secondary. If the numbers of turns in the primary and secondary coils are n_1 and n_2, the primary and secondary voltages are V_1 and V_2, and the primary and secondary currents are I_1 and I_2, then the relationships between these quantities may be expressed as: $V_1/V_2 = I_2/I_1 = n_1/n_2$.

---

transistor

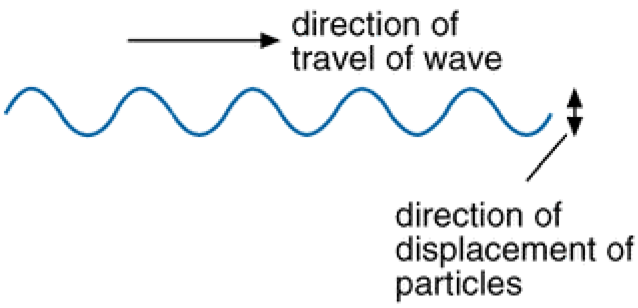
solid-state electronic component, made of semiconductor material, with three or more electrical contacts that can regulate a current passing through it. A transistor can act as an amplifier, oscillator, photocell, or switch, and (unlike earlier thermionic valves) usually operates on a very small amount of power. Transistors commonly consist of a tiny sandwich of germanium or silicon, alternate layers having different electrical properties because they are impregnated with minute amounts of different impurities.

---

transverse wave

wave in which the displacement of the medium's particles, or in electromagnetic waves the direction of the electric and magnetic fields, is at right angles to the direction of travel of the wave motion.

transverse wave



(Image © Research Machines plc)

The diagram illustrates the motion of a transverse wave. Light waves are examples of transverse waves: they undulate at right angles to the direction of travel and are characterized by alternating crests and troughs. Simple water waves, such as the ripples produced when a stone is dropped into a pond, are also examples of transverse waves.

---

ultrasonics

branch of physics dealing with the theory and application of ultrasound: sound waves occurring at frequencies too high to be heard by the human ear (that is, above about 20 kHz).

---

ultraviolet radiation

light rays invisible to the human eye, of wavelengths from about 4×10^{-4} to 5×10^{-6} millimeters (where the X-ray range begins). Physiologically, they are important but also dangerous, causing the formation of vitamin D in the skin and producing sunburn in excess. They are strongly germicidal and may be produced artificially by mercury vapour and arc lamps for therapeutic use.

uncertainty principle

or *indeterminacy principle*,

in quantum mechanics, the principle that it is impossible to know with unlimited accuracy the position and momentum of a particle. The principle arises because in order to locate a particle exactly, an observer must bounce light (in the form of a photon) off the particle, which must alter its position in an unpredictable way.

unified field theory

in physics, the theory that attempts to explain the four fundamental forces (strong nuclear, weak nuclear, electromagnetic, and gravity) in terms of a single unified force.

UV

in physics, abbreviation for **ultraviolet**.

v

in physics, symbol for velocity.

V

in physics, symbol for volt, the SI unit of emf or potential difference, equal to the potential difference between two points in an electrical circuit when a current of 1 ampere flowing between them dissipates a power of 1 watt.

V

Roman numeral for **five**; in physics, symbol for volt.

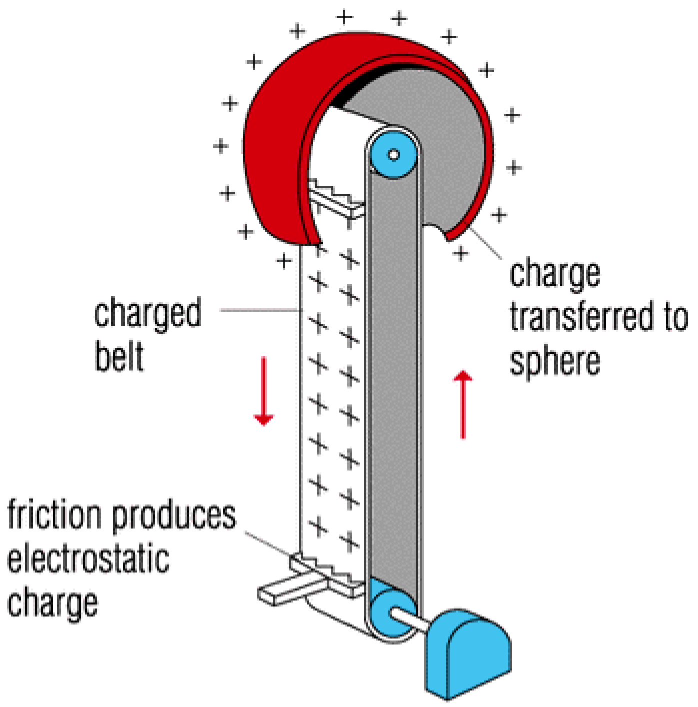
vacuum

in general, a region completely empty of matter; in physics, any enclosure in which the gas pressure is considerably less than atmospheric pressure (101,325 pascals).

