1a Working as a physicist

Units, estimation and measurement

- Can you distinguish between base and derived quantities and state their SI units?
- Can you demonstrate and describe practical skills and techniques for both familiar and unfamiliar experiments?
- Can you estimate values of physical quantities and use your estimates to solve problems?
- Can you explain the limitations of physical measurement, including uncertainties, and apply these to practical situations?

Communication and science in society

- Can you communicate information and ideas in appropriate ways using correct scientific terminology?
- Can you describe applications of science and evaluate their associated benefits and risks?
- Can you explain the role of the scientific community, including peer review, in validating new knowledge and ensuring integrity?
- Can you explain the ways in which society uses science to inform decision making?

2a Motion

Kinematics

Can you use the equations for uniformly accelerated motion in one dimension ($s = (u + v)t/2$, $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$)?

Can you draw and interpret displacement-time, velocity-time and acceleration-time graphs?

Can you derive and use quantities from the gradients of and areas under these graphs, including for non-uniform acceleration?

Vectors and projectiles

Can you distinguish between scalar and vector quantities and recognise vector notation?

Can you resolve a vector into two perpendicular components, both by scale drawing and by calculation?

Can you find the resultant of two coplanar vectors by drawing, and by calculation when they are perpendicular?

Can you use the independence of horizontal and vertical motion to solve projectile problems under gravity?

2b Forces

Newton's laws

Can you draw and interpret free-body force diagrams to represent the forces on a particle or an extended but rigid body?

Can you use $\Sigma F = ma$, including situations where the resultant force is zero (equilibrium) and terminal velocity?

Can you use $g = F/m$ and $W = mg$?

Can you determine the acceleration of a freely-falling object (CP1)?

Can you apply Newton's third law to interaction pairs and state the properties of the forces in a pair?

Momentum and moments

Can you use $p = mv$ to define and calculate momentum?

Can you apply the principle of conservation of linear momentum to problems in one dimension?

Can you use moment of force = Fx, where x is the perpendicular distance from the pivot?

Can you use the concept of centre of gravity of an extended body and apply the principle of moments to a body in equilibrium?

2c Energy and power

Work and energy

Can you use $\Delta W = F\Delta s$, including when the force is not parallel to the displacement?

Can you use $E_k = \frac{1}{2}mv^2$?

Can you use $\Delta E_{grav} = mg\Delta h$ near the Earth's surface?

Can you apply the principle of conservation of energy, including work done, gravitational potential energy and kinetic energy?

Power and efficiency

Can you use $P = E/t$ and $P = W/t$?

Can you use efficiency = useful energy output / total energy input and efficiency = useful power output / total power input?

3a Current, p.d. and power

Charge, current and p.d.

- Can you describe electric current as the rate of flow of charged particles and use $I = \Delta Q/\Delta t$?
- Can you use $V = W/Q$?
- Can you use $R = V/I$ and recognise Ohm's law as a special case where I is proportional to V at constant temperature?
- Can you explain the distribution of current in a circuit as a consequence of conservation of charge?
- Can you explain the distribution of potential difference in a circuit as a consequence of conservation of energy?

Resistor combinations and power

- Can you derive and use the equations for combined resistance in series ($R = R_1 + R_2 + R_3$) and parallel ($1/R = 1/R_1 + 1/R_2 + 1/R_3$)?
- Can you use $P = VI$, $W = VIt$, $P = I^2R$ and $P = V^2/R$?

3b Resistance and resistivity

I-V characteristics

- Can you sketch, recognise and interpret I-V graphs for an ohmic conductor, a filament bulb, a thermistor and a diode?

Resistivity and charge carriers

- Can you use $R = \rho l/A$?
- Can you determine the electrical resistivity of a material (CP2)?
- Can you use $I = nqvA$ to explain the large range of resistivities of different materials?

3c Potential dividers and e.m.f.

Potential dividers

- Can you explain how the potential varies along a uniform current-carrying wire?

Can you explain the principle of a potential divider and calculate potentials and resistances in it?

Can you analyse potential divider circuits that include variable resistors such as thermistors and light dependent resistors?

