

1.1.1 Planning

Can you design an experiment, including solving physics problems set in a practical context?



Can you identify the variables that must be controlled in an experiment, where appropriate?



Can you evaluate whether an experimental method is appropriate to meet the expected outcomes?

**1.1.2 Implementing**

Can you describe how to use a wide range of practical apparatus and techniques correctly?



Can you use appropriate units for measurements?



Can you present observations and data in an appropriate format, such as a results table with correct headings?

**1.1.3 Analysis**

Can you process, analyse and interpret qualitative and quantitative experimental results?



Can you use appropriate mathematical skills to analyse quantitative data?



Can you use significant figures appropriately in data and answers?



Can you plot suitable graphs, selecting and labelling the axes with appropriate scales, quantities and units?



Can you interpret graphs by measuring gradients and intercepts?

**1.1.4 Evaluation**

Can you evaluate results and draw conclusions from them?



Can you identify anomalies in experimental measurements?



Can you identify limitations in experimental procedures?



Can you identify uncertainties in measurements and use simple techniques to find margins of error and percentage errors?



Can you explain precision and accuracy of measurements and data, including apparatus uncertainties?



Can you refine an experimental design by suggesting improvements to the procedures and apparatus?



1.2

Practical skills assessed in the practical endorsement

1.2.1 Practical skills

Can you apply investigative approaches and methods when using instruments and equipment?



Can you use a range of practical equipment and materials safely and correctly?



Can you follow written instructions accurately?



Can you make and record observations and measurements?



Can you keep appropriate records of experimental activities?



Can you present information and data in a scientific way?



Can you use appropriate software and tools to process data, carry out research and report findings?



Can you use online and offline research skills, including websites, textbooks and other printed scientific sources?



Can you correctly cite sources of information?



Can you use a wide range of experimental and practical instruments, equipment and techniques appropriate to physics?



1.2.2 Use of apparatus and techniques

Can you use analogue apparatus to record a range of measurements (length, mass, time, volume, temperature, current, p.d.) and interpolate between scale markings?



Can you use digital instruments, including multimeters, to obtain a range of measurements?



Can you use methods to increase accuracy, such as timing over multiple oscillations or using a fiducial marker, set square or plumb line?



Can you use a stopwatch or light gates for timing?



Can you use calipers and micrometers to measure small distances, using digital or vernier scales?



Can you correctly construct circuits from circuit diagrams using d.c. power supplies, cells and components, including those where polarity is important?



Can you design, construct and check circuits using d.c. power supplies, cells and a range of circuit components?



Can you use a signal generator and oscilloscope, including volts/division and time-base settings?



Can you generate and measure waves using a microphone and loudspeaker, a ripple tank, a vibration transducer or microwave/radio wave source?



Can you use a laser or light source to investigate characteristics of light, including interference and diffraction?



Can you use ICT such as computer modelling, or a data logger with a variety of sensors, to collect data, or software to process data?



Can you use ionising radiation safely, including detectors?



2.1 Physical quantities and units

2.1.1 Physical quantities

Can you explain that physical quantities have a numerical value and a unit?



Can you make estimates of physical quantities listed in the specification?



2.1.2 S.I. units

Can you state the S.I. base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K) and amount of substance (mol)?



Can you express derived units in terms of S.I. base units?



Can you use the units listed in the specification correctly?



Can you check the homogeneity of physical equations using S.I. base units?



Can you use the prefixes and their symbols from pico (p) to tera (T) to indicate decimal submultiples or multiples of units?



Can you use the conventions for labelling graph axes and table columns, e.g. speed / m s^{-1} ?



2.2 Making measurements and analysing data

2.2.1 Measurements and uncertainties

Can you distinguish between systematic errors (including zero errors) and random errors?



Can you distinguish between precision and accuracy?



Can you calculate absolute and percentage uncertainties when data are combined by addition, subtraction, multiplication, division and raising to powers?



Can you show uncertainties graphically using error bars?



Can you draw lines of best fit and worst fit and use them to find the uncertainty in a gradient or intercept?



2.3 Nature of quantities

2.3.1 Scalars and vectors

Can you distinguish between scalar and vector quantities and give examples of each?



Can you add and subtract coplanar vectors?



Can you draw and use a vector triangle to determine the resultant of two coplanar vectors, such as displacement, velocity and force?



Can you resolve a vector into two perpendicular components, using $F_x = F \cos \theta$ and $F_y = F \sin \theta$?



3.1 Motion

3.1.1 Kinematics

Can you define displacement, instantaneous speed, average speed, velocity and acceleration?



Can you use graphical representations of displacement, speed, velocity and acceleration, including data from data-loggers?



Can you use displacement-time graphs, where velocity is the gradient?



Can you use velocity-time graphs, where acceleration is the gradient and displacement is the area under the graph, including estimating the area under non-linear graphs?



3.1.2 Linear motion

Can you derive and use the equations of motion for constant acceleration in a straight line, including free fall without air resistance ($v = u + at$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$)?



