Physics Highlights

MECHANICAL WAVES

■ A body is in simple harmonic motion when its acceleration is proportional to its displacement but opposite in sign. Simple harmonic motion is a sinusoidal function of time.

■ In the ideal case, the mechanical energy of a harmonic oscillator is constant and independent of time – even though its kinetic and potential energy change – and is proportional to the square of the amplitude of the oscillation.

■ However, in the presence of friction or other energy-dissipating mechanisms damping occurs: the oscillation amplitude decreases as time passes, and part of the oscillator's energy is converted into thermal energy. In contrast, an external driving force that transmits energy to the oscillator can lead to motion with larger amplitude. If the frequency of the force matches the natural frequency at which the object oscillates, resonance occurs.

■ When all the particles in a medium undergo simple harmonic motion, a wave is set up in the medium. A wave is a travelling disturbance that carries energy but not matter from place to place. It propagates at a speed that depends on the properties of the medium in which the wave travels.

■ Waves reflect and exhibit interference, adding or cancelling according to the **principle of linear superposition**:

when two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbances from the individual waves.

■ Standing waves, in which the locations of the maxima and minima (often referred to as crest and trough) do not change, can be set up on a string that is fixed at both ends. They arise because waves travelling along the string are reflected back onto the string at each end.

GLOSSARY AND RELEVANT EXPRESSIONS

to be in simple harmonic motion ▸ muoversi di moto armonico
transverse / longitudinal wave ▸ onda trasversale / longitudinale
disturbance, perturbation ▸ perturbazione
medium ▸ mezzo
wavelength ▸ lunghezza d'onda
amplitude ▸ ampiezza
standing wave ▸ onda stazionaria
damping ▸ smorzamento
principle of linear superposition ▸ principio di sovrapposizione
angular frequency ▸ velocità angolare

Activities

1 Complete the following definitions with the words listed below.

equilibrium • wave • cycles • standing • occurs • required • disturbance • amplitude • distance • motion • medium

- Any ..... that repeats at regular intervals is called periodic motion.
- The maximum excursion from ..... is called the amplitude of the motion.
- For any object in periodic motion, the time ..... to complete a cycle is called the period.
- The number of ..... of the motion per second is called the frequency.
- A mechanical wave is a wave that propagates in a ..... .
- A transverse wave is one in which the ..... is perpendicular to the direction of travel of the wave.
- A longitudinal ..... is one in which the disturbance is parallel to the direction of travel of the wave.
- The wavelength of a wave is the horizontal ..... between any two successive equivalent points on the wave.
- Wavefronts are surfaces over which the ..... of the oscillations has the same value.
- In ..... waves, nodes are places that do not vibrate at all.
- Antinodes are places where maximum vibration ..... .

2 Complete the following sentences with the names of the quantities that typically occur in simple harmonic motion: amplitude, acceleration, angular frequency, energy, velocity, displacement.

- In simple harmonic motion, ... and ..... do not have constant values as time passes.
- In simple harmonic motion, ... is proportional to negative ..... , and the two quantities are related by the square of the ..... .
- An increase in ..... results when ..... is continually added to an oscillating system.
- Resonance is the phenomenon that occurs when a time-dependent force transmits large amounts of ..... to an oscillating object.

3 State whether the following statements are true or false. Rewrite the false ones in their correct form.

- The amplitude of a wave is the maximum excursion of a particle of the medium in which the wave exists from the particle's undisturbed position.
- The dependence of the energy carried by a wave on the square of its amplitude is true only for transverse and not for longitudinal waves.
- In horizontal standing waves, the wave patterns do not move left or right. Every particle of the string comes to a momentary stop at the extreme points and has greatest acceleration when passing through the centre point.
- Waves travelling on a string undergo reflection at each end.
- When two or more waves traverse the same medium, the displacement of any particle of the medium is the sum of the square of the displacements that the individual waves would give it.

