

3.1.1 Use of SI units and their prefixes

3.1.1 Use of SI units and their prefixes

Can you name the SI base units for mass, length, time, amount of substance, temperature and electric current?



Can you express derived SI units in terms of base units (e.g. the newton as kg m s^{-2})?



Can you use the prefixes T, G, M, k, c, m, μ , n, p and f and write values in standard form?



Can you convert between different units of the same quantity, such as J and eV, or J and kW h?



3.1.2 Limitation of physical measurements

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Can you distinguish between random and systematic errors, giving an example of each?



Can you identify random and systematic errors in an experiment and suggest ways to reduce or remove them?



Can you define precision, repeatability, reproducibility, resolution and accuracy?



Can you calculate absolute, fractional and percentage uncertainties?



Can you state the uncertainty in a final answer to an appropriate number of significant figures?



Can you explain the link between the number of significant figures in a value and its uncertainty?



Can you combine uncertainties when quantities are added or subtracted (add absolute uncertainties)?



Can you combine uncertainties when quantities are multiplied, divided or raised to a power (add percentage uncertainties)?



Can you draw error bars on a graph to represent the uncertainty in a data point?



Can you find the uncertainty in the gradient and intercept of a straight-line graph using best and worst lines?



3.1.3**Estimation of physical quantities****3.1.3 Estimation of physical quantities**

Can you give a value to the nearest order of magnitude?



Can you estimate approximate values of everyday physical quantities?



Can you combine estimates with physics knowledge to produce derived estimates to the nearest order of magnitude?



3.2.1.1 Constituents of the atom

Can you describe the simple model of the atom in terms of protons, neutrons and electrons?



Can you state the charge and mass of the proton, neutron and electron in SI units and relative units?



Can you calculate the specific charge of a proton, electron, nucleus or ion?



Can you use proton number Z , nucleon number A and nuclide notation?



Can you define isotopes and use isotopic data?

**3.2.1.2 Stable and unstable nuclei**

Can you explain the role of the strong nuclear force in keeping a nucleus stable?



Can you describe the range of the strong force (attractive up to about 3 fm, repulsive below about 0.5 fm)?



Can you explain why some nuclei are unstable and undergo alpha or beta-minus decay?



Can you write balanced equations for alpha decay and beta-minus decay, including the antineutrino?



Can you explain why the existence of the neutrino was hypothesised to conserve energy in beta decay?

**3.2.1.3 Particles, antiparticles and photons**

Can you state that every particle has a corresponding antiparticle?



Can you compare the mass, charge and rest energy (in MeV) of a particle and its antiparticle?



Can you name the positron, antiproton, antineutron and antineutrino as antiparticles?



Can you describe the photon model of electromagnetic radiation?



Can you use $E = hf = hc/\lambda$ to calculate photon energy?



Can you describe annihilation and pair production and the energies involved?



Can you calculate the minimum photon energy for pair production and the photon energy from annihilation?



3.2.1.4 Particle interactions

Can you name the four fundamental interactions: gravity, electromagnetic, weak nuclear and strong nuclear?



Can you explain the idea of exchange particles to describe forces between elementary particles?



Can you state that the virtual photon is the exchange particle for the electromagnetic force?



Can you describe the weak interaction in beta-minus decay, beta-plus decay, electron capture and electron-proton collisions?



Can you identify W^+ and W^- bosons as the exchange particles of the weak interaction?



Can you draw and interpret simple Feynman-style diagrams showing incoming, outgoing and exchange particles?

**3.2.1.5 Classification of particles**

Can you define hadrons as particles subject to the strong interaction?



Can you classify hadrons as baryons (proton, neutron), antibaryons or mesons (pion, kaon)?



Can you use baryon number as a quantum number and apply its conservation?



Can you state that the proton is the only stable baryon and other baryons eventually decay into it?



Can you state that the pion is the exchange particle of the strong nuclear force?



Can you state that the kaon is a particle that can decay into pions?



Can you classify leptons (electron, muon, neutrinos) and their antiparticles?



Can you apply conservation of lepton number separately for electron leptons and muon leptons?



Can you state that the muon decays into an electron?



Can you explain that strange particles are produced by the strong interaction but decay by the weak interaction?



Can you explain why strange particles are always produced in pairs and strangeness is conserved in strong interactions?



Can you state that strangeness can change by 0, +1 or -1 in weak interactions?



Can you explain why particle physics relies on large collaborative teams to confirm new knowledge?



3.2.1.6 Quarks and antiquarks

Can you state the charge, baryon number and strangeness of the up, down and strange quarks and their antiquarks?



Can you give the quark combinations of the proton, neutron, antiproton and antineutron?



Can you give the quark-antiquark combinations of pions and kaons?



Can you describe the decay of the neutron in terms of particles and quarks?

**3.2.1.7 Applications of conservation laws**

Can you describe the change of quark character in beta-minus and beta-plus decay?



Can you apply conservation of charge, baryon number, lepton number and strangeness to decide whether an interaction is allowed?



Can you state that energy and momentum are conserved in particle interactions?

**3.2.2****Electromagnetic radiation and quantum phenomena****3.2.2.1 The photoelectric effect**

Can you describe the photoelectric effect and the existence of a threshold frequency?



Can you explain the threshold frequency using the photon model of light?



Can you define work function and stopping potential?



Can you use the photoelectric equation $hf = \phi + E_{k(max)}$?

**3.2.2.2 Collisions of electrons with atoms**

Can you explain ionisation and excitation of atoms by electron collisions?



Can you explain how a fluorescent tube works in terms of excitation and de-excitation?



Can you define the electron volt and convert between eV and J?

**3.2.2.3 Energy levels and photon emission**

Can you explain how line spectra (e.g. atomic hydrogen) provide evidence for discrete energy levels?



Can you use $hf = E_1 - E_2$ to calculate the frequency or wavelength of an emitted photon?



Can you work with energy levels given in either J or eV?



3.2.2.4 Wave-particle duality

Can you explain how electron diffraction shows that particles have wave properties?



Can you explain how the photoelectric effect shows that electromagnetic waves have particle properties?



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



Can you explain how changing a particle's momentum changes the amount of diffraction?



Can you describe how understanding of the nature of matter has changed and been validated by peer review?