van de Graaff generator

electrostatic generator capable of producing a voltage of over a million volts. It consists of a continuous vertical conveyor belt that carries electrostatic charges (resulting from friction) up to a large hollow sphere supported on an insulated stand. The lower end of the belt is earthed, so that charge accumulates on the sphere. The size of the voltage built up in air depends on the radius of the sphere, but can be increased by enclosing the generator in an inert atmosphere, such as nitrogen.

van de Graaff generator



US physicist Robert Jemison van de Graaff developed this high-powered generator, which can produce more than a million volts. Experiments involving high-energy charged particles make use of a van de Graaff generator, generally for the initial acceleration of the particles, which are then passed to more powerful accelerators.

vapour

one of the three states of matter (see also solid and liquid). The molecules in a vapour move randomly and are far apart, the distance between them, and therefore the volume of the vapour, being limited only by the walls of any vessel in which they might be contained. A vapour differs from a gas only in that a vapour can be liquefied by increased pressure, whereas a gas cannot unless its temperature is lowered below its critical temperature; it then becomes a vapour and may be liquefied.

vapour density

density of a gas, expressed as the mass of a given volume of the gas divided by the mass of an equal volume of a reference gas (such as hydrogen or air) at the same temperature and pressure. If the reference gas is hydrogen, it is equal to half the relative molecular weight (mass) of the gas.

---

vapour pressure

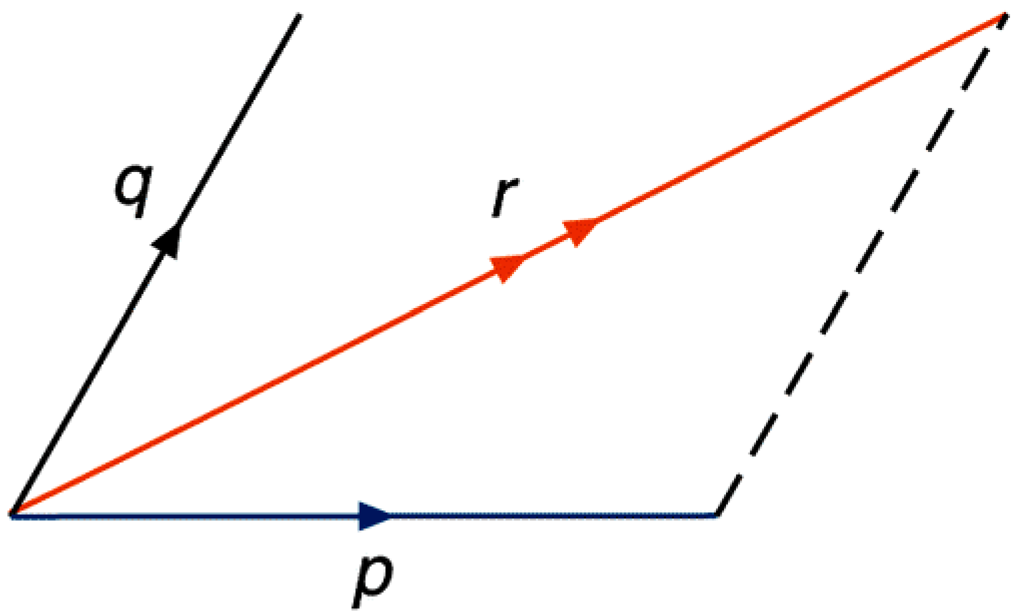
pressure of a vapour given off by (evaporated from) a liquid or solid, caused by atoms or molecules continuously escaping from its surface. In an enclosed space, a maximum value is reached when the number of particles leaving the surface is in equilibrium with those returning to it; this is known as the **saturated vapour pressure** or **equilibrium vapour pressure**.