SOUND

■ Sound is a longitudinal wave that is created by a vibrating object. Firstly, air is compressed in front of the vibrating source forming a region of increased pressure called a compression that travels at the speed of sound. After that, the vibrating source produces a region of lower pressure called a rarefaction. Thus, air molecules vibrate back and forth parallel to the line of travel of the wave, but they are not carried along with the wave. These molecules impart the compressions and rarefactions to their neighbours through collisions and the sound wave moves forward.

■ Sound can be transmitted, with different speeds, in media other than air, but cannot exist in a vacuum.

■ Sound is characterised by pitch, loudness and intensity. While pitch and loudness are subjective qualities related to the perception, respectively, of the frequency and the amplitude of a sound wave, the intensity level of a sound is a physical quantity that is measured in dB (decibel).

■ As a wave, sound undergoes reflection, interference, diffraction and the Doppler effect. The Doppler effect is a change in the observed frequency of the sound wave that occurs whenever the sound source and the observer have different velocities with respect to the medium of propagation.

■ Musical sounds can be set up by oscillating strings, membranes, air columns and other oscillating bodies. Standing waves arise in all these situations, because waves travelling along the string or air column are reflected back at each end.

GLOSSARY AND RELEVANT EXPRESSIONS

pitch ▶ altezza (di una nota)
loudness ▶ volume
to bend ▶ piegare / piegarsi

Activities

1 Complete the following definitions with the words listed below.

frequency • intensities • energy • wave • perpendicularly • interference • harmonic

- A periodic wave can always be obtained as a superposition of ..... waves.
- A sound with a single ..... is called a pure tone.
- Sound power is the average rate per unit area at which ..... is transferred by a wave through a surface.
- Sound intensity is the sound power that passes ..... through a surface divided by the area of that surface.
- The decibel is a measurement unit used when comparing two sound ..... .
- Wave ..... occurs when two or more waves exist simultaneously at the same place.
- The bending of a ..... around an obstacle or the edges of an opening is called diffraction.

2 Complete the following sentences with the words and expressions listed below.

loudness • high-pitched • low-pitched • equal amplitude • louder the sound • remains unchanged • different frequency • wavelength • quality • physical quantities

- Pitch and loudness are not ..... .
- Pitch is a subjective ..... related to the perception of the frequency of a sound: a ..... sound is one with a high frequency; a ..... sound is one with a low frequency.
- ..... is determined primarily by the amplitude of the sound wave: the larger the amplitude, the ..... .
- Human ears are not equally sensitive to all frequencies of sound: sound waves of ..... but different frequencies will not have the same perceived loudness to everyone.
- When a sound source moves, the ..... of the sound perceived by an observer changes, so the observer perceives a ..... than the frequency produced by the source.
- When the observer moves, the wavelength ..... but the observer perceives a different number of wave compressions per second.

3 Choose the correct option from the pairs of expressions.

- A quantity called intensity / intensity level is used to compare the intensity of one sound to the intensity of a reference sound.
- An intensity level of zero decibels means / does not mean that the sound intensity is zero.
- An intensity level of zero decibels is equal to / less than the intensity of the reference level.
- If the intensity level increases by 10 dB, the new sound seems approximately twice / ten times as loud as the original sound.
- The intensity / loudness of sound from a source that radiates sound uniformly in all directions varies as $1/r^2$.
- The so-called intensity level is / is not an intensity and is / is not dimensionless.
- 1 dB is the unit / smallest perceivable increment in loudness.
- In order to double the maximum loudness of an audio system, its power must be increased by a factor of two / ten.

PHYSICAL OPTICS

■ In order to study simple phenomena, light can be usefully modelled as a ray travelling in a straight line. A more proper understanding can be achieved by considering light as a wave propagating with speed *c*. Reflection and refraction are equally well explained by both models, but only the wave theory can account for two fundamental features of light's behaviour: interference and diffraction.

■ Interference of light can be observed not only in Young's double slit experiment, but also in all situations in which very thin films of some transparent substance are formed, allowing the light waves reflected from the front and back surfaces to interfere.

