Rotational motion and astrophysics Mandatory content	Suggested activities
Kinematic relationships	
Knowledge that differential calculus notation is used to represent rate of change. Knowledge that velocity is the rate of change of displacement with time, acceleration is the rate of change of velocity with time, and acceleration is the second differential of displacement with time. Derivation of the equations of motion $v = u + at$ and $s = ut + \frac{1}{2}at^2$, using calculus methods. Use of calculus methods to calculate instantaneous displacement, velocity and acceleration for straight line motion with a constant or varying acceleration. Use of appropriate relationships to carry out calculations involving displacement, velocity, acceleration, and time for straight line motion with constant or varying acceleration.	

Rotational motion and astrophysics Mandatory content	Suggested activities
Kinematic relationships (continued)	
$v = \frac{ds}{dt}$ $a = \frac{dv}{dt} = \frac{d^2s}{dt^2}$ $\left.\begin{array}{l} v = u + at \\ s = ut + \frac{1}{2}at^2 \\ v^2 = u^2 + 2as \end{array}\right\}$ for constant acceleration only	
Knowledge that the gradient of a curve (or a straight line) on a motion-time graph represents instantaneous rate of change, and can be found by differentiation. Knowledge that the gradient of a curve (or a straight line) on a displacement-time graph is the instantaneous velocity, and that the gradient of a curve (or a straight line) on a velocity-time graph is the instantaneous acceleration.	
Knowledge that the area under a line on a graph can be found by integration. Knowledge that the area under an acceleration-time graph between limits is the change in velocity and that the area under a velocity-time graph between limits is the displacement.	Using motion sensors, data logging and video analysis to enable graphical representation of motion.

Rotational motion and astrophysics Mandatory content	Suggested activities
Kinematic relationships (continued)	
Determination of displacement, velocity or acceleration by the calculation of the gradient of the line on a graph or the calculation of the area under the line between limits on a graph.	
Angular motion	
Use of the radian as a measure of angular displacement. Conversion between degrees and radians. Use of appropriate relationships to carry out calculations involving angular displacement, angular velocity, angular acceleration, and time.	Introduce angular motion by considering the rotational equivalents of displacement, velocity and acceleration. Experiment to determine the average angular velocity of a rotating object.

Rotational motion and astrophysics Mandatory content	Suggested activities
Angular motion (continued)	
$\omega = \frac{d\theta}{dt}$ $\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$ $\left.\begin{array}{l}\omega = \omega_o + \alpha t \\ \omega^2 = \omega_o^2 + 2\alpha\theta \\ \theta = \omega_o t + \frac{1}{2}\alpha t^2\end{array}\right\}$ for constant angular acceleration only Use of appropriate relationships to carry out calculations involving angular and tangential motion. $s = r\theta$ $v = r\omega$ $a_t = r\alpha$	Experiment to determine the angular acceleration of an object rotating with constant angular acceleration.

Rotational motion and astrophysics **Mandatory content**	**Suggested activities**
Angular motion (continued)	
Use of appropriate relationships to carry out calculations involving constant angular velocity, period and frequency. $\omega = \frac{2\pi}{T}$ $\omega = 2\pi f$ Knowledge that a centripetal (radial or central) force acting on an object is necessary to maintain circular motion, and results in centripetal (radial or central) acceleration of the object. Use of appropriate relationships to carry out calculations involving centripetal acceleration and centripetal force. $a_r = \frac{v^2}{r} = r\omega^2$ $F = \frac{mv^2}{r} = mr\omega^2$	Investigate factors that determine size of centripetal (radial or central) force required to maintain circular motion. Experiment to verify the relationship $F = mr\omega^2$ Consider centripetal forces acting in 'loop-the-loop' experiments, conical pendulum aircraft banking, cycle velodromes, and theme park rides.