Can you describe techniques and procedures for investigating the motion and collisions of objects using trolleys, air-track gliders, ticker timers, light gates, data-loggers and video?



Can you state what is meant by the acceleration of free fall, g ?



Can you describe techniques for determining g , using a trapdoor and electromagnet arrangement or a light gate and timer?



Can you explain reaction time and thinking distance, braking distance and stopping distance for a vehicle?



3.1.3 Projectile motion

Can you explain the independence of the vertical and horizontal motion of a projectile?



Can you analyse the two-dimensional motion of a projectile with constant velocity in one direction and constant acceleration in a perpendicular direction?



3.2 Forces in action

3.2.1 Dynamics

Can you recall and use net force = mass $\times$ acceleration, $F = ma$?



Can you define the newton as the unit of force?



Can you recall and use weight $W = mg$?



Can you explain the terms tension, normal contact force, upthrust and friction?



Can you draw and interpret free-body diagrams?



Can you analyse one- and two-dimensional motion under constant force?



3.2.2 Motion with non-uniform acceleration

Can you describe drag as the resistive force on an object travelling through a fluid?



Can you state the factors affecting drag for an object travelling through air?



Can you describe the motion of objects falling in a uniform gravitational field in the presence of drag?



Can you explain terminal velocity?



Can you describe techniques for determining terminal velocity in fluids, e.g. a ball-bearing in a viscous liquid or cones falling in air?



3.2.3 Equilibrium

Can you define and calculate the moment of a force?



Can you define a couple and calculate the torque of a couple?



Can you state and apply the principle of moments?



Can you explain centre of mass and centre of gravity, and describe how to determine the centre of gravity experimentally?



Can you state the conditions for equilibrium of an object under forces and torques?



Can you use a triangle of forces to represent three coplanar forces acting on an object in equilibrium?



3.2.4 Density and pressure

Can you define and use density, $\rho = m/V$?



Can you define and use pressure, $p = F/A$, for solids, liquids and gases?



Can you use $p = h\rho g$ for pressure in a fluid?



Can you explain upthrust on an object in a fluid and apply Archimedes' principle?



3.3 Work, energy and power

3.3.1 Work and conservation of energy

Can you define work done by a force and the joule as its unit?



Can you calculate work done using $W = Fx \cos \theta$?



Can you state and apply the principle of conservation of energy?



Can you describe examples of energy in different forms, its conversion and conservation, and apply this to energy transfers?



Can you explain that work done is equal to the energy transferred?



3.3.2 Kinetic and potential energies

Can you derive and use the kinetic energy equation $E_k = \frac{1}{2}mv^2$?



Can you derive and use the gravitational potential energy equation $E_p = mgh$ in a uniform field?



Can you describe and calculate the exchange between gravitational potential energy and kinetic energy?



3.3.3 Power

Can you define power and the watt as its unit, using $P = W/t$?



Can you derive and use $P = Fv$?



Can you calculate the efficiency of a mechanical system?



3.4 Materials

3.4.1 Springs

Can you distinguish between tensile and compressive deformation, and define extension and compression?



Can you state and use Hooke's law?



Can you use $F = kx$, where k is the force constant of a spring or wire?



Can you sketch and interpret force-extension (or force-compression) graphs for springs and wires?



Can you describe techniques and procedures for investigating the force-extension characteristics of arrangements of springs, rubber bands and polythene strips?



3.4.2 Mechanical properties of matter

Can you explain that the area under a force-extension graph is the work done by the force?



Can you calculate elastic potential energy using $E = \frac{1}{2}Fx$ and $E = \frac{1}{2}kx^2$?



Can you define and use stress, strain and ultimate tensile strength?



Can you define and use the Young modulus, $E = \text{stress/strain}$?



Can you describe techniques and procedures for determining the Young modulus of a metal?



Can you sketch and interpret stress-strain graphs for ductile materials, brittle materials and polymeric materials?



Can you distinguish between elastic and plastic deformation of materials?



3.5

Newton's laws of motion and momentum

3.5.1 Newton's laws of motion

Can you state and apply Newton's three laws of motion?



Can you define linear momentum, $p = mv$, and explain its vector nature?



Can you explain net force as the rate of change of momentum, $F = \Delta p / \Delta t$?



Can you define impulse of a force as $F\Delta t$ and relate it to change in momentum?



Can you find impulse as the area under a force-time graph?



3.5.2 Collisions

Can you state and apply the principle of conservation of momentum?



Can you analyse collisions and interactions of bodies in one dimension and in two dimensions?



Can you distinguish between perfectly elastic and inelastic collisions in terms of kinetic energy?



4.1 Charge and current

4.1.1 Charge

Can you define electric current as the rate of flow of charge, $I = \Delta Q / \Delta t$?	☐	☐	☐
Can you define the coulomb as the unit of charge?	☐	☐	☐
Can you state the elementary charge, $e = 1.60 \times 10^{-19} \text{ C}$?	☐	☐	☐
Can you explain that net charge on a particle or object is quantised and a multiple of e ?	☐	☐	☐
Can you explain current as the movement of electrons in metals and of ions in electrolytes?	☐	☐	☐
Can you distinguish between conventional current and electron flow?	☐	☐	☐
Can you state Kirchhoff's first law and explain that it is a consequence of conservation of charge?	☐	☐	☐

4.1.2 Mean drift velocity

Can you explain mean drift velocity of charge carriers?	☐	☐	☐
Can you use $I = Anev$, where n is the number density of charge carriers?	☐	☐	☐
Can you distinguish between conductors, semiconductors and insulators in terms of n ?	☐	☐	☐

4.2 Energy, power and resistance

4.2.1 Circuit symbols

Can you recognise and use the circuit symbols listed in the specification?	☐	☐	☐
Can you draw and interpret circuit diagrams using these symbols?	☐	☐	☐

4.2.2 E.m.f. and p.d.

Can you define potential difference and the volt as its unit?	☐	☐	☐
Can you define electromotive force (e.m.f.) of a source such as a cell or power supply?	☐	☐	☐
Can you distinguish between e.m.f. and p.d. in terms of energy transfer?	☐	☐	☐
Can you use $W = VQ$ and $W = EQ$ for energy transfer?	☐	☐	☐
Can you use $eV = \frac{1}{2}mv^2$ for electrons and other charged particles accelerated through a p.d.?	☐	☐	☐

4.2.3 Resistance

Can you define resistance, $R = V/I$, and the ohm as its unit?



Can you state Ohm's law?



Can you sketch and explain the I-V characteristics of a resistor at constant temperature, a filament lamp, a thermistor, a diode and an LED?



Can you describe techniques and procedures for investigating the I-V characteristics of components?



Can you describe how the resistance of a light-dependent resistor (LDR) varies with light intensity?

**4.2.4 Resistivity**

Can you use the resistivity equation $R = \rho L/A$?



Can you describe techniques and procedures for determining the resistivity of a metal?



Can you describe how the resistivity of metals and semiconductors varies with temperature?



Can you describe how the resistance of a negative temperature coefficient (NTC) thermistor varies with temperature?

**4.2.5 Power**

Can you use the power equations $P = VI$, $P = I^2R$ and $P = V^2/R$?



Can you use $W = VIt$ for energy transferred?



Can you use the kilowatt-hour (kW h) as a unit of energy and calculate the cost of energy?

**4.3 Electrical circuits****4.3.1 Series and parallel circuits**

Can you state Kirchhoff's second law and explain that it is a consequence of conservation of energy?



Can you apply Kirchhoff's first and second laws to circuits?



Can you derive and use the formula for total resistance of resistors in series, $R = R_1 + R_2 + \dots$?



Can you derive and use the formula for total resistance of resistors in parallel, $1/R = 1/R_1 + 1/R_2 + \dots$?



Can you analyse circuits with components, including cells, in both series and parallel?



Can you analyse circuits with more than one source of e.m.f.?



4.3.2 Internal resistance

Can you explain the internal resistance of a source of e.m.f.?



Can you explain terminal p.d. and 'lost volts'?



Can you use $E = I(R + r)$ and $E = V + Ir$?



Can you describe techniques and procedures for determining the internal resistance of a chemical cell or other source of e.m.f.?



4.3.3 Potential dividers

Can you explain how a potential divider circuit with components works?



Can you explain how potential divider circuits with LDRs and thermistors act as sensors?



Can you use $V_{out} = R_2/(R_1 + R_2) \times V_{in}$ and $V_1/V_2 = R_1/R_2$?



Can you describe techniques and procedures for investigating potential divider circuits which may include a sensor such as a thermistor or LDR?



4.4a

Waves 1

4.4.1 Wave motion

Can you describe progressive waves and distinguish between longitudinal and transverse waves?



Can you define displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave?



Can you use an oscilloscope to determine the frequency of a wave?



Can you use $f = 1/T$?



Can you use the wave equation $v = f\lambda$?



Can you interpret graphical representations of transverse and longitudinal waves?



Can you describe reflection, refraction, polarisation and diffraction for all types of wave?



Can you describe how to demonstrate wave effects using a ripple tank?



Can you describe how to observe polarising effects using microwaves and light?



Can you define intensity of a progressive wave, $I = P/A$, and use intensity $\propto (\text{amplitude})^2$?



4.4.2 Electromagnetic waves

Can you describe the electromagnetic spectrum and the properties of electromagnetic waves?



Can you state the orders of magnitude of wavelengths of the principal radiations from radio waves to gamma rays?



Can you explain plane polarised waves and describe polarisation of electromagnetic waves?



Can you explain refraction of light and use refractive index $n = c/v$ and $n \sin \theta = \text{constant}$ at a boundary?



Can you describe techniques and procedures for investigating refraction and total internal reflection of light?



Can you explain total internal reflection and use the critical angle equation $\sin C = 1/n$?

**4.4b****Waves 2****4.4.3 Superposition**

Can you state the principle of superposition of waves?



Can you describe superposition experiments using sound, light and microwaves?



Can you illustrate superposition graphically?



Can you explain interference, coherence, path difference and phase difference?



Can you state the conditions for constructive and destructive interference in terms of path difference and phase difference?



Can you describe two-source interference with sound and microwaves?



Can you describe the Young double-slit experiment using visible light?



Can you use $\lambda = ax/D$ for all waves where $a \ll D$?



Can you describe how to determine the wavelength of light using a double slit and a diffraction grating?

**4.4.4 Stationary waves**

Can you describe stationary (standing) waves using microwaves, stretched strings and air columns?



Can you interpret graphical representations of a stationary wave?



Can you state the similarities and differences between stationary and progressive waves?



Can you explain nodes and antinodes?



Can you describe stationary wave patterns for a stretched string and air columns in closed and open tubes?



Can you describe techniques for determining the speed of sound in air by formation of stationary waves in a resonance tube?



Can you explain that the separation between adjacent nodes (or antinodes) is $\lambda/2$?



Can you explain fundamental mode of vibration (1st harmonic) and harmonics?



4.5 Quantum physics

4.5.1 Photons

Can you describe the particulate nature (photon model) of electromagnetic radiation?



Can you explain that a photon is a quantum of energy of electromagnetic radiation?



Can you use $E = hf$ and $E = hc/\lambda$ for the energy of a photon?



Can you define the electronvolt (eV) and convert between eV and J?



Can you explain how to use LEDs and the equation $eV = hc/\lambda$ to estimate the value of Planck constant h ?



Can you describe how to determine the Planck constant using different coloured LEDs?



4.5.2 The photoelectric effect

Can you describe the photoelectric effect, including a simple experiment to demonstrate it?



Can you describe how to demonstrate the photoelectric effect using a gold-leaf electroscope and a zinc plate?



Can you explain the one-to-one interaction between a photon and a surface electron?



Can you use Einstein's photoelectric equation $hf = \phi + KE_{\max}$?



Can you define work function and threshold frequency?



Can you explain why the maximum kinetic energy of photoelectrons is independent of the intensity of the incident radiation?



Can you explain why the rate of emission of photoelectrons above the threshold frequency is directly proportional to the intensity of the incident radiation?



4.5.3 Wave-particle duality

Can you explain electron diffraction as evidence for the wave-like behaviour of particles?



Can you describe the diffraction of electrons travelling through a thin slice of polycrystalline graphite by the atoms or planes of atoms?



Can you use the de Broglie equation $\lambda = h/p$?



5.1 Thermal physics

5.1.1 Temperature

- | | |
|--|---|
| Can you explain thermal equilibrium? | ☐ ☐ ☐ |
| Can you describe the absolute scale of temperature (thermodynamic scale) that does not depend on the property of any particular substance? | ☐ ☐ ☐ |
| Can you use temperature measurements in both degrees Celsius ($^{\circ}\text{C}$) and kelvin (K)? | ☐ ☐ ☐ |
| Can you convert between temperatures using $T (\text{K}) \approx \theta (^{\circ}\text{C}) + 273$? | ☐ ☐ ☐ |

5.1.2 Solid, liquid and gas

- | | |
|--|---|
| Can you describe solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules? | ☐ ☐ ☐ |
| Can you use a simple kinetic model for solids, liquids and gases? | ☐ ☐ ☐ |
| Can you describe an experiment that demonstrates Brownian motion and explain it using the kinetic model? | ☐ ☐ ☐ |
| Can you define internal energy as the sum of the random distribution of kinetic and potential energies of molecules in a system? | ☐ ☐ ☐ |
| Can you explain absolute zero (0 K) as the lowest limit for temperature, where a substance has minimum internal energy? | ☐ ☐ ☐ |
| Can you explain the increase in internal energy of a body as its temperature rises? | ☐ ☐ ☐ |
| Can you explain the changes in internal energy during a change of phase at constant temperature? | ☐ ☐ ☐ |

5.1.3 Thermal properties of materials

- | | |
|---|---|
| Can you define specific heat capacity and use $E = mc\Delta\theta$? | ☐ ☐ ☐ |
| Can you describe an electrical experiment to determine the specific heat capacity of a metal or a liquid? | ☐ ☐ ☐ |
| Can you describe techniques and procedures for determining specific heat capacity using the electrical method for a metal block and a liquid? | ☐ ☐ ☐ |
| Can you define specific latent heat of fusion and specific latent heat of vaporisation and use $E = mL$? | ☐ ☐ ☐ |
| Can you describe an electrical experiment to determine the specific latent heat of fusion and of vaporisation? | ☐ ☐ ☐ |
| Can you describe techniques and procedures for determining specific latent heat using the electrical method for a solid and a liquid? | ☐ ☐ ☐ |

5.1.4 Ideal gases

Can you use amount of substance in moles and the Avogadro constant $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$?



Can you state the assumptions of the kinetic theory model of gases?



Can you explain the pressure of a gas using the kinetic model?



Can you use the equation of state of an ideal gas, $pV = nRT$?



Can you describe techniques and procedures for investigating Boyle's law ($pV = \text{constant}$) and the pressure law ($p/T = \text{constant}$)?



Can you describe how to estimate absolute zero from the variation of gas pressure with temperature?



Can you use $pV = \frac{1}{3}Nm\langle c^2 \rangle$, where $\langle c^2 \rangle$ is the mean square speed (derivation not required)?



Can you explain root mean square speed and mean square speed, and sketch the general shape of the Maxwell-Boltzmann distribution?



Can you use the Boltzmann constant $k = R/N_A$?



Can you use $pV = NkT$ and $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$, including deriving the second from $pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2 \rangle$?



Can you explain the internal energy of an ideal gas as the total kinetic energy of its molecules?



5.2 Circular motion

5.2.1 Kinematics of circular motion

Can you define the radian as a measure of angle?



Can you define the period and frequency of an object in circular motion?



Can you define and use angular velocity, $\omega = 2\pi/T$ or $\omega = 2\pi f$?



5.2.2 Centripetal force

Can you explain that a constant net force perpendicular to the velocity of an object causes it to travel in a circular path?



Can you use $v = \omega r$ for constant speed in a circle?



Can you use centripetal acceleration $a = v^2/r$ and $a = \omega^2 r$?



Can you use centripetal force $F = mv^2/r$ and $F = m\omega^2 r$?



Can you describe techniques and procedures for investigating circular motion using a whirling bung?



5.3.1 Simple harmonic oscillations

Can you define displacement, amplitude, period, frequency, angular frequency and phase difference for oscillations?



Can you use angular frequency $\omega = 2\pi/T$ or $\omega = 2\pi f$?



Can you define simple harmonic motion and use its defining equation $a = -\omega^2 x$?



Can you describe techniques for determining the period or frequency of simple harmonic oscillations, such as a mass-spring system or a pendulum?



Can you use the solutions $x = A \cos \omega t$ and $x = A \sin \omega t$?



Can you use $v = \pm \omega \sqrt{A^2 - x^2}$ and $v_{\max} = \omega A$?



Can you explain that the period of a simple harmonic oscillator is independent of its amplitude (isochronous oscillator)?



Can you sketch and interpret the graphical relationships between displacement, velocity and acceleration of a simple harmonic oscillator?

**5.3.2 Energy of a simple harmonic oscillator**

Can you describe the interchange between kinetic and potential energy during simple harmonic motion?



Can you sketch and interpret energy-displacement graphs for a simple harmonic oscillator?

**5.3.3 Damping**

Can you distinguish between free and forced oscillations?



Can you describe the effects of light, heavy and very heavy damping on an oscillating system?



Can you describe techniques and procedures used to observe forced and damped oscillations for a range of systems?



Can you explain resonance and natural frequency?



Can you sketch and interpret the amplitude-driving frequency graph for a forced oscillator, including the effect of damping?



Can you describe practical examples of forced oscillations and resonance?



5.4

Gravitational fields

5.4.1 Point and spherical masses

Can you explain that a gravitational field is due to mass?



Can you explain why the mass of a spherical object can be modelled as a point mass at its centre?



Can you use gravitational field lines to map gravitational fields?



Can you define and use gravitational field strength, $g = F/m$?



Can you explain the concept of fields as one of a number of forms of field giving rise to a force?



5.4.2 Newton's law of gravitation

Can you state and use Newton's law of gravitation, $F = -GMm/r^2$?



Can you use $g = -GM/r^2$ for the gravitational field strength of a point mass?



Can you explain why gravitational field strength is approximately uniform close to the surface of the Earth and equal to the acceleration of free fall?



5.4.3 Planetary motion

Can you state Kepler's three laws of planetary motion?



Can you explain that the centripetal force on a planet is provided by gravitational force from the Sun?



Can you derive $T^2 = (4\pi^2/GM)r^3$ from first principles?



Can you apply Kepler's third law to systems other than the solar system, such as satellites around a planet?



Can you describe geostationary orbits and their uses?



5.4.4 Gravitational potential and energy

Can you define gravitational potential at a point as the work done in bringing unit mass from infinity, and explain why it is zero at infinity?



Can you use $V_g = -GM/r$ and calculate changes in gravitational potential?



Can you explain that the area under a force-distance graph is the work done?



Can you use gravitational potential energy $E = mV_g = -GMm/r$?



Can you define and calculate escape velocity?



5.5.1 Stars

Can you describe the terms planets, planetary satellites, comets, solar systems, galaxies and the universe?



Can you describe the formation of a star from interstellar dust and gas through gravitational collapse, fusion of hydrogen into helium, and the balance between radiation pressure, gas pressure and gravity?



Can you describe the evolution of a low-mass star into a red giant and then a white dwarf, including planetary nebula?



Can you explain the characteristics of a white dwarf, electron degeneracy pressure and the Chandrasekhar limit?



Can you describe the evolution of a massive star into a red super giant and then a neutron star or black hole, including supernovae?



Can you describe the characteristics of neutron stars and black holes?



Can you sketch and interpret the Hertzsprung-Russell (HR) diagram, showing main sequence, red giants, super red giants and white dwarfs?



5.5.2 Electromagnetic radiation from stars

Can you describe energy levels of electrons in isolated gas atoms?



Can you explain why energy levels have negative values?



Can you explain emission spectral lines in terms of electrons moving between energy levels?



Can you use $hf = \Delta E$ and $hc/\lambda = \Delta E$ for photons emitted or absorbed in electron transitions?



Can you explain how spectral lines are used to identify elements in stars?



Can you distinguish between continuous, emission line and absorption line spectra?



Can you describe how to use a transmission diffraction grating to determine the wavelength of light?



Can you use $d \sin \theta = n\lambda$ for a diffraction grating?



Can you use Wien's displacement law, $\lambda_{\max} \propto 1/T$, to estimate the peak surface temperature of a star?



Can you define luminosity of a star and use Stefan's law $L = 4\pi r^2 \sigma T^4$?



Can you use Wien's displacement law and Stefan's law to estimate the radius of a star?



5.5.3 Cosmology

Can you define distances using the astronomical unit (AU), light-year (ly) and parsec (pc)?



Can you explain stellar parallax?



Can you use the small angle approximation to define the parsec and use $p = 1/d$?



Can you state the cosmological principle (the universe is isotropic and homogeneous on a large scale)?



Can you describe the Doppler effect in electromagnetic radiation?



Can you use the Doppler equation $\Delta\lambda/\lambda \approx \Delta f/f \approx v/c$ for a source of electromagnetic radiation moving relative to an observer?



Can you state and use Hubble's law, $v \approx H_0 d$, for receding galaxies?



Can you explain how the redshift of galaxies supports the model of an expanding universe?



Can you express the Hubble constant in both $\text{km s}^{-1} \text{Mpc}^{-1}$ and s^{-1} ?



Can you describe the Big Bang theory?



Can you explain how the cosmic microwave background radiation at a temperature of 2.7 K provides experimental evidence for the Big Bang?



Can you explain that the Big Bang was the expansion of space-time, not an explosion into existing space?



Can you estimate the age of the universe using $t \approx 1/H_0$?



Can you describe the evolution of the universe after the Big Bang to the present?



Can you describe current ideas that the universe is made up of dark energy, dark matter and a small percentage of ordinary matter?



6.1 Capacitors

6.1.1 Capacitors

Can you define capacitance, $C = Q/V$, and the farad as its unit?	☐ ☐ ☐
Can you explain the charging and discharging of a capacitor in terms of the flow of electrons?	☐ ☐ ☐
Can you derive and use the formula for total capacitance of capacitors in series, $1/C = 1/C_1 + 1/C_2 + \dots$?	☐ ☐ ☐
Can you derive and use the formula for total capacitance of capacitors in parallel, $C = C_1 + C_2 + \dots$?	☐ ☐ ☐
Can you analyse circuits containing capacitors, including resistors?	☐ ☐ ☐
Can you describe techniques and procedures for investigating capacitors in series and parallel using ammeters and voltmeters?	☐ ☐ ☐

6.1.2 Energy

Can you explain that the area under a p.d.-charge graph is the energy stored by a capacitor?	☐ ☐ ☐
Can you use $W = \frac{1}{2}QV$, $W = \frac{1}{2}Q^2/C$ and $W = \frac{1}{2}V^2C$ for energy stored by a capacitor?	☐ ☐ ☐
Can you describe uses of capacitors as storage of energy?	☐ ☐ ☐

6.1.3 Charging and discharging capacitors

Can you describe the charging and discharging of a capacitor through a resistor?	☐ ☐ ☐
Can you describe techniques and procedures for investigating the charge and discharge of a capacitor using meters and data-loggers?	☐ ☐ ☐
Can you define and use the time constant $\tau = CR$?	☐ ☐ ☐
Can you use $x = x_0 e^{-t/CR}$ and $x = x_0(1 - e^{-t/CR})$, where x is V , Q or I , and use $\ln x$ against t graphs to determine CR ?	☐ ☐ ☐
Can you model capacitor discharge using $\Delta Q/\Delta t = -Q/CR$ with a spreadsheet or graphical method?	☐ ☐ ☐
Can you explain the constant-ratio property of the exponential decay graph?	☐ ☐ ☐

6.2.1 Point and spherical charges

Can you explain that electric fields are due to charges?



Can you explain why a uniformly charged sphere can be modelled as a point charge at its centre?



Can you use electric field lines to map electric fields?



Can you define and use electric field strength, $E = F/Q$?

**6.2.2 Coulomb's law**

Can you state and use Coulomb's law, $F = Qq/(4\pi\epsilon_0 r^2)$, for the force between two point charges?



Can you use $E = Q/(4\pi\epsilon_0 r^2)$ for the electric field strength of a point charge?



Can you state the similarities and differences between gravitational and electric fields?



Can you explain electric fields as one of a number of forms of field giving rise to a force?

**6.2.3 Uniform electric field**

Can you use $E = V/d$ for the uniform electric field strength between charged parallel plates?



Can you use $C = \epsilon_0 A/d$ and $C = \epsilon A/d$ for a parallel plate capacitor, including the effect of a dielectric and relative permittivity $\epsilon_r = \epsilon/\epsilon_0$?



Can you analyse the motion of charged particles in a uniform electric field?

**6.2.4 Electric potential and energy**

Can you define electric potential at a point as the work done in bringing unit positive charge from infinity?



Can you use $V = Q/(4\pi\epsilon_0 r)$ and calculate changes in electric potential?



Can you derive and use $C = 4\pi\epsilon_0 R$ for the capacitance of an isolated sphere?



Can you explain that the area under a force-distance graph is the work done?



Can you use electric potential energy $= Vq = Qq/(4\pi\epsilon_0 r)$?



6.3.1 Magnetic fields

Can you explain that magnetic fields are due to moving charges or permanent magnets?



Can you use magnetic field lines to map magnetic fields?



Can you draw magnetic field patterns for a long straight current-carrying conductor, a flat coil and a long solenoid?



Can you use Fleming's left-hand rule?



Can you use $F = BIL \sin \theta$ for the force on a current-carrying conductor?



Can you describe techniques and procedures for determining the uniform magnetic flux density between the poles of a magnet using a current-carrying wire and digital balance?



Can you define magnetic flux density and the tesla as its unit?

**6.3.2 Motion of charged particles**

Can you use $F = BQv$ for the force on a charged particle travelling at right angles to a uniform magnetic field?



Can you analyse the circular orbits of charged particles in a uniform magnetic field?



Can you analyse the motion of charged particles in uniform electric and magnetic fields, including a velocity selector?

**6.3.3 Electromagnetism**

Can you define magnetic flux, $\Phi = BA \cos \theta$, and the weber as its unit?



Can you define magnetic flux linkage, $N\Phi$?



Can you state Faraday's law and Lenz's law of electromagnetic induction?



Can you use e.m.f. = -(rate of change of magnetic flux linkage), $\mathcal{E} = -\Delta(N\Phi)/\Delta t$?



Can you describe techniques and procedures for investigating magnetic flux using search coils?



Can you describe and explain the simple a.c. generator?



Can you describe a simple laminated iron-cored transformer and use $n_s/n_p = V_s/V_p = I_p/I_s$ for an ideal transformer?



Can you describe techniques and procedures for investigating transformers?



6.4.1 The nuclear atom

Can you describe the alpha-particle scattering experiment and explain the evidence it gives for a small, charged, massive nucleus?



Can you describe a simple nuclear model of the atom (protons, neutrons and electrons)?



Can you compare the relative sizes of the atom and the nucleus?



Can you use proton number, nucleon number and isotopes, and use the nuclear notation $A \ Z \ X$?



Can you describe the strong nuclear force, including its short range and nature?



Can you use $R = r_0 A^{1/3}$ for the radius of a nucleus?



Can you estimate and compare the mean densities of atoms and nuclei?

**6.4.2 Fundamental particles**

Can you explain that every particle has a corresponding antiparticle?



Can you compare the masses and charges of particles and their antiparticles, e.g. the positron?



Can you describe hadrons as particles that experience the strong nuclear force?



Can you describe leptons, e.g. electrons and neutrinos, as particles that do not experience the strong nuclear force?



Can you describe the simple quark model of hadrons in terms of up (u), down (d) and strange (s) quarks and their antiquarks?



Can you describe the quark model of the proton (uud) and the neutron (udd)?



Can you state the charges of the up, down and strange quarks and their antiquarks as fractions of e ?



Can you describe beta-minus and beta-plus decay?



Can you describe beta-minus decay in terms of a quark model?



Can you describe beta-plus decay in terms of a quark model?



Can you balance quark transformation equations in terms of charge?



Can you balance equations for particle decays in terms of the quark model?



6.4.3 Radioactivity

Can you explain that radioactive decay is spontaneous and random?	☐	☐	☐
Can you describe the nature, penetration and range of alpha particles, beta particles and gamma rays?	☐	☐	☐
Can you describe techniques and procedures for investigating the absorption of alpha particles, beta particles and gamma rays by appropriate materials?	☐	☐	☐
Can you write and balance nuclear decay equations for alpha, beta-minus and beta-plus decays?	☐	☐	☐
Can you define activity and the decay constant, and use $A = \lambda N$?	☐	☐	☐
Can you define half-life?	☐	☐	☐
Can you describe techniques and procedures for determining the half-life of an isotope such as protactinium?	☐	☐	☐
Can you use $A = A_0 e^{-\lambda t}$ and $N = N_0 e^{-\lambda t}$, where A is activity and N is number of undecayed nuclei?	☐	☐	☐
Can you describe how to simulate radioactive decay using dice?	☐	☐	☐
Can you model radioactive decay using graphical methods and spreadsheets, using $\Delta N/\Delta t = -\lambda N$?	☐	☐	☐
Can you explain the techniques used in radioactive dating, such as carbon-dating, and its limitations?	☐	☐	☐

6.4.4 Nuclear fission and fusion

Can you use Einstein's mass-energy equation $\Delta E = \Delta mc^2$?	☐	☐	☐
Can you calculate the energy released or absorbed in simple nuclear reactions?	☐	☐	☐
Can you describe the creation and annihilation of particle-antiparticle pairs?	☐	☐	☐
Can you define mass defect, binding energy and binding energy per nucleon?	☐	☐	☐
Can you sketch and interpret the binding energy per nucleon against nucleon number curve, and use it to explain the energy released in fission and fusion?	☐	☐	☐
Can you calculate binding energy and binding energy per nucleon from nuclear masses?	☐	☐	☐
Can you describe induced nuclear fission of uranium-235 and chain reactions?	☐	☐	☐
Can you describe the basic construction of a fission reactor and the role of the fuel rods, control rods and moderator?	☐	☐	☐
Can you describe the environmental impact of nuclear waste?	☐	☐	☐

Can you describe nuclear fusion and explain why fusion requires very high temperatures?



Can you balance nuclear transformation equations?



6.5 Medical imaging

6.5.1 Using X-rays

Can you describe the basic structure of an X-ray tube, including heated filament (cathode), anode, rotating anode and use of high voltage?



Can you explain the production of X-ray photons from an X-ray tube?



Can you describe the X-ray attenuation mechanisms: simple scatter, photoelectric effect, Compton effect and pair production?



Can you use the attenuation equation $I = I_0 e^{-\mu x}$?



Can you explain the use of contrast media such as barium and iodine?



Can you describe computerised axial tomography (CAT) scanning with X-rays?



Can you state the advantages of a CAT scan over an X-ray image?



6.5.2 Diagnostic methods in medicine

Can you describe the use of medical tracers like technetium-99m and fluorine-18 to diagnose the function of organs?



Can you describe the main components of a gamma camera: collimator, scintillator, photomultiplier tubes, computer and display?



Can you explain how a gamma camera is used to produce an image for diagnosis?



Can you describe positron emission tomography (PET) scanning?



Can you explain the use of PET scanning as a non-invasive diagnostic technique?



6.5.3 Using ultrasound

Can you define ultrasound and state its frequency range?



Can you describe the piezoelectric effect and the use of ultrasound transducers as generators and receivers?



Can you distinguish between ultrasound A-scan and B-scan?



Can you define acoustic impedance, $Z = \rho c$?



Can you use the fraction of reflected intensity at a boundary, $I_R/I_0 = (Z_2 - Z_1)^2 / (Z_2 + Z_1)^2$?



Can you explain the importance of impedance matching and the use of a coupling gel?



Can you use the Doppler equation $\Delta f = 2fv \cos \theta / c$ to determine the speed of blood?



Practical activity groups

PAG1 Can you investigate motion, e.g. determine g by free fall, or terminal velocity of a ball-bearing in a viscous liquid?



PAG2 Can you investigate properties of materials, e.g. force-extension of springs and wires and the Young modulus of a metal wire?



PAG3 Can you investigate electrical properties, e.g. I-V characteristics, resistivity of a metal and internal resistance of a cell?



PAG4 Can you investigate electrical circuits, e.g. potential dividers including sensors such as a thermistor or LDR?



PAG5 Can you investigate waves, e.g. wavelength of light with a double slit or diffraction grating and the speed of sound with a resonance tube?



PAG6 Can you investigate quantum effects and refraction, e.g. determine the Planck constant using LEDs or the refractive index of glass?



PAG7 Can you investigate ionising radiation, e.g. determine the half-life of protactinium or the absorption of radiation by materials?



PAG8 Can you investigate gases, e.g. Boyle's law, the pressure law and an estimate of absolute zero?



PAG9 Can you investigate capacitors, e.g. charging and discharging through a resistor to find the time constant, and capacitors in series and parallel?



PAG10 Can you investigate simple harmonic motion, e.g. the period of a mass-spring system or a pendulum?



PAG11 Can you plan and carry out an open-ended investigation in physics, recording, analysing and evaluating your results?



PAG12 Can you use research skills to investigate a physics topic and correctly cite your sources?