■ Diffraction is an interference effect that can be explained with the aid of **Huygens' principle**:

every point on a wavefront acts as a source of tiny wavelets that propagates with the same speed as the source wave, and the wavefront at a later instant is the surface that is tangent to the wavelets.

■ When light passes through a single narrow slit and falls on a screen, a pattern of bright and dark fringes is formed by the superposition of Huygens' wavelets.

■ The effects of light diffraction must be taken into account when designing any optical instrument since diffraction affects the capacity to resolve, or distinguish, two distant point objects whose angular separation is small. The diffraction of light can most often be observed with diffraction gratings, which are easily encountered in everyday life. In a diffraction grating, a series of slits is used to split an incident wave into its component wavelengths by separating and displaying their diffraction maxima, thereby producing bright coloured patterns.

■ White light consists of light waves of different wavelengths, corresponding to different colours. It can be dispersed into its components colours when travelling through transparent materials – such as water droplets in the air to form rainbows – since the index of refraction depends on the wavelength of the light. These colour patterns are not to be confused with interference and diffraction patterns.

GLOSSARY AND RELEVANT EXPRESSIONS

narrow slits ▶ fenditure sottili
pattern ▶ configurazione
interference pattern ▶ figura d'interferenza
bright and dark fringes ▶ frange luminose e scure
crests and troughs ▶ creste e gole
wavelets ▶ onde elementari, piccole onde
diffraction grating ▶ reticolo di diffrazione
resolving power ▶ potere risolvente

Activities

1 Complete the following definitions with the words listed below.

crest-to-trough • optical • slits • spreading • wavelength • fringes • out of phase

- Two waves are in ..... when they are crest-to-crest or trough-to-trough.
- Two waves that are not in phase are ..... .
- A pattern of bright and dark ..... on a screen is called an interference pattern.
- The resolving power of an ..... instrument is its ability to distinguish between two closely spaced objects.
- A diffraction grating consists of a large number of parallel, closely spaced ..... .
- The ..... of light into its component colours is called dispersion.
- One important factor in thin-film interference is the thickness of the film relative to the ..... of the light impinging the film.

2 Order the following snippets of text to form a passage about the interference of light.

- In 1801,Young performed an historic experiment in which light, after
- interfere destructively to form
- a screen. What appears at each point on the screen in a Young's
- for the rays reaching the point. When ΔL is zero, or an integer number of wavelengths,
- to the principle of linear superposition,
- a bright fringe. When ΔL is an odd integer number of half-wavelengths,
- double slit interference experiment is determined by the path length difference ΔL
- the waves arrive exactly in phase at the common point on the screen and, according
- the waves interfere fully constructively there to create
- arrive at the common point on the screen exactly out of phase and
- a pattern of bright and dark fringes on
- a dark fringe.
- emerging from two narrow slits, formed

3 Complete the following sentences with the words listed below.

diffraction • interfere • bright • dark • fringes • criterion • undergoes • occurs • pattern

- Diffraction ..... because the wavelets emitted by the Huygens sources in the slit can ..... constructively or destructively.
- Light ..... diffraction when encountering an obstacle or the edges of an opening, like the circular openings that admit light into human eyes and optical instruments.
- The Rayleigh ..... says that two point objects are just resolved when the first ..... fringe in the diffraction ..... of one falls directly on the central ..... fringe in the diffraction pattern of the other.
- The ..... pattern created by a small circular opening consists of a bright circular region surrounded by alternating dark and bright circular ..... .

ELECTRIC CHARGE AND ELECTRIC FIELD

■ Electric charge is quantised, that is, any charge occurs in integer multiples of the elementary charge e, which is the magnitude of the charge of an electron or proton. During any process, the net electric charge of an isolated system is always conserved.

■ If two charged objects are near one another, they each exert an electrostatic force on the other, according to **Coulomb's law**:

the electrostatic force acting between two charged particles depends on the inverse square of the distance between the two particles, is directed along the line between them, and is proportional to the product of their charges.

