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AQA

AS AND A-LEVEL PHYSICS

AS (7407)
A-level (7408)

Specifications
For teaching from September 2015 onwards
For AS exams in May/June 2016 onwards
For A-level exams in May/June 2017 onwards

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Are you using the latest version of these specifications?

- You will always find the most up-to-date version of these specifications on our website at aqa.org.uk/7408
- We will write to you if there are significant changes to these specifications.

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1 Introduction

1.1 Why choose AQA for AS and A-level Physics

Relevant in the classroom and the real world

We involved over a thousand teachers in developing these specifications, to ensure that the subject content is relevant to real world experiences and is interesting to teach and learn. We've also presented it in a straightforward way, giving you the freedom to teach in the way that works for your students.

These Physics specifications are a stepping stone to future study, which is why we also consulted universities, to ensure these specifications allow students to develop the skills that they want to see.

This approach has led to specifications that will support you to inspire students, nurture a passion for physics and lay the groundwork for further study in science or engineering.

The way you teach – your choice

Our specifications have been written in a context-free style. This means that you can select the contexts and applications that you feel bring the subject alive. We have also produced a range of excellent teaching resources that you can use alongside your own material.

The AS and A-level courses allow for a choice of starting points. You can choose a familiar starting point for students, such as mechanics, or begin with fresh topics to create interest and a new dimension to their knowledge, such as particle physics.

We've provided five optional topics as part of the full A-level course so students can focus on their areas of interest:

- Astrophysics
- Medical physics
- Turning points in physics
- Engineering physics (re-branded Applied physics)
- Electronics.

Practical at the heart of science

Like you, we believe that Physics is fundamentally an experimental subject. These specifications provide numerous opportunities to use practical experiences to link theory to reality, and equip students with the essential practical skills they need.

Teach AS and A-level together

We've ensured that the AS and A-level are fully co-teachable. The AS exams include similar questions to those in the A-level, with less difficulty.

We've created our A-level content with our GCSE in mind to make sure that there is a seamless progression between qualifications. We've also followed ASE guidance on use of scientific terminology across our science subjects.

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Assessment success

We've tested our specimen question papers with students, making sure they're interesting, straightforward and clear and hold no hidden surprises. To ensure that your students are rewarded for the physics skills and knowledge they've developed, our exams include:

- specified content tested in each of the first two papers at A-level to help students prepare for their exams
- a variety of assessment styles within each paper so students can confidently engage with the questions
- multiple choice questions are included to allow for a wide breadth of Physics from the specifications to be tested.

With us, your students will get the results they deserve, from the exam board you trust.

You can find out about all our science qualifications at aqa.org.uk/science

1.2 Support and resources to help you teach

We know that support and resources are vital for your teaching and that you have limited time to find or develop good quality materials. So we've worked with experienced teachers to provide you with a range of resources that will help you confidently plan, teach and prepare for exams.

Teaching resources

We have too many Physics resources to list here so visit aqa.org.uk/7408 to see them all. They include:

- additional practice papers to help students prepare for exams
- guidance on how to plan both the AS and A-level courses with supporting schemes of work for co-teaching
- several AQA-approved student textbooks reviewed by experienced senior examiners
- guidance on maths skills requirements with additional support via Exampro
- resources to support key topics (including the optional topics), with detailed lesson plans written by experienced teachers
- training courses to help you deliver AQA Physics qualifications
- subject expertise courses for all teachers, from newly-qualified teachers who are just getting started to experienced teachers looking for fresh inspiration.

Preparing for exams

Visit aqa.org.uk/7408 for everything you need to prepare for our exams, including:

- past papers, mark schemes and examiners' reports
- specimen papers and mark schemes for new courses
- Exampro: a searchable bank of past AQA exam questions
- exemplar student answers with examiner commentaries.

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Analyse your students' results with Enhanced Results Analysis (ERA)

Find out which questions were the most challenging, how the results compare to previous years and where your students need to improve. ERA, our free online results analysis tool, will help you see where to focus your teaching. Register at aqa.org.uk/era

For information about results, including maintaining standards over time, grade boundaries and our post-results services, visit aqa.org.uk/results

Keep your skills up to date with professional development

Wherever you are in your career, there's always something new to learn. As well as subject-specific training, we offer a range of courses to help boost your skills.

- Improve your teaching skills in areas including differentiation, teaching literacy and meeting Ofsted requirements.
- Prepare for a new role with our leadership and management courses.

You can attend a course at venues around the country, in your school or online – whatever suits your needs and availability. Find out more at coursesandevents.aqa.org.uk

Get help and support

Visit our website for information, guidance, support and resources at aqa.org.uk/7408

You can talk directly to the Physics subject team

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T: 01483 477 756

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2 Specification at a glance

These qualifications are linear. Linear means that students will sit all the AS exams at the end of their AS course and all the A-level exams at the end of their A-level course.

2.1 Subject content

Core content

1 Measurements and their errors (page 10)

2 Particles and radiation (page 12)

3 Waves (page 17)

4 Mechanics and materials (page 21)

5 Electricity (page 27)

6 Further mechanics and thermal physics (A-level only) (page 30)

7 Fields and their consequences (A-level only) (page 34)

8 Nuclear physics (A-level only) (page 41)

Options

9 Astrophysics (A-level only) (page 45)

10 Medical physics (A-level only) (page 49)

11 Engineering physics (A-level only) (page 54)

12 Turning points in physics (A-level only) (page 58)

13 Electronics (A-level only) (page 62)

2.2 AS

Assessments

Paper 1	+	Paper 2
What's assessed Sections 1–5		**What's assessed** Sections 1–5
Assessed • written exam: 1 hour 30 minutes • 70 marks • 50% of AS		**Assessed** • written exam: 1 hour 30 minutes • 70 marks • 50% of AS
Questions 70 marks of short and long answer questions split by topic.		**Questions** Section A: 20 marks of short and long answer questions on practical skills and data analysis Section B: 20 marks of short and long answer questions from across all areas of AS content Section C: 30 multiple choice questions

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2.3 A-level

Assessments

Paper 1	Paper 2	Paper 3
What's assessed Sections 1–5 and 6.1 (Periodic motion)	**What's assessed** Sections 6.2 (Thermal Physics), 7 and 8 Assumed knowledge from sections 1 to 6.1	**What's assessed** Section A: Compulsory section: Practical skills and data analysis Section B: Students enter for **one** of sections 9, 10, 11, 12 or 13
Assessed • written exam: 2 hours • 85 marks • 34% of A-level	**Assessed** • written exam: 2 hours • 85 marks • 34% of A-level	**Assessed** • written exam: 2 hours • 80 marks • 32% of A-level
Questions 60 marks of short and long answer questions and 25 multiple choice questions on content.	**Questions** 60 marks of short and long answer questions and 25 multiple choice questions on content.	**Questions** 45 marks of short and long answer questions on practical experiments and data analysis. 35 marks of short and long answer questions on optional topic.

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3 Subject content

Sections 3.1 to 3.5 are designed to be covered in the first year of the A-level and are also the AS subject content. So you can teach AS and A-level together.

These specifications are presented in a two column format. The left hand column contains the specification content that all students must cover, and that can be assessed in the written papers. The right hand column exemplifies the opportunities for skills to be developed throughout the course. As such knowledge of individual experiments on the right hand side is **not** assumed knowledge for the assessment. The codes in the right hand column refer to the skills in relevant appendices. **MS** refers to the Mathematical Skills, **AT** refers to the Apparatus and Techniques and **PS** refers to the Practical Skills.

3.1 Measurements and their errors

Content in this section is a continuing study for a student of physics. A working knowledge of the specified fundamental (base) units of measurement is vital. Likewise, practical work in the subject needs to be underpinned by an awareness of the nature of measurement errors and of their numerical treatment. The ability to carry through reasonable estimations is a skill that is required throughout the course and beyond.

3.1.1 Use of SI units and their prefixes

Content	Opportunities for skills development
Fundamental (base) units. Use of mass, length, time, amount of substance, temperature, electric current and their associated SI units. SI units derived. Knowledge and use of the SI prefixes, values and standard form. The fundamental unit of light intensity, the candela, is excluded. Students are not expected to recall definitions of the fundamental quantities. Dimensional analysis is not required. Students should be able to use the prefixes: T, G, M, k, c, m, μ, n, p, f, Students should be able to convert between different units of the same quantity, eg J and eV, J and kW h.	