Rotational motion and astrophysics Mandatory content	Suggested activities
Rotational dynamics	
Knowledge that an unbalanced torque causes a change in the angular (rotational) motion of an object.	
Definition of moment of inertia of an object as a measure of its resistance to angular acceleration about a given axis.	Compare mass of an object (measured on a balance) with its inertial mass (determined using a wig-wag machine).
Knowledge that moment of inertia depends on mass and the distribution of mass about a given axis of rotation.	
Use of an appropriate relationship to calculate the moment of inertia for a point mass. $I = mr^2$	
Use of an appropriate relationship to calculate the moment of inertia for discrete masses. $I = \sum mr^2$	Experiment using a variable inertia bar.
Use of appropriate relationships to calculate the moment of inertia for rods, discs and spheres about given axes.	Compare qualitatively the calculated moment of inertia of different objects with the torque required to change their rotational motion.

Rotational motion and astrophysics Mandatory content	Suggested activities
Rotational dynamics (continued)	
rod about centre $I = \frac{1}{12}ml^2$ rod about end $I = \frac{1}{3}ml^2$ disc about centre $I = \frac{1}{2}mr^2$ sphere about centre $I = \frac{2}{5}mr^2$	
Use of appropriate relationships to carry out calculations involving torque, perpendicular force, distance from the axis, angular acceleration, and moment of inertia. $\tau = Fr$ $\tau = I\alpha$	Investigate the relationship between the torque applied to a turntable and the angular acceleration of the turntable. Consider the operation of a torque wrench. Consider the meaning of the term engine torque.
Use of appropriate relationships to carry out calculations involving angular momentum, angular velocity , moment of inertia, tangential velocity, mass and its distance from the axis.	

Rotational motion and astrophysics Mandatory content	Suggested activities
Rotational dynamics (continued)	
$L = mvr = mr^2\omega$ $L = I\omega$ Statement of the principle of conservation of angular momentum.	Determination of the moment of inertia of an object from a graph, drawn using experimental data, of angular acceleration against applied torque.
Use of the principle of conservation of angular momentum to solve problems. Use of appropriate relationships to carry out calculations involving potential energy, rotational kinetic energy, translational kinetic energy, angular velocity, linear velocity, moment of inertia, and mass. $E_{k\ (\text{rotational})} = \frac{1}{2}I\omega^2$ $E_P = E_{k\ (\text{translational})} + E_{k\ (\text{rotational})}$	Experiment to determine the angular momentum of a point mass m rotating at velocity v and distance r about an axis. (Mass on end of string.) Experiment to verify the principle of conservation of angular momentum. Experiment to demonstrate the conservation of angular momentum using a rotating platform, added mass and a data logger to plot a graph of angular velocity against time. Demonstrate the conservation of angular momentum using a person rotating on an office chair, with arms pulled in and then extended.

Rotational motion and astrophysics Mandatory content	Suggested activities
Rotational dynamics (continued)	
	Consider the application of the principle of conservation of angular momentum in gyroscopes, bicycle wheels, spinning tops, ice skaters, divers, and gymnasts. Experiment to determine the moment of inertia of a cylinder rolling down a slope. Experiment to determine the moment of inertia of a flywheel. Compare the motions of a solid cylinder and a hollow cylinder, of the same radius and mass, rolling down a slope. Consider the increase in rotational kinetic energy when a rotating system increases angular velocity, for example work done by a skater pulling their arms inwards.
Gravitation	
Conversion between astronomical units (AU) and metres and between light-years (ly) and metres. Definition of gravitational field strength as the gravitational force acting on a unit mass. Sketch of gravitational field lines and field line patterns around astronomical objects and astronomical systems involving two objects.	Consider Maskelyne's Schiehallion experiment. Consider Cavendish/Boys experiment. Consideration of the effects of the force of gravity on tides, tidal forces and sustainable tidal energy.

Rotational motion and astrophysics Mandatory content	Suggested activities
Gravitation (continued)	
Use of an appropriate relationship to carry out calculations involving gravitational force, masses and their separation. $F = \frac{GMm}{r^2}$	
Use of appropriate relationships to carry out calculations involving period of satellites in circular orbit, masses, orbit radius, and satellite speed. $F = \frac{GMm}{r^2} = \frac{mv^2}{r} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$	Consider the relationship between the force of gravity and the orbital altitude and period of a satellite. Consider the altitude and orbital periods of different types of satellite, for example data gathering, weather, telecommunications, mapping and surveying.
Definition of the gravitational potential of a point in space as the work done in moving unit mass from infinity to that point. Knowledge that the energy required to move mass between two points in a gravitational field is independent of the path taken.	
Use of appropriate relationships to carry out calculations involving gravitational potential, gravitational potential energy, masses and their separation.	Consideration of gravitational potential and gravitational potential energy having the value zero at infinity and of gravitational potential wells used as an illustration of the capture of masses.