E.m.f. and internal resistance

Can you define e.m.f. and internal resistance and distinguish between e.m.f. and terminal potential difference?

Can you determine the e.m.f. and internal resistance of an electrical cell (CP3)?

Explaining resistance changes

Can you explain how changes of resistance with temperature can be modelled in terms of lattice vibrations and the number of conduction electrons?

Can you explain how changes of resistance with illumination (LDRs) can be modelled in terms of the number of conduction electrons?

4a Fluids

Density, upthrust and viscosity

- Can you use $\rho = m/V$?
- Can you use the principle that upthrust equals the weight of fluid displaced?
- Can you use Stokes' law, $F = 6\pi\eta rv$, for viscous drag and state the conditions (small spheres, low speed, laminar flow) under which it applies?
- Can you use a falling-ball method to determine the viscosity of a liquid (CP4)?

4b Solid materials

Stretching materials

- Can you use Hooke's law, $\Delta F = k\Delta x$, where k is the stiffness of the object?
- Can you use stress = F/A, strain = $\Delta x/x$ and Young modulus E = stress/strain?
- Can you draw and interpret force-extension and force-compression graphs, including limit of proportionality, elastic limit, yield point, elastic deformation and plastic deformation?
- Can you draw and interpret tensile or compressive stress-strain graphs and explain breaking stress?
- Can you determine the Young modulus of a material (CP5)?
- Can you calculate elastic strain energy using $\Delta E_{el} = \frac{1}{2}F\Delta x$, including from the area under a force-extension graph?

5a Wave properties

Describing waves

- Can you define amplitude, frequency, period, speed and wavelength?
- Can you use the wave equation $v = f\lambda$?
- Can you describe longitudinal waves in terms of pressure variation and the displacement of molecules?
- Can you describe transverse waves?
- Can you draw and interpret graphs representing transverse and longitudinal waves, including standing (stationary) waves?
- Can you determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone (CP6)?

Superposition and standing waves

- Can you define the terms wavefront, coherence, path difference, superposition, interference and phase?
- Can you use the relationship between phase difference and path difference?
- Can you explain how a standing wave is formed and identify nodes and antinodes?
- Can you use $v = \sqrt{(T/\mu)}$ for the speed of a transverse wave on a string?
- Can you investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire (CP7)?
- Can you use $I = P/A$ for intensity?

5b Refraction and lenses

Refraction

- Can you use $n_1 \sin \theta_1 = n_2 \sin \theta_2$ at a boundary and define refractive index as $n = c/v$?
- Can you calculate the critical angle using $\sin C = 1/n$?
- Can you predict whether total internal reflection will occur at an interface?
- Can you describe how to measure the refractive index of a solid material?

Lenses

- Can you define focal length for converging and diverging lenses?

- Can you use ray diagrams to trace the path of light through a lens and locate the position of an image?
- Can you use power of a lens $P = 1/f$?
- Can you use $P = P_1 + P_2 + P_3$ for combinations of thin lenses?
- Can you explain the terms real image and virtual image?
- Can you use $1/u + 1/v = 1/f$ for a thin converging or diverging lens using the real is positive convention?
- Can you use magnification = image height / object height and $m = v/u$?

5c Polarisation and diffraction

Polarisation

- Can you explain what is meant by plane polarisation?

Diffraction

- Can you describe diffraction and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle?
- Can you use $n\lambda = d \sin \theta$ for a diffraction grating?
- Can you determine the wavelength of light from a laser or other light source using a diffraction grating (CP8)?
- Can you explain how electron diffraction provides evidence for the wave nature of electrons?
- Can you use the de Broglie equation $\lambda = h/p$?

5d Waves at interfaces and photons

Waves at interfaces

- Can you describe how waves are transmitted and reflected at an interface between media?
- Can you explain how pulse-echo techniques use reflection to locate objects, and how wavelength and pulse duration limit the information obtained?

Particle nature of light

- Can you describe electromagnetic radiation using both a wave model and a photon model, and explain how these models developed over time?