■ We say that an electric charge creates an electric field in the space around it. In fact, if a second charge is located in that space, an electrostatic force acts on it. Thus, the electric field at any point is defined as the ratio of the electrostatic force – that would be exerted on a positive test charge placed there – to the charge itself.

■ If more than one charge sets up an electric field at a point, the net electric field is the vector sum of the individual electric field vectors, and can be visualised by field lines. The electric field at points on a closed surface is related to the net charge enclosed by that surface by **Gauss' law**:

the electric flux through a Gaussian surface is equal to the net charge enclosed by the surface divided by the permittivity of free space.

■ When point charges are arranged in a symmetrical fashion, it is often possible to deduce useful information about the field by taking advantage of symmetry and of Gauss' law.

GLOSSARY AND RELEVANT EXPRESSIONS

quantised ▶ quantizzato
electric field ▶ campo elettrico
integer multiples ▶ multipli interi
electric flux ▶ flusso del campo elettrico
field lines ▶ linee di forza del campo
permittivity of free space ▶ costante dielettrica del vuoto
to attract / to repel each other ▶ attrarsi / respingersi

Activities

1 Complete the following definitions with the words listed below.

point • closed • charged • component • conductors • proportionality • metals • set • any

- Conductors, such as ..... , are materials through which charge can move rather freely.
- Materials that are poor ..... of electric charge, such as rubber, plastic, glass, are called electrical insulators or dielectrics.
- An object can be charged either by placing it in contact with a second object that is already ..... or without touching the second charged object (charging by induction).
- The ..... constant in Coulomb's law is $1/4\pi\varepsilon_0$, the reciprocal of the product of four pi and the permittivity of free space.
- The electric field vector at ..... point is tangent to the field line at that point.
- Electric field vectors ..... up by a positively / negatively charged particle are directed radially outward / inward.
- The field set up by a ..... charge has spherical symmetry.
- A Gaussian surface is an imaginary ..... surface.
- Electric flux is the product of the ..... of the electric field that is perpendicular to a surface and the surface itself.

2 State whether the following statements are true or false. Rewrite the false ones in their correct form.

- The magnitude of the charge on a proton approximately equals the magnitude of the charge on an electron.
- An object with equal amounts of the two kinds of charge on protons and electrons is electrically neutral, and one with an imbalance is electrically charged.
- Charges of larger magnitude than the charge of an election are formed on an object by adding or removing protons.
- The greater the charges and the greater the distance between them, the greater the force that point charges exert on each other.
- The net force on a charged particle due to two or more other charged particles is the vector sum of the forces.
- Coulomb's law has a form that is remarkably similar to Newton's law of gravitation, but particles with the same sign of electric charge attract each other while particles with opposite signs repel each other.

3 Complete the following sentences using the properties of the electric field summarised above

- The electric field is a vector, and its direction is ..... the force on a positive test charge.
- The electric field created by a positive point charge is directed ..... .
- The field consists of a distribution of electric field vectors, one for ..... in the space around a charged object.
- The electric field vector is represented with an arrow with its tail anchored on the point where ..... .
- The ..... in a region is proportional to the magnitude of the electric field there, so that closer field lines represent a stronger ..... .

4 Choose the correct option from the pairs of words.

- Flux is a scalar / vector quantity involving both the electric field and the surface through which it passes.
- The SI unit of flux is the newton-square-metre on / per coulomb.
- Gauss' law is often used to find the magnitude / direction of the electric field produced by a distribution of charges.
- Gauss' law describes the fact that electric field lines originate on positive / negative charges and terminate on positive / negative charges.
- The electric field due to a charge outside a Gaussian surface never / always contributes to the net flux through the surface.
- Gauss' law is equivalent / analogous to Coulomb's law.

ELECTRIC POTENTIAL

■ Coulomb's law and Newton's equation for the gravitational force both describe inverse square laws – that is, a $1/r^2$ dependence. Like the gravitational force, the electrostatic force is conservative and an electric potential energy exists that is analogous to the gravitational potential energy.

■ The potential energy of a charge at a point *P* in a field is the negative of the work done by the forces of the field on the charge when it is brought from an infinite distance to that point.

■ The electric potential at the point *P* is the amount of electric potential energy per unit charge.

■ An excess charge placed on an isolated conductor will, in the equilibrium state, distribute itself on the surface of that conductor so that all points of the conductor, whether on the surface or inside, are at the same potential. The internal electric field of such a charged conductor is zero, while – as stated by **Coulomb's theorem** –

the external field at nearby points is perpendicular to the surface and has a magnitude that is proportional to the surface charge density.

■ A parallel-plate capacitor is a very common device consisting of two parallel metal plates. When the plates are charged, the potential difference between them is proportional to the charge and the proportionality constant is called the capacitance of the capacitor. The electric field existing between the plates is uniform.

■ The conservative nature of the electrostatic field is reflected in the shape of its field lines: they never form loops and hence

the electrostatic field has no circulation.

GLOSSARY AND RELEVANT EXPRESSIONS

capacitor ▶ condensatore; parallel-plate capacitor = condensatore piano
plate ▶ piastra, armatura
capacitance ▶ capacità
conductor ▶ conduttore (sostantivo)
conducting ▶ conduttore (aggettivo)
assumption ▶ assunto, ipotesi
to assume ▶ porre, assumere come ipotesi, postulare
connection in series / parallel ▶ collegamento in serie / in parallelo
loop ▶ linea o percorso chiuso
to store ▶ immagazzinare

Activities

1 Complete the following definitions with the words listed below.

infinity • sum • distance • closed • electric • at

- The points on an equipotential surface all have the same ..... potential.
- In a uniform electric field, the change in potential from one equipotential surface to another is the negative of the product of the field and the ..... between the surfaces.
- The electric potential due to a single charged particle q at a distance r from that charged particle is $V = kq/r$, with the arbitrary assumption that the potential at ..... is zero.
- The total potential energy of a system of charged particles is the ..... of the potential energies for every pair of particles in the system.
- A uniform field is one that has the same magnitude and direction ..... all points.
- The circulation of a vector field is the sum of the scalar products of the field itself and the displacement around a ..... path.

2 Complete the following sentences with appropriate words or expressions.

- If a particle with charge q is placed at a point where a charged object sets up an electric potential, the electric potential energy of the particle-object system is the product of ..... .
- If a particle moves through a potential difference, the change in potential energy is the product of ..... .
- If a charged particle moves through an electric field with only the electric force due to the field acting on it, then mechanical energy is ..... .
- When two or more charges are present, the potential due to all the charges is obtained by ..... .
- If a charge spontaneously moves from a region of higher electric potential toward a region of lower electric potential, the sign of that charge is ..... .

3 Choose the correct option from the pairs of expressions.

- A parallel-plate capacitor is made up of two plates separated by a certain distance, and the charges on the two surfaces have the same / opposite magnitude but the same / opposite signs.
- The capacitance is affected by the geometry of the plates and the dielectric constant of the material between them; it increases / decreases with the area of the plates and increases / decreases with their separation.
- The equivalent capacitance of two or more capacitors connected in parallel / series is calculated by adding the individual capacitances.
- The reciprocal of the equivalent capacitance of two or more capacitors connected in parallel / series is calculated by adding the reciprocals of the individual capacitances.
- The equivalent capacitance of a parallel / series of capacitances is less than the smallest capacitance in the combination.

DIRECT CURRENT CIRCUITS

■ Electrons can flow in conductors, such as metal wires, when a potential difference is applied. This flow of charge is known as electric current, even though, by convention, the current must be imagined as a flow of imaginary positive charge carriers moving in the opposite direction.

■ An emf device provides the potential difference. In direct-current circuits, the emf device is normally a battery, which does work on charges at the expenses of its internal chemistry.

■ The **first Ohm's law** reads as follows.

In conducting devices, the resulting current is proportional to the applied potential difference. The proportionality constant between V *and* i *is called the resistance of the device.*

■ The **second Ohm's law** describes the way in which the resistance of a conducting device depends on the geometry of the device, called resistor, and on its constituent material.

■ An electric circuit can contain several resistances, connected in series and in parallel. The flow of charge distributes itself among the resistances according to the law of conservation of charge, and is described by **Kirchhoff's current law or junction rule**:

the sum of the currents entering any junction must be equal to the sum of the currents leaving that junction.

■ Potential drops existing at various places in a circuit obey the law of conservation of energy, and are described by **Kirchhoff's voltage law or loop rule**:

the algebraic sum of the changes in potential existing in any loop of a circuit must be zero.

■ The energy lost by a charge while traversing a resistance is converted into the internal thermal energy of the resistor. The rate at which this conversion occurs is called dissipated power.

GLOSSARY AND RELEVANT EXPRESSIONS

electrical devices ▶ dispositivi elettrici, che funzionano utilizzando energia elettrica
wire ▶ filo (elettrico)
charge carriers ▶ portatori di carica
to provide ▶ fornire
negligible ▶ trascurabile
emf device ▶ generatore di forza elettromotrice o di corrente
direct current ▶ corrente continua
junction ▶ nodo
electrical grounding ▶ collegamento a terra

Activities

1 Complete the following definitions with the words listed below.

resistances • does • device • area • surface • length • reciprocals

- Electric current is defined as the amount of charge per unit time that crosses the imaginary ..... perpendicular to their motion.
- The resistance of a conducting wire is proportional to its length ..... and inversely proportional to its cross-sectional ....., and the proportionality constant is called resistivity.
- The emf, or electromotive force, of an emf device is the work per unit charge that the device ..... in moving charge between its terminals.
- The equivalent resistance that can replace a series combination of resistances is the sum of the ..... .
- The reciprocal of the equivalent resistance that can replace a parallel combination of resistances is the sum of the ..... of the individual resistances.
- The power, or rate of energy transfer, in an electrical ..... is the product of the current and the voltage.

2 Match the name of each element of a circuit to its description.

1. An electric circuit
2. A battery
3. A resistor
4. An emf device
5. A junction
6. Devices connected in parallel
7. Devices connected in series

a. maintains a certain potential difference between its terminals by means of internal electrochemical reactions.
b. have the same voltage applied across each of them.
c. a point where the wires for two branches are joined together.
d. a conductor with a specified resistance.
e. a path through which charge can flow.
f. have the same electric current through each them.
g. does work on charge carriers, maintains a potential difference between a pair of terminals and provides an electromotive force.

3 **Order the following snippets of text** to form a passage about energy transfers in circuits.

- An ideal emf device is one with no
- circuits, proper electrical grounding is necessary.
- other devices, in some other form, such as
- dissipated inside them. The emf device, usually a battery, creates an
- internal resistance. We also assume that wires in circuits have
- chemical reaction occurs that transfers energy to the
- electric field within and parallel to the wire, directed
- charge carriers passing through it. This energy will then be transferred from the charge carriers to
- from the positive to the negative terminal. Within the battery, a
- light, sound, or thermal energy. To reduce the danger inherent in using
- negligible resistance, so that no energy is

ELECTRIC CURRENT IN MATTER

■ When an external electric field is applied to a metal, the conduction electrons drift very slowly in a direction opposite to that of the field – with a drift speed that is several orders of magnitude less than their random-motion speed – producing an electric current. The variables needed to describe these microscopic motions can be related to some macroscopic properties of the metal, such as resistivity.

■ When an external electric field is applied to a polar dielectric, the electric dipoles tend to align with the external field. If the dielectric is non-polar, induced dipole moments are formed by the displacement of the centres of positive and negative charge in the molecules. In both cases, the alignment of the dipoles produces an electric field that opposes the applied field and makes it weaker.

■ When an external electric field is applied to a liquid, in which some kind of electrolyte is diluted, positive and negative ions resulting from the splitting of the electrolyte form a current consisting of both positive and negative carriers that move to the electrodes. This phenomenon is called electrolysis and obeys **Faraday's first and second laws of electrolysis**:

the amount of substance produced at each electrode is directly proportional to the number of electrons flowing and inversely proportional to the valence of the ions flowing.

■ When an electric field exists in a gas, electrical discharge occurs when the magnitude of the field exceeds a certain critical value. In this case, the electric field removes electrons from the atoms in the gas and sets them in motion.

GLOSSARY AND RELEVANT EXPRESSIONS

conduction electrons ▶ elettroni di conduzione
drift speed ▶ velocità di deriva
discharge ▶ scarica
time variation ▶ andamento in funzione del tempo
order of magnitude ▶ ordine di grandezza
dielectric breakdown ▶ scarica disruptiva nel dielettrico
time variation ▶ variazione in funzione del tempo

Activities

1 Complete the following definitions with the words listed below.

molecule • capacitor • electrodes • visible • electrically

- Electrostatic discharge is the sudden flow of charge between two ..... charged objects that are close together.
- Electrostatic discharge may cause the dielectric breakdown in a ....., may radiate ..... light in gases and may produce sparks in the air.
- Polar dielectrics are made up of molecules that have a permanent dipole moment, that is, each end of the ..... has a small excess of charge.
- Electrolysis is the passing of a direct electric current through an ionic substance, producing chemical reactions at the ..... .

2 Order the following snippets of text to form a paragraph about conduction electrons.

- Conduction electrons in a metal
- start drifting very slowly in the opposite direction to that of the field. The
- move with a single effective speed that
- is thus a superposition of the motion
- collide with the atoms of the metal and
- due to random collisions and the motion
- continue to move randomly, but also
- is very high and does not depend on the temperature. If an external electric field
- resulting motion of conduction electrons in an electric field
- is applied to the metal, the electrons not only
- due to the electric field.
- are free to move, just like the molecules of a gas. They often

3 Complete the following sentences with the words listed below.

across • dimensions • capacitor • current • rule • value • rate • time • charge • uncharged • constant • exponentially

- During the charging process of a capacitor, the current increases the ..... on the plates and the potential difference ..... the capacitor.
- The ..... variation of the charge can be obtained by applying the loop ..... to the circuit and solving the corresponding equation.
- The product *RC* has the ..... of time and is called the capacitive time ..... of the circuit.
- The ..... has the initial value emf/*R* and decreases to zero as the ..... becomes fully charged.
- During the time constant the charge on the initially ..... capacitor increases to 63% of its final ..... .
- When the capacitor discharges through the resistance, charge and current decrease ..... with time, at a ..... that is set by the time constant.

MAGNETIC FIELD

■ Magnets can exert forces on each other: like poles repel each other and unlike poles attract, but it is not possible to separate north from south poles and produce separate poles.

■ Surrounding a magnet, there is a **magnetic field** $\vec{B}$, which is defined in terms of the deflecting force it exerts on moving charges. This force is called the magnetic force or **Lorentz force**.

The Lorentz force is equal to the charge q *times the vector product of the velocity of the charge* $\vec{v}$ *and the magnetic field* $\vec{B}$:

$$\vec{F} = q\vec{v} \times \vec{B}$$

■ Magnetic field lines always form closed loops. This fact is expressed by **Gauss' law for magnetic fields**:

the net magnetic flux through any Gaussian surface is zero.

■ Since an electric current is a collection of moving charges, a current in the presence of a magnetic field also experiences a magnetic force. Any current-carrying wire of length L is acted upon by a force that is the net Lorentz force acting on the total charge moving in the wire:

$$\vec{F} = i\,\vec{L} \times \vec{B}$$

■ If the wire is shaped in the form of a loop, the magnetic force produces a torque that tends to rotate the loop, so that the loop's normal becomes aligned with the magnetic field. All electric motors operate according to this property.

■ A current-carrying wire not only experiences a sideways magnetic force, but it also produces a magnetic field of its own. The relationship between an electric current circulating in a wire of any geometrical shape and the magnetic field that it creates is described by **Ampere's law**:

the circulation of a magnetic field is equal to $\mu_0 i$, *where* i *is the net current passing through the surface bounded by the path.*

■ In the special case of a long, straight wire, **Biot-Savart's law** states that:

the magnetic field lines produced by the current are circles centred on the wire; the field magnitude is directly proportional to the current and inversely proportional to the radial distance from the wire.

GLOSSARY AND RELEVANT EXPRESSIONS

right hand rule ▶ regola della mano destra
loop ▶ giro, spira
coil ▶ bobina
bar magnet, horseshoe magnet ▶ magnete a barra, magnete a ferro di cavallo
permeability of free space ▶ permeabilità magnetica del vuoto
compass needle ▶ ago di una bussola

Activities

1 Complete the following definitions with the words listed below.

magnet • material • wire • parallel • scalar • tangential • direction • closed • carrying • constant

- As is the case with electric field lines, the magnetic field at any point is ..... to the magnetic field line at that point.
- The right hand rule gives the ..... of the magnetic field due to a current in a wire.
- Parallel wires ..... current in the same / opposite direction attract / repel each other.
- A solenoid is a long coil of ..... in the shape of a helix, in which the length is much greater than the diameter.
- The magnetic field in the interior of a solenoid is approximately ..... to the solenoid axis.
- The magnetic field lines in the neighbourhood of a bar ..... are very similar to those around a current carrying loop.
- The ..... μ_0 is called the permeability of free space.
- The magnetism induced in a ferromagnetic ..... can be surprisingly large, even in the presence of a weak external field.
- The circulation of a vector field is the sum of the ..... products of the field itself and the displacement around a ..... path of arbitrary shape.

2 Choose the correct option from the pairs of expressions.

- The direction of the magnetic force is parallel / perpendicular to the plane defined by the charge's velocity and the magnetic field.
- If a charge moves parallel or antiparallel to a magnetic field, the charge experiences no / the maximum possible magnetic force. If the charge moves perpendicular to the field, it experiences no / the maximum possible force. If a charge moves at an angle θ with respect to the field, only the velocity component $v\cos\theta$ / $v\sin\theta$, which is perpendicular to the field, gives rise to a magnetic force.
- The magnetic force / field is equal to zero if the particle is stationary.
- Since it is always perpendicular to the direction of the velocity, the magnetic force always does / cannot do work on the charged particle nor change its kinetic / potential energy. The force alters / does not alter the direction of motion, but the speed / velocity of the particle does not change.
- A charge travelling in a magnetic / an electric field experiences a deflecting force that is always perpendicular to the field. In contrast, a force applied by a magnetic / an electric field is always parallel to the field direction.

3 Complete the following sentences with the words listed below.

closed • greatest • weaker • spaced • south • passing • parallel • north • approximately • compass • closest • north

- The direction of the magnetic field at any point in space is indicated by the ..... pole of a small ..... needle at that point.
- The magnetic field near a bar magnet can be represented by magnetic field lines all ..... through the magnet and all forming ..... loops.
- The end of a magnet from which the field lines emerge is called the ..... pole of the magnet, while the field lines enter the magnet at its ..... pole.
- The Earth's magnetic field lines are ..... together near the north and south poles, reflecting the fact that the strength of the field is ..... in these regions. Away from the poles, the magnetic field becomes ..... .
- In a horseshoe magnet and in a magnet that has been bent into the shape of a C, the field lines in the gap between the poles are almost ..... and equally ....., indicating that the magnetic field there is ..... constant.