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3.1.2 Limitation of physical measurements

Content	Opportunities for skills development
Random and systematic errors. Precision, repeatability, reproducibility, resolution and accuracy. Uncertainty: Absolute, fractional and percentage uncertainties represent uncertainty in the final answer for a quantity. Combination of absolute and percentage uncertainties. Represent uncertainty in a data point on a graph using error bars. Determine the uncertainties in the gradient and intercept of a straight-line graph. Individual points on the graph may or may not have associated error bars.	**PS 2.3** Students should be able to identify random and systematic errors and suggest ways to reduce or remove them. **PS 3.3** Students should understand the link between the number of significant figures in the value of a quantity and its associated uncertainty. **MS 1.5** Students should be able to combine uncertainties in cases where the measurements that give rise to the uncertainties are added, subtracted, multiplied, divided, or raised to powers. Combinations involving trigonometric or logarithmic functions will not be required.

3.1.3 Estimation of physical quantities

Content	Opportunities for skills development
Orders of magnitude. Estimation of approximate values of physical quantities.	**MS 1.4** Students should be able to estimate approximate values of physical quantities to the nearest order of magnitude. Students should be able to use these estimates together with their knowledge of physics to produce further derived estimates also to the nearest order of magnitude.

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3.2 Particles and radiation

This section introduces students both to the fundamental properties of matter, and to electromagnetic radiation and quantum phenomena. Teachers may wish to begin with this topic to provide a new interest and knowledge dimension beyond GCSE. Through a study of these topics, students become aware of the way ideas develop and evolve in physics. They will appreciate the importance of international collaboration in the development of new experiments and theories in this area of fundamental research.

3.2.1 Particles

3.2.1.1 Constituents of the atom

Content	Opportunities for skills development
Simple model of the atom, including the proton, neutron and electron. Charge and mass of the proton, neutron and electron in SI units and relative units. The atomic mass unit (amu) is included in the A-level Nuclear physics section. Specific charge of the proton and the electron, and of nuclei and ions. Proton number Z, nucleon number A, nuclide notation. Students should be familiar with the ${}^{A}_{Z}\mathrm{X}$ notation. Meaning of isotopes and the use of isotopic data.	

3.2.1.2 Stable and unstable nuclei

Content	Opportunities for skills development
The strong nuclear force; its role in keeping the nucleus stable; short-range attraction up to approximately 3 fm, very-short range repulsion closer than approximately 0.5 fm. Unstable nuclei; alpha and beta decay. Equations for alpha decay, β^- decay including the need for the neutrino. The existence of the neutrino was hypothesised to account for conservation of energy in beta decay.	**AT i** Demonstration of the range of alpha particles using a cloud chamber, spark counter or Geiger counter. **MS 0.2** Use of prefixes for small and large distance measurements.

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3.2.1.3 Particles, antiparticles and photons

Content	Opportunities for skills development
For every type of particle, there is a corresponding antiparticle. Comparison of particle and antiparticle masses, charge and rest energy in MeV. Students should know that the positron, antiproton, antineutron and antineutrino are the antiparticles of the electron, proton, neutron and neutrino respectively. Photon model of electromagnetic radiation, the Planck constant. $E = hf = \frac{hc}{\lambda}$ Knowledge of annihilation and pair production and the energies involved. The use of $E = mc^2$ is not required in calculations.	**AT i** Detection of gamma radiation. **MS 1.1, 2.2** Students could determine the frequency and wavelength of the two gamma photons produced when a 'slow' electron and a 'slow' positron annihilate each other. The PET scanner could be used as an application of annihilation.

3.2.1.4 Particle interactions

Content	Opportunities for skills development
Four fundamental interactions: gravity, electromagnetic, weak nuclear, strong nuclear. (The strong nuclear force may be referred to as the strong interaction.) The concept of exchange particles to explain forces between elementary particles. Knowledge of the gluon, Z^0 and graviton will not be tested. The electromagnetic force; virtual photons as the exchange particle. The weak interaction limited to β^- and β^+ decay, electron capture and electron–proton collisions; W^+ and W^- as the exchange particles. Simple diagrams to represent the above reactions or interactions in terms of incoming and outgoing particles and exchange particles.	**PS 1.2** Momentum transfer of a heavy ball thrown from one person to another.

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3.2.1.5 Classification of particles

Content	Opportunities for skills development
Hadrons are subject to the strong interaction. The two classes of hadrons: • baryons (proton, neutron) and antibaryons (antiproton and antineutron) • mesons (pion, kaon). Baryon number as a quantum number. Conservation of baryon number. The proton is the only stable baryon into which other baryons eventually decay. The pion as the exchange particle of the strong nuclear force. The kaon as a particle that can decay into pions. Leptons: electron, muon, neutrino (electron and muon types only) and their antiparticles. Lepton number as a quantum number; conservation of lepton number for muon leptons and for electron leptons. The muon as a particle that decays into an electron. Strange particles Strange particles as particles that are produced through the strong interaction and decay through the weak interaction (eg kaons). Strangeness (symbol s) as a quantum number to reflect the fact that strange particles are always created in pairs. Conservation of strangeness in strong interactions. Strangeness can change by 0, +1 or -1 in weak interactions. Appreciation that particle physics relies on the collaborative efforts of large teams of scientists and engineers to validate new knowledge.	**AT k** Use of computer simulations of particle collisions. **ATI** Cosmic ray showers as a source of high energy particles including pions and kaons; observation of stray tracks in a cloud chamber; use of two Geiger counters to detect a cosmic ray shower.

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3.2.1.6 Quarks and antiquarks

Content	Opportunities for skills development
Properties of quarks and antiquarks: charge, baryon number and strangeness. Combinations of quarks and antiquarks required for baryons (proton and neutron only), antibaryons (antiproton and antineutron only) and mesons (pion and kaon only). Only knowledge of up (u), down (d) and strange (s) quarks and their antiquarks will be tested. The decay of the neutron should be known.	

3.2.1.7 Applications of conservation laws

Content	Opportunities for skills development
Change of quark character in β^- and in β^+ decay. Application of the conservation laws for charge, baryon number, lepton number and strangeness to particle interactions. The necessary data will be provided in questions for particles outside those specified. Students should recognise that energy and momentum are conserved in interactions.	

3.2.2 Electromagnetic radiation and quantum phenomena

3.2.2.1 The photoelectric effect

Content	Opportunities for skills development
Threshold frequency; photon explanation of threshold frequency. Work function ϕ, stopping potential. Photoelectric equation: $hf = \phi + E_{k\,(max)}$ $E_{k\,(max)}$ is the maximum kinetic energy of the photoelectrons. The experimental determination of stopping potential is not required.	**PS 3.2 / MS 2.3** Demonstration of the photoelectric effect using a photocell or an electroscope with a zinc plate attachment and UV lamp.

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3.2.2.2 Collisions of electrons with atoms

Content	Opportunities for skills development
Ionisation and excitation; understanding of ionisation and excitation in the fluorescent tube. The electron volt. Students will be expected to be able to convert eV into J and vice versa.	

3.2.2.3 Energy levels and photon emission

Content	Opportunities for skills development
Line spectra (eg of atomic hydrogen) as evidence for transitions between discrete energy levels in atoms. $hf = E_1 - E_2$ In questions, energy levels may be quoted in J or eV.	**AT j / MS 0.1, 0.2** Observation of line spectra using a diffraction grating.

3.2.2.4 Wave-particle duality

Content	Opportunities for skills development
Students should know that electron diffraction suggests that particles possess wave properties and the photoelectric effect suggests that electromagnetic waves have a particulate nature. Details of particular methods of particle diffraction are not expected. de Broglie wavelength $\lambda = \frac{h}{mv}$ where mv is the momentum. Students should be able to explain how and why the amount of diffraction changes when the momentum of the particle is changed. Appreciation of how knowledge and understanding of the nature of matter changes over time. Appreciation that such changes need to be evaluated through peer review and validated by the scientific community.	**PS 1.2** Demonstration using an electron diffraction tube. **MS 1.1, 2.3** Use prefixes when expressing wavelength values.

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3.3 Waves

GCSE studies of wave phenomena are extended through a development of knowledge of the characteristics, properties, and applications of travelling waves and stationary waves. Topics treated include refraction, diffraction, superposition and interference.

3.3.1 Progressive and stationary waves

3.3.1.1 Progressive waves

Content	Opportunities for skills development
Oscillation of the particles of the medium; amplitude, frequency, wavelength, speed, phase, phase difference, $c = f\lambda$ $\quad f = \frac{1}{T}$ Phase difference may be measured as angles (radians and degrees) or as fractions of a cycle.	**PS 2.3 / MS 0.1, 4.7 / AT a, b** Laboratory experiment to determine the speed of sound in free air using direct timing or standing waves with a graphical analysis.

3.3.1.2 Longitudinal and transverse waves

Content	Opportunities for skills development
Nature of longitudinal and transverse waves. Examples to include: sound, electromagnetic waves, and waves on a string. Students will be expected to know the direction of displacement of particles/fields relative to the direction of energy propagation and that all electromagnetic waves travel at the same speed in a vacuum. Polarisation as evidence for the nature of transverse waves. Applications of polarisers to include Polaroid material and the alignment of aerials for transmission and reception. Malus's law will not be expected.	**PS 2.2, 2.4 / MS 1.2, 3.2, 3.4, 3.5 / AT i** Students can investigate the factors that determine the speed of a water wave.

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3.3.1.3 Principle of superposition of waves and formation of stationary waves

Content	Opportunities for skills development
Stationary waves. Nodes and antinodes on strings. $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ for first harmonic. The formation of stationary waves by two waves of the same frequency travelling in opposite directions. A graphical explanation of formation of stationary waves will be expected. Stationary waves formed on a string and those produced with microwaves and sound waves should be considered. Stationary waves on strings will be described in terms of harmonics. The terms fundamental (for first harmonic) and overtone will **not** be used.	**MS 4.7 / PS 1.2, 2.1 / AT i** Students can investigate the factors that determine the frequency of stationary wave patterns of a stretched string.
Required practical 1: Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.	

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3.3.2 Refraction, diffraction and interference

3.3.2.1 Interference

Content	Opportunities for skills development
Path difference. Coherence. Interference and diffraction using a laser as a source of monochromatic light. Young's double-slit experiment: the use of two coherent sources or the use of a single source with double slits to produce an interference pattern. Fringe spacing, $w = \frac{\lambda D}{s}$ Production of interference pattern using white light. Students are expected to show awareness of safety issues associated with using lasers. Students will not be required to describe how a laser works. Students will be expected to describe and explain interference produced with sound and electromagnetic waves. Appreciation of how knowledge and understanding of nature of electromagnetic radiation has changed over time.	**AT i** Investigation of two-source interference with sound, light and microwave radiation.
Required practical 2: Investigation of interference effects to include the Young's slit experiment and interference by a diffraction grating.	

3.3.2.2 Diffraction

Content	Opportunities for skills development
Appearance of the diffraction pattern from a single slit using monochromatic and white light. Qualitative treatment of the variation of the width of the central diffraction maximum with wavelength and slit width. The graph of intensity against angular separation is not required. Plane transmission diffraction grating at normal incidence. Derivation of $d\sin\theta = n\lambda$ Use of the spectrometer will not be tested. Applications of diffraction gratings.	

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3.3.2.3 Refraction at a plane surface

Content	Opportunities for skills development
Refractive index of a substance, $n = \frac{c}{c_s}$ Students should recall that the refractive index of air is approximately 1. Snell's law of refraction for a boundary $n_1 \sin\theta_1 = n_2 \sin\theta_2$ Total internal reflection $\sin\theta_c = \frac{n_2}{n_1}$ Simple treatment of fibre optics including the function of the cladding. Optical fibres will be limited to step index only. Material and modal dispersion. Students are expected to understand the principles and consequences of pulse broadening and absorption.	**MS 0.6, 4.1**

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3.4 Mechanics and materials

Vectors and their treatment are introduced followed by development of the student's knowledge and understanding of forces, energy and momentum. The section continues with a study of materials considered in terms of their bulk properties and tensile strength. As with earlier topics, this section and also the following section Electricity would provide a good starting point for students who prefer to begin by consolidating work.

3.4.1 Force, energy and momentum

3.4.1.1 Scalars and vectors

Content	Opportunities for skills development
Nature of scalars and vectors. Examples should include: velocity/speed, mass, force/weight, acceleration, displacement/distance. Addition of vectors by calculation or scale drawing. Calculations will be limited to two vectors at right angles. Scale drawings may involve vectors at angles other than 90 °. Resolution of vectors into two components at right angles to each other. Examples should include components of forces along and perpendicular to an inclined plane. Problems may be solved either by the use of resolved forces or the use of a closed triangle. Conditions for equilibrium for two or three coplanar forces acting at a point. Appreciation of the meaning of equilibrium in the context of an object at rest or moving with constant velocity.	**MS 0.6, 4.2, 4.4, 4.5 / PS 1.1** Investigation of the conditions for equilibrium for three coplanar forces acting at a point using a force board.

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3.4.1.2 Moments

Content	Opportunities for skills development
Moment of a force about a point. Moment defined as *force* × *perpendicular distance from the point to the line of action of the force*. Couple as a pair of equal and opposite coplanar forces. Moment of couple defined as *force* × *perpendicular distance between the lines of action of the forces*. Principle of moments. Centre of mass. Knowledge that the position of the centre of mass of uniform regular solid is at its centre.	

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3.4.1.3 Motion along a straight line

Content	Opportunities for skills development
Displacement, speed, velocity, acceleration. $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$ Calculations may include average and instantaneous speeds and velocities. Representation by graphical methods of uniform and non-uniform acceleration. Significance of areas of velocity–time and acceleration–time graphs and gradients of displacement–time and velocity–time graphs for uniform and non-uniform acceleration eg graphs for motion of bouncing ball. Equations for uniform acceleration: $v = u + at$ $s = \left(\frac{u + v}{2}\right)t$ $s = ut + \frac{at^2}{2}$ $v^2 = u^2 + 2as$ Acceleration due to gravity, g.	**MS 3.6, 3.7 / PS 1.1, 3.1** Distinguish between instantaneous velocity and average velocity. **MS 3.5, 3.6** Measurements and calculations from displacement–time, velocity–time and acceleration–time graphs. **MS 0.5, 2.2, 2.3, 2.4** Calculations involving motion in a straight line.
Required practical 3: Determination of g by a freefall method.	**MS 0.3, 1.2, 3.7 / AT d** Students should be able to identify random and systematic errors in the experiment and suggest ways to remove them. **MS 3.9** Determine g from a graph.

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3.4.1.4 Projectile motion

Content	Opportunities for skills development
Independent effect of motion in horizontal and vertical directions of a uniform gravitational field. Problems will be solvable using the equations of uniform acceleration. Qualitative treatment of friction. Distinctions between static and dynamic friction will not be tested. Qualitative treatment of lift and drag forces. Terminal speed. Knowledge that air resistance increases with speed. Qualitative understanding of the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle.	**PS 2.2, 3.1** Investigation of the factors that determine the motion of an object through a fluid.

3.4.1.5 Newton's laws of motion

Content	Opportunities for skills development
Knowledge and application of the three laws of motion in appropriate situations. $F = ma$ for situations where the mass is constant.	**PS 4.1 / MS 0.5, 3.2 / AT a, b, d** Students can verify Newton's second law of motion. **MS 4.1, 4.2** Students can use free-body diagrams.

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3.4.1.6 Momentum

Content	Opportunities for skills development
$momentum = mass \times velocity$ Conservation of linear momentum. Principle applied quantitatively to problems in one dimension. Force as the rate of change of momentum, $F = \frac{\Delta(mv)}{\Delta t}$ Impulse = change in momentum $F\Delta t = \Delta(mv)$, where F is constant. Significance of the area under a force–time graph. Quantitative questions may be set on forces that vary with time. Impact forces are related to contact times (eg kicking a football, crumple zones, packaging). Elastic and inelastic collisions; explosions. Appreciation of momentum conservation issues in the context of ethical transport design.	**MS 2.2, 2.3** Students can apply conservation of momentum and rate of change of momentum to a range of examples.

3.4.1.7 Work, energy and power

Content	Opportunities for skills development
Energy transferred, $W = Fs\cos\theta$ $rate\ of\ doing\ work = rate\ of\ energy\ transfer,\ \ P = \frac{\Delta W}{\Delta t} = Fv$ Quantitative questions may be set on variable forces. Significance of the area under a force–displacement graph. $efficiency = \frac{useful\ output\ power}{input\ power}$ Efficiency can be expressed as a percentage.	**MS 0.3 / PS 3.3, 4.1 / AT a, b, f.** Investigate the efficiency of an electric motor being used to raise a mass through a measured height. Students should be able to identify random and systematic errors in the experiment and suggest ways to remove them.

3.4.1.8 Conservation of energy

Content	Opportunities for skills development
Principle of conservation of energy. $\Delta E_p = mg\Delta h$ and $E_k = \frac{1}{2}mv^2$ Quantitative and qualitative application of energy conservation to examples involving gravitational potential energy, kinetic energy, and work done against resistive forces.	**MS 0.4, 2.2** Estimate the energy that can be derived from food consumption.

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3.4.2 Materials

3.4.2.1 Bulk properties of solids

Content	Opportunities for skills development
Density, $\rho = \frac{m}{V}$ Hooke's law, elastic limit, $F = k\Delta L$, k as stiffness and spring constant. Tensile strain and tensile stress. Elastic strain energy, breaking stress. $energy\ stored = \frac{1}{2}F\Delta L = area\ under\ force–extension\ graph$ Description of plastic behaviour, fracture and brittle behaviour linked to force–extension graphs. Quantitative and qualitative application of energy conservation to examples involving elastic strain energy and energy to deform. Spring energy transformed to kinetic and gravitational potential energy. Interpretation of simple stress–strain curves. Appreciation of energy conservation issues in the context of ethical transport design.	**MS 0.2, 4.3 / PS 3.3, 4.1** Students can compare the use of analogue and digital meters. **MS 0.4, 4.3 / AT e** Estimate the volume of an object leading to an estimate of its density.

3.4.2.2 The Young modulus

Content	Opportunities for skills development
$Young\ modulus = \frac{tensile\ stress}{tensile\ strain} = \frac{FL}{A\Delta L}$ Use of stress–strain graphs to find the Young modulus. (One simple method of measurement is required.)	**MS 3.1**
Required practical 4: Determination of the Young modulus by a simple method.	

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3.5 Electricity

This section builds on and develops earlier study of these phenomena from GCSE. It provides opportunities for the development of practical skills at an early stage in the course and lays the groundwork for later study of the many electrical applications that are important to society.

3.5.1 Current electricity

3.5.1.1 Basics of electricity

Content	Opportunities for skills development
Electric current as the rate of flow of charge; potential difference as work done per unit charge. $I = \frac{\Delta Q}{\Delta t}$, $V = \frac{W}{Q}$ Resistance defined as $R = \frac{V}{I}$	**AT b, f** Students can construct circuits from the range of components.

3.5.1.2 Current–voltage characteristics

Content	Opportunities for skills development
For an ohmic conductor, semiconductor diode, and filament lamp. Ohm's law as a special case where $I \propto V$ under constant physical conditions. Unless specifically stated in questions, ammeters and voltmeters should be treated as ideal (having zero and infinite resistance respectively). Questions can be set where either I or V is on the horizontal axis of the characteristic graph.	

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3.5.1.3 Resistivity

Content	Opportunities for skills development
Resistivity, $\rho = \frac{RA}{L}$ Description of the qualitative effect of temperature on the resistance of metal conductors and thermistors. Only negative temperature coefficient (ntc) thermistors will be considered. Applications of thermistors to include temperature sensors and resistance–temperature graphs. Superconductivity as a property of certain materials which have zero resistivity at and below a critical temperature which depends on the material. Applications of superconductors to include the production of strong magnetic fields and the reduction of energy loss in transmission of electric power. Critical field will not be assessed.	**MS 3.2, 4.3 / PS 1.2 / AT a, b, f, g** Investigation of the variation of resistance of a thermistor with temperature.
Required practical 5: Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.	

3.5.1.4 Circuits

Content	Opportunities for skills development
Resistors: $in\ series,\ R_T = R_1 + R_2 + R_3 + \ldots$ $in\ parallel, \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$ $Energy\ and\ power\ equations: E = IVt;$ $P = IV = I^2R = \frac{V^2}{R}$ The relationships between currents, voltages and resistances in series and parallel circuits, including cells in series and identical cells in parallel. Conservation of charge and conservation of energy in dc circuits.	**MS 0.3 / PS 4.1 / AT a, b, f, g** Students can construct circuits with various component configurations and measure currents and potential differences.

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3.5.1.5 Potential divider

Content	Opportunities for skills development
The potential divider used to supply constant or variable potential difference from a power supply. The use of the potentiometer as a measuring instrument is not required. Examples should include the use of variable resistors, thermistors, and light dependent resistors (LDR) in the potential divider.	**MS 3.2 / PS 4.1 / AT f** Students can investigate the behaviour of a potential divider circuit. **MS 3.2 / AT g** Students should design and construct potential divider circuits to achieve various outcomes.

3.5.1.6 Electromotive force and internal resistance

Content	Opportunities for skills development
$\varepsilon = \frac{E}{Q}$, $\varepsilon = I(R + r)$ Terminal pd; emf Students will be expected to understand and perform calculations for circuits in which the internal resistance of the supply is not negligible.	
Required practical 6: Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.	**MS 3.1, 3.3 / PS 2.2, 3.1 / AT f**

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3.6 Further mechanics and thermal physics (A-level only)

The earlier study of mechanics is further advanced through a consideration of circular motion and simple harmonic motion (the harmonic oscillator). A further section allows the thermal properties of materials, the properties and nature of ideal gases, and the molecular kinetic theory to be studied in depth.

3.6.1 Periodic motion (A-level only)

3.6.1.1 Circular motion (A-level only)

Content	Opportunities for skills development
Motion in a circular path at constant speed implies there is an acceleration and requires a centripetal force. Magnitude of angular speed $\omega = \frac{v}{r} = 2\pi f$ Radian measure of angle. Direction of angular velocity will not be considered. Centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$ The derivation of the centripetal acceleration formula will not be examined. Centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$	**MS 0.4** Estimate the acceleration and centripetal force in situations that involve rotation.

3.6.1.2 Simple harmonic motion (SHM) (A-level only)

Content	Opportunities for skills development
Analysis of characteristics of simple harmonic motion (SHM). Condition for SHM: $a \propto -x$ Defining equation: $a = -\omega^2 x$ $x = A\cos\omega t$ and $v = \pm\omega\sqrt{(A^2 - x^2)}$ Graphical representations linking the variations of x, v and a with time. Appreciation that the $v - t$ graph is derived from the gradient of the $x - t$ graph and that the $a - t$ graph is derived from the gradient of the $v - t$ graph. Maximum speed = ωA Maximum acceleration = $\omega^2 A$	**AT i, k** Data loggers can be used to produce $s - t$, $v - t$ and $a - t$ graphs for SHM. **MS 3.6, 3.8, 3.9, 3.12** Sketch relationships between x, v, a and t for simple harmonic oscillators.

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3.6.1.3 Simple harmonic systems (A-level only)

Content	Opportunities for skills development
Study of mass-spring system: $T = 2\pi\sqrt{\frac{m}{k}}$ Study of simple pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$ Questions may involve other harmonic oscillators (eg liquid in U-tube) but full information will be provided in questions where necessary. Variation of E_k, E_p, and total energy with both displacement and time. Effects of damping on oscillations.	**MS 4.6 / AT b, c** Students should recognise the use of the small-angle approximation in the derivation of the time period for examples of approximate SHM.
Required practical 7: Investigation into simple harmonic motion using a mass–spring system and a simple pendulum.	

3.6.1.4 Forced vibrations and resonance (A-level only)

Content	Opportunities for skills development
Qualitative treatment of free and forced vibrations. Resonance and the effects of damping on the sharpness of resonance. Examples of these effects in mechanical systems and situations involving stationary waves.	**AT g, i, k** Investigation of the factors that determine the resonant frequency of a driven system.

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3.6.2 Thermal physics (A-level only)

3.6.2.1 Thermal energy transfer (A-level only)

Content	Opportunities for skills development
Internal energy is the sum of the randomly distributed kinetic energies and potential energies of the particles in a body. The internal energy of a system is increased when energy is transferred to it by heating or when work is done on it (and vice versa), eg a qualitative treatment of the first law of thermodynamics. Appreciation that during a change of state the potential energies of the particle ensemble are changing but not the kinetic energies. Calculations involving transfer of energy. For a change of temperature: $Q = mc\Delta\theta$ where c is specific heat capacity. Calculations including continuous flow. For a change of state $Q = ml$ where l is the specific latent heat.	**MS 1.5 / PS 2.3 / AT a, b, d, f** Investigate the factors that affect the change in temperature of a substance using an electrical method or the method of mixtures. Students should be able to identify random and systematic errors in the experiment and suggest ways to remove them. **PS 1.1, 4.1 / AT k** Investigate, with a data logger and temperature sensor, the change in temperature with time of a substance undergoing a phase change when energy is supplied at a constant rate.

3.6.2.2 Ideal gases (A-level only)

Content	Opportunities for skills development
Gas laws as experimental relationships between p, V, T and the mass of the gas. Concept of absolute zero of temperature. Ideal gas equation: $pV = nRT$ for n moles and $pV = NkT$ for N molecules. $Work\ done = p\Delta V$ Avogadro constant N_A, molar gas constant R, Boltzmann constant k Molar mass and molecular mass.	
Required practical 8: Investigation of Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas.	**MS 3.3, 3.4, 3.14 / AT a**

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3.6.2.3 Molecular kinetic theory model (A-level only)

Content	Opportunities for skills development
Brownian motion as evidence for existence of atoms. Explanation of relationships between p, V and T in terms of a simple molecular model. Students should understand that the gas laws are empirical in nature whereas the kinetic theory model arises from theory. Assumptions leading to $pV = \frac{1}{3}Nm\langle c_{\text{rms}}\rangle^2$ including derivation of the equation and calculations. A simple algebraic approach involving conservation of momentum is required. Appreciation that for an ideal gas internal energy is kinetic energy of the atoms. Use of *average molecular kinetic energy* = $\frac{1}{2}m\langle c_{\text{rms}}\rangle^2 = \frac{3}{2}kT = \frac{3RT}{2N_{\text{A}}}$ Appreciation of how knowledge and understanding of the behaviour of a gas has changed over time.	

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3.7 Fields and their consequences (A-level only)

The concept of field is one of the great unifying ideas in physics. The ideas of gravitation, electrostatics and magnetic field theory are developed within the topic to emphasise this unification. Many ideas from mechanics and electricity from earlier in the course support this and are further developed. Practical applications considered include: planetary and satellite orbits, capacitance and capacitors, their charge and discharge through resistors, and electromagnetic induction. These topics have considerable impact on modern society.

3.7.1 Fields (A-level only)

Content	Opportunities for skills development
Concept of a force field as a region in which a body experiences a non-contact force. Students should recognise that a force field can be represented as a vector, the direction of which must be determined by inspection. Force fields arise from the interaction of mass, of static charge, and between moving charges. Similarities and differences between gravitational and electrostatic forces: Similarities: Both have inverse-square force laws that have many characteristics in common, eg use of field lines, use of potential concept, equipotential surfaces etc Differences: masses always attract, but charges may attract or repel	

3.7.2 Gravitational fields (A-level only)

3.7.2.1 Newton's law (A-level only)

Content	Opportunities for skills development
Gravity as a universal attractive force acting between all matter. Magnitude of force between point masses: $F = \frac{Gm_1m_2}{r^2}$ where G is the gravitational constant.	**MS 0.4** Students can estimate the gravitational force between a variety of objects.

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3.7.2.2 Gravitational field strength (A-level only)

Content	Opportunities for skills development
Representation of a gravitational field by gravitational field lines. g as force per unit mass as defined by $g = \frac{F}{m}$ Magnitude of g in a radial field given by $g = \frac{GM}{r^2}$	

3.7.2.3 Gravitational potential (A-level only)

Content	Opportunities for skills development
Understanding of definition of gravitational potential, including zero value at infinity. Understanding of gravitational potential difference. Work done in moving mass m given by $\Delta W = m\Delta V$ Equipotential surfaces. Idea that no work is done when moving along an equipotential surface. V in a radial field given by $V = -\frac{GM}{r}$ Significance of the negative sign. Graphical representations of variations of g and V with r. V related to g by: $g = -\frac{\Delta V}{\Delta r}$ ΔV from area under graph of g against r.	**MS 3.8, 3.9** Students use graphical representations to investigate relationships between v, r and g.

3.7.2.4 Orbits of planets and satellites (A-level only)

Content	Opportunities for skills development
Orbital period and speed related to radius of circular orbit; derivation of $T^2 \propto r^3$ Energy considerations for an orbiting satellite. Total energy of an orbiting satellite. Escape velocity. Synchronous orbits. Use of satellites in low orbits and geostationary orbits, to include plane and radius of geostationary orbit.	**MS 0.4** Estimate various parameters of planetary orbits, eg kinetic energy of a planet in orbit. **MS 3.11** Use logarithmic plots to show relationships between T and r for given data.

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3.7.3 Electric fields (A-level only)

3.7.3.1 Coulomb's law (A-level only)

Content	Opportunities for skills development
Force between point charges in a vacuum: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ Permittivity of free space, ε_0 Appreciation that air can be treated as a vacuum when calculating force between charges. For a charged sphere, charge may be considered to be at the centre. Comparison of magnitude of gravitational and electrostatic forces between subatomic particles.	**MS 0.3, 2.3** Students can estimate the magnitude of the electrostatic force between various charge configurations.

3.7.3.2 Electric field strength (A-level only)

Content	Opportunities for skills development
Representation of electric fields by electric field lines. Electric field strength. E as force per unit charge defined by $E = \frac{F}{Q}$ Magnitude of E in a uniform field given by $E = \frac{V}{d}$ Derivation from work done moving charge between plates: $Fd = Q\Delta V$ Trajectory of moving charged particle entering a uniform electric field initially at right angles. Magnitude of E in a radial field given by $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$	**PS 1.2, 2.2 / AT b** Students can investigate the patterns of various field configurations using conducting paper (2D) or electrolytic tank (3D).

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3.7.3.3 Electric potential (A-level only)

Content	Opportunities for skills development
Understanding of definition of absolute electric potential, including zero value at infinity, and of electric potential difference. Work done in moving charge Q given by $\Delta W = Q \Delta V$ Equipotential surfaces. No work done moving charge along an equipotential surface. Magnitude of V in a radial field given by $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ Graphical representations of variations of E and V with r. V related to E by $E = \frac{\Delta V}{\Delta r}$ ΔV from the area under graph of E against r.	

3.7.4 Capacitance (A-level only)

3.7.4.1 Capacitance (A-level only)

Content	Opportunities for skills development
Definition of capacitance: $C = \frac{Q}{V}$	

3.7.4.2 Parallel plate capacitor (A-level only)

Content	Opportunities for skills development
Dielectric action in a capacitor $C = \frac{A\varepsilon_0\varepsilon_r}{d}$ Relative permittivity and dielectric constant. Students should be able to describe the action of a simple polar molecule that rotates in the presence of an electric field.	**PS 1.2, 2.2, 4.3 / AT f, g** Determine the relative permittivity of a dielectric using a parallel-plate capacitor. Investigate the relationship between C and the dimensions of a parallel-plate capacitor eg using a capacitance meter.

3.7.4.3 Energy stored by a capacitor (A-level only)

Content	Opportunities for skills development
Interpretation of the area under a graph of charge against pd. $E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$	

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3.7.4.4 Capacitor charge and discharge (A-level only)

Content	Opportunities for skills development
Graphical representation of charging and discharging of capacitors through resistors. Corresponding graphs for Q, V and I against time for charging and discharging. Interpretation of gradients and areas under graphs where appropriate. Time constant RC. Calculation of time constants including their determination from graphical data. Time to halve, $T_{½} = 0.69RC$ Quantitative treatment of capacitor discharge, $Q = Q_0 e^{-\frac{t}{RC}}$ Use of the corresponding equations for V and I. Quantitative treatment of capacitor charge, $Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$	
Required practical 9: Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, RC	**MS 3.8, 3.10, 3.11 / PS 2.2, 2.3 / AT f, k**

3.7.5 Magnetic fields (A-level only)

3.7.5.1 Magnetic flux density (A-level only)

Content	Opportunities for skills development
Force on a current-carrying wire in a magnetic field: $F = BIl$ when field is perpendicular to current. Fleming's left hand rule. Magnetic flux density B and definition of the tesla.	
Required practical 10: Investigate how the force on a wire varies with flux density, current and length of wire using a top pan balance.	

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3.7.5.2 Moving charges in a magnetic field (A-level only)

Content	Opportunities for skills development
Force on charged particles moving in a magnetic field, $F = BQv$ when the field is perpendicular to velocity. Direction of force on positive and negative charged particles. Circular path of particles; application in devices such as the cyclotron.	**MS 4.3** Convert between 2D representations and 3D situations.

3.7.5.3 Magnetic flux and flux linkage (A-level only)

Content	Opportunities for skills development
Magnetic flux defined by $\Phi = BA$ where B is normal to A. Flux linkage as $N\Phi$ where N is the number of turns cutting the flux. Flux and flux linkage passing through a rectangular coil rotated in a magnetic field: flux linkage $N\Phi = BAN\cos\theta$	
Required practical 11: Investigate, using a search coil and oscilloscope, the effect on magnetic flux linkage of varying the angle between a search coil and magnetic field direction.	

3.7.5.4 Electromagnetic induction (A-level only)

Content	Opportunities for skills development
Simple experimental phenomena. Faraday's and Lenz's laws. Magnitude of induced emf = rate of change of flux linkage $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$ Applications such as a straight conductor moving in a magnetic field. emf induced in a coil rotating uniformly in a magnetic field: $\varepsilon = BAN\omega\sin\omega t$	

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3.7.5.5 Alternating currents (A-level only)

Content	Opportunities for skills development
Sinusoidal voltages and currents only; root mean square, peak and peak-to-peak values for sinusoidal waveforms only. $I_{rms} = \frac{I_0}{\sqrt{2}}$; $V_{rms} = \frac{V_0}{\sqrt{2}}$ Application to the calculation of mains electricity peak and peak-to-peak voltage values. Use of an oscilloscope as a dc and ac voltmeter, to measure time intervals and frequencies, and to display ac waveforms. No details of the structure of the instrument are required but familiarity with the operation of the controls is expected.	

3.7.5.6 The operation of a transformer (A-level only)

Content	Opportunities for skills development
The transformer equation: $\frac{N_s}{N_p} = \frac{V_s}{V_p}$ Transformer efficiency = $\frac{I_S V_S}{I_P V_P}$ Production of eddy currents. Causes of inefficiencies in a transformer. Transmission of electrical power at high voltage including calculations of power loss in transmission lines.	**MS 0.3 / AT b, h** Investigate relationships between currents, voltages and numbers of coils in transformers.

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3.8 Nuclear physics (A-level only)

This section builds on the work of Particles and radiation to link the properties of the nucleus to the production of nuclear power through the characteristics of the nucleus, the properties of unstable nuclei, and the link between energy and mass. Students should become aware of the physics that underpins nuclear energy production and also of the impact that it can have on society.

3.8.1 Radioactivity (A-level only)

3.8.1.1 Rutherford scattering (A-level only)

Content	Opportunities for skills development
Qualitative study of Rutherford scattering. Appreciation of how knowledge and understanding of the structure of the nucleus has changed over time.	

3.8.1.2 α, β and γ radiation (A-level only)

Content	Opportunities for skills development
Their properties and experimental identification using simple absorption experiments; applications eg to relative hazards of exposure to humans. Applications also include thickness measurements of aluminium foil paper and steel. Inverse-square law for γ radiation: $I = \frac{k}{x^2}$ Experimental verification of inverse-square law. Applications eg to safe handling of radioactive sources. Background radiation; examples of its origins and experimental elimination from calculations. Appreciation of balance between risk and benefits in the uses of radiation in medicine.	
Required practical 12: Investigation of the inverse-square law for gamma radiation.	

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3.8.1.3 Radioactive decay (A-level only)

Content	Opportunities for skills development
Random nature of radioactive decay; constant decay probability of a given nucleus; $\frac{\Delta N}{\Delta t} = -\lambda N$ $N = N_0 e^{-\lambda t}$ Use of activity, $A = \lambda N$ Modelling with constant decay probability. Questions may be set which require students to use $A = A_0 e^{-\lambda t}$ Questions may also involve use of molar mass or the Avogadro constant. Half-life equation: $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ Determination of half-life from graphical decay data including decay curves and log graphs. Applications eg relevance to storage of radioactive waste, radioactive dating etc.	**MS 1.3, 3.10, 3.11 / PS 3.1, 3.2** Investigate the decay equation using a variety of approaches (including the use of experimental data, dice simulations etc) and a variety of analytical methods.

3.8.1.4 Nuclear instability (A-level only)

Content	Opportunities for skills development
Graph of N against Z for stable nuclei. Possible decay modes of unstable nuclei including α, β^+, β^- and electron capture. Changes in N and Z caused by radioactive decay and representation in simple decay equations. Questions may use nuclear energy level diagrams. Existence of nuclear excited states; γ ray emission; application eg use of technetium-99m as a γ source in medical diagnosis.	

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3.8.1.5 Nuclear radius (A-level only)

Content	Opportunities for skills development
Estimate of radius from closest approach of alpha particles and determination of radius from electron diffraction. Knowledge of typical values for nuclear radius. Students will need to be familiar with the Coulomb equation for the closest approach estimate. Dependence of radius on nucleon number: $R = R_0 A^{1/3}$ derived from experimental data. Interpretation of equation as evidence for constant density of nuclear material. Calculation of nuclear density. Students should be familiar with the graph of intensity against angle for electron diffraction by a nucleus.	**MS 1.4** Make order of magnitude calculations of the radius of different atomic nuclei.

3.8.1.6 Mass and energy (A-level only)

Content	Opportunities for skills development
Appreciation that $E = mc^2$ applies to all energy changes, Simple calculations involving mass difference and binding energy. Atomic mass unit, u. Conversion of units; 1 u = 931.5 MeV. Fission and fusion processes. Simple calculations from nuclear masses of energy released in fission and fusion reactions. Graph of average binding energy per nucleon against nucleon number. Students may be expected to identify, on the plot, the regions where nuclei will release energy when undergoing fission/fusion. Appreciation that knowledge of the physics of nuclear energy allows society to use science to inform decision making.	

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3.8.1.7 Induced fission (A-level only)

Content	Opportunities for skills development
Fission induced by thermal neutrons; possibility of a chain reaction; critical mass. The functions of the moderator, control rods, and coolant in a thermal nuclear reactor. Details of particular reactors are not required. Students should have studied a simple mechanical model of moderation by elastic collisions. Factors affecting the choice of materials for the moderator, control rods and coolant. Examples of materials used for these functions.	

3.8.1.8 Safety aspects (A-level only)

Content	Opportunities for skills development
Fuel used, remote handling of fuel, shielding, emergency shut-down. Production, remote handling, and storage of radioactive waste materials. Appreciation of balance between risk and benefits in the development of nuclear power.	

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3.9 Astrophysics (A-level only)

Fundamental physical principles are applied to the study and interpretation of the Universe. Students gain deeper insight into the behaviour of objects at great distances from Earth and discover the ways in which information from these objects can be gathered. The underlying physical principles of the devices used are covered and some indication is given of the new information gained by the use of radio astronomy. The discovery of exoplanets is an example of the way in which new information is gained by astronomers.

3.9.1 Telescopes (A-level only)

3.9.1.1 Astronomical telescope consisting of two converging lenses (A-level only)

Content

Ray diagram to show the image formation in normal adjustment.

Angular magnification in normal adjustment.

$$M = \frac{\textit{angle subtended by image at eye}}{\textit{angle subtended by object at unaided eye}}$$

Focal lengths of the lenses.

$$M = \frac{f_o}{f_e}$$

3.9.1.2 Reflecting telescopes (A-level only)

Content

Cassegrain arrangement using a parabolic concave primary mirror and convex secondary mirror.

Ray diagram to show path of rays through the telescope up to the eyepiece.

Relative merits of reflectors and refractors including a qualitative treatment of spherical and chromatic aberration.

3.9.1.3 Single dish radio telescopes, I-R, U-V and X-ray telescopes (A-level only)

Content

Similarities and differences of radio telescopes compared to optical telescopes. Discussion should include structure, positioning and use, together with comparisons of resolving and collecting powers.

3.9.1.4 Advantages of large diameter telescopes (A-level only)

Content

Minimum angular resolution of telescope.

Rayleigh criterion, $\theta \approx \frac{\lambda}{D}$

Collecting power is proportional to $diameter^2$.

Students should be familiar with the rad as the unit of angle.

Comparison of the eye and CCD as detectors in terms of quantum efficiency, resolution, and convenience of use.

No knowledge of the structure of the CCD is required.

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3.9.2 Classification of stars (A-level only)

3.9.2.1 Classification by luminosity (A-level only)

Content

Apparent magnitude, m.

The Hipparcos scale.

Dimmest visible stars have a magnitude of 6.

Relation between brightness and apparent magnitude. Difference of 1 on magnitude scale is equal to an intensity ratio of 2.51.

Brightness is a subjective scale of measurement.

3.9.2.2 Absolute magnitude, *M* (A-level only)

Content

Parsec and light year.

Definition of M, relation to m: $m - M = 5 \log \frac{d}{10}$

3.9.2.3 Classification by temperature, black-body radiation (A-level only)

Content

Stefan's law and Wien's displacement law.

General shape of black-body curves, use of Wien's displacement law to estimate black-body temperature of sources.

Experimental verification is not required.

$\lambda_{max} T = constant = 2.9 \times 10^{-3}$ m K

Assumption that a star is a black body.

Inverse square law, assumptions in its application.

Use of Stefan's law to compare the power output, temperature and size of stars

$P = \sigma A T^4$

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3.9.2.4 Principles of the use of stellar spectral classes (A-level only)

Description of the main classes:

Spectral class	Intrinsic colour	Temperature / K	Prominent absorption lines
O	blue	25 000 – 50 000	He^+, He, H
B	blue	11 000 – 25 000	He, H
A	blue-white	7 500 – 11 000	H (strongest) ionized metals
F	white	6 000 – 7 500	ionized metals
G	yellow-white	5 000 – 6 000	ionized & neutral metals
K	orange	3 500 – 5 000	neutral metals
M	red	< 3 500	neutral atoms, TiO

Temperature related to absorption spectra limited to Hydrogen Balmer absorption lines: requirement for atoms in an n = 2 state.

3.9.2.5 The Hertzsprung-Russell (HR) diagram (A-level only)

Content
General shape: main sequence, dwarfs and giants.
Axis scales range from –10 to +15 (absolute magnitude) and 50 000 K to 2 500 K (temperature) or OBAFGKM (spectral class).
Students should be familiar with the position of the Sun on the HR diagram.
Stellar evolution: path of a star similar to our Sun on the HR diagram from formation to white dwarf.

3.9.2.6 Supernovae, neutron stars and black holes (A-level only)

Content
Defining properties: rapid increase in absolute magnitude of supernovae; composition and density of neutron stars; escape velocity > c for black holes.
Gamma ray bursts due to the collapse of supergiant stars to form neutron stars or black holes.
Comparison of energy output with total energy output of the Sun.
Use of type 1a supernovae as standard candles to determine distances. Controversy concerning accelerating Universe and dark energy.
Students should be familiar with the light curve of typical type 1a supernovae.
Supermassive black holes at the centre of galaxies.
Calculation of the radius of the event horizon for a black hole, Schwarzschild radius (R_s), $R_s \approx \frac{2GM}{c^2}$

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3.9.3 Cosmology (A-level only)

3.9.3.1 Doppler effect (A-level only)

Content

$\frac{\Delta f}{f} = \frac{v}{c}$ and $z = \frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$ for $v \ll c$ applied to optical and radio frequencies.

Calculations on binary stars viewed in the plane of orbit.

Galaxies and quasars.

3.9.3.2 Hubble's law (A-level only)

Content

Red shift $v = Hd$

Simple interpretation as expansion of universe; estimation of age of universe, assuming H is constant.

Qualitative treatment of Big Bang theory including evidence from cosmological microwave background radiation, and relative abundance of hydrogen and helium.

3.9.3.3 Quasars (A-level only)

Content

Quasars as the most distant measurable objects.

Discovery of quasars as bright radio sources.

Quasars show large optical red shifts; estimation involving distance and power output.

Formation of quasars from active supermassive black holes.

3.9.3.4 Detection of exoplanets (A-level only)

Content

Difficulties in the direct detection of exoplanets.

Detection techniques will be limited to variation in Doppler shift (radial velocity method) and the transit method.

Typical light curve.

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3.10 Medical physics (A-level only)

Students with an interest in biological and medical topics are offered the opportunity to study some of the applications of physical principles and techniques in medicine. The physics of the eye and ear as sensory organs is discussed. The important and developing field of medical imaging, with both non-ionising and ionising radiations is considered. Further uses of ionising radiation are developed in a section on radiation therapy.

3.10.1 Physics of the eye (A-level only)

3.10.1.1 Physics of vision (A-level only)

Content

The eye as an optical refracting system, including ray diagrams of image formation.

Sensitivity of the eye; spectral response as a photodetector.

Spatial resolution of the eye; explanation in terms of the behaviour of rods and cones.

3.10.1.2 Defects of vision and their correction using lenses (A-level only)

Content

Properties of converging and diverging lenses; principal focus, focal length and power, $power = \frac{1}{f}$; $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$; $m = \frac{v}{u}$

Myopia, hypermetropia, astigmatism.

Ray diagrams and calculations of powers (in dioptres) of correcting lenses for myopia and hypermetropia.

The format of prescriptions for astigmatism.

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3.10.2 Physics of the ear (A-level only)

3.10.2.1 Ear as a sound detection system (A-level only)

Content

Simple structure of the ear, transmission processes.

3.10.2.2 Sensitivity and frequency response (A-level only)

Content

Production and interpretation of equal loudness curves.

Human perception of relative intensity levels and the need for a logarithmic scale to reflect this.

Definition of intensity.

$Intensity\ level$ = 10 log $\frac{I}{I_0}$ where the threshold of hearing $I_0 = 1.0 \times 10^{-12}\ \mathrm{W\ m^{-2}}$

Measurement of sound intensity levels and the use of dB and dBA scales; relative intensity levels of sounds.

3.10.2.3 Defects of hearing (A-level only)

Content

The effect on equal loudness curves and the changes experienced in terms of hearing loss due to injury resulting from exposure to excessive noise or deterioration with age (excluding physiological changes).

3.10.3 Biological measurement (A-level only)

3.10.3.1 Simple ECG machines and the normal ECG waveform (A-level only)

Content

Principles of operation for obtaining the ECG waveform; explanation of the characteristic shape of a normal ECG waveform.

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3.10.4 Non-ionising imaging (A-level only)

3.10.4.1 Ultrasound imaging (A-level only)

Content

Reflection and transmission characteristics of sound waves at tissue boundaries, acoustic impedance, Z, and attenuation.

Advantages and disadvantages of ultrasound imaging in comparison with alternatives including safety issues and resolution.

Piezoelectric devices

Principles of generation and detection of ultrasound pulses.

A-scans and B-scans.

Examples of applications.

Use of the equations $Z = \rho c$ and $\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

3.10.4.2 Fibre optics and endoscopy (A-level only)

Content

Properties of fibre optics and applications in medical physics; including total internal reflection at the core–cladding interface.

Physical principles of the optical system of a flexible endoscope; the use of coherent and non-coherent fibre bundles; examples of use for internal imaging and related advantages.

3.10.4.3 Magnetic resonance (MR) scanner (A-level only)

Content

Basic principles of MR scanner:

- cross-section of patient scanned using magnetic fields
- protons initially aligned with spins parallel
- spinning hydrogen nuclei (protons) precess about the magnetic field lines of a superconducting magnet
- 'gradient' field coils used to scan cross-section
- short radio frequency (RF) pulses cause excitation and change of spin state in successive small regions
- protons excited during the scan emit RF signals as they de-excite
- RF signals detected and the resulting signals are processed by a computer to produce a visual image.

Students will not be asked about the production of magnetic fields used in an MR scanner, or about de-excitation relaxation times.