---

vector quantity

any physical quantity that has both magnitude (size) and direction, such as velocity, acceleration, or force, as distinct from a scalar quantity such as speed, density, or mass, which has magnitude but no direction. A vector is represented either geometrically by an arrow whose length corresponds to its magnitude and points in an appropriate direction, or by two or three numbers representing the magnitude of its components. Vectors can be added graphically by constructing a parallelogram of vectors (such as the parallelogram of forces commonly employed in physics and engineering). This will give a **resultant vector**.

vector quantity



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A parallelogram of vectors. Vectors can be added graphically using the parallelogram rule. According to the rule, the sum of vectors *p* and *q* is the vector *r* which is the diagonal of the parallelogram with sides *p* and *q*.

---

velocity

symbol *v*,

speed of an object in a given direction, or how fast an object changes its position in a given direction. Velocity is a vector quantity, since its direction is important as well as its magnitude (or speed). For example, a car could have a speed of 48 kph/30 mph and a velocity of 48 kph/30 mph northwards. Velocity = change in position/time taken.

---

viscosity

the resistance of a fluid to flow, caused by its internal friction, which makes it resist flowing past a solid surface or other layers of the fluid. Treacle and other thick, sticky liquids are highly viscous liquids. Water and petrol are runny liquids and have low viscosity.

---

vision

ability or act of seeing. Light that enters the eye is focused by the eye lens, creating a sharp image on the retina. Electrical signals from the retina travel down the optic nerve where they are interpreted by the brain.

---

vision defect

any abnormality of the eye that causes less-than-perfect sight. Common defects are short-sightedness or myopia; long-sightedness or hypermetropia; lack of accommodation or presbyopia; and astigmatism. Other eye defects include color blindness.

VLF

in physics, abbreviation for **very low frequency**. VLF radio waves have frequencies in the range 3–30 kHz.

---

volt

symbol V,

SI unit of electromotive force or electric potential (see potential, electric). A small battery usually has a potential of one or two volts; the domestic electricity supply in the USA is 110 volts. A high-tension transmission line may carry up to 765,000 volts.

---

voltage amplifier

electronic device that increases an input signal in the form of a voltage or potential difference, delivering an output signal that is larger than the input by a specified ratio.

W

in physics, symbol for watt, the SI unit of power, equal to a power output of 1 joule per second. Multiple units include the kilowatt (kW, 1,000 watts) and megawatt (MW, 1,000,000 watts).

W

abbreviation for **west**; in physics, symbol for **watt**.

---

watt

symbol W,

SI unit of power (the rate of expenditure or transformation of energy from one form to another) defined as one joule per second. A light bulb, for example, may use 40, 60, 100, or 150 watts of power; an electric heater will use several kilowatts (thousands of watts). The watt is named after the Scottish engineer James Watt.

---

wave

in physics, oscillation that is propagated from a source. Mechanical waves require a medium through which to travel. Electromagnetic waves do not; they can travel through a vacuum. Waves carry energy but they do not transfer matter. The medium (for example the Earth, for seismic waves) is not permanently displaced by the passage of a wave. The model of waves as a pattern is used to help understand the properties of light and sound. Experiments conducted in a ripple tank with water waves can explain how waves slow down as water becomes shallower, how waves change direction when travelling through another medium, and how waves are reflected from different surfaces. See also standing wave.

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waveguide

hollow metallic tube, either empty or containing a dielectric, used to guide a high-frequency electromagnetic wave (microwave) travelling within it. The wave is reflected from the internal surfaces of the guide. Waveguides are extensively used in radar systems.

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wavelength

distance between successive crests or troughs of a wave. The wavelength of a light wave determines its colour; red light has a wavelength of about 700 nanometres, for example. The complete range of wavelengths of electromagnetic waves is called the electromagnetic spectrum.

Wb

in physics, symbol for weber, the SI unit of magnetic flux, equal to the flux that (linking a circuit of one turn) produces an emf (electromotive force) of 1 volt when the flux is reduced at a constant rate to zero in 1 second.

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weak nuclear force

or *weak interaction*,

one of the four fundamental forces of nature, the other three being the gravitational force or gravity, the electromagnetic force, and the strong nuclear force. It causes radioactive beta decay and other subatomic reactions. The particles that carry the weak force are called weakons (or intermediate vector bosons) and comprise the positively and negatively charged W particles and the neutral Z particle.

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weber

symbol Wb,

SI unit of magnetic flux (the magnetic field strength multiplied by the area through which the field passes). It is named after German chemist Wilhelm Weber. One weber equals 10^8 maxwells.