Rotational motion and astrophysics Mandatory content	Suggested activities
Gravitation (continued)	
$V=-\frac{GM}{r}$ $E_P=Vm=-\frac{GMm}{r}$ Definition of escape velocity as the minimum velocity required to allow a mass to escape a gravitational field to infinity, where the mass achieves zero kinetic energy and maximum (zero) potential energy. Derivation of the relationship $v_{esc}=\sqrt{\frac{2GM}{r}}$. Use of an appropriate relationship to carry out calculations involving escape velocity, mass and distance. $v_{esc}=\sqrt{\frac{2GM}{r}}$.	Consider changes in potential, potential energy and kinetic energy when the altitude of a satellite changes. Consider the link between the composition of a planet's atmosphere and its escape velocity. For example, consideration of the low abundance of helium in Earth's atmosphere. Consider the implications of the escape velocity of a planet for space flight.
General relativity	
Knowledge that special relativity deals with motion in inertial (non-accelerating) frames of reference and that general relativity deals with motion in non-inertial (accelerating) frames of reference.	Compare the implications of general relativity and special relativity.

Rotational motion and astrophysics Mandatory content	Suggested activities
General relativity (continued)	
Statement of the equivalence principle (that it is not possible to distinguish between the effects on an observer of a uniform gravitational field and of a constant acceleration) and knowledge of its consequences. Consideration of spacetime as a unified representation of three dimensions of space and one dimension of time. Knowledge that general relativity leads to the interpretation that mass curves spacetime, and that gravity arises from the curvature of spacetime. Knowledge that light or a freely moving object follows a geodesic (the path with the shortest distance between two points) in spacetime.	View videos showing simulations of the effects of general relativity and special relativity. Consider clocks in non-inertial frames of reference, for example accelerating spacecraft, and the application of the equivalence principle. This leads to the conclusion that, for a distant observer, time runs more slowly at lower altitudes than at higher altitudes in a gravitational field. (This explains the need for GPS clock adjustment.) Consider the reasons for the precession of the perihelion of Mercury.
Representation of world lines for objects which are stationary, moving with constant velocity and accelerating.	Use a rubber sheet and masses to demonstrate the effect of masses on spacetime.
Knowledge that the escape velocity from the event horizon of a black hole is equal to the speed of light.	View videos showing simulations of black holes.
Knowledge that, from the perspective of a distant observer, time appears to be frozen at the event horizon of a black hole.	Consider the phenomenon of gravitational lensing.

Rotational motion and astrophysics Mandatory content	Suggested activities
General relativity (continued)	
Knowledge that the Schwarzschild radius of a black hole is the distance from its centre (singularity) to its event horizon. Use of an appropriate relationship to solve problems relating to the Schwarzschild radius of a black hole. $r_{Schwarzschild} = \frac{2GM}{c^2}$	
Stellar physics	
Use of appropriate relationships to solve problems relating to luminosity, apparent brightness b, distance between the observer and the star, power per unit area, stellar radius, and stellar surface temperature. (Using the assumption that stars behave as black bodies.) $b = \frac{L}{4\pi d^2}$ $\frac{P}{A} = \sigma T^4$ $L = 4\pi r^2 \sigma T^4$	

Rotational motion and astrophysics Mandatory content	Suggested activities
Stellar physics (continued)	
Knowledge that stars are formed in interstellar clouds when gravitational forces overcome thermal pressure and cause a molecular cloud to contract until the core becomes hot enough to sustain nuclear fusion, which then provides a thermal pressure that balances the gravitational force. Knowledge of the stages in the proton-proton chain (p-p chain) in stellar fusion reactions which convert hydrogen to helium. One example of a p-p chain is: $^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{+1}e + \nu_e$ $^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \gamma$ $^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2{}^{1}_{1}H$ Knowledge that Hertzsprung-Russell (H-R) diagrams are a representation of the classification of stars. Classification of stars and position in Hertzsprung-Russell (H-R) diagrams, including main sequence, giant, supergiant, and white dwarf. Use of Hertzsprung-Russell (H-R) diagrams to determine stellar properties, including prediction of colour of stars from their position in an H-R diagram.	View videos describing and explaining stellar evolution. View videos describing H-R diagrams. Consider the range of data that can be displayed in an H-R diagram.