3.3.1 Progressive and stationary waves

3.3.1.1 Progressive waves

- | | |
|---|---|
| Can you describe the oscillation of particles in a medium as a progressive wave passes? | ☐ ☐ ☐ |
| Can you define amplitude, frequency, wavelength, speed, phase and phase difference? | ☐ ☐ ☐ |
| Can you use $c = f\lambda$ and $f = 1/T$? | ☐ ☐ ☐ |
| Can you express phase difference in degrees, radians and as fractions of a cycle? | ☐ ☐ ☐ |

3.3.1.2 Longitudinal and transverse waves

- | | |
|--|---|
| Can you describe the nature of longitudinal and transverse waves with examples (sound, EM waves, waves on a string)? | ☐ ☐ ☐ |
| Can you describe the direction of displacement relative to the direction of energy transfer for each type? | ☐ ☐ ☐ |
| Can you state that all EM waves travel at the same speed in a vacuum? | ☐ ☐ ☐ |
| Can you explain how polarisation provides evidence for the transverse nature of light? | ☐ ☐ ☐ |
| Can you describe applications of polarisers, such as Polaroid material and aligning aerials? | ☐ ☐ ☐ |

3.3.1.3 Principle of superposition and formation of stationary waves

- | | |
|---|---|
| Can you explain how a stationary wave forms from two waves of the same frequency travelling in opposite directions? | ☐ ☐ ☐ |
| Can you use a graphical method to explain the formation of a stationary wave? | ☐ ☐ ☐ |
| Can you identify nodes and antinodes on a stationary wave? | ☐ ☐ ☐ |
| Can you use $f = (1/2l) \sqrt{T/\mu}$ for the first harmonic on a string? | ☐ ☐ ☐ |
| Can you describe stationary waves on strings, with microwaves and with sound waves? | ☐ ☐ ☐ |
| Can you describe harmonics on a string and find the frequency of higher harmonics? | ☐ ☐ ☐ |

3.3.2 Refraction, diffraction and interference

3.3.2.1 Interference

- | | |
|---|---|
| Can you explain path difference and the meaning of coherence? | ☐ ☐ ☐ |
|---|---|

Can you describe interference and diffraction using a laser as a monochromatic source?	☐	☐	☐
Can you describe Young's double-slit experiment using two coherent sources or one source with double slits?	☐	☐	☐
Can you use the fringe spacing equation $w = \lambda D/s$?	☐	☐	☐
Can you describe the interference pattern produced with white light?	☐	☐	☐
Can you describe the safety precautions needed when using lasers?	☐	☐	☐
Can you describe and explain interference effects with sound and electromagnetic waves?	☐	☐	☐
Can you describe how knowledge of the nature of EM radiation has changed over time?	☐	☐	☐

3.3.2.2 Diffraction

Can you describe the single-slit diffraction pattern with monochromatic and white light?	☐	☐	☐
Can you explain qualitatively how slit width and wavelength affect the width of the central maximum?	☐	☐	☐
Can you use the diffraction grating equation $d \sin \theta = n\lambda$ at normal incidence?	☐	☐	☐
Can you find the maximum order visible with a diffraction grating?	☐	☐	☐
Can you describe applications of diffraction gratings?	☐	☐	☐

3.3.2.3 Refraction at a plane surface

Can you define refractive index as $n = c/v$ and state that n for air is approximately 1?	☐	☐	☐
Can you use Snell's law $n_1 \sin \theta_1 = n_2 \sin \theta_2$?	☐	☐	☐
Can you explain total internal reflection and use $\sin \theta_c = n_2/n_1$?	☐	☐	☐
Can you describe how a step-index optical fibre works, including the function of the cladding?	☐	☐	☐
Can you explain material dispersion and modal dispersion in optical fibres?	☐	☐	☐
Can you explain the causes and consequences of pulse broadening and absorption, and how to reduce them?	☐	☐	☐

3.4.1 Force, energy and momentum

3.4.1.1 Scalars and vectors

Can you explain the difference between scalars and vectors with examples?	☐	☐	☐
Can you add two perpendicular vectors by calculation and other vectors by scale drawing?	☐	☐	☐
Can you resolve a vector into two perpendicular components, including on an inclined plane?	☐	☐	☐
Can you solve problems using resolved forces or a closed vector triangle?	☐	☐	☐
Can you state the conditions for equilibrium of two or three coplanar forces acting at a point?	☐	☐	☐
Can you explain that equilibrium means at rest or moving at constant velocity?	☐	☐	☐

3.4.1.2 Moments

Can you define the moment of a force about a point?	☐	☐	☐
Can you define a couple and calculate the moment of a couple?	☐	☐	☐
Can you apply the principle of moments?	☐	☐	☐
Can you explain centre of mass and locate it for a uniform regular solid?	☐	☐	☐

3.4.1.3 Motion along a straight line

Can you define displacement, speed, velocity and acceleration using $v = \Delta s / \Delta t$ and $a = \Delta v / \Delta t$?	☐	☐	☐
Can you calculate average and instantaneous speed and velocity?	☐	☐	☐
Can you represent uniform and non-uniform acceleration on graphs?	☐	☐	☐
Can you interpret gradients and areas of displacement-time, velocity-time and acceleration-time graphs?	☐	☐	☐
Can you use the suvat equations for uniform acceleration?	☐	☐	☐
Can you solve problems involving the acceleration due to gravity, g ?	☐	☐	☐

3.4.1.4 Projectile motion

Can you treat the horizontal and vertical motion of a projectile independently?	☐	☐	☐
Can you solve projectile problems using the equations for uniform acceleration?	☐	☐	☐
Can you describe qualitatively the effects of friction, lift and drag?	☐	☐	☐

Can you explain terminal speed?



Can you explain the qualitative effect of air resistance on the trajectory of a projectile?



Can you explain the factors that affect the maximum speed of a vehicle?



3.4.1.5 Newton's laws of motion

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



Can you use $F = ma$ for situations where mass is constant?



Can you draw and use free-body force diagrams?



3.4.1.6 Momentum

Can you define momentum as mass $\times$ velocity?



Can you apply conservation of linear momentum in one dimension?



Can you use force as the rate of change of momentum, $F = \Delta(mv)/\Delta t$?



Can you define impulse and use $F\Delta t = \Delta(mv)$?



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



Can you explain how increasing contact time reduces impact force (e.g. crumple zones, packaging)?



Can you distinguish between elastic and inelastic collisions and analyse explosions?



Can you apply momentum ideas to the ethical design of safer transport?



3.4.1.7 Work, energy and power

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



Can you use $P = \Delta W/\Delta t$ and $P = Fv$?



Can you use the area under a force-displacement graph to find work done?



Can you calculate efficiency as useful output power / input power, including as a percentage?



3.4.1.8 Conservation of energy

Can you apply the principle of conservation of energy?



Can you use $\Delta E_p = mg\Delta h$ and $E_k = \frac{1}{2}mv^2$?



Can you solve problems involving changes between potential energy, kinetic energy and work done against resistive forces?



3.4.2 Materials

3.4.2.1 Bulk properties of solids

Can you use density $\rho = m/V$?	☐	☐	☐
Can you use Hooke's law $F = k\Delta L$ and explain the elastic limit?	☐	☐	☐
Can you define tensile stress and tensile strain?	☐	☐	☐
Can you define breaking stress?	☐	☐	☐
Can you calculate elastic strain energy using $E = \frac{1}{2}F\Delta L$ or the area under a force-extension graph?	☐	☐	☐
Can you describe plastic behaviour, fracture and brittle behaviour from force-extension graphs?	☐	☐	☐
Can you apply energy conservation to elastic strain energy and energy used to permanently deform a material?	☐	☐	☐
Can you calculate energy transfers from a stretched spring to kinetic and gravitational potential energy?	☐	☐	☐
Can you interpret simple stress-strain curves?	☐	☐	☐
Can you apply energy conservation to the ethical design of safer transport?	☐	☐	☐

3.4.2.2 The Young modulus

Can you define the Young modulus as tensile stress / tensile strain = $FL/(A\Delta L)$?	☐	☐	☐
Can you find the Young modulus from the gradient of a stress-strain graph?	☐	☐	☐
Can you describe a simple method for measuring the Young modulus of a wire?	☐	☐	☐

3.5.1.1 Basics of electricity

Can you define current as the rate of flow of charge, $I = \Delta Q / \Delta t$?



Can you define potential difference as work done per unit charge, $V = W/Q$?



Can you define resistance as $R = V/I$?

**3.5.1.2 Current-voltage characteristics**

Can you sketch and explain the I-V characteristics of an ohmic conductor, a semiconductor diode and a filament lamp?



Can you state Ohm's law as a special case where I is proportional to V under constant physical conditions?



Can you treat ammeters as having zero resistance and voltmeters as having infinite resistance?



Can you interpret I-V graphs with either I or V on the horizontal axis?

**3.5.1.3 Resistivity**

Can you define resistivity and use $\rho = RA/L$?



Can you describe how the resistance of a metal varies with temperature?



Can you describe how the resistance of an NTC thermistor varies with temperature and interpret R-T graphs?



Can you describe applications of thermistors, such as temperature sensors?



Can you explain what a superconductor is and the meaning of critical temperature?



Can you describe applications of superconductors, such as strong magnetic fields and reducing power transmission losses?

**3.5.1.4 Circuits**

Can you calculate the total resistance of resistors in series and in parallel?



Can you use $E = IVt$ and $P = IV = I^2R = V^2/R$?



Can you calculate currents, potential differences and resistances in series and parallel circuits?



Can you analyse circuits with cells in series and identical cells in parallel?



Can you apply conservation of charge and conservation of energy to dc circuits?



3.5.1.5 Potential divider

Can you explain how a potential divider supplies a constant or variable potential difference?



Can you calculate output voltages from a potential divider?



Can you explain how potential dividers with variable resistors, thermistors and LDRs work as sensors?

**3.5.1.6 Electromotive force and internal resistance**

Can you define emf as energy transferred per unit charge, $\epsilon = E/Q$?



Can you use $\epsilon = I(R + r)$?



Can you distinguish between terminal pd and emf and explain 'lost volts'?



Can you solve circuit problems where the internal resistance of the supply is not negligible?



3.6.1.1 Circular motion

Can you explain why an object moving in a circle at constant speed is accelerating and needs a centripetal force?



Can you use angular speed $\omega = v/r = 2\pi f$ and work in radians?



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



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



Can you estimate the acceleration and centripetal force in rotating situations?



3.6.1.2 Simple harmonic motion (SHM)

Can you state the defining condition for SHM, that acceleration is proportional to and opposite to displacement?



Can you use $a = -\omega^2 x$?



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



Can you sketch and relate graphs of displacement, velocity and acceleration against time?



Can you use the gradients of x-t and v-t graphs to obtain v-t and a-t graphs?



Can you use maximum speed = ωA and maximum acceleration = $\omega^2 A$?



3.6.1.3 Simple harmonic systems

Can you use $T = 2\pi\sqrt{m/k}$ for a mass-spring system?



Can you use $T = 2\pi\sqrt{l/g}$ for a simple pendulum and explain the small-angle approximation?



Can you analyse other simple harmonic oscillators given suitable information?



Can you describe how kinetic, potential and total energy vary with displacement and time in SHM?



Can you describe the effects of damping on oscillations?



3.6.1.4 Forced vibrations and resonance

Can you describe free and forced vibrations qualitatively?



Can you explain resonance and the effect of damping on the sharpness of resonance?



Can you give examples of resonance in mechanical systems and stationary wave situations?



3.6.2.1 Thermal energy transfer

Can you define internal energy as the sum of the randomly distributed kinetic and potential energies of the particles?



Can you explain how internal energy changes by heating or by work done (first law, qualitatively)?



Can you explain why temperature stays constant during a change of state in terms of particle energies?



Can you use $Q = mc\Delta\theta$, including continuous-flow situations?



Can you use $Q = ml$ for specific latent heat?



3.6.2.2 Ideal gases

Can you state the gas laws as experimental relationships between p , V , T and mass?



Can you explain the concept of absolute zero?



Can you use $pV = nRT$ and $pV = NkT$?



Can you calculate the work done on or by a gas using $p\Delta V$?



Can you use the Avogadro constant, the molar gas constant and the Boltzmann constant?



Can you distinguish between molar mass and molecular mass?



3.6.2.3 Molecular kinetic theory model

Can you explain how Brownian motion provides evidence for atoms?



Can you explain the relationships between p , V and T using a simple molecular model?



Can you explain why the gas laws are empirical while kinetic theory is based on theory?



Can you state the assumptions of the kinetic theory model?



Can you derive $pV = \frac{1}{3}Nm(c_{\text{rms}})^2$ from the assumptions using conservation of momentum?



Can you explain that the internal energy of an ideal gas is the kinetic energy of its atoms?



Can you use $\frac{1}{2}m(c_{\text{rms}})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$?



Can you describe how knowledge and understanding of gas behaviour has changed over time?



3.7.1 Fields

A-LEVEL ONLY

3.7.1 Fields

Can you define a force field as a region in which a body experiences a non-contact force?



Can you explain that force fields arise from mass, static charge and moving charge?



Can you state the similarities between gravitational and electrostatic fields as inverse-square fields?



Can you state the key difference that masses always attract while charges can attract or repel?



3.7.2 Gravitational fields

A-LEVEL ONLY

3.7.2.1 Newton's law

Can you describe gravity as a universal attractive force between all matter?



Can you use $F = Gm_1m_2/r^2$ for point masses?



Can you estimate the gravitational force between everyday or astronomical objects?



3.7.2.2 Gravitational field strength

Can you represent gravitational fields using field lines?



Can you define gravitational field strength as $g = F/m$?



Can you use $g = GM/r^2$ for a radial field?



3.7.2.3 Gravitational potential

Can you define gravitational potential, with zero at infinity?



Can you use $\Delta W = m\Delta V$ for work done moving a mass?



Can you explain why no work is done moving along an equipotential surface?



Can you use $V = -GM/r$ and explain the significance of the negative sign?



Can you sketch graphs of g and V against r ?



Can you use $g = -\Delta V/\Delta r$ and find ΔV from the area under a g - r graph?



3.7.2.4 Orbits of planets and satellites

Can you relate orbital period and speed to orbital radius and derive $T^2 \propto r^3$?	☐	☐	☐
Can you calculate the kinetic, potential and total energy of an orbiting satellite?	☐	☐	☐
Can you derive and use the escape velocity?	☐	☐	☐
Can you explain what a synchronous orbit is?	☐	☐	☐
Can you compare low-orbit and geostationary satellites, including the plane and radius of a geostationary orbit?	☐	☐	☐
Can you use a log-log plot to show the relationship between T and r?	☐	☐	☐

3.7.3 Electric fields**A-LEVEL ONLY****3.7.3.1 Coulomb's law**

Can you use $F = Q_1 Q_2 / (4\pi\epsilon_0 r^2)$ for point charges in a vacuum?	☐	☐	☐
Can you state the meaning of ϵ_0 , the permittivity of free space?	☐	☐	☐
Can you treat air as a vacuum and a charged sphere as a point charge at its centre?	☐	☐	☐
Can you compare the gravitational and electrostatic forces between subatomic particles?	☐	☐	☐

3.7.3.2 Electric field strength

Can you represent electric fields using field lines?	☐	☐	☐
Can you define electric field strength as $E = F/Q$?	☐	☐	☐
Can you use $E = V/d$ for a uniform field?	☐	☐	☐
Can you derive and use work done $Fd = Q\Delta V$?	☐	☐	☐
Can you describe the trajectory of a charged particle entering a uniform field at right angles?	☐	☐	☐
Can you use $E = Q/(4\pi\epsilon_0 r^2)$ for a radial field?	☐	☐	☐

3.7.3.3 Electric potential

Can you define absolute electric potential, with zero at infinity?	☐	☐	☐
Can you use $\Delta W = Q\Delta V$ for work done moving a charge?	☐	☐	☐
Can you explain why no work is done moving a charge along an equipotential surface?	☐	☐	☐
Can you use $V = Q/(4\pi\epsilon_0 r)$ for a radial field?	☐	☐	☐

Can you sketch graphs of E and V against r ?



Can you use $E = -\Delta V/\Delta r$ and find ΔV from the area under an E - r graph?



3.7.4 Capacitance

A-LEVEL ONLY

3.7.4.1 Capacitance

Can you define capacitance as $C = Q/V$?



3.7.4.2 Parallel plate capacitor

Can you use $C = A\epsilon_0\epsilon_r/d$?



Can you define relative permittivity (dielectric constant)?



Can you explain dielectric action in terms of polar molecules rotating in an electric field?



3.7.4.3 Energy stored by a capacitor

Can you find the energy stored from the area under a Q - V graph?



Can you use $E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}Q^2/C$?



3.7.4.4 Capacitor charge and discharge

Can you sketch graphs of Q , V and I against time for charging and discharging through a resistor?



Can you interpret the gradients and areas of these graphs?



Can you define the time constant RC and find it from graphical data?



Can you use time to halve $T_{1/2} = 0.69RC$?



Can you use $Q = Q_0 e^{-t/RC}$ and the matching equations for V and I during discharge?



Can you use $Q = Q_0(1 - e^{-t/RC})$ and the matching equation for V during charging?



Can you use a log-linear plot to find the time constant?



3.7.5 Magnetic fields

A-LEVEL ONLY

3.7.5.1 Magnetic flux density

Can you use $F = BIl$ for a current-carrying wire perpendicular to a magnetic field?



Can you use Fleming's left-hand rule to find the direction of the force?



Can you define magnetic flux density B and the tesla?



3.7.5.2 Moving charges in a magnetic field

Can you use $F = BQv$ for a charge moving perpendicular to a field?



Can you find the direction of the force on positive and negative charges?



Can you explain why charged particles move in circular paths in a magnetic field and derive $r = mv/BQ$?



Can you explain how a cyclotron works?



3.7.5.3 Magnetic flux and flux linkage

Can you define magnetic flux $\Phi = BA$ where B is normal to A ?



Can you define flux linkage as $N\Phi$?



Can you use $N\Phi = BAN \cos \theta$ for a rectangular coil at angle θ to a field?



3.7.5.4 Electromagnetic induction

Can you describe simple experiments that demonstrate electromagnetic induction?



Can you state and apply Faraday's law and Lenz's law?



Can you use $\epsilon = N\Delta\Phi/\Delta t$?



Can you calculate the emf induced across a straight conductor moving through a magnetic field?



Can you use $\epsilon = BAN\omega \sin \omega t$ for a coil rotating uniformly in a field?



3.7.5.5 Alternating currents

Can you define rms, peak and peak-to-peak values for sinusoidal ac?



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



Can you calculate the peak and peak-to-peak voltage of the mains supply?



Can you use an oscilloscope as a dc and ac voltmeter, to measure time intervals and frequencies, and to display waveforms?



3.7.5.6 The operation of a transformer

Can you use the transformer equation $N_s/N_p = V_s/V_p$?



Can you calculate transformer efficiency = $I_s V_s / I_p V_p$?



Can you explain how eddy currents are produced in the core?



Can you explain the causes of transformer inefficiency and how they are reduced?



Can you explain why electricity is transmitted at high voltage and calculate power loss in cables?



3.8.1.1 Rutherford scattering

Can you describe and explain qualitatively the results of Rutherford scattering?



Can you describe how ideas about the structure of the atom have changed over time?

**3.8.1.2 α , β and γ radiation**Can you compare the properties of α , β and γ radiation?

Can you describe simple absorption experiments to identify the type of radiation?



Can you explain the relative hazards of each type of radiation to humans?



Can you describe how radiation is used to monitor the thickness of foil, paper or steel?

Can you use the inverse-square law $I = k/x^2$ for γ radiation and describe how to verify it?

Can you describe how radioactive sources are handled safely?



Can you describe the origins of background radiation and correct for it?



Can you weigh up the risks and benefits of using radiation in medicine?

**3.8.1.3 Radioactive decay**

Can you explain that decay is random with a constant probability of decay per nucleus?

Can you use $\Delta N/\Delta t = -\lambda N$?Can you use $N = N_0 e^{-\lambda t}$?Can you use $A = \lambda N$ and $A = A_0 e^{-\lambda t}$?

Can you use molar mass and the Avogadro constant in decay calculations?

Can you use $T_{1/2} = \ln 2/\lambda$?

Can you determine half-life from decay curves and log graphs?



Can you model radioactive decay using a constant probability (e.g. dice simulation)?



Can you explain the applications of decay in storing radioactive waste and radioactive dating?

**3.8.1.4 Nuclear instability**

Can you sketch and interpret the N-Z graph for stable nuclei?

Can you identify the decay modes α , β^- , β^+ and electron capture for unstable nuclei?

Can you describe how each decay mode changes N and Z and write decay equations?



Can you use nuclear energy level diagrams?



Can you explain γ emission from excited nuclear states, including the use of technetium-99m?



3.8.1.5 Nuclear radius

Can you estimate nuclear radius from the closest approach of an α particle?



Can you determine nuclear radius from electron diffraction and interpret the intensity-angle graph?



Can you state typical values for nuclear radius?



Can you use $R = R_0 A^{1/3}$ and show from data that it supports constant nuclear density?



Can you calculate nuclear density?



3.8.1.6 Mass and energy

Can you apply $E = mc^2$ to all energy changes?



Can you calculate mass difference and binding energy?



Can you use the atomic mass unit and $1 \text{ u} = 931.5 \text{ MeV}$?



Can you describe fission and fusion processes?



Can you calculate the energy released in fission or fusion from nuclear masses?



Can you sketch the binding energy per nucleon against nucleon number graph and identify where fission and fusion release energy?



Can you explain how knowledge of nuclear energy informs decisions made by society?



3.8.1.7 Induced fission

Can you describe fission induced by thermal neutrons and the possibility of a chain reaction?



Can you explain the meaning of critical mass?



Can you explain the functions of the moderator, control rods and coolant in a thermal reactor?



Can you explain moderation using a simple model of elastic collisions?



Can you explain the factors affecting the choice of materials for moderator, control rods and coolant, with examples?



3.8.1.8 Safety aspects

Can you describe safety features of a reactor, including fuel used, remote handling, shielding and emergency shut-down?



Can you describe how radioactive waste is produced, handled remotely and stored?



Can you weigh up the risks and benefits of nuclear power?



3.9.1 Telescopes**OPTION****3.9.1.1 Astronomical telescope consisting of two converging lenses**

Can you draw a ray diagram for an astronomical refracting telescope in normal adjustment?



Can you define angular magnification in normal adjustment?



Can you use $M = f_o/f_e$?

**3.9.1.2 Reflecting telescopes**

Can you describe the Cassegrain arrangement with a parabolic concave primary and convex secondary mirror?



Can you draw a ray diagram showing the path of rays through a Cassegrain telescope to the eyepiece?



Can you compare reflecting and refracting telescopes, including spherical and chromatic aberration?

**3.9.1.3 Single dish radio telescopes, I-R, U-V and X-ray telescopes**

Can you compare the structure, positioning and use of radio, I-R, U-V and X-ray telescopes with optical telescopes?



Can you compare the resolving and collecting powers of these telescopes?

**3.9.1.4 Advantages of large diameter telescopes**

Can you use the Rayleigh criterion $\theta \approx \lambda/D$ for minimum angular resolution?



Can you explain why collecting power is proportional to diameter squared?



Can you work with angles in radians?



Can you compare the eye and a CCD in terms of quantum efficiency, resolution and convenience of use?

**3.9.2 Classification of stars****OPTION****3.9.2.1 Classification by luminosity**

Can you define apparent magnitude m and describe the Hipparcos scale?



Can you state that the dimmest stars visible to the naked eye have magnitude 6?



Can you use the fact that a magnitude difference of 1 corresponds to an intensity ratio of 2.51?



Can you explain why brightness is a subjective scale?



3.9.2.2 Absolute magnitude

Can you define the parsec and the light year?



Can you define absolute magnitude M and use $m - M = 5 \log(d/10)$?



3.9.2.3 Classification by temperature, black-body radiation

Can you sketch black-body curves for different temperatures?



Can you use Wien's displacement law $\lambda_{\max} T = 2.9 \times 10^{-3} \text{ m K}$ to estimate temperature?



Can you use Stefan's law $P = \sigma AT^4$ to compare the power output, temperature and size of stars?



Can you use the inverse-square law for intensity and state its assumptions?



3.9.2.4 Principles of the use of stellar spectral classes

Can you describe spectral classes O, B, A, F, G, K and M by colour, temperature and absorption lines?



Can you explain why Balmer absorption lines depend on temperature (hydrogen atoms in the $n = 2$ state)?



3.9.2.5 The Hertzsprung-Russell (HR) diagram

Can you sketch the HR diagram with correct axes (absolute magnitude -10 to +15, temperature 50 000 K to 2 500 K)?



Can you locate the main sequence, dwarfs, giants and the Sun on the HR diagram?



Can you describe the evolution of a Sun-like star from formation to white dwarf on the HR diagram?



3.9.2.6 Supernovae, neutron stars and black holes

Can you describe the defining properties of supernovae, neutron stars and black holes?



Can you explain how gamma-ray bursts arise from the collapse of supergiant stars?



Can you compare the energy output of a supernova with the total energy output of the Sun?



Can you explain how type 1a supernovae are used as standard candles and their link to dark energy?



Can you sketch the light curve of a typical type 1a supernova?



Can you describe supermassive black holes at the centres of galaxies?



Can you calculate the Schwarzschild radius $R_s \approx 2GM/c^2$?



3.9.3 Cosmology

OPTION

3.9.3.1 Doppler effect

Can you use $\Delta f/f = v/c$ and $z = \Delta\lambda/\lambda \approx -v/c$ for v much less than c ?



Can you apply the Doppler effect to binary stars viewed in the plane of their orbit?



Can you apply the Doppler effect to galaxies and quasars?



3.9.3.2 Hubble's law

Can you use Hubble's law $v = Hd$?



Can you explain that red shift implies the Universe is expanding and estimate its age from H ?



Can you describe the Big Bang theory and the evidence from the CMB and the relative abundance of hydrogen and helium?



3.9.3.3 Quasars

Can you describe quasars as the most distant measurable objects, discovered as bright radio sources?



Can you estimate the distance and power output of a quasar from its large optical red shift?



Can you explain that quasars are powered by active supermassive black holes?



3.9.3.4 Detection of exoplanets

Can you explain why exoplanets are difficult to observe directly?



Can you describe the radial velocity (Doppler shift) and transit methods of detecting exoplanets?



Can you sketch and interpret the typical light curve of a transit?



3.10.1 Physics of the eye**OPTION****3.10.1.1 Physics of vision**

Can you describe the eye as an optical refracting system and draw ray diagrams of image formation?



Can you describe the sensitivity and spectral response of the eye as a photodetector?



Can you explain the spatial resolution of the eye in terms of rods and cones?

**3.10.1.2 Defects of vision and their correction using lenses**

Can you define principal focus, focal length and power ($P = 1/f$) for converging and diverging lenses?



Can you use the lens equation $1/u + 1/v = 1/f$ and magnification $m = v/u$?



Can you describe myopia, hypermetropia and astigmatism?



Can you draw ray diagrams and calculate the power of correcting lenses for myopia and hypermetropia?



Can you interpret the format of prescriptions for astigmatism?

**3.10.2 Physics of the ear****OPTION****3.10.2.1 Ear as a sound detection system**

Can you describe the simple structure of the ear and the transmission of sound through it?

**3.10.2.2 Sensitivity and frequency response**

Can you produce and interpret equal loudness curves?



Can you explain why a logarithmic scale is used for perceived loudness?



Can you define intensity?



Can you use intensity level $= 10 \log(I/I_0)$ with $I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$?



Can you use the dB and dBA scales and compare relative intensity levels?

**3.10.2.3 Defects of hearing**

Can you describe how noise-induced and age-related hearing loss change equal loudness curves?



3.10.3 Biological measurement**OPTION****3.10.3.1 Simple ECG machines and the normal ECG waveform**

Can you describe how an ECG waveform is obtained?



Can you explain the characteristic shape of a normal ECG waveform?

**3.10.4 Non-ionising imaging****OPTION****3.10.4.1 Ultrasound imaging**

Can you explain reflection and transmission of ultrasound at tissue boundaries, including acoustic impedance and attenuation?

Can you use $Z = \rho c$ and $I_r/I_i = ((Z_2 - Z_1)/(Z_2 + Z_1))^2$?

Can you describe how piezoelectric devices generate and detect ultrasound pulses?



Can you distinguish between A-scans and B-scans?



Can you give examples of applications of ultrasound?



Can you compare the advantages and disadvantages of ultrasound with other imaging methods, including safety and resolution?

**3.10.4.2 Fibre optics and endoscopy**

Can you describe the properties of optical fibres and total internal reflection at the core-cladding boundary?



Can you explain the optical principles of a flexible endoscope?



Can you distinguish between coherent and non-coherent fibre bundles and their uses?



Can you give examples of internal imaging using endoscopes and their advantages?

**3.10.4.3 Magnetic resonance (MR) scanner**

Can you explain how hydrogen nuclei align and precess in the strong field of a superconducting magnet?



Can you explain how gradient field coils select the cross-section to be scanned?



Can you explain how RF pulses excite protons and how the RF signals emitted on de-excitation are processed into an image?



3.10.5 X-ray imaging**OPTION****3.10.5.1 The physics of diagnostic X-rays**

Can you explain how X-rays are produced, including maximum photon energy and the continuous and characteristic spectra?



Can you describe the rotating-anode X-ray tube?



Can you explain how beam intensity, photon energy, image sharpness, contrast and patient dose are controlled?

**3.10.5.2 Image detection and enhancement**

Can you describe a flat panel detector using a scintillator, photodiode pixels and electronic scanning?



Can you state the advantages of flat panel detectors over photographic detection?



Can you explain contrast enhancement using X-ray opaque material, such as a barium meal?



Can you explain the use of intensifying screens and fluoroscopic image intensification?

**3.10.5.3 Absorption of X-rays**

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



Can you define the linear attenuation coefficient, mass attenuation coefficient $\mu_m = \mu/\rho$ and half-value thickness?



Can you explain differential tissue absorption of X-rays?

**3.10.5.4 CT scanner**

Can you describe the basic principles of a CT scanner (rotating tube, narrow beam, detector array, computer image)?



Can you compare CT scans with other techniques in terms of resolution, cost and safety?

**3.10.6 Radionuclide imaging and therapy****OPTION****3.10.6.1 Imaging techniques**

Can you describe the use of gamma-emitting tracers technetium-99m, iodine-131 and indium-111 and the properties that suit them?



Can you explain the use and importance of the molybdenum-technetium generator?



Can you describe the principles of a PET scan?



3.10.6.2 Half-life

Can you define physical, biological and effective half-life?



Can you use $1/T_E = 1/T_B + 1/T_P$?



3.10.6.3 Gamma camera

Can you describe the structure and operation of a photomultiplier tube and a gamma camera?



3.10.6.4 Use of high-energy X-rays

Can you describe external treatment using high-energy X-rays?



Can you describe methods used to limit exposure of healthy cells?



3.10.6.5 Use of radioactive implants

Can you describe internal treatment using beta-emitting implants?



3.10.6.6 Imaging comparisons

Can you compare imaging techniques in terms of resolution, convenience and safety?



3.11.1.1 Concept of moment of inertia

Can you use $I = mr^2$ for a point mass and $I = \sum mr^2$ for an extended object?



Can you explain qualitatively the factors that affect the moment of inertia of a rotating object?

**3.11.1.2 Rotational kinetic energy**

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



Can you explain the factors that affect the energy storage capacity of a flywheel?



Can you describe uses of flywheels in smoothing torque and speed, storing energy in vehicles and in production processes?

**3.11.1.3 Rotational motion**

Can you define angular displacement, angular speed, angular velocity and angular acceleration ($\omega = \Delta\theta/\Delta t$, $\alpha = \Delta\omega/\Delta t$)?



Can you represent uniform and non-uniform angular acceleration on graphs?



Can you use the equations for uniform angular acceleration?



Can you explain the analogy between rotational and translational dynamics?

**3.11.1.4 Torque and angular acceleration**

Can you use torque $T = Fr$?



Can you use $T = I\alpha$?

**3.11.1.5 Angular momentum**

Can you define angular momentum as $I\omega$?



Can you apply conservation of angular momentum, for example in sport?



Can you use angular impulse $T\Delta t = \Delta(I\omega)$?

**3.11.1.6 Work and power**

Can you use $W = T\theta$ and $P = T\omega$?



Can you account for frictional torque in rotating machinery?



3.11.2 Thermodynamics and engines

OPTION

3.11.2.1 First law of thermodynamics

Can you use $Q = \Delta U + W$ with the correct sign conventions?



Can you apply the first law to practical situations?



3.11.2.2 Non-flow processes

Can you describe isothermal, adiabatic, constant pressure and constant volume changes?



Can you use $pV = nRT$, $pV^\gamma = \text{constant}$ for adiabatic changes and $pV = \text{constant}$ for isothermal changes?



Can you use $W = p\Delta V$ for a constant-pressure change?



Can you apply the first law of thermodynamics to each type of non-flow process?



3.11.2.3 The p-V diagram

Can you represent thermodynamic processes on a p-V diagram?



Can you estimate work done from the area under a p-V graph?



Can you find the work done per cycle from the area enclosed by a p-V loop?



3.11.2.4 Engine cycles

Can you describe four-stroke petrol and diesel engine cycles and their theoretical indicator diagrams?



Can you compare real and theoretical indicator diagrams?



Can you calculate input power = calorific value x fuel flow rate?



Can you calculate indicated power = area of p-V loop x cycles per second x number of cylinders?



Can you calculate brake power $P = T\omega$ and friction power = indicated power - brake power?



Can you calculate overall, thermal and mechanical efficiencies?



Can you interpret unfamiliar engine cycles from given information?



3.11.2.5 Second law and engines

Can you explain why a heat engine needs a hot source and a cold sink (second law)?



Can you use $\text{efficiency} = W/Q_H = (Q_H - Q_C)/Q_H$?



Can you use maximum theoretical efficiency = $(T_H - T_C)/T_H$?



Can you explain why practical engines are less efficient than the theoretical maximum?



Can you describe ways of using waste heat, such as combined heat and power schemes?



3.11.2.6 Reversed heat engines

Can you describe the basic principles and uses of refrigerators and heat pumps?



Can you calculate the coefficient of performance of a refrigerator?



Can you calculate the coefficient of performance of a heat pump?



3.12.1**The discovery of the electron****OPTION****3.12.1.1 Cathode rays**

Can you explain how cathode rays are produced in a discharge tube?

**3.12.1.2 Thermionic emission of electrons**

Can you explain the principle of thermionic emission?

Can you use $\frac{1}{2}mv^2 = eV$ for an electron accelerated through a pd?**3.12.1.3 Specific charge of the electron**Can you describe one method of determining the specific charge of the electron, e/me ?Can you explain the significance of Thomson's determination of e/me ?

Can you compare the specific charge of the electron with that of the hydrogen ion?

**3.12.1.4 Millikan's determination of the electronic charge, e** Can you use $QV/d = mg$ for a stationary charged oil droplet?

Can you describe the motion of a falling droplet with and without an electric field and use terminal speed to find mass and charge?

Can you use Stokes' law $F = 6\pi\eta rv$ to find the droplet radius?

Can you explain the significance of Millikan's results and the quantisation of charge?

**3.12.2****Wave-particle duality****OPTION****3.12.2.1 Newton's corpuscular theory of light**

Can you compare Newton's corpuscular theory with Huygens' wave theory?



Can you explain why Newton's theory was preferred at the time?

**3.12.2.2 Significance of Young's double slits experiment**

Can you explain the fringes in Young's experiment qualitatively using wave theory?



Can you explain why Huygens' wave theory was not accepted for a long time?



3.12.2.3 Electromagnetic waves

Can you describe the nature of electromagnetic waves?	☐	☐	☐
Can you use Maxwell's formula $c = 1/\sqrt{\mu_0 \epsilon_0}$?	☐	☐	☐
Can you explain what ϵ_0 and μ_0 relate to?	☐	☐	☐
Can you describe Hertz's discovery of radio waves and his measurement of their speed?	☐	☐	☐
Can you describe Fizeau's determination of the speed of light and its implications?	☐	☐	☐

3.12.2.4 The discovery of photoelectricity

Can you explain the ultraviolet catastrophe and black-body radiation?	☐	☐	☐
Can you describe Planck's explanation of black-body radiation using quanta?	☐	☐	☐
Can you explain why classical wave theory fails to explain the photoelectric effect?	☐	☐	☐
Can you explain Einstein's explanation of photoelectricity and its significance for the nature of EM radiation?	☐	☐	☐

3.12.2.5 Wave-particle duality

Can you use de Broglie's hypothesis $p = h/\lambda$ and $\lambda = h/\sqrt{2meV}$?	☐	☐	☐
Can you describe low-energy electron diffraction experiments?	☐	☐	☐
Can you explain qualitatively how electron speed affects the diffraction pattern?	☐	☐	☐

3.12.2.6 Electron microscopes

Can you estimate the anode voltage needed for electron wavelengths similar to atomic sizes?	☐	☐	☐
Can you describe the operation of a transmission electron microscope (TEM)?	☐	☐	☐
Can you describe the operation of a scanning tunnelling microscope (STM)?	☐	☐	☐

3.12.3 Special relativity**OPTION****3.12.3.1 The Michelson-Morley experiment**

Can you describe the principle of the Michelson-Morley interferometer?	☐	☐	☐
Can you explain how the experiment aimed to detect absolute motion and why its null result mattered?	☐	☐	☐
Can you explain how the result supports the invariance of the speed of light?	☐	☐	☐

3.12.3.2 Einstein's theory of special relativity

Can you define an inertial frame of reference?



Can you state Einstein's two postulates of special relativity?

**3.12.3.3 Time dilation**

Can you define proper time and explain time dilation?

Can you use $t = t_0 / \sqrt{1 - v^2/c^2}$?

Can you explain how muon decay provides evidence for time dilation?

**3.12.3.4 Length contraction**Can you use $l = l_0 \sqrt{1 - v^2/c^2}$?**3.12.3.5 Mass and energy**Can you explain the equivalence of mass and energy using $E = mc^2$?Can you use $E = m_0 c^2 / \sqrt{1 - v^2/c^2}$?

Can you sketch graphs of relativistic mass and kinetic energy against speed?



Can you describe Bertozzi's experiment as evidence for relativistic kinetic energy?



3.13.1

Discrete semiconductor devices

OPTION

3.13.1.1 MOSFET

Can you describe the simplified structure and characteristics of an N-channel enhancement-mode MOSFET, including drain, source and gate?



Can you use the quantities V_{DS} , V_{GS} , I_{DSS} and V_{th} ?



Can you explain the use of a MOSFET as a switch and as a device with very high input resistance?



3.13.1.2 Zener diode

Can you sketch the Zener diode characteristic showing breakdown voltage and minimum operating current?



Can you identify the anode and cathode of a Zener diode?



Can you use a Zener diode with a resistor as a constant voltage source or reference voltage?



3.13.1.3 Photodiode

Can you interpret photodiode characteristic curves and spectral response curves?



Can you explain the use of a photodiode in photoconductive mode as a detector in optical systems?



Can you explain the use of a photodiode with a scintillator to detect atomic particles?



3.13.1.4 Hall effect sensor

Can you describe the use of a Hall effect sensor as a magnetic field sensor to monitor attitude?



Can you describe the use of a Hall effect sensor in a tachometer?



3.13.2

Analogue and digital signals

OPTION

3.13.2.1 Difference between analogue and digital signals

Can you define bits and bytes and write binary numbers?



Can you explain how audio signals are sampled for digital transmission?



Can you explain conversion of analogue signals to digital data using two voltage levels and quantisation?



Can you explain how sampling rate and bits per sample affect the quality of conversion?



Can you state the advantages and disadvantages of digital sampling?



Can you explain how original data can be recovered from a noisy digital signal and the effect of noise in communication systems?



Can you describe pulse code modulation?



Can you give examples of sensors used to collect analogue data?



3.13.3

Analogue signal processing

OPTION

3.13.3.1 LC resonance filters

Can you use $f_0 = 1/(2\pi\sqrt{LC})$ for a parallel LC circuit?



Can you explain the analogy between an LC circuit and a mass-spring system?



Can you sketch and interpret the energy (voltage) response curve of an LC circuit?



Can you use $Q = f_0/f_B$, where f_B is the bandwidth at the 50% energy points?



3.13.3.2 The ideal operational amplifier

Can you describe the properties of an ideal op-amp, including infinite open-loop gain and infinite input resistance?



Can you use the open-loop transfer function $V_{out} = A_{OL}(V_+ - V_-)$?



Can you explain the use of an op-amp as a comparator?



3.13.4

Operational amplifier configurations

OPTION

3.13.4.1 Inverting amplifier configuration

Can you derive and use $V_{out}/V_{in} = -R_f/R_{in}$?



Can you explain the meaning of virtual earth and use virtual earth analysis?



3.13.4.2 Non-inverting amplifier configuration

Can you use $V_{out}/V_{in} = 1 + R_f/R_1$?



3.13.4.3 Summing amplifier configuration

Can you use $V_{out} = -R_f(V_1/R_1 + V_2/R_2 + V_3/R_3 + \dots)$ for a summing amplifier?



Can you use $V_{out} = (V_+ - V_-)R_f/R_1$ for a difference amplifier?

**3.13.4.4 Real operational amplifiers**

Can you describe the limitations of real op-amps?



Can you interpret the frequency response curve of a real op-amp and use gain x bandwidth = constant?

**3.13.5 Digital signal processing****OPTION****3.13.5.1 Combinational logic**

Can you link Boolean algebra (NOT, AND, OR) to truth tables and logic gates?



Can you identify and use AND, NAND, OR, NOR, NOT and EOR gates in combination?



Can you construct a logic circuit from a truth table and deduce a truth table from a circuit?

**3.13.5.2 Sequential logic**

Can you describe binary, BCD and Johnson counters?



Can you explain the clock, reset and up/down inputs and the outputs of a counter?



Can you design a modulo-n counter using logic to drive the reset pin?

**3.13.5.3 Astables**

Can you describe an astable as an oscillator providing a clock pulse?



Can you define clock rate, pulse width, period, duty cycle and mark-to-space ratio?



Can you explain how an external RC network varies the frequency of an astable?

**3.13.6 Data communication systems****OPTION****3.13.6.1 Principles of communication systems**

Can you describe the purpose of each stage in the block diagram of a real-time communication system?



3.13.6.2 Transmission media

Can you compare metal wire, optical fibre and electromagnetic radiation (radio and microwave) as transmission media?



Can you describe ground wave propagation, sky wave refraction and reflection, and diffraction of long wavelengths around the Earth?



Can you describe satellite systems and typical frequencies, and why up-link and down-link frequencies differ?



Can you compare transmission media in terms of data rate, cost and security?

**3.13.6.3 Time-division multiplexing**

Can you explain the basic principles of time-division multiplexing?

**3.13.6.4 Amplitude (AM) and frequency modulation (FM) techniques**

Can you explain the principles of modulation, including carrier wave and information signal?



Can you sketch and interpret graphs of AM and FM signals and identify carrier and information frequencies?



Can you calculate bandwidth for AM ($2f_m$) and FM ($2(\Delta f + f_m)$)?



Can you explain the data capacity of a channel and compare bandwidth availability across media?



The 12 required practical activities

1 Can you investigate how the frequency of stationary waves on a string varies with length, tension and mass per unit length?	☐ ☐ ☐
2 Can you investigate interference effects using Young's double slits and diffraction by a diffraction grating?	☐ ☐ ☐
3 Can you determine g using a free-fall method?	☐ ☐ ☐
4 Can you determine the Young modulus of a wire using a simple method?	☐ ☐ ☐
5 Can you determine the resistivity of a wire using a micrometer, ammeter and voltmeter?	☐ ☐ ☐
6 Can you investigate the emf and internal resistance of a cell by measuring how terminal pd varies with current?	☐ ☐ ☐
7 Can you investigate simple harmonic motion using a mass-spring system and a simple pendulum?	☐ ☐ ☐
8 Can you investigate Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas?	☐ ☐ ☐
9 Can you investigate the charge and discharge of capacitors and use a log-linear plot to find the time constant RC ?	☐ ☐ ☐
10 Can you investigate how the force on a wire varies with flux density, current and length using a top pan balance?	☐ ☐ ☐
11 Can you investigate how flux linkage varies with the angle between a search coil and a magnetic field using an oscilloscope?	☐ ☐ ☐
12 Can you investigate the inverse-square law for γ radiation?	☐ ☐ ☐