Can you use E = hf?	○ ○ ○
Can you explain that absorption of a photon can result in the emission of a photoelectron?	○ ○ ○
Can you define threshold frequency and work function and use $hf = \varphi + \frac{1}{2}mv^2max$?	○ ○ ○
Can you use the electronvolt (eV) to express small energies and convert between eV and joules?	○ ○ ○
Can you explain how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation?	○ ○ ○
Can you explain atomic line spectra in terms of transitions between discrete energy levels and calculate the frequency of radiation emitted or absorbed?	○ ○ ○

6a Momentum and collisions

Impulse and momentum

- Can you use impulse = $F\Delta t = \Delta p$ and relate it to Newton's second law?
- Can you investigate the relationship between the force exerted on an object and its change of momentum (CP9)?
- Can you apply the principle of conservation of linear momentum to problems in two dimensions?
- Can you use ICT to analyse collisions between small spheres, such as ball bearings on a table top (CP10)?
- Can you determine whether a collision is elastic or inelastic?
- Can you derive and use $E_k = p^2/2m$ for the kinetic energy of a non-relativistic particle?

6b Circular motion

Circular motion

- Can you express angular displacement in radians and in degrees and convert between them?
- Can you explain what is meant by angular velocity and use $v = \omega r$ and $T = 2\pi/\omega$?
- Can you use vector diagrams to derive $a = v^2/r = r\omega^2$ for centripetal acceleration?
- Can you explain that a resultant (centripetal) force is required to produce and maintain circular motion?
- Can you use $F = ma = mv^2/r = mr\omega^2$ for centripetal force?

7a Electric fields

Field strength and force

- Can you explain that an electric field is a region where a charged particle experiences a force?
- Can you define and use electric field strength $E = F/Q$?
- Can you use Coulomb's law $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$ for the force between two point charges?
- Can you use $E = Q/(4\pi\varepsilon_0 r^2)$ for the field strength due to a point charge?

Potential and field patterns

- Can you explain the relationship between electric field strength and electric potential?
- Can you use $E = V/d$ for the uniform field between parallel plates?
- Can you use $V = Q/(4\pi\varepsilon_0 r)$ for the potential in a radial field?
- Can you draw and interpret diagrams using field lines and equipotentials to describe radial and uniform electric fields?

7b Capacitors

Capacitance and energy

- Can you use $C = Q/V$?
- Can you derive and use $W = \frac{1}{2}QV = \frac{1}{2}CV^2 = Q^2/2C$ for the energy stored by a capacitor, including from the area under a graph of V against Q?

Charging and discharging

- Can you draw and interpret charge and discharge curves for resistor-capacitor circuits and explain the significance of the time constant RC?
- Can you use an oscilloscope or data logger to display and analyse the p.d. across a capacitor as it charges and discharges through a resistor (CP11)?
- Can you use $Q = Q_0\, e^{-t/RC}$ and the corresponding equations for I and V, together with their logarithmic forms such as $\ln Q = \ln Q_0 - t/RC$?

7c Magnetic fields and induction

Magnetic forces

Can you explain and use the terms magnetic flux density B, flux $\varphi = BA$ and flux linkage $N\varphi$?

Can you use $F = Bqv \sin\theta$ and Fleming's left hand rule for the force on a charged particle moving in a magnetic field?

Can you use $F = BIl \sin\theta$ and Fleming's left hand rule for the force on a current-carrying conductor in a magnetic field?

Electromagnetic induction

Can you identify the factors affecting the e.m.f. induced in a coil when there is relative motion between the coil and a permanent magnet?

Can you identify the factors affecting the e.m.f. induced in a coil when there is a change of current in another coil linked with it?

Can you use Lenz's law to predict the direction of an induced e.m.f. and explain how it relates to conservation of energy?

Can you use Faraday's law combined with Lenz's law, $\varepsilon = -d(N\varphi)/dt$, to find the magnitude of an induced e.m.f.?

Alternating current

Can you explain frequency, period, peak value and root-mean-square (r.m.s.) value for sinusoidal alternating currents and potential differences?

Can you use $V_{rms} = V_0/\sqrt{2}$ and $I_{rms} = I_0/\sqrt{2}$?

