Our dynamic Universe Mandatory content	Suggested activities
Motion — equations and graphs	
Use of appropriate relationships to solve problems involving distance, displacement, speed, velocity, and acceleration for objects moving with constant acceleration in a straight line. $d = \bar{v}t$ $s = \bar{v}t$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u + v)t$	Undertake experiments to verify the relationships shown. Use light gates or motion sensors, and software/hardware to measure displacement, velocity and acceleration. Use software to analyse videos of motion.
Interpretation and drawing of motion-time graphs for motion with constant acceleration in a straight line, including graphs for bouncing objects and objects thrown vertically upwards. Knowledge of the interrelationship of displacement-time, velocity-time and acceleration-time graphs. Calculation of distance, displacement, speed, velocity, and acceleration from appropriate graphs (graphs restricted to constant acceleration in one dimension, inclusive of change of direction). Description of an experiment to measure the acceleration of an object down a slope.	Use motion sensors to enable graphical representation of motion. Analyse displacement-time graphs. Gradient is velocity. Analyse velocity-time graphs. Area under graph is change in displacement during the selected time interval. Gradient is acceleration. Analyse acceleration-time graphs. Area under graph is change in velocity during the selected time interval. Analyse the motion of athletes and of equipment used in sports. Investigate the initial acceleration of an object projected vertically upwards (for example popper toy). Investigate the variation of acceleration on a slope with the sine of the angle of the slope.

Our dynamic Universe Mandatory content	Suggested activities
Forces, energy and power	
Use of vector addition and appropriate relationships to solve problems involving balanced and unbalanced forces, mass, acceleration, and gravitational field strength. $F = ma$ $W = mg$ Knowledge of the effects of friction on a moving object (no reference to static and dynamic friction). Explanation, in terms of forces, of an object moving with terminal velocity. Interpretation of velocity-time graphs for a falling object when air resistance is taken into account. Use of Newton's first and second laws to explain the motion of an object. Use of free body diagrams and appropriate relationships to solve problems involving friction and tension. $F = ma$ $W = mg$ Resolution of a vector into two perpendicular components.	Analyse forces acting in one or two dimensions. Analyse forces in rocket motion, jet engines, pile driving, scuba diving, lifts, haulage systems, and sport. Analyse forces involved in space flight. Analyse forces involved in skydiving and parachuting and falling raindrops. Investigate the effect of the cross-sectional area of a falling object on its terminal velocity. Analyse the motion of a rocket involving a constant force on changing mass as fuel is used up. Analyse situations when forces are exerted by strings, cables, couplings, or by objects in contact.

Our dynamic Universe Mandatory content	Suggested activities
Forces, energy and power (continued)	
Resolution of the weight of an object on a slope into component forces parallel and normal to the surface of the slope.	Investigate the variation of the force parallel to slope with the sine of the angle of the slope.
Use of the principle of conservation of energy and appropriate relationships to solve problems involving work done, potential energy, kinetic energy, and power. $E_w = Fd$, or $W = Fd$ $E_P = mgh$ $E_k = \frac{1}{2}mv^2$ $P = \frac{E}{t}$	Determine frictional forces acting on a trolley rolling down a slope, by the difference between potential and kinetic energy.
Collisions, explosions, and impulse	
Use of the principle of conservation of momentum and an appropriate relationship to solve problems involving the momentum, mass and velocity of objects interacting in one dimension. $p = mv$	Investigate the conservation of momentum in elastic collisions, inelastic collisions, and explosions.
Knowledge of energy interactions involving the total kinetic energy of systems of objects undergoing inelastic collisions, elastic collisions, and explosions.	Investigate the conservation of kinetic energy in elastic collisions, the loss of kinetic energy from the system in an inelastic collision, and the gain of kinetic energy to the system in an explosion.

Our dynamic Universe Mandatory content	Suggested activities
Collisions, explosions, and impulse (continued)	
Use of an appropriate relationship to solve problems involving the total kinetic energy of systems of interacting objects. $E_k = \frac{1}{2}mv^2$	
Use of Newton's third law to explain the motion of objects involved in interactions.	Consider propulsion systems such as jet engines and rockets. Investigate collisions using sensors and data loggers.
Interpretation of force-time graphs involving interacting objects.	
Knowledge that the impulse of a force is equal to the area under a force-time graph and is equal to the change in momentum of an object involved in the interaction.	Consider forces in collisions involving hammers and pile drivers.
Use of data from a force-time graph to solve problems involving the impulse of a force, the average force and its duration.	Consider the role of crumple zones and airbags in car safety.
Use of an appropriate relationship to solve problems involving mass, change in velocity, average force and duration of the force for an object involved in an interaction. $Ft = mv - mu$	

Our dynamic Universe **Mandatory content**	**Suggested activities**
Gravitation	
Description of an experiment to measure the acceleration of a falling object.	Experimental determination of the acceleration due to gravity.
Knowledge that the horizontal motion and the vertical motion of a projectile are independent of each other.	Use software to analyse videos of projectile motion.
Knowledge that satellites are in free fall around a planet/star.	Consider Newton's thought experiment and an explanation of why satellites remain in orbit. Consider low orbit and geostationary satellites. Investigate the use of satellites in communication, surveying and environmental monitoring of the conditions of the atmosphere.
Resolution of the initial velocity of a projectile into horizontal and vertical components and their use in calculations.	
Use of resolution of vectors, vector addition, and appropriate relationships to solve problems involving projectiles. $d = \bar{v}t$ $s = \bar{v}t$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u + v)t$	

Our dynamic Universe Mandatory content	Suggested activities
Gravitation (continued)	
Use of Newton's Law of Universal Gravitation to solve problems involving force, masses and their separation. $F = G\frac{m_1 m_2}{r^2}$	Experimental determination of the gravitational field strength on Earth. Consider the Cavendish/Boys experiment. Consider Masketyne's Schiehallion experiment. Consider the use of the slingshot (catapult) effect in space travel. Consider lunar and planetary orbits, the formation of the solar system by the aggregation of matter, and stellar formation and collapse.
Special relativity	
Knowledge that the speed of light in a vacuum is the same for all observers. Knowledge that measurements of space, time and distance for a moving observer are changed relative to those for a stationary observer, giving rise to time dilation and length contraction. Use of appropriate relationships to solve problems involving time dilation, length contraction and speed. $t' = \frac{t}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$ $l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$	Consideration of Galilean invariance, Newtonian relativity and the concept of absolute space. Newtonian relativity can be experienced in an intuitive way. Examples include walking in a moving train and moving sound sources. Use of animations to study length contraction and time dilation, which are non-intuitive relativistic effects. Consider the experimental verification of special relativity — including muon detection at the surface of the Earth and comparison of time measurements on travelling and stationary clocks. Derive the time dilation equation from the geometrical consideration of a light beam moving relative to a stationary observer.

Our dynamic Universe **Mandatory content**	**Suggested activities**
The expanding Universe	
Knowledge that the Doppler effect causes shifts in wavelengths of sound and light. Use of an appropriate relationship to solve problems involving the observed frequency, source frequency, source speed and wave speed. $f_o = f_s\left(\frac{v}{v \pm v_s}\right)$ Knowledge that the light from objects moving away from us is shifted to longer wavelengths (redshift). Knowledge that the redshift of a galaxy is the change in wavelength divided by the emitted wavelength. For slowly moving galaxies, redshift is the ratio of the recessional velocity of the galaxy to the velocity of light. Use of appropriate relationships to solve problems involving redshift, observed wavelength, emitted wavelength, and recessional velocity. $z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$ $z = \frac{v}{c}$	Investigate the Doppler effect in terms of sound, for example the apparent change in frequency as a source moves towards or away from a stationary observer. Investigate the apparent shift in frequency using a moving sound source and data logger. Consider applications of the Doppler effect, including measurement of speed (radar), echocardiogram and flow measurement. (Note that the Doppler effect relationships used for sound cannot be used with light from fast moving galaxies because relativistic effects need to be taken into account.) Consider the units used by astronomers — light years and parsecs rather than SI units.

Our dynamic Universe **Mandatory content**	**Suggested activities**
The expanding Universe (continued)	
Use of an appropriate relationship to solve problems involving the Hubble constant, the recessional velocity of a galaxy and its distance from us. $v = H_0 d$ Knowledge that the Hubble-Lemaître Law allows us to estimate the age of the Universe. Knowledge that measurements of the velocities of galaxies and their distance from us lead to the theory of the expanding Universe. Knowledge that the mass of a galaxy can be estimated by the orbital speed of stars within it. Knowledge that evidence supporting the existence of dark matter comes from estimations of the mass of galaxies. Knowledge that evidence supporting the existence of dark energy comes from the accelerating rate of expansion of the Universe. Knowledge that the temperature of stellar objects is related to the distribution of emitted radiation over a wide range of wavelengths.	Data analysis of measurements of galactic velocity and distance to determine a value for the Hubble constant and an estimate of the age of the Universe. Consider: ♦ measurements of the velocities of galaxies and their distance from us leading to the theory of the expanding Universe ♦ gravity as the force which slows down the expansion ♦ the eventual fate of the Universe depending on its mass-energy density ♦ the orbital speed of the Sun and other stars giving a way of determining the mass of our galaxy ♦ the Sun’s orbital speed being determined almost entirely by the gravitational pull of matter inside its orbit ♦ measurements of the mass of our galaxy and others leading to the conclusion that there is significant mass which cannot be detected — dark matter

Our dynamic Universe Mandatory content	Suggested activities
The expanding Universe (continued)	
Knowledge that the peak wavelength of this distribution is shorter for hotter objects than for cooler objects. Knowledge that hotter objects emit more radiation per unit surface area per unit time than cooler objects.	♦ measurements of the expansion rate of the Universe leading to the conclusion that it is increasing, suggesting that there is something that overcomes the force of gravity — dark energy ♦ the revival of Einstein's cosmological constant in the context of the accelerating Universe
Knowledge of evidence supporting the Big Bang theory and subsequent expansion of the Universe: cosmic microwave background radiation, the abundance of the elements hydrogen and helium, the darkness of the sky (Olbers' paradox) and the large number of galaxies showing redshift rather than blueshift.	Use of the Hertzsprung-Russell diagram in the study of stellar evolution. Investigate the temperature of hot objects using infrared sensors. Consider the change in colour of steel at high temperatures. Consider the history of cosmic microwave background radiation discovery and measurement, and of the COBE satellite. Consider the peak wavelength of cosmic microwave background radiation. This wavelength corresponds to the temperature that was predicted after the Big Bang. Teaching Astronomy and Space videos are available from the Institute of Physics (IoP), for example: https://www.youtube.com/watch?v=K_xZuopg4Sk https://www.youtube.com/watch?v=jms_vklUeHA

Particles and waves Mandatory content	Suggested activities
Forces on charged particles	
Knowledge that charged particles experience a force in an electric field. Knowledge that electric fields exist around charged particles and between charged parallel plates. Sketch electric field patterns for single-point charges, systems of two-point charges and between two charged parallel plates (ignore end effects). Determination of the direction of movement of charged particles in an electric field. Definition of voltage (potential difference) in terms of work done and charge. Use of appropriate relationships to solve problems involving the charge, mass, speed, and energy of a charged particle in an electric field and the potential difference through which it moves. $W = QV$ $E_k = \frac{1}{2}mv^2$	Consider electrostatic hazards, for example lightning and potential damage to microchips. Research practical applications that use electric fields, for example precipitators, Xerography, paint spraying, inkjet printing, and electrostatic propulsion. Demonstrate electron beams using Teltron tubes.

Particles and waves **Mandatory content**	**Suggested activities**
Forces on charged particles (continued)	
Knowledge that a moving charge produces a magnetic field.	
Determination of the direction of the force on a charged particle moving in a magnetic field for negative and positive charges.	Use of the right-hand rule.
Knowledge of the basic operation of particle accelerators in terms of acceleration by electric fields, deflection by magnetic fields and high-energy collisions of charged particles to produce other particles.	Consider: ♦ accelerators, including linear accelerator, cyclotron, and synchrotron ♦ medical applications of the cyclotron ♦ the use of accelerators to investigate the structure of matter, for example the LHC at CERN
The Standard Model	
Knowledge that the Standard Model is a model of fundamental particles and interactions.	
Use of orders of magnitude and awareness of the range of orders of magnitude of length from the very small (sub-nuclear) to the very large (distance to furthest known celestial objects).	Consider the scale of our macro world compared to astronomical and sub-nuclear scales. A useful animation that allows candidates to visualise orders of magnitude can be found at: http://htwins.net/scale2/
Knowledge that evidence for the existence of quarks comes from high-energy collisions between electrons and nucleons, carried out in particle accelerators.	Consider experiments carried out in the LHC at CERN.
Knowledge that in the Standard Model, every particle has an antiparticle and that the production of energy in the annihilation of particles is evidence for the existence of antimatter.	Use of the sub-atomic Particle Zoo App (and toys). Consider the uses of the PET scanner.

Particles and waves Mandatory content	Suggested activities
The Standard Model (continued)	
Description of beta decay as the first evidence for the neutrino. $^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}_e$ (β+ decay not required) Knowledge that fermions, the matter particles, consist of quarks (six types: up, down, strange, charm, top, bottom) and leptons (electron, muon and tau, together with their neutrinos). Knowledge that hadrons are composite particles made of quarks. Knowledge that baryons are made of three quarks. Knowledge that mesons are made of quark-antiquark pairs. Knowledge that the force-mediating particles are bosons: photons (electromagnetic force), W- and Z-bosons (weak force), and gluons (strong force).	Consideration of the Higgs boson — history, discovery and implications. Discuss the linking of electromagnetic, strong and weak forces, but not, as yet, of gravity.

Particles and waves Mandatory content	Suggested activities
Nuclear reactions	
Use of nuclear equations to describe radioactive decay, fission (spontaneous and induced) and fusion reactions, with reference to mass and energy equivalence. Use of an appropriate relationship to solve problems involving the mass loss and the energy released by a nuclear reaction. $E = mc^2$ Knowledge that nuclear fusion reactors require charged particles at a very high temperature (plasma) which have to be contained by magnetic fields.	Consider examples of radioactive decay series. Compare the energy available from chemical and nuclear sources. Consideration of the magnetic containment of plasma, for example in the Joint European Torus (JET) and ITER tokamak.
Inverse square law	
Knowledge that irradiance is the power per unit area incident on a surface. Use of an appropriate relationship to solve problems involving irradiance, the power of radiation incident on a surface and the area of the surface. $I = \frac{P}{A}$ Knowledge that irradiance is inversely proportional to the square of the distance from a point source.	

Particles and waves Mandatory content	Suggested activities
Inverse square law (continued)	
Description of an experiment to verify the inverse square law for a point source of light. Use of an appropriate relationship to solve problems involving irradiance and distance from a point source of light. $I = \frac{k}{d^2}$ $I_1 d_1^2 = I_2 d_2^2$	Investigate irradiance as a function of distance from a point source of light. Application of the inverse square law to other e-m radiation. Compare irradiance as a function of distance from a point source of light with irradiance as a function of distance from a laser.
Wave-particle duality	
Knowledge that the photoelectric effect is evidence for the particle model of light. Knowledge that photons of sufficient energy can eject electrons from the surface of materials (photoemission). Use of an appropriate relationship to solve problems involving the frequency and energy of a photon. $E = hf$ Knowledge that the threshold frequency is the minimum frequency of a photon required for photoemission. Knowledge that the work function of a material is the minimum energy of a photon required to cause photoemission.	Demonstrate the photoelectric effect using a gold-leaf electroscope. Consider practical applications of photoemission, for example light meters in cameras, channel plate image intensifiers, photomultipliers.

Particles and waves Mandatory content	Suggested activities
Wave-particle duality (continued)	
Use of appropriate relationships to solve problems involving the mass, maximum kinetic energy and speed of photoelectrons, the threshold frequency of the material, and the frequency and wavelength of the photons. $E_k = hf - hf_0$ $E_k = \frac{1}{2}mv^2$ $v = f\lambda$	
Interference	
Knowledge that interference is evidence for the wave model of light. Knowledge that coherent waves have a constant phase relationship. Description of the conditions for constructive and destructive interference in terms of the phase difference between two waves. Knowledge that maxima and minima are produced when the path difference between waves is a whole number of wavelengths or an odd number of half-wavelengths respectively.	Investigation of interference patterns with microwaves, radio waves, sound, light, and electrons. Consider practical applications, for example holography, the industrial imaging of surfaces in stress analysis, and the coating of lenses in optical instruments. Observe interference colours, for example thin films of petrol on water or soap bubbles.

Particles and waves Mandatory content	Suggested activities
Interference (continued)	
Use of an appropriate relationship to solve problems involving the path difference between waves, wavelength and order number. $\text{path difference} = m\lambda \text{ or } \left(m+\frac{1}{2}\right)\lambda \text{ where } m = 0,1,2...$ Use of an appropriate relationship to solve problems involving grating spacing, wavelength, order number and angle to the maximum. $d\sin\theta = m\lambda$	Investigation with microwaves leading to the relationship between the wavelength, path difference and order number. Investigations using a grating leading to the relationship between the grating spacing, wavelength and angle to a maximum. Investigate the effect on fringe separation of varying distance between the grating and the screen. Use of interferometers to measure small changes in path difference.
Spectra	
Knowledge of the Bohr model of the atom. Knowledge of the terms *ground state*, *energy levels*, *ionisation* and *zero potential energy* in relation to the Bohr model of the atom. Knowledge of the mechanism of production of line emission spectra, continuous emission spectra and absorption spectra in terms of electron energy level transitions. Use of appropriate relationships to solve problems involving energy levels and the frequency of the radiation emitted/absorbed. $E_2 - E_1 = hf$ $E = hf$ Knowledge that the absorption lines (Fraunhofer lines) in the spectrum of sunlight provide evidence for the composition of the Sun's outer atmosphere.	Use of a spectroscope/spectrometer/spectrophotometer to examine line and continuous spectra, for example from a tungsten filament lamp, an electric heater element, fluorescent tubes, gas discharge tubes or various salts in a Bunsen flame. Use a sodium discharge lamp to produce a shadow of a sodium flame. Consider practical uses of spectroscopy, for example in extending our knowledge of space.

Particles and waves Mandatory content	Suggested activities
Refraction of light	
Definition of absolute refractive index of a medium as the ratio of the speed of light in a vacuum to the speed of light in the medium. Use of an appropriate relationship to solve problems involving absolute refractive index, the angle of incidence and the angle of refraction. $n = \frac{\sin\theta_1}{\sin\theta_2}$	Consider applications of refraction, for example lens design, and colours seen in cut diamonds.
Description of an experiment to determine the refractive index of a medium. Use of appropriate relationships to solve problems involving the angles of incidence and refraction, the wavelength of light in each medium, the speed of light in each medium, and the frequency, including situations where light is travelling from a more dense to a less dense medium. $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$ $v = f\lambda$ Knowledge that the refractive index of a medium increases as the frequency of incident radiation increases.	Experiments to determine the refractive index of different transparent materials, for example glass, Perspex.

Particles and waves Mandatory content	Suggested activities
Refraction of light (continued)	
Definition of critical angle as the angle of incidence which produces an angle of refraction of 90°. Knowledge that total internal reflection occurs when the angle of incidence is greater than the critical angle. Use of an appropriate relationship to solve problems involving critical angle and absolute refractive index. $\sin\theta_c = \frac{1}{n}$	Consider applications of total internal reflection, for example reflective road signs, prism reflectors (binoculars, periscopes, SLR cameras), and the use of optical fibres for communications, medicine and sensors. Investigate total internal reflection, including critical angle and its relationship with refractive index.

Electricity Mandatory content	Suggested activities
Monitoring and measuring AC	
Knowledge that AC is a current which changes direction and instantaneous value with time. Use of appropriate relationships to solve problems involving root mean square (rms) and peak values. $V_{rms} = \frac{V_{peak}}{\sqrt{2}}$ $I_{rms} = \frac{I_{peak}}{\sqrt{2}}$ Determination of frequency, peak and rms values from graphical data. $T = \frac{1}{f}$	Use an oscilloscope to monitor AC signals, including the measurement of frequency, peak and rms values.

Electricity Mandatory content	Suggested activities
Current, potential difference, power, and resistance	
Use of appropriate relationships to solve problems involving potential difference, current, power, and resistance. Solutions may involve several steps. $V = IR$ $P = IV = I^2R = \frac{V^2}{R}$ $R_T = R_1 + R_2 + \ldots$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$	Investigate circuits with switches and resistive components.
Use of appropriate relationships to solve problems involving potential divider circuits. $V_1 = \left(\frac{R_1}{R_1 + R_2}\right)V_S$ $\frac{V_1}{V_2} = \frac{R_1}{R_2}$	Use of potential dividers to set and control voltages in circuits.

Electricity **Mandatory content**	**Suggested activities**
Electrical sources and internal resistance	
Knowledge of the terms *electromotive force (EMF)*, *internal resistance*, *lost volts*, *terminal potential difference (t.p.d.)*, *ideal supplies*, *short circuit* and *open circuit*. Use of appropriate relationships to solve problems involving EMF, lost volts, t.p.d., current, external resistance, and internal resistance. $E = V + Ir$ $V = IR$ Description of an experiment to measure the EMF and internal resistance of a cell. Determination of EMF, internal resistance and short circuit current using graphical analysis.	Determination of the EMF and internal resistance of cells. Investigate load matching. Maximum power is transferred when internal and external resistances are equal. Investigate the variation of t.p.d. of a low voltage supply as a function of external resistance, including the addition of resistors connected in parallel with the supply.

Electricity Mandatory content	Suggested activities
Capacitors	
Knowledge that a capacitor of 1 farad will store 1 coulomb of charge when the potential difference across it is 1 volt. Use of an appropriate relationship to solve problems involving capacitance, charge and potential difference. $C = \frac{Q}{V}$ Use of an appropriate relationship to determine the charge stored on a capacitor for a constant charging current. $Q = It$ Knowledge that the total energy stored in a charged capacitor is equal to the area under a charge-potential difference graph. Use of appropriate relationships to solve problems involving energy, charge, capacitance, and potential difference. $E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$ Knowledge of the variation of current and potential difference with time for both charging and discharging cycles of a capacitor in an RC circuit (charging and discharging curves).	Experimental determination of the capacitance of a capacitor. Consider practical uses of capacitors, for example energy storage, flash bulbs, smoothing and suppressing and in capacitance-based touch screens.

Electricity **Mandatory content**	**Suggested activities**
Capacitors (continued)	
Knowledge of the effect of resistance and capacitance on charging and discharging curves in an RC circuit. Description of experiments to investigate the variation of current in a capacitor and voltage across a capacitor with time, for the charging and discharging of capacitors.	Investigate the charging/discharging of a capacitor using data loggers or other methods.
Semiconductors and p-n junctions	
Knowledge of the terms *conduction band* and *valence band*. Knowledge that solids can be categorised into conductors, semiconductors or insulators by their band structure and their ability to conduct electricity. Every solid has its own characteristic energy band structure. For a solid to be conductive, both free electrons and accessible empty states must be available. Qualitative explanation of the electrical properties of conductors, insulators and semiconductors using the electron population of the conduction and valence bands and the energy difference between the conduction and valence bands. (Reference to Fermi levels is not required.) The electrons in atoms are contained in energy levels. When the atoms come together to form solids, the electrons then become contained in energy bands separated by gaps. For metals we have the situation where one or more bands are partially filled.	Consider conducting and insulating materials in terms of the electron population of the conduction band. Consider the breakdown voltage of an insulator, for example in the context of lightning. A computer simulation will be available from Strathclyde University.

Electricity Mandatory content	Suggested activities
Semiconductors and p-n junctions (continued)	
Some metals have free electrons and partially filled valence bands, therefore they are highly conductive. Some metals have overlapping valence and conduction bands. Each band is partially filled and therefore they are conductive. In an insulator, the highest occupied band (called the valence band) is full. The first unfilled band above the valence band is the conduction band. For an insulator, the gap between the valence band and the conduction band is large and at room temperature there is not enough energy available to move electrons from the valence band into the conduction band where they would be able to contribute to conduction. There is no electrical conduction in an insulator. In a semiconductor, the gap between the valence band and conduction band is smaller and at room temperature there is sufficient energy available to move some electrons from the valence band into the conduction band allowing some conduction to take place. An increase in temperature increases the conductivity of a semiconductor. Knowledge that, during manufacture, semiconductors may be doped with specific impurities to increase their conductivity, resulting in two types of semiconductor: p-type and n-type.	

Electricity **Mandatory content**	**Suggested activities**
Semiconductors and p-n junctions (continued)	
Knowledge that, when a semiconductor contains the two types of doping (p-type and n-type) in adjacent layers, a p-n junction is formed. There is an electric field in the p-n junction. The electrical properties of this p-n junction are used in a number of devices. Knowledge of the terms *forward bias* and *reverse bias*. Forward bias reduces the electric field; reverse bias increases the electric field in the p-n junction. Knowledge that LEDs are forward biased p-n junction diodes that emit photons. The forward bias potential difference across the junction causes electrons to move from the conduction band of the n-type semiconductor towards the conduction band of the p-type semiconductor. Photons are emitted when electrons 'fall' from the conduction band into the valence band either side of the junction. Knowledge that solar cells are p-n junctions designed so that a potential difference is produced when photons are absorbed. (This is known as the photovoltaic effect.) The absorption of photons provides energy to 'raise' electrons from the valence band of the semiconductor to the conduction band. The p-n junction causes the electrons in the conduction band to move towards the n-type semiconductor and a potential difference is produced across the solar cell.	Investigate the operation of a Hall effect sensor. Investigate the variation in resistance of a negative temperature coefficient thermistor as a function of its temperature. Investigate the switch on voltage of LEDs emitting different frequencies of light. Investigate the variation in the output voltage of a solar cell as a function of the irradiance and frequency of incident light.

Units, prefixes and uncertainties Mandatory content	Suggested activities
Units, prefixes and scientific notation	
Appropriate use of units and prefixes. SI units should be used with all physical quantities, where appropriate. Prefixes should be used where appropriate. These include pico (p), nano (n), micro (μ), milli (m), kilo (k), mega (M), giga (G) and tera (T). Use of the appropriate number of significant figures in final answers. This means that the final answer can have no more significant figures than the value with least number of significant figures used in the calculation. Appropriate use of scientific notation	
Uncertainties	
Knowledge of scale reading, random and systematic uncertainties in a measured quantity. All measurements of physical quantities are liable to uncertainty, which should be expressed in absolute or percentage form.	

Units, prefixes and uncertainties **Mandatory content**	**Suggested activities**
Uncertainties (continued)	
Scale reading uncertainty is an indication of how precisely an instrument scale can be read. Random uncertainties arise when measurements are repeated and slight variations occur. Random uncertainties may be reduced by increasing the number of repeated measurements. Use of an appropriate relationship to determine the approximate random uncertainty in a value using repeated measurements. $random\ uncertainty = \frac{max.\ value\ -\ min.\ value}{number\ of\ values}$ or $\Delta R = \frac{R_{max} - R_{min}}{n}$ Systematic uncertainties occur when readings taken are either all too small or all too large. This can arise due to measurement techniques or experimental design.	

Units, prefixes and uncertainties Mandatory content	Suggested activities
Uncertainties (continued)	
The mean of a set of repeated measurements is the best estimate of the 'true' value of the quantity being measured. When systematic uncertainties are present, the mean value will be offset. When mean values are used, the approximate random uncertainty should be calculated. Appropriate use of uncertainties in data analysis. When an experiment is being undertaken and more than one physical quantity is measured, the quantity with the largest percentage uncertainty should be identified and this may often be used as a good estimate of the percentage uncertainty in the final numerical result of an experiment. The numerical result of an experiment should be expressed in the form *final value ± uncertainty.*	