Rotational motion and astrophysics Mandatory content	Suggested activities
Stellar physics (continued)	
Knowledge that the fusion of hydrogen occurs in the core of stars in the main sequence of a Hertzsprung-Russell (H-R) diagram. Knowledge that hydrogen fusion in the core of a star supplies the energy that maintains the star's outward thermal pressure to balance inward gravitational forces. When the hydrogen in the core becomes depleted, nuclear fusion in the core ceases. The gas surrounding the core, however, will still contain hydrogen. Gravitational forces cause both the core and the surrounding shell of hydrogen to shrink. In a star like the Sun, the hydrogen shell becomes hot enough for hydrogen fusion in the shell of the star. This leads to an increase in pressure which pushes the surface of the star outwards, causing it to cool. At this stage, the star will be in the giant or supergiant regions of a Hertzspung-Russell (H-R) diagram. Knowledge that, in a star like the Sun, the core shrinks and will become hot enough for the helium in the core to begin fusion. Knowledge that the mass of a star determines its lifetime. Knowledge that every star ultimately becomes a white dwarf, a neutron star or a black hole. The mass of the star determines its eventual fate.	

<table>
<tr><th>Quanta and waves
Mandatory content</th><th>Suggested activities</th></tr>
<tr><th colspan="2">Introduction to quantum theory</th></tr>
<tr><td>Knowledge of experimental observations that cannot be explained by classical physics, but can be explained using quantum theory:

♦ black-body radiation curves (ultraviolet catastrophe)
♦ the formation of emission and absorption spectra
♦ the photoelectric effect

Use of an appropriate relationship to solve problems involving photon energy and frequency.

$E = hf$

Knowledge of the Bohr model of the atom in terms of the quantisation of angular momentum, the principal quantum number n and electron energy states, and how this explains the characteristics of atomic spectra.

Use of an appropriate relationship to solve problems involving the angular momentum of an electron and its principal quantum number.

$mvr = \frac{nh}{2\pi}$</td><td>Analyse black body radiation curves.

Observe emission and absorption spectra.

Use a spectroscope/spectrometer to examine line emission spectra.

Experimental observation of the photoelectric effect

Observe stationary waves in wire loops.</td></tr>
</table>

Quanta and waves **Mandatory content**	**Suggested activities**
Introduction to quantum theory (continued)	
Description of experimental evidence for the particle-like behaviour of 'waves' and for the wave-like behaviour of 'particles'. Use of an appropriate relationship to solve problems involving the de Broglie wavelength of a particle and its momentum. $\lambda = \frac{h}{p}$ Knowledge that it is not possible to know the position and the momentum of a quantum particle simultaneously. Knowledge that it is not possible to know the lifetime of a quantum particle and the associated energy change simultaneously. Use of appropriate relationships to solve problems involving the uncertainties in position, momentum, energy, and time. The lifetime of a quantum particle can be taken as the uncertainty in time. $\Delta x \Delta p_x \geq \frac{h}{4\pi}$ $\Delta E \Delta t \geq \frac{h}{4\pi}$	View videos showing simulations of double-slit experiments with single particles (photons or electrons). Examine evidence of wave-particle duality — for example electron diffraction, photoelectric effect and Compton scattering. View videos of explanations and demonstrations of the Heisenberg uncertainty principle. View videos showing simulations of quantum tunnelling. Consider frustrated total internal reflection as an optical analogue of quantum tunnelling.

Quanta and waves Mandatory content	Suggested activities
Introduction to quantum theory (continued)	
Knowledge of implications of the Heisenberg uncertainty principle, including the concept of quantum tunnelling, in which a quantum particle can exist in a position that, according to classical physics, it has insufficient energy to occupy.	Class discussion, allowing each individual to describe their understanding of quantum physics and of the Heisenberg uncertainty principle.
Particles from space	
Knowledge of the origin and composition of cosmic rays and the interaction of cosmic rays with Earth's atmosphere. Knowledge of the composition of the solar wind as charged particles in the form of plasma. Explanation of the helical motion of charged particles in the Earth's magnetic field. Use of appropriate relationships to solve problems involving the force on a charged particle, its charge, its mass, its velocity, the radius of its path, and the magnetic induction of a magnetic field.	View videos showing an aurora. Research on how an aurora is produced in the upper atmosphere. Research on the solar cycle and solar flares, for example the Carrington flare of 1859.

Quanta and waves Mandatory content	Suggested activities
Particles from space (continued)	
$F = qvB$ $F = \frac{mv^2}{r}$	
Simple harmonic motion (SHM)	
Definition of SHM in terms of the restoring force and acceleration proportional to, and in the opposite direction to, the displacement from the rest position. Use of calculus methods to show that expressions in the form of $y = A\sin\omega t$ and $y = A\cos\omega t$ are consistent with the definition of SHM ($a = -\omega^2 y$). Derivation of the relationships $v = \pm\omega\sqrt{\left(A^2 - y^2\right)}$ and $E_k = \frac{1}{2}m\omega^2(A^2 - y^2)$. Use of appropriate relationships to solve problems involving the displacement, velocity, acceleration, force, mass, spring constant k, angular frequency, period, and energy of an object executing SHM.	Investigate different oscillating SHM systems, for example simple pendulum, compound pendulum, mass on a spring, trolley and two spring system, and loaded test tube in water. Demonstrate the link between circular motion and SHM. Experiment using SHM to measure the acceleration due to gravity. Investigate the factors affecting the period of oscillation of an object moving with SHM. Investigate the relationship between force applied and extension of a spring.

Quanta and waves **Mandatory content**	**Suggested activities**
Simple harmonic motion (SHM) (continued)	
$F = -ky$ $\omega = 2\pi f = \frac{2\pi}{T}$ $a = \frac{d^2 y}{dt^2} = -\omega^2 y$ $y = A\cos\omega t$ or $y = A\sin\omega t$ $v = \pm\omega\sqrt{\left(A^2 - y^2\right)}$ $E_k = \frac{1}{2}m\omega^2\left(A^2 - y^2\right)$ $E_P = \frac{1}{2}m\omega^2 y^2$ Knowledge of the effects of damping in SHM to include underdamping, critical damping and overdamping.	Investigate the relationship between kinetic and potential energy for an object moving with SHM. Investigate damped and undamped systems using a motion sensor or a smartphone as an accelerometer.
Waves	
Use of an appropriate relationship to solve problems involving the energy transferred by a wave and its amplitude. $E = kA^2$	

Quanta and waves Mandatory content	Suggested activities
Waves (continued)	
Knowledge of the mathematical representation of travelling waves. Use of appropriate relationships to solve problems involving wave motion, phase difference and phase angle. $y = A\sin 2\pi\left(ft - \frac{x}{\lambda}\right)$ $\phi = \frac{2\pi x}{\lambda}$	Simulation of a transverse wave leading to understanding of the mathematical representation.
Knowledge that stationary waves are formed by the interference of two waves, of the same frequency and amplitude, travelling in opposite directions. A stationary wave can be described in terms of nodes and antinodes.	Demonstrate stationary waves using a slinky. Investigate stationary waves using vibrator and elastic string, using Melde's experiment. Experiment to measure the wavelength of sound or of microwaves, using stationary waves. Experiment to determine the speed of sound in air using stationary waves, using a resonance tube. Investigate synthesisers, related to the addition of waves, leading to Fourier analysis.

Quanta and waves Mandatory content	Suggested activities
Waves (continued)	
	Investigate the source of sound from wind- and string-musical instruments. Investigate fundamental and harmonic frequencies. Investigate the use of beats to tune musical instruments.
Interference	
Knowledge that two waves are coherent if they have a constant phase relationship. Knowledge of the conditions for constructive and destructive interference in terms of coherence and phase. Use of an appropriate relationship to solve problems involving optical path difference opd, geometrical path difference gpd and refractive index. $opd = n \times gpd$	
Knowledge that a wave experiences a phase change of π when it is travelling in a less dense medium and reflects from an interface with a more dense medium.	Slinky demonstration of a phase change of π in a wave reflected from a boundary.
Knowledge that a wave does not experience a phase change when it is travelling in a more dense medium and reflects from an interface with a less dense medium.	Slinky demonstration of no phase change in a wave reflected from a boundary.

Quanta and waves Mandatory content	Suggested activities
Interference (continued)	
Explanation of interference by division of amplitude, including optical path length, geometrical path length, phase difference, and optical path difference. Knowledge of thin film interference and wedge fringes. For light interfering by division of amplitude, use of an appropriate relationship to solve problems involving the optical path difference between waves, wavelength and order number. $opd = m\lambda$ or $\left(m+\frac{1}{2}\right)\lambda$ where $m = 0,1,2\ldots$ Knowledge that a coated (bloomed) lens can be made non-reflective for a specific wavelength of light. Derivation of the relationship $d = \frac{\lambda}{4n}$ for glass lenses with a coating such as magnesium fluoride.	Investigate thin-film interference in oil films or soap bubbles using an extended light source. Investigate Newton's Rings. Wiener's experiment Experiment to determine the thickness of a sheet of paper or a human hair using wedge fringes.

Quanta and waves Mandatory content	Suggested activities
Interference (continued)	
Use of appropriate relationships to solve problems involving interference of waves by division of amplitude. $\Delta x = \frac{\lambda l}{2d}$ $d = \frac{\lambda}{4n}$ Explanation of interference by division of wavefront. Knowledge of Young's slits interference. Use of an appropriate relationship to solve problems involving interference of waves by division of wavefront. $\Delta x = \frac{\lambda D}{d}$	Experiment to determine the wavelength of laser light using Young's slits.
Polarisation	
Knowledge of what is meant by a plane-polarised wave. Knowledge of the effect on light of polarisers and analysers.	Use a polariser and analyser to observe the difference between plane-polarised and unpolarised waves. Investigate the polarisation of microwaves and light.

Quanta and waves Mandatory content	Suggested activities
Polarisation (continued)	
Knowledge that when a ray of unpolarised light is incident on the surface of an insulator at Brewster's angle the reflected ray becomes plane-polarised.	Investigate reflected laser (polarised) light from a glass surface through a polarising filter, as the angle of incidence is varied.
Derivation of the relationship $n = \tan i_p$.	Research liquid crystal displays, computer/phone displays, polarising lenses, optical activity, photoelasticity, and saccharimetry.
Use of an appropriate relationship to solve problems involving Brewster's angle and refractive index. $n = \tan i_p$	Stress analysis of Perspex models of structures.

Electromagnetism Mandatory content	Suggested activities
Fields	
Knowledge that an electric field is the region that surrounds electrically charged particles in which a force is exerted on other electrically charged particles. Definition of electric field strength as the electrical force acting on unit positive charge. Sketch of electric field patterns around single point charges, a system of charges and in a uniform electric field. Definition of electrical potential at a point as the work done in moving unit positive charge from infinity to that point. Knowledge that the energy required to move charge between two points in an electric field is independent of the path taken. Use of appropriate relationships to solve problems involving electrical force, electrical potential and electric field strength around a point charge and a system of charges.	Observe field lines around charged objects. Research the physics underlying electrostatic spray painting Research the physics underlying the operation of virtual-reality (VR) goggles.

Electromagnetism Mandatory content	Suggested activities
Fields (continued)	
$F = \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}$ $V = \frac{Q}{4\pi\varepsilon_o r}$ $E = \frac{Q}{4\pi\varepsilon_o r^2}$ Use of appropriate relationships to solve problems involving charge, energy, potential difference, and electric field strength in situations involving a uniform electric field. $F = QE$ $V = Ed$ $W = QV$	
Knowledge of Millikan's experimental method for determining the charge on an electron.	View videos showing simulations of Millikan's experiment. Carry out Millikan's experiment.
Use of appropriate relationships to solve problems involving the motion of charged particles in uniform electric fields.	Investigate the motion of charged particles in uniform electric fields, using a Teltron deflection tube. Research particle accelerators, cosmic rays, Compton scattering, and oscilloscope deflecting plates.

Electromagnetism Mandatory content	Suggested activities
Fields (continued)	
$F = QE$ $V = Ed$ $W = QV$ $E_k = \frac{1}{2}mv^2$ Knowledge that the electronvolt (eV) is the energy acquired when one electron accelerates through a potential difference of one volt. Conversion between electronvolts and joules Knowledge that electrons are in motion around atomic nuclei and individually produce a magnetic effect. Knowledge that, for example, iron, nickel, cobalt, and some rare earths exhibit a magnetic effect called ferromagnetism, in which magnetic dipoles can be made to align, resulting in the material becoming magnetised. Sketch of magnetic field patterns between magnetic poles, and around solenoids, including the magnetic field pattern around Earth.	Investigate field patterns around permanent magnets and electromagnets, for example a straight wire and a coil.

Electromagnetism Mandatory content	Suggested activities
Fields (continued)	
Comparison of gravitational, electrostatic, magnetic, and nuclear forces in terms of their relative strength and range. Use of an appropriate relationship to solve problems involving magnetic induction around a current-carrying wire, the current in the wire and the distance from the wire. $B = \frac{\mu_o I}{2\pi r}$ Explanation of the helical path followed by a moving charged particle in a magnetic field. Use of appropriate relationships to solve problems involving the forces acting on a current-carrying wire in a magnetic field and a charged particle in a magnetic field. $F = IlB\sin\theta$ $F = qvB$ $F = \frac{mv^2}{r}$	Investigate the magnetic induction at a distance from a long current-carrying wire, using a Hall probe, smartphone or search coil. Investigate factors affecting the magnitude of the force on a current-carrying conductor in a magnetic field.

Electromagnetism Mandatory content	Suggested activities
Circuits	
Knowledge of the variation of current and potential difference with time in an RC circuit during charging and discharging.	Investigate the variation of the current and potential difference with time in RC circuits during charging and discharging.
Definition of the time constant for an RC circuit as the time to increase the charge stored by 63% of the difference between initial charge and full charge, or the time taken to discharge the capacitor to 37% of initial charge.	Research applications of capacitors in DC circuits.
Use of an appropriate relationship to determine the time constant for an RC circuit. $\tau = RC$	Experiment to determine the time constant (τ) of an RC circuit.
Knowledge that, in an RC circuit, an uncharged capacitor can be considered to be fully charged after a time approximately equal to 5τ .	
Knowledge that, in an RC circuit, a fully charged capacitor can be considered to be fully discharged after a time approximately equal to 5τ .	
Graphical determination of the time constant for an RC circuit. Knowledge that capacitive reactance is the opposition of a capacitor to changing current.	Experiment to investigate the relationship between voltage, current and capacitive reactance.

Electromagnetism Mandatory content	Suggested activities
Circuits (continued)	
Use of appropriate relationships to solve problems involving capacitive reactance, voltage, current, frequency, and capacitance. $X_C = \frac{V}{I}$ $X_C = \frac{1}{2\pi fC}$	Experiment to investigate the relationship between current, frequency and capacitive reactance.
Knowledge of the growth and decay of current in a DC circuit containing an inductor.	Investigate the factors affecting the size of the back EMF in a coil
Explanation of the self-inductance (inductance) of a coil. Knowledge of Lenz's law and its implications. Definition of inductance and of back EMF. Knowledge that energy is stored in the magnetic field around a current-carrying inductor. Knowledge of the variation of current with frequency in an AC circuit containing an inductor. Knowledge that inductive reactance is the opposition of an inductor to changing current.	Demonstrate electromagnetic braking by dropping neodymium magnets through an aluminium tube. Demonstrate the effect of back EMF in an inductive circuit, for example a neon bulb lit from 1·5 V cell. Investigate the growth and decay of current in a DC circuit containing an inductor. Experiment to determine the self-inductance (inductance) of a coil by use of datalogging or waveform capture.

Electromagnetism Mandatory content	Suggested activities
Circuits (continued)	
Use of appropriate relationships to solve problems relating to inductive reactance, voltage, current, frequency, energy, and self-inductance (inductance). $\varepsilon = -L\frac{dI}{dt}$ $E = \frac{1}{2}LI^2$ $X_L = \frac{V}{I}$ $X_L = 2\pi fL$	Experiments to investigate the relationship between current, frequency and inductive reactance. Research applications of inductors, for example induction hobs, hearing-aid loops, electromagnetic braking, LC filters, and tuned circuits.

Electromagnetism Mandatory content	Suggested activities
Electromagnetic radiation	
Knowledge of the unification of electricity and magnetism. Knowledge that electromagnetic radiation exhibits wave properties as it transfers energy through space. It has both electric and magnetic field components which oscillate in phase, perpendicular to each other and to the direction of energy propagation. Use of an appropriate relationship to solve problems involving the speed of light, the permittivity of free space and the permeability of free space. $c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$	Research the nature of electromagnetic radiation. Estimate the speed of light in air by determining permittivity using a parallel plate capacitor and determining permeability using a current balance.

Units, prefixes and uncertainties Mandatory content	Suggested activities
Units, prefixes and scientific notation	
Appropriate use of units, including electronvolt (eV), light-year (ly) and astronomical unit (AU). Use of SI units with all physical quantities, where appropriate. Use of prefixes where appropriate. These include femto (f), pico (p), nano (n), micro (μ), milli (m), kilo (k), mega (M), giga (G), tera (T), and peta (P). Use of the appropriate number of significant figures in final answers. The final answer can have no more significant figures than the data with the fewest number of significant figures used in the calculation. Appropriate use of scientific notation.	
Uncertainties	
Knowledge and use of uncertainties, including systematic uncertainties, scale reading uncertainties, random uncertainties, and calibration uncertainties.	

Units, prefixes and uncertainties Mandatory content	Suggested activities
Uncertainties (continued)	
Systematic uncertainty occurs when readings taken are either all too small or all too large. This can arise due to faulty measurement techniques or experimental design. Scale reading uncertainty is an indication of how precisely an instrument scale can be read. Random uncertainty arises when measurements are repeated and slight variations occur. Random uncertainty may be reduced by increasing the number of repeated measurements. Calibration uncertainty arises when there is a difference between a manufacturer's claim for the accuracy of an instrument when compared with an approved standard. Solve problems involving absolute uncertainties and fractional/percentage uncertainties. Appropriate use of significant figures in absolute uncertainties. Absolute uncertainty should normally be rounded to one significant figure. In some instances, a second significant figure may be retained.	

Units, prefixes and uncertainties Mandatory content	Suggested activities
Data analysis	
Combination of various types of uncertainties to obtain the total uncertainty in a measurement. Knowledge that, when uncertainties in a single measurement are combined, an uncertainty can be ignored if it is less than one-third of one of the other uncertainties in the measurement. Use of an appropriate relationship to determine the total uncertainty in a measured value. $\Delta W = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$ Combination of uncertainties in measured values to obtain the total uncertainty in a calculated value. Knowledge that, when uncertainties in measured values are combined, a fractional/percentage uncertainty in a measured value can be ignored if it is less than one-third of the fractional/percentage uncertainty in another measured value. Use of an appropriate relationship to determine the total uncertainty in a value calculated from the product or quotient of measured values.	

Units, prefixes and uncertainties **Mandatory content**	
Data analysis (continued)	
$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$ Use of an appropriate relationship to determine the uncertainty in a value raised to a power. $\left(\frac{\Delta W^n}{W^n}\right) = n\left(\frac{\Delta W}{W}\right)$ Use of error bars to represent absolute uncertainties on graphs. Estimation of uncertainty in the gradient and intercept of the line of best fit on a graph. Correct use of the terms accuracy and precision in the context of an evaluation of experimental results. The accuracy of a measurement compares how close the measurement is to the 'true' or accepted value. The uncertainty in a measurement gives an indication of the precision of the measurement.	

Units, prefixes and uncertainties Mandatory content	
Evaluation of significance of experimental uncertainties	
Identification of the dominant uncertainty/uncertainties in an experiment or in experimental data. Suggestion of potential improvements to an experiment, which may reduce the dominant uncertainty/uncertainties.	