8a Nuclear structure and accelerators

The nucleus

- Can you define nucleon (mass) number and proton (atomic) number?
- Can you explain how large-angle alpha particle scattering gives evidence for a nuclear model of the atom, and how our understanding of atomic structure has changed over time?

Accelerating and detecting particles

- Can you explain thermionic emission and how electrons can be accelerated by electric and magnetic fields?
- Can you explain the role of electric and magnetic fields in particle accelerators (linac and cyclotron) and detectors (ionisation and deflection only)?
- Can you derive and use $r = p/BQ$ for a charged particle moving in a magnetic field?
- Can you apply conservation of charge, energy and momentum to interactions between particles and interpret particle tracks?
- Can you explain why high energies are required to investigate the structure of nucleons?

8b Particle physics

Mass, energy and units

- Can you use $\Delta E = c^2\Delta m$ in situations involving the creation and annihilation of matter and antimatter particles?
- Can you use MeV and GeV (energy) and MeV/c^2 and GeV/c^2 (mass) and convert them to SI units?
- Can you recognise situations in which the relativistic increase in particle lifetime is significant (no relativistic equations required)?

The standard model

- Can you use the quark-lepton model to classify particles as baryons (e.g. proton, neutron), mesons (e.g. pion), leptons (e.g. electron, neutrino) and photons, and explain how symmetry led to the prediction of the top quark?
- Can you explain that every particle has a corresponding antiparticle and deduce the properties of an antiparticle from its particle?
- Can you use conservation of charge, baryon number and lepton number to decide whether a particle interaction is possible?

Can you write and interpret particle equations given the relevant particle symbols?

9a Heat and internal energy

Specific heat and latent heat

- Can you use $\Delta E = mc\Delta\theta$ and $\Delta E = L\Delta m$ for specific heat capacity and specific latent heat?
- Can you calibrate a thermistor in a potential divider circuit for use as a thermostat (CP12)?
- Can you determine the specific latent heat of a phase change (CP13)?

Internal energy and temperature

- Can you explain the concept of internal energy as the random distribution of potential and kinetic energy among molecules?
- Can you explain the concept of absolute zero and how the average kinetic energy of molecules is related to absolute temperature?

9b Gases and black bodies

Ideal gases

- Can you derive and use $pV = \frac{1}{3}Nm\langle c^2\rangle$ using the kinetic theory model?
- Can you use $pV = NkT$ for an ideal gas?
- Can you investigate the relationship between pressure and volume of a gas at fixed temperature (CP14)?
- Can you derive and use $\langle \frac{1}{2}mc^2\rangle = 3/2\ kT$ for the average molecular kinetic energy?

Black body radiation

- Can you explain the concept of a black body radiator and interpret black body radiation curves?
- Can you use the Stefan-Boltzmann law $L = \sigma AT^4$ for black body radiators?
- Can you use Wien's law $\lambda_{max}\ T = 2.898 \times 10^{-3}$ m K for black body radiators?

10a Space

Astronomical distances

Can you use $I = L/(4\pi d^2)$, where L is the luminosity and d the distance from the source?

Can you explain how trigonometric parallax is used to determine astronomical distances?

Can you explain how standard candles of known luminosity are used, with the intensity received, to determine astronomical distances?

Stars

Can you sketch and interpret a simple Hertzsprung-Russell diagram that relates stellar luminosity to surface temperature?

Can you relate the Hertzsprung-Russell diagram to the life cycle of stars?

Cosmology

Can you explain how the movement of a source of waves relative to an observer causes a change in observed frequency and wavelength (Doppler effect)?

Can you use $z = \Delta\lambda/\lambda \approx \Delta f/f \approx v/c$ and $v = H_0 d$ for objects at cosmological distances?

Can you explain the controversy over the age and ultimate fate of the universe, linked to uncertainty in the Hubble constant and possible dark matter?