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weight

force exerted on an object by gravity. The weight of an object depends on its mass – the amount of material in it – and the strength of the Earth's gravitational pull (the acceleration due to gravity), which decreases with height. Consequently, an object weighs less at the top of a mountain than at sea level. On the surface of the Moon, an object has only one-sixth of its weight on Earth (although its mass is unchanged), because the Moon's surface gravity is one-sixth that of the Earth's.

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weightlessness

apparent loss in weight of a body in free fall. Astronauts in an orbiting spacecraft do not feel any weight because they are falling freely in the Earth's gravitational field (not because they are beyond the influence of Earth's gravity). The same phenomenon can be experienced in a falling lift or in an aircraft imitating the path of a freely falling object.

Wien's displacement law

in physics, a law of radiation stating that the wavelength carrying the maximum energy is inversely proportional to the absolute temperature of a black body: the hotter a body is, the shorter the wavelength. It has the form $\lambda_{max}T$ = constant, where λ_{max} is the wavelength of maximum intensity and T is the temperature. The law is named after German physicist Wilhelm Wien.

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work

in physics, a measure of the result of transferring energy from one system to another to cause an object to move. Work should not be confused with energy (the capacity to do work, which is also measured in joules) or with power (the rate of doing work, measured in joules per second).

W particle

elementary particle, one of the intermediate vector bosons responsible for transmitting the weak nuclear force. The W particle exists as both W^+ and W^-

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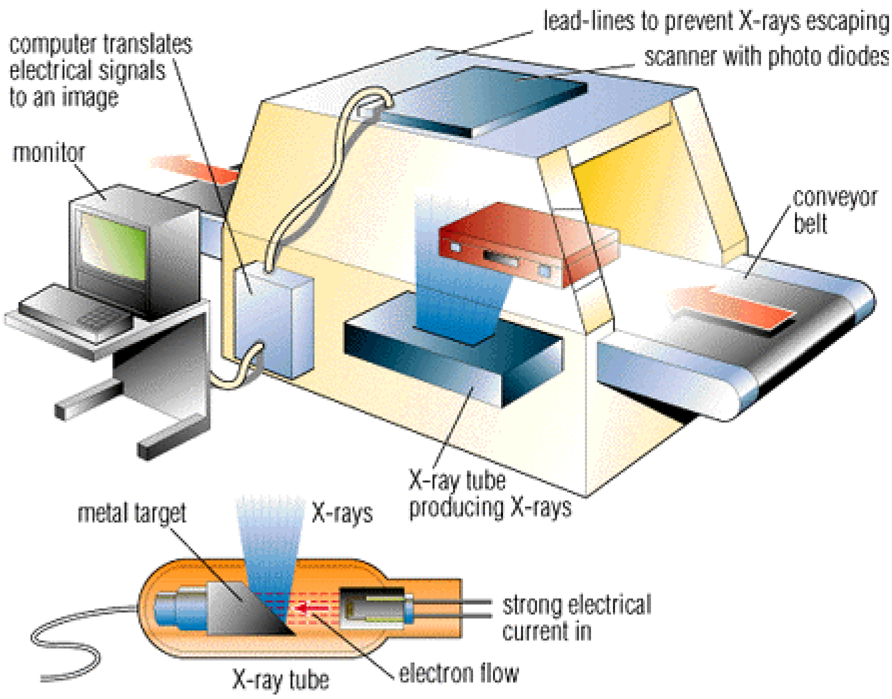
X-ray

band of electromagnetic radiation in the wavelength range 10^{-12} to 10^{-8} m (between gamma rays and ultraviolet radiation; see electromagnetic waves). Applications of X-rays make use of their short wavelength (as in X-ray diffraction) or their penetrating power (as in medical X-rays of internal body tissues). X-rays are dangerous and can cause cancer.

X-ray



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An X-ray image. The X-rays are generated by high-speed electrons impinging on a tungsten target. The rays pass through the specimen and on to a photographic plate or imager.

X-ray diffraction

method of studying the atomic and molecular structure of crystalline substances by using X-rays. X-rays directed at such substances spread out as they pass through the crystals owing to diffraction (the slight spreading of waves around the edge of an opaque object) of the rays around the atoms. By using measurements of the position and intensity of the diffracted waves, it is possible to calculate the shape and size of the atoms in the crystal. The method has been used to study substances such as DNA that are found in living material.

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yield point

or *elastic limit*,

stress beyond which a material deforms by a relatively large amount for a small increase in stretching force. Beyond this stress, the material no longer obeys Hooke's law.

Z particle

in physics, an elementary particle, one of the intermediate vector bosons responsible for carrying the weak nuclear force. The Z particle is neutral.