## Glossary

*ab initio* calculation: calculation from theoretical data, without using simplifying **models**, and meant to be totally predictive.

accelerometer: device used to measure acceleration.

**adiabatic** (process): occurring with no heat exchange with the surroundings.

**adsorption:** retention, often selective, of a gas or a liquid on the surface of a solid; **desorption** is the opposite process.

**algorithm:** string of logical and mathematical operations and operating rules necessary to carry out a calculation.

**alloy** (metal): material obtained by adding one or more elements to a base metal.

**amino acid:** organic **molecule** containing an amino group and a carboxyl group. **Proteins** are made up of amino acids.

**amorphous** (state): displaying no ordering in the distribution of particles of matter, unlike the **crystalline** state.

**Ampere's law:** for a constant or near-constant electric field, in a vacuum, the integrated **magnetic field** circulation around a closed loop generated by a current flowing through it is equal to the algebraic sum of the currents that penetrate through the surface bounded by the loop, multiplied by the **permeability of the vacuum** ( $\mu_0 = 4\pi \ge 10^{-7} \text{ H/m}$ ).

**anisotropy:** characteristic of a material whose properties vary according to the direction in which they are measured. (*ant.* **isotropy**).

**annealing:** heat treatment of a material to modify its properties by reforming **grains**.

**ASIC** (application-specific integrated circuit): electronic component with "tailored" functions.

**atom:** fundamental building block of ordinary matter, composed of a **nucleus** (**neutrons** and **protons**) surrounded by orbiting **electrons**.

atomic force microscopy: method of microscopy based on the measurement of force or force gradient in the three spatial planes between a probe (the tip of which is formed of a few **atoms**) and a solid surface. The needle-tip probe is fixed to a thin strip that acts as a spring. Its bending is measured by the deviation of a laser beam. The data is then computer-processed to produce an image.

atomic number: number of protons in the nucleus of an element.

**bar:** unit of pressure: 1 bar = 10<sup>5</sup> Pa (the **pascal** is the SI unit).

**BiCMOS** (bipolar-CMOS): high-integration **CMOS** circuit with a high processing speed.

**bit:** elementary unit of information. It can take either of two values, generally written 0 or 1; **megabit:** 10<sup>4</sup> bits; **terabit:** 10<sup>12</sup> bits.

**Bloch walls:** boundary regions that spontaneously separate domains whose **magnetic moments** are oriented according to minimal magnetic energy, the overall magnetic moment of the sample being null.

**BOLD** (blood-oxygen-level-dependent contrast): contrast **MRI** sensitive to blood oxygenation. It indirectly reflects **neuron** activity. See **Focus C**.

**broadband:** bandwidth using several channels or, in a network, bandwidth with a high or very high data transfer rate (at least several **megabits**/second).

**Brownian motion:** random movement, that can be described mathematically, of a particle subjected solely to collisions with neighbouring particles suspended in the medium.

**byte:** unit of information storage equal to 8 **bits**, which can store 1/8 of a floating point number or a character. Multiples are most commonly used: the **kilobyte** (1,024 bytes), **megabyte** (1,024 kilobytes), **gigabyte** (1,024 megabytes) and **terabyte** (1,024 gigabytes).

cantilever: beam supported at only one end.

**chaotic:** for a deterministic phenomenon, presenting a high *sensitive dependency on initial conditions* and displaying *recurrence*, making it in practice unpredictable.

charge carrier, conduction electron: electric current is a movement of charge-carriers, **electrons** or **holes**.

**CMOS** (complementary metal oxide semiconductor): device technology most often used in microelectronics for the development, from MOS-type field-effect transistors, of logic circuits with very high degrees of integration and low energy consumption.

**coalescence:** process by which two identical objects or substances that are dispersed (for example two droplets) tend to join.

**coercive excitation (demagnetisation):** excitation necessary to demagnetise a material.

**coercive field: magnetic field** needed to change the **magnetisation** of a **ferromagnetic** material. See **Focus A**.

**cognitive:** concerning knowledge, its functions and its mechanisms (perception, language, memory, reasoning, etc.)

**coil, wind:** electrically conducting wire wound in turns to create a **magnetic field** by **induction**.

**cold mass:** in **cryogenic** facilities, all the parts that are to be cooled (e.g., **superconducting magnets**) plus the chambers containing cryogenic fluids (e.g. liquid **helium**).

**composite:** material formed by the assembly of several different materials and that exhibits properties that the individual components do not possess separately.

**conductance:** electric current divided by potential difference. Reciprocal of **resistance**. Its SI derived unit is the **siemens (S)**. **Conductivity** is conductance per unit length (S/m).

## conduction electron: see semi-conductor.

**convection:** all the movements of a fluid caused by density, temperature or pressure gradients. Plays a role in the transport of heat.

**convolution:** mathematical operation whereby two series of signals are combined to obtain a third, continuous signal with the same dimensions.

**Cooper pair: electrons** bound in a pair to form a system that behaves as a **boson**, a particle with an integer **spin**, unlike lone electrons, which are **fermions** (with half-integer spin). This pairing in particular underlies **superconductivity** and **superfluidity**. The two electrons have the same quantity of movement, but are of opposite sign.

**cortex:** outer layer of an organic tissue, especially the brain. The cerebral cortex, made up of a layer of **grey matter** located at the surface of the hemispheres containing the **neuron** cell bodies, is the site of the higher brain functions.

**Coulomb interaction:** electrical interaction between two charged particles, *attractional* when the charges are of opposite sign, *repulsional* when they are the same. Occurs with two different intensities: inside the **nucleus**, the force of repulsion between two **protons**, of the order of a **MeV**, is overridden by the *strong interaction* which holds the nucleus together; at larger distances, the force of repulsion predominates, with an energy of about 1 **eV**.

**coulombic attraction:** force of attraction between two electrical charges of opposite sign.

covalent (bond): chemical bond between two atoms achieved by the sharing of electrons.

**critical point:** point in a *phase diagram* (temperature/pressure) of a body beyond which liquid and gaseous forms are no longer distinct.

**cryogenic:** literally "cold-producing", by extension "pertaining to low temperatures". Liquid oxygen and liquid **hydrogen**, for example, are held at -183 °C (90 **K**) and -253 °C (20 K), respectively.

**cryomagnetism:** magnetism occurring in the very-low-temperature conditions that cause **magnets** to enter the **superconductor** state.

**cryostat:** device to maintain a very low temperature, generally by circulation of a liquefied gas.

**crystal:** assembly of **atoms**, **ions** or **molecules** regularly arrayed in three dimensions.

**crystal growth:** formation of a **crystal** by continuous aggregation of **atoms** on a *seed*.

**current density:** electric current delivered per unit area of the cross section of a conductor (A/cm<sup>2</sup>).

**dalton:** mass unit (**Da**) equal to the mass of an **atom** of **hydrogen**, i.e., 1.66 x 10<sup>-24</sup> g.

**dielectric permittivity** (or **dielectric constant**): measure of the electrical insulating power of a material. It is expressed relative to that of air (equal to that of a **vacuum** or free space) in pico-farads/metre (pF/m).

discrete: discontinuous (to discretise is to separate).

divalent (atom): able to form two chemical bonds.

**DNA (deoxyribonucleic acid):** the support for genetic information in a living cell.

**dynamo action:** self-sustaining effect by which mechanical energy is spontaneously converted into **electromagnetic** energy.

electrical conductivity: measure of the electrical conduction capacity of a material. Expressed in **siemens** per unit length.

**electrode:** conducting component (**anode** or **cathode**) that emits, captures or controls **electrons** or **ions** using an electric field.

**electroencephalography:** measurement of brain activity via variations in electrical potential at the skull surface.

**electromagnet:** device that generates a **magnetic field** using a circulating electric current.

**electromagnetic radiation:** radiation that travels in a vacuum at the speed of light by the interaction of oscillating electrical and **magnetic fields**, and which transports energy (**photons**).

**electromagnetism:** interaction of **magnetic fields** with electric fields.

electron: negatively charged elementary particle (lepton).

electron or ion conduction: property of a material that allows an electron or an ion to travel in it.

electron paramagnetic resonance (EPR): method for the structural analysis of matter based on the interaction between a powerful high frequency alternating magnetic field and *unpaired* electrons in the material being analysed, inducing transitions between their spin levels (of different energy). The electrons align their magnetic moment parallel or antiparallel to this field.

**electronvolt** (**eV**): unit of energy corresponding to the energy acquired by an **electron** accelerated by a potential difference of 1 volt, 1 eV =  $1.602 \times 10^{-19}$  joule. Main multiples: the **keV** ( $10^3 \text{ eV}$ ), the **MeV** ( $10^6 \text{ eV}$ ) and the **GeV** ( $10^9 \text{ eV}$ ).

**electrostatics:** branch of physics concerned with electric charges at rest and their interactions. An **electrostatic effect** involves only *coulombic* forces.

element: atom distinguished by its atomic number, i.e., its number of electrons.

emu: electromagnetic unit (1 A/m<sup>2</sup> = 10<sup>3</sup> emu).

**entropy:** quantity, expressed in **joules** per **kelvin**, a change in which is equal to the heat added to a system by a reversible process at constant temperature divided by that temperature. It is a measure of the degree of disorder of a system.

**enzyme:** substance made up of **proteins** that activates a biochemical reaction by **catalysis**.

exothermic: heat-releasing.

**ferrite:** (1) low-density mixed metal and iron(III) oxide with composition  $Fe_2O_3XO$ , where X is a **divalent** metal such as cobalt, nickel, manganese or zinc. (2)  $\alpha$ -iron, the stable phase of pure iron, which is **ferromagnetic** at low temperature. See **Focus A**.

**field lines** (magnetic) or **lines of force:** imaginary lines indicating the intensity and direction of a **magnetic field**, and along which charged particles travel.

**Foucault currents:** induced electrical currents formed, for example, in a conducting mass moving in a constant **magnetic field**, or in an immobile metallic solid subjected to a varying magnetic field. They are thus the result of the variation of the **induction** inside a material over time (rot E = - dB/dt and  $J = \sigma E$ ).

**Fourier transform:** result of a complex mathematical operation consisting in converting a time-domain function into a frequencydomain function to obtain a spectral representation of a signal.

**free electron: electron** not tightly bound to the structure of an **atom** or a **molecule**, and moving freely under the influence of an electric field.

fringe field: magnetic field radiated by an electrical device.

fusion (thermonuclear): reaction by which small atomic nuclei combine at high temperature to form larger nuclei possessing a smaller mass than the sum of the initial masses. The difference is converted into energy according to Einstein's law of massenergy equivalence,  $E = mc^2$ .

**gamma:** former unit of **magnetic field** intensity, a submultiple of the **œrsted**  $(1 \gamma = 10^{-5} \text{ Oe})$ ;  $1 \gamma = 10^{-5} \text{ gauss}$ ; 1 gamma is equivalent to 1 **nanotesla** (**nT**).

gauss: unit of magnetic induction (1 G = 10<sup>-4</sup> T) (1 G = 1 maxwell/cm<sup>2</sup>).



garnet: complex silicate; mixture of silicates of various metals.

**Gauss's law:** in statistics, law that governs the distribution of a random variable, the graphical representation of which is a bell-shaped curve (Gauss curve).

giant magnetoresistance (GMR): quantum effect observed in thin-film structures composed of alternating ferromagnetic and non-magnetic layers. It manifests as a fall in resistance observed when an external magnetic field is applied. When the field is nil, the two adjacent ferromagnetic layers have an *antiparallel* magnetisation, as they undergo weak ferromagnetic coupling. Under the effect of an external field the respective magnetisations of the two layers line up and the resistance of the multilayer drops sharply. The **spins** of the **electrons** in the non-magnetic metal are distributed evenly, parallel and antiparallel, and so undergo less marked magnetic scattering when the ferromagnetic layers are magnetised parallel. See Focus A.

**grain:** elementary **crystallite** that forms the crystalline structure of a material, in particular a metal.

grain boundary: fault delimiting two crystals with different orientations in a material.

**granulometry:** measurement of the size and shape of powdered or suspended materials.

**gravity:** effect by which a large mass such as the Earth attracts other bodies. Gravitational force is a mutual attraction between two bodies in proportion to the product of their masses. Gravity is transmitted by a hypothetical elementary particle, the *graviton*.

gyromagnetic: pertaining to a quantity linked to precession around the axis of a magnetic field.

**haemoglobin:** main component of red blood cells. It is composed of four sub-units composed of an **atom** of iron coordinated by a porphyrin (haem), a **protein** chain and possibly a small **molecule** such as CO, NO, or  $O_2$ . When oxygen is bound to the iron oxyhaemoglobin is formed. Release of the oxygen gives **deoxyhaemoglobin**.

Hall effect: discovered by Edwin H. Hall, generation of a potential difference between the sides of a bar of conducting or **semiconductor** material perpendicular to a current flowing through it when a **magnetic field** is applied. This potential difference is proportional to the field and the current, and increases in steps, showing its **quantum** nature. The **Hall sensor** uses this effect.

hard (ferromagnetic material): having a broad hysteresis cycle with a saturation magnetisation greater than 1 tesla. See Focus A.

helium (He): the lightest element after hydrogen. Its nucleus is composed of two protons and two neutrons for the isotope helium-4. The nucleus of the rarest isotope (helium-3) has only one neutron. Helium-4 condenses to a liquid at 4.22 K and becomes superfluid at 2.17 K.

**hertz:** SI unit of frequency (**Hz**), equal to a cycle per second, of an alternating process. The main multiples include the **megahertz** (1 **MHz** =  $10^6$  Hz) and the **gigahertz** (1 **GHz** =  $10^9$  Hz).

hydrogen (H): chemical element with three isotopes, one of which is an **atom** composed simply of a **proton** and an **electron**. The others are **deuterium** and **tritium**.

hyperfrequency: frequency equal to or higher than 3,000 MHz (3 GHz).

## hysteresis loop: see Focus A.

inductance: induction flux through a circuit created by a current flowing through it, divided by the current (in amperes). Expressed in henrys (H). By extension, any circuit or electric dipole that presents a certain inductance value, generally a coil.

**induction:** production of a potential difference at the terminals of a conductor subjected to a variable **electromagnetic field**.

**inductor:** electrical circuit or **dipole** that displays a certain value of **inductance**.

**ion: atom** that has lost or gained one or more **electrons** and so is electrically charged.

**ionisation:** state of matter in which **electrons** are separated from **nuclei**; processes by which **ions** are produced, by collision with **atoms** or electrons (*collision ionisation*) or by interaction with **electromagnetic radiation** (*photoionisation*).

**ischaemia:** drop in the arterial blood supply to an organ, causing lowered oxygenation of its tissues.

**isotope:** one of a number of **atomic** forms of a chemical **element** in which the **nucleus** possesses the same number of **protons** but different numbers of **neutrons**.

Josephson effect: effect occurring at a junction (Josephson junction) between two superconducting electrodes separated by an insulating layer so thin that electron pairs are able to pass through it by the tunnel effect.

Josephson junction: junction between two superconducting electrodes made by separating them with an insulating spacer so thin that electron pairs can cross it via the tunnel effect (tunnel junction).

**joule (J):** SI unit of work produced by a force of 1 **newton** of which the point of application moves 1 m in the direction of the force: 1 J =  $2.778 \times 10^{-7}$  kilowatt hours. Multiples include the **megajoule** (10<sup>6</sup> J) and the **gigajoule** (10<sup>9</sup> J).

**Joule effect:** release of heat due to the **resistance** of a conductor to an electric current.

**kelvin:** SI unit of temperature (symbol **K**). The kelvin scale has a single fixed point, which is by convention the thermodynamic temperature of the triple point of water (at which solid, liquid and vapour phases coexist) at 273.16 K, or 0.01 °C. The zero on the kelvin scale ("absolute zero") corresponds to nil **molecular** agitation. The **millikelvin** is 10<sup>-3</sup> K.

**Laplace force:** force on a current-carrying wire  $(\vec{l})$  in which an electric current *l* is flowing in a **magnetic field**  $(\vec{B})$  given by the formula  $d\vec{F} = l \cdot d\vec{l} \wedge \vec{B}$ . It results from the **electrostatic** balance of the charges on the wire in response to the external field. Its action, unlike the **Lorentz force** of which it is the electrostatic part at macroscopic scale, can be non-nil.

**Lentz's law:** law defining the electromotive force (EMF) generated in a **solenoid** as a **magnet** approaches it. The magnet creates a flux  $\phi$  in the **coil** and its movement brings about a variation  $d\phi$  in this flux, inducing an EMF where  $e = -d\phi/dt$ . The induced current thus opposes the change in flux.

**ligand: molecule** that can bind to another one, in particular an organic molecule able to bind selectively and with high affinity to a biological *receptor*. Molecule or **ion** linked to the central **atom** of a **complex** by a **coordinate** bond.

**light element: element** with an **atomic number** less than or equal to 5 (**hydrogen, helium**, lithium, beryllium or boron).

**lithography** (or **photolithography**): process used to obtain highdefinition *integrated circuit* patterns. The operation consists in exposing a photosensitive resin to high-energy particles through a reducing lens system. The particles range from the ultraviolet (UV) **photons** currently in use, to **electrons**, via X-ray photons and **ions**. They are directed through a mask representing the circuit. The **resolution** is roughly speaking directly proportional to the wavelength of the radiation used. The image is transferred to the stack of insulating or conducting layers previously deposited on a wafer of **semi-conductor** material, generally **silicon**.

**lithosphere:** solid shell of the matter making up telluric bodies. On Earth, it comprises the crust and the outermost part of the upper mantle.

**logic gate:** circuit able to process logic states, i.e., existence of a constant positive potential (state 1) or nil potential (state 0).

**Lorentz force:** force acting on moving electric fields. Designates the **electromagnetic** force  $\vec{F}$  (expressed in **newtons**) as a function of the charge q of the particle (in **coulombs**), the electric field  $\vec{E}$  (in V/m), the velocity  $\vec{v}$  of the particle (in m/s) and the **magnetic field**  $\vec{B}$  (in **teslas**), according to the formula  $\vec{F} = q\vec{E} + q\vec{v} \wedge \vec{B}$ .

The action of the magnetic part of the Lorentz force is always nil. In the special case when there is no electric field, it manifests as **Laplace force**. A charged particle moving in a field is subject to Lorentz force, proportional to its charge, velocity and field, at right angles to its path and to the field.

M: moles/litre. A measure of concentration.

**M(D)RAM:** magnetic (dynam*i*c) random access memory for data storage.

**macromolecule: molecule** with a molecular weight greater than several thousand **daltons** (e.g., **proteins** and *nucleic acids*).

magnet: material with a significant residual magnetic field and high coercive field.

**magnetic confinement:** together with *inertial confinement*, one of the two main methods for confining a **plasma** of **light elements** to create conditions for **fusion**.

**magnetic dipole:** a near-point magnetic source created by the movement of an electric charge in a closed loop. Its **magnetic moment** is perpendicular to the loop. The simplest magnetic system.

**magnetic excitation** (or **field**): ratio of **induction** to **permeability** (that **of a vacuum**,  $\mu_0$ , is equal to  $4\pi \times 10^{-7}$  H/m). Noted *H* and expressed in amperes/metre or in **œrsteds** (1 A/m =  $4\pi/10^3$  Oe), it measures a **magnetic field** at a point in space.

**magnetic field:** force field, defined by its intensity and direction, resulting from the movement of electrical charges. Expressed in amperes per metre (A/m) or **œrsteds** (0e).

**magnetic force microscopy (MFM):** method of microscopy that detects spatial variations in a **magnetic field** with a **resolution** to below one **micrometre**. An ultra-thin **magnetised** tip, mounted at the end of a **silicon** arm, sweeps across the surface of the sample to be analysed. The field from this surface exerts a force on the tip that causes the arm to bend. This movement can be measured using optical or piezoresistive sensors. The force of interaction between the tip and the material gives information about the magnetic state of its surface. This method is particularly well suited to the study of spatial distributions of magnetisation in magnetic nanostructures. magnetic force microscopy or Lorentz microscopy: method of microscopy based on the use of electromagnetic coils as 'lenses' and on the fact that electrons react to crossing a magnetic sample by a change in path. Lorentz microscopy (so-named by analogy with the Lorentz force that characterises the interaction between a charged particle and a magnetic field) breaks down into two modes, one for the observation of magnetic walls and the other for domain walls. See Focus A.

**magnetic induction:** total **magnetic field** created in a magnetic body placed in an external field, equal to the product of the field and the **permeability**. Notated *B*, it is expressed in **tesla**, **gauss** or **webers**/m<sup>2</sup>. In a **magnetised** material it is a **magnetic moment**; in a conductor, a **current density**.

**magnetic induction flux:** measure of **magnetic induction**, expressed in **webers** (Wb). When an induction **magnetic field** of strength *B* (in **teslas**) crosses a surface area *S* (in m<sup>2</sup>) with an angle  $\theta$ , the flux  $\phi$  is given by  $\phi = B \cdot S \cdot \cos \theta$ .

**magnetic moment:** quantity *M* described mathematically by a vector with the dimensions of a current (in amperes) multiplied by an area (A.m<sup>2</sup>) linked to the torque  $\Gamma$  experienced by a **magnet** placed in a uniform **magnetic field** *B* by the formula  $\Gamma = M \cdot B \cdot \sin \theta$ , where  $\theta$  is the angle between *M* and *B*. Expressed in **debyes** (1 D = 3.355 x10<sup>-30</sup> cm).

magnetic permeability: capacity of a material to increase magnetic induction strongly by concentrating field lines. Notated  $\mu$ , and expressed in henrys per metre, it is the product of the **per**meability of a vacuum ( $4\pi \times 10^{-7}$  H/m) and the *relative permeability*  $\mu^{r}$  (dimensionless).

magnetic resonance: effect occurring when a radiofrequency wave excites electrons at the same frequency as that of the precession of their spins. After the radiofrequency excitation is stopped, the system emits the energy absorbed and returns to its initial state: this is called relaxation.

magnetic resonance force microscopy (MRFM): hybrid of magnetic resonance imaging and atomic force microscopy. It can be used to detect an evanescent magnetic signal, e.g., the spin of a single electron. See Focus A and C.

magnetic resonance microscopy: method of microscopy combining near-field microscopy and magnetic resonance imaging with mechanical detection and measurement of the longitudinal component of the magnetisation by means of an oscillating arm sensitive to the tiniest forces. Under certain conditions, the force that acts between an electron and the tip measurably modifies the vibrations of the arm. This makes it possible to measure the dynamics of transverse and longitudinal relaxation on the nanosecond scale in both paramagnetic spin and ferromagnetic spin systems. See Focus A and C.

**magnetic susceptibility:** quantity (notated  $\chi$ , expressed in m<sup>3</sup>/kg or **emu/Oe**·g) that determines the interaction between a material and a **magnetic field** in which it is placed and its magnetisability in a direction parallel to that field. It is the ratio of the **magnetisation** of the material (*M*) to the **magnetic excitation** (*H*) of the field.

magnetic tunnel junction: non-magnetic tunnel barrier inserted between two ferromagnetic metal layers. See Focus A.

**magnetisation:** effects of different types of magnetism resulting from microscopic **magnetic moments** of **electrons** in matter: the sum of these moments in a given direction; *permanent* (**magnet**) or *induced* by an outside **magnetic field** or a current (**induction**). Its intensity *M* is related to the magnetic field *B* and its **excita**- tion *H* by the relation:  $B = \mu_0$  (*H*+*M*), where  $\mu_0$  is the **permeability of a vacuum**, multiplied by a relative permeability in a medium. *Stricto sensu*, magnetic moment per unit volume.

**magnetohydrodynamics (MHD):** theory analogous to hydrodynamics for neutral fluids, which makes it possible to study the large-scale behaviour of an electrically-conducting fluid, liquid metal or **plasma**.

**magnetometer:** apparatus used to measure the modulus of a **magnetic field** (scalar), one of its components (vectorial) or its three components (triaxial). The most accurate ones include the **SQUIDs** (*superconducting quantum interference devices*) which make use of the **Josephson effect**. Fluxgate magnetometers can provide greater sensitivity.

**magnetoresistive:** varying in **electrical resistance** according to a **magnetic field**.

**magnetosphere:** region of space in which a planet's **magnetic field** overrides *solar wind*, protecting the planet from its **ionised** particles. The Earth's magnetosphere is located beyond the **ionosphere**, beginning about a thousand kilometres above the surface, and extending to the *magnetopause*, which marks the transition to interplanetary space.

magnetostatics: study of magnetic phenomena in static magnetic fields.

**magnetostriction:** property (*piezomagnetism*) of **ferromagnetic** materials whereby they change shape in a **magnetic field**. When the material is **magnetised to saturation**, the maximum change in shape produced is generally of the order of 1 µm per cm of the material. Ferromagnetic materials can also exhibit an *inverse magnetostrictive* effect (**rare earth elements**). See **Focus A**.

mass number: sum of the number of neutrons and the number of protons in an atomic nucleus, characteristic of an element.

**maxwell (M):** SI unit of **magnetic flux density** equal to 10<sup>-8</sup> **weber**. Used in particular for low flux values.

**MEMS:** micro-electromechanical system.

**metabolism:** the chemical processes that occur in living organisms and in every cell.

**metabolite:** organic substance formed in **metabolic** processes (synthesis or breakdown) or involved in them.

**metalloid: element** with properties that are in between those of *metals* and *non-metals*. Most are **semi-conductors** (boron, **sili-con**, germanium, arsenic, antimony, tellurium and polonium).

**metastable** (atomic state): able to remain for a certain time at energy levels close to the ground state but isolated **spectroscopically** (where radiative transition to the ground state is forbidden).

microflux gate: magnetometer based on the fluxgate principle, which makes use of the hysteresis of soft magnetic materials. The sensitive part of the system (produced on silicon substrates by high-volume production) consists of copper coils wound on ferromagnetic Permalloy cores. A first series of coils excites these cores with a known magnetic field that is superimposed on the ambient magnetic field. A second series serves to observe their response to this excitation and so measure the field in the coil-core axis. This type of magnetometer needs electronic devices for synchronous detection that measure the excitation harmonics created by the presence of the field to be measured and re-inject the measured field into the ferromagnetic material through the coils to obtain a null ambient field. See **Focus A**.

**microgravity:** residual gravity that is extremely small compared with that represented by weight, in particular on Earth.

micrometre (or micron): 1 µm = 10<sup>-6</sup> metre.

**micromolar** ( $\mu$ **M**): related to a millionth of a **mole**. The mole is the SI unit of amount of substance (symbol: **mol**). It stands for a number of elementary objects equal to the number of **atoms** in 0.012 kg of carbon-12.

microwave: see hyperfrequency.

**modelling:** simplified representation of a system or process used to simulate it, embodied in a computer program (*code*), in the form of mathematical expressions.

**molecular beam epitaxy:** method of physical deposition first developed for growing **crystals** for **semi-conductors**, but which was extended to metals and insulators. It is based on the evaporation of the different pure constituents of the material to be produced in a chamber under a high vacuum. One or several heated jets of **atoms** or **molecules** react on the clean surface of a **monocrystalline** substrate placed on a support maintained at high temperature, which serves as a baseplate to form a film a few atomic layers thick.

**molecular dynamics:** method by which the movements of **atoms** in **molecular** systems are simulated by applying the laws of classical mechanics to predict changes in their spatial configuration. These movements correspond to vibrations about a minimum or a jump from one minimum energy to another. Provides insight into structural properties and thermodynamic quantities.

molecule: group of atoms linked by chemical bonds.

**monocrystal: crystal** formed of a single continuous block of an assembly of **atoms**, **ions** or **molecules** distributed periodically and regularly in all three spatial directions, unlike a **polycrystal**.

**monolithic** (device): assembled entirely on the same substrate.

Monte-Carlo method: statistical method used to obtain an approximate value for an integral using a set of points randomly distributed according to a certain probability. The method consists in repeatedly assigning a numerical value in a random sampling process and calculating mean and statistical dispersion values across all the values obtained.

**Mössbauer spectroscopy:** method of absorption **spectroscopy** based on the effect discovered in 1958 by Rudolf L. Mössbauer, and which makes it possible to determine the degree of oxidation of a chemical **element** with a non-nil **nuclear spin**, in particular iron, and the geometry of the neighbouring elements. It employs a source of gamma **photons**, varying its energy via the *Doppler effect*. When the incident radiation energy corresponds to the **electron** transition energy the radiation is absorbed with no measurable recoil of the **atoms**.

MRAM: magnetic random access memory.

**muon spectroscopy:** method of **spectroscopy** using the *muon*, a particle of the same family as the **electron** but 200 times heavier, implanted in the compound under study. When subjected to a **magnetic field**, the **spin** of the muons undergoes a movement of **precession** that can be observed because the **positron** resulting from the disintegration of the muon is emitted preferentially in the muon's direction of spin. This makes it possible to study magnetic fields at the **atomic** scale.

**NAND** (gate or memory): 'not-and' logic function with at least two input variables.

nanocrystallisation: formation of crystals of nanometric size (nanocrystals) in a heat-treated amorphous structure.

**nanomagnetism:** magnetism of individual **nanometre**-sized magnetic objects (e.g., **molecular magnets**), in thin layers or assemblies (magnetic **aggregates**). Applies in particular to systems that can only be described accounting for **atomic** structure via Heisenberg **spins**.

**nanometre:** 1 **nm** = 10<sup>-9</sup> metre.

**nanoparticles:** grains of matter composed of a very small number of **atoms** "glued" together in a cluster by various weak forces.

**nanowire:** one-dimensional structure of **semi-conducting** material with a diameter of the order of 1 to 10 **nm** and a length ranging from a few nm to a few  $\mu$ m.

**near-field microscopy** (optical): method of microscopy, by reflection or by transmission, using a probe with a diameter far smaller than the wavelength of the light used for the observation. It makes it possible to see details of the object that are also much smaller than this wavelength.

Néel walls: special case of walls separating magnetic domains in a thin film of material as thick as one of the dimensions of the wall. The energy of the demagnetising field for this wall then becomes substantially higher and the minimum free energy state corresponds to a distribution of the magnetisation in the wall that is different from that found in the Bloch walls. See Focus A.

Néel's model: model that predicts the existence of surface or interface magnetic **anisotropy** in **ferromagnetic** metals. The energy of this anisotropy is the sum of the energies of pairs of **atoms** making a contribution to this energy, which depends on the distance between the atoms and the angle between their direction and the direction of the **magnetisation**. See Focus A.

**NEMS:** nano-electro-mechanical system.

**neuron:** differentiated cell acting as the functional unit of the nervous system and responsible for the transmission of nerve impulses. It has a single projecting **axon** and numerous **dendrites**.

**neurotransmitter:** chemical substance that transmits information from one **neuron** to another through the *synapse*.

**neutron:** electrically neutral particle 1,839 times heavier than an **electron**.

**neutron diffusion:** method used for the real-time analysis of reaction processes, using a high flux *source* of **neutrons**, which are very weakly absorbed by many materials, and a *detector* covering a wide angular domain.

**newton** (N): SI unit of force. One of its submultiples is the **attonewton** (10<sup>-18</sup> N).

**NOR** (gate or memory): 'not-or' logic function with at least two input variables.

nuclear magnetic resonance (NMR): effect resulting from the properties of certain nuclei of atoms when they are placed in an intense magnetic field. They then interact with radio waves to emit signals that can be used to identify molecular structures.

nucleus (atomic): essential part of an atom, positively charged and composed of protons and neutrons (except for hydrogen) and around which electrons orbit. **nuclide:** a substance made up of **atoms** with identical **nuclei**, i.e., with the same **atomic number** (number of **protons** *Z*) and the same **mass number** *A* (sum of the number of **neutrons** *N* and the number of protons *Z*).

numerical simulation: method by which the operation of a system is described by computation from a model or a set of models.

**cersted:** unit of **magnetic field** intensity. 1 cersted (**Oe**) is the equivalent of  $10^5$  gamma ( $\gamma$ ).

**Ohm's law:** law linking a current flowing through a **dipole** to the potential difference across it. The potential difference U (in volts) across the terminals of a load of resistance R (in ohms) is proportional to the electric current I (in amperes) flowing through it. The law is general for sinusoidal currents, using complex notations. Ohm's law then becomes:  $\underline{U} = \underline{Z}.\underline{I}$  where  $\underline{Z}$  = complex impedance of the dipole, which can be made up of linear dipoles (resistors, capacitors or **inductors**).

**optical pumping:** process used in lasers to achieve *population inversion*, by providing the energy necessary to obtain more excited **atoms** (raised to a higher energy level) than non-excited atoms (at a lower level), such as with a high-power flashlamp.

**orbital** (atomic): region in the space around the **nucleus** of an **atom** where there is a strong probability of finding an **electron**.

**particle accelerator:** machine designed to produce, shape the course of and accelerate a beam of charged particles towards targets or other accelerated particle beams. The forces of acceleration it uses can be **electrostatic** (Van de Graaff or tandem) or **electromagnetic** (cyclotrons, linear accelerators, or synchrotrons).

**Permalloy:** magnetic alloy of iron and nickel, originally developed at Bell Labs. Permalloy<sup>™</sup> typically contains 20% iron and 80% nickel, but there are many types that have a nickel content ranging from 30% to 90% and are alloyed with another metal (e.g. molybdenum). Permalloy has a high **magnetic permeability**, low **coercivity**, near-nil **magnetostriction**, and a significant **anisotropic magnetoresistance**.

**permanent magnet: magnet** that retains its **magnetic field** with no outside assistance.

**perovskite: crystalline** structure common to many oxides of general formula ABO<sub>3</sub>. Named after the Russian mineralogist L. A. Perowski, perovskites present varying electrical and magnetic properties according to the nature of A and B.

phonon: quantum of vibration of the crystal lattice of a solid.

**photon: quantum** of energy of **electromagnetic radiation**. Massless, chargeless elementary particle associated with such radiation (visible, infrared or ultraviolet, gamma or X-ray according to its energy).

**piezoelectric** (material): able to change its electrical **polarisation** when pressure is applied to it. The opposite effect also exists.

**plasma:** gas heated to a temperature such that its **atoms** are **ionised**. Its properties are determined by the **electromagnetic** forces at play among its constituents (**ions** and **electrons**), which give rise to ranging behaviour.

**polarisation:** alignment of the electric field vector describing an **electromagnetic** vibration in a defined plane. The vibration is said to be **polarised**.



**polariser:** device used to restrict an **electromagnetic** vibration to a defined plane.

**polarity:** positive or negative sign that distinguishes between the poles of a **magnet** or the terminals of an electrical generator.

**polycrystal:** assembly of several **monocrystals** (grains) the lattices of which are not aligned with each other.

**polymerisation:** progressive accretion of **molecules** of *monomers* through **covalent bonds** to form a **polymer**, a **macromolecule** of high molecular weight repeating the same motif.

**positron:** positively charged *antiparticle* counterpart of the **electron**, whose charge is negative.

**positron camera:** device used in medical imaging to detect annihilation **photons** from **positron** emitters such as fluorine-18.

**ppm:** part per million.

**precession:** movement that takes the form of a gradual change in the orientation of the axis of rotation of an object or a vector in response an outside action, in particular of a particle that possesses a **magnetic moment** under the effect of a **magnetic field** [*Larmor precession*] or the **spin** of an accelerated particle (*Thomas precession*).

**protein: macromolecular** constituent of cells, made up of strings of **amino acids** coded by **DNA**.

**proton:** particle carrying a positive electric charge equal and opposite to that of an **electron** and 1,836 times heavier.

**pseudovector:** mathematical quantity that behaves like a true (or polar) vector for a proper rotation, but that changes direction under improper rotation, such as inversion of all three axes, or plane symmetry.

**quantum:** pertaining to the theory developed from the principle of Planck (energy is transferred in a **discrete** quantity called a **quantum**) and *Heisenberg's uncertainty principle*, which states that it is not possible to determine accurately and simultaneously both the position and the velocity of a particle.

**radioactivity:** property of some naturally-occurring or artificial **elements** that undergo spontaneous transmutation or *decay*, emitting **alpha** particles (**helium nuclei**), **beta** particles (**positrons** [beta +] or **electrons** [beta -]) and/or *gamma* radiation (high-energy **photons**). Term generally used to describe the emission of radiation that accompanies the *disintegration* of an unstable element or nuclear *fission*.

radioelement: strictly speaking, element all of whose isotopes are radioactive.

**radio-frequency (RF):** frequency of alternating electrical signals in the spectrum used to produce radio waves. An **RF component** is used to process signals in this frequency spectrum.

**radionuclide: radioactive isotope**, also known as **radio-isotope**, of a chemical **element**.

**rare earth element:** member of the family of **elements** that essentially comprise the **lanthanides**, of **atomic number** between 57 (lanthanum) and 71 (lutetium) plus yttrium (39) and scandium (21). Examples include europium, gadolinium and erbium.

**rare gas: element** in column 18 of the *periodic classification of Mendeleiev* (**helium**, neon, argon, krypton, xenon and radon), present in small amounts in air. Its outer **electron** layer is saturated, making it chemically inert. **reduction:** process by which an **atom** or **ion** gains peripheral **elec-trons**.

relaxation: see magnetic resonance.

**repulsion** or **coulomb barrier:** electrical repulsion that keeps apart two charged particles that have the same sign (e.g., **protons** of two **nuclei**).

**residual field: magnetic field** remaining in a material in the absence of **excitation**.

**resistance** (electrical): ability of a material to impede an electric current flow.

**resistivity:** specific resistance of a material to the movement of **electrons**.

**resolution:** *resolving power* of a detection device. It can be **spatial** (smallest angular or linear separation between two objects, characterising in particular the ability of an optical system to discern or reproduce details of a scene or of its image), or **temporal** (smallest time interval between two successive occurrences of a time signal that allows them to be perceived as distinct). **Spectral** resolution is the ability of a detection system to distinguish between **electromagnetic radiation** of different frequencies.

**resonance:** effect occurring when the frequency of an excitation mechanism matches a frequency characteristic of the system, causing oscillations through a feedback loop.

**RNA** (**ribonucleic acid**): substance involved in the replication of **DNA** information, in particular *messenger RNA*, a copy of DNA that specifies the **amino acid** sequence of a **protein**.

**saturation magnetisation:** limit at which the **magnetisation** of a **ferromagnetic** material no longer increases with increasing **magnetic excitation**. See **Focus A**.

**semi-conductor:** material that possesses a **forbidden band**, neither a pure insulator nor a pure conductor at non-nil temperatures, and whose electronic properties can be varied. Some of its **electrons** are weakly linked to their **atoms** and can become **conduction electrons**.

## siemens: see conductivity.

**silicon: semi-conductor** element most often used in the manufacture of integrated circuits.

**sodium:** alkali metal used in the liquid state as a heat exchange medium in **fast neutron reactors** owing to its 'transparency' to **neutrons**.

soft (ferromagnetic material): having a narrow hysteresis cycle
(low coercive field) with a saturation magnetisation lower than
1 tesla. See Focus A.

**solenoid: coil** of a certain length made of a wire wound in a spiral, and which produces a practically uniform **magnetic field** when an electric current flows through it.

**specific heat:** quantity of energy needed to raise the temperature of 1 gramme of a substance by 1 °C.

**spectrometer:** device used to record **electromagnetic spectra element** by element using detectors, and to measure the intensity of radiation according to its wavelength.

**spectroscopy:** study of matter from the radiation it emits or the effects that materials placed in its path have on it.

**spherical harmonics:** spherical functions used in mathematics when orientation (**anisotropy**) and thus rotation are involved. A harmonic function is characterised by a vanishing *Laplacian* (differential operator equal to the sum of all the unmixed second partial derivatives of a dependent variable).

spin: angular moment (or intrinsic internal rotational moment)
of a particle; it has an integer or half-integer value. Electron spin:
spin of the electron; nuclear spin: spin of the atomic nucleus.

**spin glass:** state of matter characterised at the microscopic scale by a **magnetisation** of each **atom** in a random direction and no magnetic ordering at long distance. Thus named by analogy with the non-**crystalline** structure of glass.

spin resonance (electron-): see electron paramagnetic resonance.

**spintronics** (or **spin electronics**): branch of physics concerned with the **electron spin**.

**spin valve:** material exhibiting **giant magnetoresistance** at low field.

**SQUIDs** (superconducting quantum interference devices): extremely sensitive **magnetic field** sensors.

stable isotope: a non-radioactive isotope of an element.

submicron: of dimensions less than a micrometre.

**superconductor:** metal or alloy whose *resistivity* (specific resistance to the movement of **electrons**) suddenly drops to a nearnil value at a *critical temperature* (**superconductivity**).

**superfluidity: quantum** state of an **element** that loses its **visco-sity** at a certain temperature, producing a *Bose-Einstein condensate*.

**superparamagnetic:** non-magnetic at ambient temperature.

**tempering:** heat-treating a material (historically by immersing a heated metal into a cold liquid) to lend it new properties by freezing some of the properties it displays at high temperature.

**tesla:** SI unit (symbol **T**) of **magnetic induction** corresponding to the production of a flux of 1 **weber** over 1 m<sup>2</sup> by a uniform induction. Its common submultiples include the **nanotesla** (**nT**) equal to 10-<sup>9</sup> T (value of the former unit, the **gamma**) and the **femto-tesla** (**fT**; 10-<sup>15</sup> T).

thermal agitation: continual motion, directly correlated to temperature, of **atoms** and **molecules**.

**tokamak:** acronym of the Russian *toroidal'naya kamera s magnit-nymi katushkami* (toroidal chamber with magnetic **coils**) or association of the three Russian words *tok* (current), *kamera* (chamber) and *mak* (magnetic). It designates a torus-shaped device in which **thermonuclear fusion** is studied by **magnetic confinement**, the fusion **plasma** being confined by **magnetic fields**.

tracer: organism, element or substance, either naturally-occurring or artificial, used to study physical, chemical or biological processes in a medium in which it is placed. A tracer can for example be a radioactive or stable isotope.

transition metal: member of a family of 30 elements with atomic numbers 21 to 30, 39 to 48 and 71 to 80. Examples include manganese, iron, cobalt, nickel, chromium, and platinum.

**tunnel effect:** a **quantum**-type effect that allows a particle (**proton**, **electron**) to overcome a potential barrier without possessing the energy classically required to do so. This is possible because the

wave function associated with this particle has a non-nil value on the other side of the barrier. This effect can allow two protons to overcome their mutual electrical **repulsion** at lower relative velocities than those indicated by classical calculations.

tunnel magnetoresistance (TMR): property of two ferromagnetic materials separated by a thin insulating membrane (~ 1 nm). The electrical resistance against a current flowing via the tunnel effect from one material to the other through the insulating spacer varies according to the relative orientation of the two magnetic layers, resistance generally being highest in an *antiparallel* alignment. This effect is used in MRAM magnetic data storage devices and hard-drive readers. See Focus A.

**turbulence:** pattern of flow of a fluid in which a random movement of agitation is superimposed on an average movement.

vapour pressure: pressure exerted by the vapour phase above a liquid or solid phase of a substance when the two phases are at equilibrium. Maximum value of the pressure of this substance required for it to release vapour, directly proportional to its temperature.

viscosity: ability of a fluid to flow.

**volumetric density:** ratio of mass *m* of a substance to its volume *V* (expressed in kg/m<sup>3</sup>).

**voxel:** elementary unit of volume used in 3D digital image processing, especially in **MRI**. See **Focus C**.

**wave function:** in **quantum** physics, the amplitude of the probability that a particle is present, given by the *Schrödinger equation*.

wave guide: device designed to guide one or more electromagnetic waves between two points fairly close together with minimal energy loss by radiation.

weber: unit of magnetic flux representing the flux that produces an *electromotive force* of 1 volt in a single **coil** turn when it decreases evenly to zero in one second (symbol **Wb**). 1 Wb =  $1T \times 1 \text{ m}^2$ .

white matter (of the brain): tissue composed of nerve fibres that connect different parts of the brain and transmit nerve impulses between the **neurons**. It is made up of neuron processes called **axons** organised in bundles of myelinated fibres. **Grey matter**: see **cortex**.

X-ray diffraction: method used to study the structure of a material in its crystal form. The wavelength of the X-rays is of the same order of magnitude as internuclear distances, i.e. sufficiently small to be scattered by the crystal lattice and yield a density pattern.

Zeeman effect: effect that occurs in certain atoms subjected to a magnetic field, where characteristic spectral lines (energy levels) split into several sub-levels (Zeeman levels) that are frequency-shifted and polarised. The gap (Zeeman transition) is proportional to the intensity of the ambient magnetic field.