11a Binding energy, fission and fusion

Binding energy

Can you explain the concept of nuclear binding energy and use $\Delta E = c^2 \Delta m$ to calculate mass deficit and binding energy? ○ ○ ○

Can you use the atomic mass unit (u) and convert between u and SI units? ○ ○ ○

Fission and fusion

Can you explain nuclear fusion and fission in terms of the binding energy per nucleon curve? ○ ○ ○

Can you explain the mechanism of nuclear fusion and why very high densities and temperatures are needed for it to occur? ○ ○ ○

11b Radioactive decay

Nuclear radiation

Can you identify sources of background radiation and correct for it in calculations? ○ ○ ○

Can you compare the nature, penetrating power, ionising ability and range in different materials of alpha, beta and gamma radiation? ○ ○ ○

Can you write and interpret nuclear equations given the relevant symbols? ○ ○ ○

Can you investigate the absorption of gamma radiation by lead (CP15)? ○ ○ ○

Decay and half-life

Can you explain the spontaneous and random nature of nuclear decay? ○ ○ ○

Can you determine half-lives graphically and use $A = \lambda N$, $dN/dt = -\lambda N$, $\lambda = \ln 2/t_{½}$, $N = N_0 e^{-\lambda t}$ and $A = A_0 e^{-\lambda t}$, including their logarithmic forms? ○ ○ ○

12a Gravitational fields

Gravitational fields and potential

- Can you explain that a gravitational field is a region where a mass experiences a force?
- Can you define and use gravitational field strength $g = F/m$?
- Can you use Newton's law of universal gravitation $F = Gm_1m_2/r^2$?
- Can you derive and use $g = Gm/r^2$ for the field strength due to a point mass?
- Can you use $V_{grav} = -Gm/r$ for the potential in a radial gravitational field?

Comparing fields and orbits

- Can you recognise and compare the similarities and differences between electric and gravitational fields?
- Can you apply Newton's laws of motion and universal gravitation to orbital motion, including deriving relationships between orbital speed, period and radius?

13a Simple harmonic motion

Conditions and equations of SHM

Can you state that the condition for simple harmonic motion is $F = -kx$ and identify situations in which SHM occurs?

Can you use $a = -\omega^2 x$, $x = A \cos \omega t$, $v = -A\omega \sin \omega t$, $a = -A\omega^2 \cos \omega t$, $T = 1/f = 2\pi/\omega$ and $\omega = 2\pi f$?

Can you use $T = 2\pi\sqrt{(m/k)}$ for a mass-spring system and $T = 2\pi\sqrt{(l/g)}$ for a simple pendulum?

SHM graphs

Can you draw and interpret a displacement-time graph for an object oscillating, knowing that its gradient gives the velocity?

Can you draw and interpret a velocity-time graph for an oscillating object, knowing that its gradient gives the acceleration?

13b Resonance and damping

Resonance

Can you explain what is meant by resonance?

Can you determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses (CP16)?

Energy, forced oscillations and damping

Can you apply conservation of energy to damped and undamped oscillating systems, including energy interchange between kinetic and potential energy?

Can you distinguish between free and forced oscillations?

Can you explain how the amplitude of a forced oscillation changes at and around the natural frequency of a system, and describe qualitatively how damping affects resonance?

Can you explain how damping and the plastic deformation of ductile materials reduce the amplitude of oscillation?

CP Core Practicals

Core practical activities

1 Can you determine the acceleration of a freely-falling object?

2 Can you determine the electrical resistivity of a material?

3 Can you determine the e.m.f. and internal resistance of an electrical cell?

4 Can you use a falling-ball method to determine the viscosity of a liquid?

5 Can you determine the Young modulus of a material?

6 Can you determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone?

7 Can you investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire?

8 Can you determine the wavelength of light from a laser or other light source using a diffraction grating?

9 Can you investigate the relationship between the force exerted on an object and its change of momentum?

10 Can you use ICT to analyse collisions between small spheres, e.g. ball bearings on a table top?

11 Can you use an oscilloscope or data logger to display and analyse the potential difference across a capacitor as it charges and discharges through a resistor?

12 Can you calibrate a thermistor in a potential divider circuit as a thermostat?

13 Can you determine the specific latent heat of a phase change?

14 Can you investigate the relationship between pressure and volume of a gas at fixed temperature?

15 Can you investigate the absorption of gamma radiation by lead?

16 Can you determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses?