kinematics

motion in a straight line

● describe uniform straight-line (rectilinear) motion and uniformly accelerated motion through: – qualitative descriptions – the use of scalar and vector quantities (ACSPH060)

● conduct a practical investigation to gather data to facilitate the analysis of instantaneous and average velocity through: – quantitative, first-hand measurements – the graphical representation and interpretation of data (ACSPH061)

● calculate the relative velocity of two objects moving along the same line using vector analysis

● conduct practical investigations, selecting from a range of technologies, to record and analyse the motion of objects in a variety of situations in one dimension in order to measure or calculate: – time – distance – displacement – speed – velocity – acceleration

● use mathematical modelling and graphs, selected from a range of technologies, to analyse and derive relationships between time, distance, displacement, speed, velocity and acceleration in rectilinear motion, including:

– $s = ut + 1/2\ at^2$

– $v = u + at$

– $v^2 = u^2 + 2as$ (ACSPH061)

summary

Displacement is a measure of the change in position of an object, and a vector quantity. To fully describe any vector quantity, magnitude and direction must be specified. **Speed** is a measure of the rate at which an object moves over distance and is a scalar quantity. **Velocity** is the time rate of displacement and is a vector quantity.

When a velocity of an object it measured by a moving observer, it is referred to as the relative velocity. Relative velocity is the difference between the velocity of the object relative to the ground and the velocity of the observer relative to the ground.

Average speed=distance travelled/time interval

The average velocity of an object, vav during a time interval, t, can be expressed as vav=s/t. Instantaneous speed is the speed at a particular instant of time. Instantaneous velocity is the velocity at a particular instant of time. Acceleration is the rate at which an object changes its velocity. Acceleration is a vector quantity. The average acceleration of an object, aav can be expressed as aav=Δv/Δt where Δv = the change in velocity during the time interval Δt.

When the acceleration of an object is constant, the following formulae can be used to describe its motion:

$$v=u+at$$
$$s+1/2(u+v)t$$
$$s=ut+1/2at^2$$

The instantaneous velocity of an object can be found from a graph of its displacement versus time *by calculating the gradient of the graph*. The instantaneous speed can be found from a graph of its distance versus time by calculating the gradient of the graph. The displacement of an object during a time interval can be found by determining the area under its velocity-versus-time graph. The distance travelled by an object can be found by determining the area under its speed-versus-time graph. The instantaneous acceleration of an object can be found from a graph of its velocity versus time by calculating the gradient of the graph.

motion on a plane

- analyse vectors in one and two dimensions to: – resolve a vector into two perpendicular components – add two perpendicular vector components to obtain a single vector

- represent the distance and displacement of objects moving on a horizontal plane using: – vector addition – resolution of components of vectors (ACSPH060)

- describe and analyse algebraically, graphically and with vector diagrams, the ways in which the motion of objects changes, including: – velocity – displacement (ACSPH060, ACSPH061)

- describe and analyse, using vector analysis, the relative positions and motions of one object relative to another object on a plane (ACSPH061)

- analyse the relative motion of objects in two dimensions in a variety of situations, for example: – a boat on a flowing river relative to the bank, two moving cars – an aeroplane in a crosswind relative to the ground (ACSPH060, ACSPH132)

summary

A vector is represented by an arrowed line with a length that represents the magnitude of the vector quantity and that points in the direction that the quantity acts. Displacement, velocity and acceleration are all vector quantities and are given in terms of a magnitude and a direction.

A vector can be resolved into two independent, perpendicular components:

$$Vx = V \cos \theta, \text{ and } V_y = V \sin \theta$$

Two vectors are added by placing the tail of the second vector at the head of the first vector. The sum of the vectors is represented by a resultant vector, which is drawn from the tail of the first vector to the head of the last vector.

The horizontal and vertical components of the resultant vector are found by adding the horizontal and vertical components of the individual vectors being added.

In vector subtraction, the resultant of **A − B = A + (−B)** where **(−B)** has the same magnitude as B but is directed in the opposite direction. • Relative velocity is the velocity of an object as measured by a moving observer. The velocity of **A** relative to **B** ($V_{A \text{ relative } B}$) is found from the velocities of A and B relative to a stationary frame of reference: ($V_{A \text{ relative } B}$) = $V_A - V_B$

dynamics

forces

- using Newton's Laws of Motion, describe static and dynamic interactions between two or more objects and the changes that result from: – a contact force – a force mediated by fields

- explore the concept of net force and equilibrium in one-dimensional and simple two-dimensional contexts using: – algebraic addition – vector addition – vector addition by resolution into components

- solve problems or make quantitative predictions about resultant and component forces by applying the following relationships:

  – $\vec{F}_{AB} = -\vec{F}_{BA}$

  – $F_x = F\cos\theta$, $F_y = F\sin\theta$

- conduct a practical investigation to explain and predict the motion of objects on inclined planes

summary

Force is a *vector quantity*. Weight is a measure of the force on an object due to the pull of gravity, and the weight of an object is directly proportional to its mass.

The vector sum of the forces acting on an object is called the net force. The velocity of an object can only change if there is a non-zero net force acting on it. This statement is an expression of **Newton's First Law of Motion.**

When a non-zero net force acts on an object, it accelerates in the direction of the net force. Acceleration occurs when there is a change in speed and/or direction.

Inertia is the tendency of an object to resist a change in its motion. The forces acting on a moving vehicle are:

– weight, downwards

– the normal reaction force, applied perpendicular to the surface of the road

– the driving force, applied in the direction of motion by the road

– road friction, applied to the non-driving wheels opposite to the direction of motion

– air resistance, applied opposite to the direction of motion.

The motion of a vehicle depends on the net force acting on the vehicle.

Newton's Second Law of Motion describes the relationship between the acceleration of an object, the net force acting on it, and the object's mass. It can be expressed as

$$F_{net} = ma.$$

Newton's Second Law can be applied to a single object, or a system of multiple bodies that are in contact or connected together.

When an object applies a force (an action) to a second object, the second object applies an equal and opposite force (a reaction) to the first object. This statement is an expression of **Newton's Third Law of Motion**. The frictional force, F_f, acts between pairs of surfaces such that it opposes the relative motion of one surface across the other. The frictional force always acts parallel to the surface interface.

Ff = μR where μ is the coefficient of friction and R is the normal force.

forces, acceleration and energy

● apply Newton's first two laws of motion to a variety of everyday situations, including both static and dynamic examples, and include the role played by friction

$\vec{f}$ friction = μF

● investigate, describe and analyse the acceleration of a single object subjected to a constant net force and relate the motion of the object to Newton's Second Law of Motion through the use of: – qualitative descriptions – graphs and vectors – deriving relationships from graphical representations including

$\vec{F}$net = $m\vec{a}$

and relationships of uniformly accelerated motion

● apply the special case of conservation of mechanical energy to the quantitative analysis of motion involving:

– work done and change in the kinetic energy of an object undergoing accelerated rectilinear motion in one dimension ($W = F_{\parallel}s = Fs\cos\theta$)

– changes in gravitational potential energy of an object in a uniform field ($\Delta U = mg\Delta h$)

● conduct investigations over a range of mechanical processes to analyse qualitatively and quantitatively the concept of average power ($P = \Delta E/\Delta t$, $P = F_{\parallel}v = Fv\cos\theta$ including but not limited to: – uniformly accelerated rectilinear motion – objects raised against the force of gravity – work done against air resistance, rolling resistance and friction

summary

The Law of Conservation of Energy states that energy cannot be created or destroyed. **Work** is done when energy is transferred to or from an object by the action of a force. The work done on an object by a force is the product of the magnitude of the force and the magnitude of the displacement in the direction of the force.

All moving objects possess **kinetic energy**. The kinetic energy of an object can be expressed as

$$E_k = 1/2\ mv^2$$

The work done on an object by the net force is equal to the object's change in kinetic energy. The change in gravitational potential energy of an object near the Earth's surface can be expressed as

$$\Delta U_g = mg\Delta h$$

where Δh is the object's change in height.

Kinetic energy and gravitational potential energy are referred to as forms of mechanical energy. During a mechanical interaction, it is usually reasonable to assume that total mechanical energy is conserved. The efficiency of an energy transfer is calculated from the ratio: efficiency, η = useful energy out/ total energy in.

Power is the rate at which energy is transferred or transformed. In mechanical interactions, power is also equal to the rate at which work is done. The power delivered by a force is the product of the magnitude of the force and the velocity of the object on which the force acts.

momentum, energy and simple systems

● conduct an investigation to describe and analyse one-dimensional (collinear) and two-dimensional interactions of objects in simple closed systems

● analyse quantitatively and predict, using the law of conservation of momentum $\sum m\vec{v}_{before} = \sum m\vec{v}_{after}$ and, where appropriate, conservation of kinetic energy

$\sum 1\ 2\ mv^2_{before}\ 2 = \sum 1\ 2\ mv^2_{after}$, the results of interactions in elastic collisions

● investigate the relationship and analyse information obtained from graphical representations of force as a function of time

● evaluate the effects of forces involved in collisions and other interactions, and analyse quantitatively the interactions using the concept of impulse

$\Delta\vec{p} = \vec{F}_{net}\Delta t$

● analyse and compare the momentum and kinetic energy of elastic and inelastic collisions

summary

The **momentum** of an object is the product of its mass and its velocity. The **impulse** delivered to an object by a force is the product of the force and the time interval during which the force acts on the object. The impulse delivered by the net force on an object is equal to the change in momentum of the object:

$$F\Delta_t = {}_m\Delta_v$$

The impulse delivered by a force can be found by determining the area under a graph of the force versus time. The net force on a human body during a collision can be decreased by increasing the time interval during which its momentum changes. Vehicle safety features such as crumple zones, together with seatbelts and airbags, are designed to increase this time interval. Low-speed zones and speed humps encourage people to drive at lower speeds and, therefore, with less momentum- reducing the likelihood of injury when a collision does occur. •When two objects collide, the force applied by the first object on the second is equal and opposite to the force applied by the second object on the first.

Momentum is conserved in one-, two- and three-dimensional collisions.

The kinetic energy, E_k, of an object is proportional to its mass and the square of its velocity. Kinetic energy is measured in joules (J).

An inelastic collision is one in which only momentum is conserved, while an elastic collision is one in which both kinetic energy and momentum are conserved.

waves and thermodynamics

wave properties

● conduct a practical investigation involving the creation of mechanical waves in a variety of situations in order to explain: – the role of the medium in the propagation of mechanical waves – the transfer of energy involved in the propagation of mechanical waves

● conduct practical investigations to explain and analyse the differences between: – transverse and longitudinal waves – mechanical and electromagnetic waves

● construct and/or interpret graphs of displacement as a function of time and as a function of position of transverse and longitudinal waves, and relate the features of those graphs to the following wave characteristics: – velocity – frequency – period – wavelength – displacement and amplitude

● solve problems and/or make predictions by modelling and applying the following relationships to a variety of situations:

$$– v = f\lambda – f = 1\ T$$

summary

Waves can be categorised as:

– mechanical waves, consisting of particles with energy, which do require a medium for propagation

– electromagnetic waves, which do not require a medium for propagation. •

A wave consists of two motions:

1. a uniform motion in the direction of wave travel; this is the direction of energy transfer
2. a vibration of particles or fields about an equilibrium or central point.

The vibration disturbance component of the wave may occur:

– at right angles (90°) to the direction of propagation; these waves are called transverse waves

– in the same direction as the direction of propagation; these waves are called longitudinal waves.

For transverse and longitudinal waves,

$$v = f\lambda \text{ and } f = 1/T$$

•Waves transmit energy but do not transfer matter. Properties of waves that can be measured include speed, wavelength, period, amplitude, wave number and frequency. A **displacement-time graph** represents a wave as a function of time for a specific location in the medium. A **displacement-position graph** represents the wave as a function of position at a specific moment in time.

wave behaviour

● explain the behaviour of waves in a variety of situations by investigating the phenomena of: – reflection – refraction – diffraction – wave superposition

● conduct an investigation to distinguish between progressive and standing waves

● conduct an investigation to explore resonance in mechanical systems and the relationships between: – driving frequency – natural frequency of the oscillating system – amplitude of motion – transfer/transformation of energy within the system

summary

Superposition is the adding together of amplitudes of two or more waves passing through the same point. **Destructive interference** is the addition of two wave disturbances to give an amplitude that is less than either of the two waves. **Constructive interference** describes the addition of two wave disturbances to give an amplitude that is greater than either of the two waves.

Reflection is the returning of the wave into the medium in which it was originally travelling. When a wave strikes a barrier or comes to the end of the medium in which it is travelling, at least a part of the wave is reflected. **Standing waves** are caused by the superposition of two wave trains of the same frequency travelling in opposite directions.

Nodes are points on a standing wave that undergo the least disturbance, while antinodes form where the medium undergoes the most disturbance. Diffraction is the spreading out, or bending of, waves as they pass through a small opening or move past the edge of an object.

Refraction describes the change in the direction of travel that occurs when waves enter a medium through which they travel at a different speed.

Resonance is the condition where a medium responds to a periodic external force by vibrating with the same frequency as the force.

sound waves

● conduct a practical investigation to relate the pitch and loudness of a sound to its wave characteristics

● model the behaviour of sound in air as a longitudinal wave

● relate the displacement of air molecules to variations in pressure

● investigate quantitatively the relationship between distance and intensity of sound

● conduct investigations to analyse the reflection, diffraction, resonance and superposition of sound waves

● investigate and model the behaviour of standing waves on strings and/or in pipes to relate quantitatively the fundamental and harmonic frequencies of the waves that are produced to the physical characteristics (e.g. length, mass, tension, wave velocity) of the medium

● analyse qualitatively and quantitatively the relationships of the wave nature of sound to explain:

– beats $f_{\text{beat}} = |f2 - f1|$
– the Doppler effect $f' = f(v\text{wave}+v\text{observer}) / (v\text{wave}-v\text{source})$

summary

Sound waves are vibrations of particles in a medium. **Compressions** relate to the crests of a transverse wave and rarefactions relate to the troughs of a transverse wave. The pitch of a sound wave increases as the frequency of the sound wave increases. The amplitude of a sound wave increases as the sound's volume grows louder.

An **echo** is a reflection of a sound wave. Waves can interfere when they come into contact. This can result in the amplitude of the waves increasing if the waves are in phase or decreasing if the waves are out of phase. The addition of waves is called superposition.

Beats occur when sound waves that are close but not identical in frequency are played at the same time. The beat frequency is equal to the difference in the frequencies of the two sound waves:

$$f_{beat} = |f2 - f1|$$

Sound waves can be studied with a cathode-ray oscilloscope (CRO) or cathode-ray oscilloscope simulator application. Different musical instruments produce sound waves that produce different shaped traces on a CRO.

The Doppler effect is the result of a wave source moving through the medium. The waves move at constant speed relative to the medium, resulting in a higher frequency in front of the moving source and a lower frequency behind. For an observer and a source moving towards each other, the effective frequency heard by the observer is

$$f' = f(v + v_o) / (v - v_s)$$

For an observer and a sound source moving away from each other $f' = f(v + v_o) / (v - v_s$, where v is the speed of sound in the medium, v_o is the speed of the observer and v_s is the speed of the source.

The intensity (I) of a sound is the acoustic power per unit area at a point separated from the sound source by a distance d, and it is measured in

$$W\ m^{-2}: I = P / 4\pi d2$$

The intensity level (L) of a sound is measured in decibels (dB): L = 10 log (I / I_0) where I_0 is the intensity of the softest audible sound (10^{-12} W m^{-2}).

The **fundamental frequency,** f_0, of a string or pipe is the lowest frequency at which a standing wave occurs. **Harmonics** are whole number multiples of the fundamental frequency. **Resonant frequencies** are frequencies above the fundamental frequency at which resonance occurs.

Stringed instruments form standing waves that have a node at each end. A closed pipe will form a pressure node at its open end and a pressure antinode at its closed end. An open pipe will form pressure nodes at both ends. **Pitch** is a qualitative measurement of frequency. **Timbre** is a qualitative measure of the complexity of sound produced by an instrument. It is dependent upon the number of harmonic frequencies that are produced.

ray model of light

- conduct a practical investigation to analyse the formation of images in mirrors and lenses via reflection and refraction using the ray model of light
- conduct investigations to examine qualitatively and quantitatively the refraction and total internal reflection of light
- predict quantitatively, using Snell's Law, the refraction and total internal reflection of light in a variety of situations
- conduct a practical investigation to demonstrate and explain the phenomenon of the dispersion of light
- conduct an investigation to demonstrate the relationship between inverse square law, the intensity of light and the transfer of energy
- solve problems or make quantitative predictions in a variety of situations by applying the following relationships to:
  – $n_x = c / v_x$ – for the refractive index of medium x, v_x is the speed of light in the medium
  – $n1 \sin\theta 1 = n2 \sin\theta 2$ (Snell's Law)
  – $\sin\theta_c = n2 / n1$
  – $I_1 r_1{}^2 = I_2 r2 / 2$ – to compare the intensity of light at two points, $r1$ and $r2$

summary

The ray model depicts light as straight lines in a uniform medium. All electromagnetic waves travel at the same speed in a vacuum and are slowed down when they enter any other media. The **speed of light in a vacuum** is 299 792 458 m s^{-1}, usually approximated to 3 × 108 m s^{-1}.
A luminous body is one that can directly produce light. A body that produces light when heated is said to be incandescent. A non-luminous or illuminated body is one that does not itself produce light but reflects it from another source of light. The **incident ray, reflected ray and the normal to the surface all lie in the same plane**. The absolute refractive index of a transparent medium is the ratio of the speed of light in a vacuum to the speed of light in the medium. The refractive index is always larger than 1.

A **transparent** material is one through which an object may be clearly seen. A **translucent** material allows light through it but does not allow an object to be seen coherently through it. An **opaque** material is one through which light cannot pass at all.

A material may reflect, transmit or absorb light, or a combination of these, depending upon the nature of the material.

The Law of Reflection: the angle of incidence is equal to the angle of reflection. A **concave** (converging) mirror reflects parallel light rays so that they converge on the focal plane of the mirror. A **convex** (diverging mirror) reflects parallel light rays so that they spread out.
Light is refracted when it passes between different transparent materials. The degree of refraction is described by Snell's Law:

$$n1 / \sin i = n2 / \sin r$$

A **lens** is a device made from a transparent medium that allows the refraction of light to be controlled. **A converging lens** is thicker in the middle than at the edges. Parallel rays passing through a converging lens coincide at the focus of the lens. A diverging lens is thicker at its edges than in its middle. Parallel rays passing through a diverging lens spread out so that they appear to originate at a point on the focal plane nearest the object.
The focal length of a lens depends upon the curvature of the faces and the refractive index of the medium from which it is made. The **object distance** (u) for lenses is assumed to be positive. The **image distance** (v) is negative for virtual images and positive for real images.
A converging lens has a positive focal length, f, while a diverging lens has a negative focal length.
The position of an image formed by thin lenses can be determined by accurate ray tracing and by using the thin lens equation: $1/ f = 1 / u + 1 / v$

thermodynamics

- explain the relationship between the temperature of an object and the kinetic energy of the particles within it
- explain the concept of thermal equilibrium

- analyse the relationship between the change in temperature of an object and its specific heat capacity through the equation $Q = mc\Delta T$
- investigate energy transfer by the process of: – conduction – convection – radiation
- conduct an investigation to analyse qualitatively and quantitatively the latent heat involved in a change of state
- model and predict quantitatively energy transfer from hot objects by the process of thermal conductivity
- apply the following relationships to solve problems and make quantitative predictions in a variety of situations:
  – $Q = mc\Delta T$, where c is the specific heat capacity of a substance
  – $Q / t = kA\Delta T / d$ where k is the thermal conductivity of a material

summary

A thermometer measures temperature, and various properties of materials can be used to make one. There are different temperature scales, with **Celsius** and **Kelvin** being the common ones. Temperatures in one scale can be converted to any other.

The **kinetic particle model of matter** explains heat phenomena. **Internal energ**y is the energy associated with the random movement of molecules and it comes in many forms, including translational kinetic energy, rotational and vibrational kinetic energy, and potential energy.

Temperature is a measure of the average translational kinetic energy of the atoms and molecules in a substance. Objects at different temperatures, if placed in contact, will reach a common temperature. This process is called **thermal equilibrium** and is described as the Zeroth Law of Thermodynamics.

The First Law of Thermodynamics states that if energy is transferred to or from a system, then the total energy must be conserved, with any changes in the internal energy of the system given by

$$\Delta U = Q - W$$

where ΔU is the change in internal energy, Q is the heat added to the system and W is the work done by the system.

The **specific heat capacity**, c, of a substance is the amount of energy required to increase the temperature of 1kg of the substance by 1°C. When substances of different specific heat capacities and different temperatures are mixed, the final temperature can be determined by using the conservation of energy and the relationship

$$Q = m\,c\,\Delta T$$

for each substance.

The **latent heat**, L, of a substance is the amount of energy required to change the state from solid to liquid or liquid to gas of 1kg of the substance. For a substance of mass mkg, the energy required is given by Q = m L.

Evaporation of a liquid occurs because some of the faster particles have sufficient energy and speed to break free of the surface. The removal of these particles lowers the overall average kinetic energy of the remaining particles and consequently the temperature of the liquid.

Heat energy can be transferred by conduction, convection and radiation. **Conduction** is the transfer of heat energy through a material by collisions between adjacent particles. Some materials conduct heat energy well and are called conductors. Others do not and are called insulators. The thermal conductivity constant is a measure of how well a material conducts heat energy.

The rate of heat transfer through a material can be calculated using the equation

$$Q / t = k A\Delta T / d$$

Convection is the transfer of heat energy through a substance, usually a liquid or a gas, by the movement of particles between regions of different temperature. Hotter material is less dense because faster moving particles push each other further apart. If free to move, the less dense and hotter material will rise, displacing cooler material.

Radiation is the transfer of heat energy by the emission of electromagnetic radiation. The emitted radiation comes from a range of wavelengths across the electromagnetic spectrum. The graph of the energy contribution of different wavelengths of emitted radiation has a characteristic shape. For a given temperature, there is a specific wavelength at which the most energy is emitted. Its symbol is λ_{max}. The graph of the energy contribution of different wavelengths for a higher temperature has a lower λ_{max} and a larger area under the graph. The amount of energy emitted per second is called power.

electricity and magnetism

electrostatics

- conduct investigations to describe and analyse qualitatively and quantitatively: – processes by which objects become electrically charged– the forces produced by other objects as a result of their interactions with charged objects– variables that affect electrostatic forces between those objects
- using the electric field lines representation, model qualitatively the direction and strength of electric fields produced by: – simple point charges – pairs of charges – dipoles – parallel charged plates
- apply the electric field model to account for and quantitatively analyse interactions between charged objects using:
  – $\vec{F} = q\vec{E}$
  – $E = V / d$
  – $F = 1 / 4\pi\varepsilon 0 \quad q1q2 / r2$
- analyse the effects of a moving charge in an electric field, in order to relate potential energy, work and equipotential lines, by applying:
  – $V = \Delta U / q$ where U is potential energy and q is the charge

summary

Protons have a **positive** electric charge; **electrons** have a **negative** electric charge**. Like charges repel; unlike charges attract**.

The SI unit of charge is the **coulomb** (C).

Positively charged bodies have a deficiency of electrons; negatively charged bodies have an excess of electrons. Bodies can be given electrostatic charges by **friction, contact and induction**.

An **electric field** is a region where an electric charge experiences a force.

The **electric force** between two objects with charges q1 and q2 separated by a distance of r metres is given by

$$F = k\, q1q2 / r2 \text{ where } k = 1 / 4\pi\varepsilon 0$$

This equation is called **Coulomb's Law**, and k = 9 × 109 N m2C–2 in air.

Every electric charge is surrounded by an electric field E. The electric field strength at a point is defined as the force per unit charge on a positive charge placed at that point: E = F / q

The direction of the electric field strength at a point is the direction of the force on a positive charge placed at the point.

The direction of the electric field surrounding a positive charge is away from the charge; the direction of the electric field surrounding a negative charge is towards the charge.
A charge in an electric field has **electric potential energy**. When a positive charge moves in the direction of an electric field, its electric potential energy decreases. When a negative charge moves in the opposite direction to an electric field its electric potential energy decrease.
The potential difference between two points in an electric field is the change in electric potential energy per coulomb when a charge moves between the two points:

$$V = \Delta U / q$$

The SI unit of potential difference is the volt. One volt is equivalent to one joule per coulomb.
A uniform electric field exists between two metal plates connected to a DC supply. The strength of the electric field, E, is given by the voltage drop or potential difference across the plates, V, over the plate separation,

d: $E = V / d$

electric circuits

● investigate the flow of electric current in metals and apply models to represent current, including:

– $I = q / t$

● investigate quantitatively the current–voltage relationships in ohmic and non-ohmic resistors to explore the usefulness and limitations of Ohm's Law using:

– $W = qV$
– $V = IR$

● investigate quantitatively and analyse the rate of conversion of electrical energy in components of electric circuits, including the production of heat and light, by applying $P = VI$ and $E = Pt$ and variations that involve Ohm's Law

● investigate qualitatively and quantitatively series and parallel circuits to relate the flow of current through the individual components, the potential differences across those components and the rate of energy conversion by the components to the laws of conservation of charge and energy, by deriving the following relationships:

– $\Sigma I = 0$ (Kirchhoff's current law – conservation of charge)
– $\Sigma V = 0$ (Kirchhoff's voltage law – conservation of energy)
– RSeries = R1 +R2+...+ Rn
– 1 / RParallel = 1 / R1 + 1 / R2 +...+ 1 / Rn

● investigate quantitatively the application of the law of conservation of energy to the heating effects of electric currents, including the application of $P = VI$ and variations of this involving Ohm's Law

summary

An **electric current** is a net movement of electric charge. The SI unit of current is the **ampere** (A). One ampere is equivalent to one coulomb per second: I = q / t
Metals are electrical conductors because they have free electrons that act as charge carriers. **Insulators** are materials that have no charge carriers and, therefore, cannot carry an electric current. **The potential difference (voltage)** between the terminals of a power supply is the number of joules of electric potential energy given to each coulomb of electric charge:

$$V = W / q$$

If a conductor connects the terminals of a power supply, a current will flow through the conductor. The movement of electrons is from the negative to the positive terminal of the power supply. The conventional current direction is from the positive to the negative terminal of the power supply. A resistor is a conductor that resists the movement of the current through it. When current flows through a resistor, electric potential energy is dissipated as heat energy: $W = I^2 R$.

The potential difference (voltage) between the ends of a resistor is the number of joules of electric potential energy dissipated for each coulomb of charge that passes through the resistor. The resistance of a resistor is equal to the potential difference across the resistor divided by the current passing through the resistor:

$$R = V / I$$

The SI unit of resistance is the ohm (Ω).

The resistance of a resistor depends on length, cross-section area, material and temperature:

$$R = \rho L / A$$

at constant temperature.

An **ammeter** is used to measure current and is connected into a circuit in series. A **voltmeter** is used to measure electric potential difference and is connected into a circuit in parallel.

When resistors are connected in series to a power supply, the same current passes through each resistor and through the power supply. When resistors are connected in series to a power supply, the sum of the voltage drops across the resistors equals the voltage rise across the power supply. When resistors are connected in parallel to a power supply, the sum of the currents through the resistors equals the current through the power supply. When resistors are connected in parallel to a power supply, the voltage drop across each resistor equals the voltage rise across the power supply.

Non-ohmic devices such as LDRs, LEDs, diodes and thermistors do not obey Ohm's Law. Circuits containing non-ohmic devices can be analysed using the rules for series and parallel circuits with their voltage–current characteristic graphs.

The total power used in a circuit equals the sum of the powers used in individual devices.

A voltage divider is used to reduce an input voltage to some required value. A voltage divider consists of two or more resistors arranged in series to produce a smaller voltage at its output. The output of a voltage divider can be calculated using the equation:

$$V_{out} = [R2 / R1 + R2]\ V_{in}$$

magnetism

- investigate and describe qualitatively the force produced between magnetised and magnetic materials in the context of ferromagnetic materials
- use magnetic field lines to model qualitatively the direction and strength of magnetic fields produced by magnets, current-carrying wires and solenoids and relate these fields to their effect on magnetic materials that are placed within them
- conduct investigations into and describe quantitatively the magnetic fields produced by wires and solenoids, including:
  - $B = \mu 0 I / 2\pi r$
  - $B = \mu 0 N I / L$
- investigate and explain the process by which ferromagnetic materials become magnetised
- apply models to represent qualitatively and describe quantitatively the features of magnetic fields

summary

Like magnetic poles repel; unlike magnetic poles attract.

The direction of a magnetic field is the direction of the force that acts on a very small north pole placed in the field. Magnetic fields point away from north poles and towards south poles. **Magnetic field lines** are used to represent magnetic fields.
An electric current in a long, straight wire produces a magnetic field represented by field lines in the form of concentric circles around the wire. The right-hand grip rule relates the direction of the current in a wire to the direction of the magnetic field.
The magnetic field produced by a current in a **solenoid** is similar to that produced by a magnet. **An electromagnet consists of a solenoid with a soft iron core**. When current flows through the solenoid, the soft iron core becomes strongly magnetised.
A magnetic field exerts a force on a wire carrying an electric current. When the magnetic field and electric current are perpendicular to each other, the magnitude of the force can be calculated using the formula

$$F = ILB$$

The magnetic field affects moving charge as if it were an electric current in a wire. The force by a magnetic field on a moving charged particle is always at right angles to the direction the particle is heading. The force constantly changes the direction of travel, producing a circular path.
The size of the magnetic force on a moving charged particle is equal to qvB, where q and v are the charge and speed of the particle respectively, and B is the strength of the magnetic field.