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3.10.5 X-ray imaging (A-level only)

3.10.5.1 The physics of diagnostic X-rays (A-level only)

Content

Physical principles of the production of X-rays; maximum photon energy, energy spectrum; continuous spectrum and characteristic spectrum.

Rotating-anode X-ray tube; methods of controlling the beam intensity, the photon energy, the image sharpness and contrast, and the patient dose.

3.10.5.2 Image detection and enhancement (A-level only)

Content

Flat panel (FTP) detector including X-ray scintillator, photodiode pixels, electronic scanning.

Advantages of FTP detector compared with photographic detection.

Contrast enhancement; use of X-ray opaque material as illustrated by the barium meal technique.

Photographic detection with intensifying screen and fluoroscopic image intensification; reasons for using these.

3.10.5.3 Absorption of X-rays (A-level only)

Content

Exponential attenuation.

Linear coefficient μ, mass attenuation coefficient μ_m, half-value thickness

$I = I_0 e^{-\mu x}$ $\mu_m = \frac{\mu}{\rho}$

Differential tissue absorption of X-rays excluding details of the absorption processes.

3.10.5.4 CT scanner (A-level only)

Content

Basic principles of CT scanner:

- movement of X-ray tube
- narrow, monochromatic X-ray beam
- array of detectors
- computer used to process the signals and produce a visual image.

Comparisons will be limited to advantages and disadvantages of image resolution, cost and safety issues. Students will not be asked about the construction or operation of the detectors.

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3.10.6 Radionuclide imaging and therapy (A-level only)

3.10.6.1 Imaging techniques (A-level only)

Content

Use of a gamma-emitting radioisotope as a tracer; technetium-99_m, iodine-131 and indium-111 and their relevant properties.

The properties should include the radiation emitted, the half-life, the energy of the gamma radiation, the ability for it to be labelled with a compound with an affinity for a particular organ.

The Molybdenum-Technetium generator, its basic use and importance.

PET scans.

3.10.6.2 Half-life (A-level only)

Content

Physical, biological and effective half-lives; $\frac{1}{T_E} = \frac{1}{T_B} + \frac{1}{T_P}$; definitions of each term.

3.10.6.3 Gamma camera (A-level only)

Content

Basic structure and workings of a photomultiplier tube and gamma camera.

3.10.6.4 Use of high-energy X-rays (A-level only)

Content

External treatment using high-energy X-rays. Methods used to limit exposure to healthy cells.

3.10.6.5 Use of radioactive implants (A-level only)

Content

Internal treatment using beta emitting implants.

3.10.6.6 Imaging comparisons (A-level only)

Content

Students will be required to make comparisons between imaging techniques. Questions will be limited to consideration of image resolution, convenience and safety issues.

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3.11 Engineering physics (A-level only)

This option offers opportunities for students to reinforce and extend the work of core units by considering applications in areas of engineering and technology. It extends the student's understanding in areas of rotational dynamics and thermodynamics. The emphasis in this option is on an understanding of the concepts and the application of physics. Questions can be set in novel or unfamiliar contexts, but in such cases the scene is set and any relevant required information is given.

3.11.1 Rotational dynamics (A-level only)

3.11.1.1 Concept of moment of inertia (A-level only)

Content

$I = mr^2$ for a point mass. $I = \Sigma mr^2$ for an extended object.

Qualitative knowledge of the factors that affect the moment of inertia of a rotating object.

Expressions for moment of inertia will be given where necessary.

3.11.1.2 Rotational kinetic energy (A-level only)

Content

$E_k = \frac{1}{2}I\omega^2$

Factors affecting the energy storage capacity of a flywheel.

Use of flywheels in machines.

Use of flywheels for smoothing torque and speed, and for storing energy in vehicles, and in machines used for production processes.

3.11.1.3 Rotational motion (A-level only)

Content

Angular displacement, angular speed, angular velocity, angular acceleration, $\omega = \frac{\Delta\theta}{\Delta t}$, $\alpha = \frac{\Delta\omega}{\Delta t}$

Representation by graphical methods of uniform and non-uniform angular acceleration.

Equations for uniform angular acceleration;

$\omega_2 = \omega_1 + \alpha t$, $\theta = \left(\frac{\omega_1 + \omega_2}{2}\right)t$

$\theta = \omega_1 t + \frac{\alpha t^2}{2}$, $\omega_2^2 = \omega_1^2 + 2\alpha\theta$

Students should be aware of the analogy between rotational and translational dynamics.

3.11.1.4 Torque and angular acceleration (A-level only)

Content

$T = Fr$

$T = I\alpha$

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3.11.1.5 Angular momentum (A-level only)

Content

$angular\ momentum = I\omega$

Conservation of angular momentum.

Angular impulse = change in angular momentum; $T\Delta t = \Delta(I\omega)$ where T is constant.

Applications may include examples from sport.

3.11.1.6 Work and power (A-level only)

Content

$W = T\theta$; $P = T\omega$

Awareness that frictional torque has to be taken into account in rotating machinery.

3.11.2 Thermodynamics and engines (A-level only)

3.11.2.1 First law of thermodynamics (A-level only)

Content

Quantitative treatment of first law of thermodynamics, $Q = \Delta U + W$

where Q is energy transferred to the system by heating, ΔU is increase in internal energy and W is work done **by** the system.

Applications of first law of thermodynamics.

3.11.2.2 Non-flow processes (A-level only)

Content

Isothermal, adiabatic, constant pressure and constant volume changes.

$pV = nRT$

adiabatic change : $pV^{\gamma} = constant$

isothermal change : $pV = constant$

at constant pressure $W = p\Delta V$

Application of first law of thermodynamics to the above processes.

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3.11.2.3 The *p–V* diagram (A-level only)

Content

Representation of processes on p–V diagram.

Estimation of work done in terms of area below the graph.

Extension to cyclic processes: *work done per cycle = area of loop*

Expressions for work done are not required except for the constant pressure case, $W = p\Delta V$

3.11.2.4 Engine cycles (A-level only)

Content

Understanding of a four-stroke petrol engine cycle and a diesel engine cycle, and of the corresponding indicator diagrams.

Comparison with the theoretical diagrams for these cycles; use of indicator diagrams for predicting and measuring power and efficiency

$input\ power = calorific\ value \times fuel\ flow\ rate$

Indicated power as $(area\ of\ p-V\ loop) \times (no.\ of\ cycles\ per\ second) \times (no.\ of\ cylinders)$

Output or brake power, $P = T\omega$

$friction\ power = indicated\ power - brake\ power$

Engine efficiency; overall, thermal and mechanical efficiencies.

$$Overall\ efficiency = \frac{brake\ power}{input\ power}$$

$$Thermal\ efficiency = \frac{indicated\ power}{input\ power}$$

$$Mechanical\ efficiency = \frac{brake\ power}{indicated\ power}$$

A knowledge of engine constructional details is not required.

Questions may be set on other cycles, but they will be interpretative and all essential information will be given.

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3.11.2.5 Second Law and engines (A-level only)

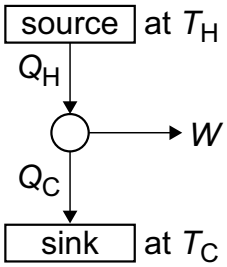
Content

Impossibility of an engine working only by the First Law.

Second Law of Thermodynamics expressed as the need for a heat engine to operate between a source and a sink.

efficiency = $\frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

maximum theoretical efficiency = $\frac{T_H - T_C}{T_H}$



Reasons for the lower efficiencies of practical engines.

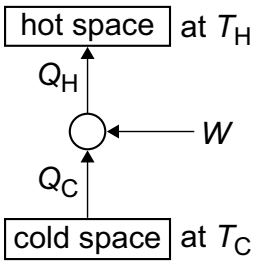
Maximising use of W and Q_H for example in combined heat and power schemes.

3.11.2.6 Reversed heat engines (A-level only)

Content

Basic principles and uses of heat pumps and refrigerators.

A knowledge of practical heat pumps or refrigerator cycles and devices is not required.



Coefficients of performance:

refrigerator: $COP_{ref} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C}$

heat pump: $COP_{hp} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} = \frac{T_H}{T_H - T_C}$

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3.12 Turning points in physics (A-level only)

This option is intended to enable key concepts and developments in physics to be studied in greater depth than in the core content. Students will be able to appreciate, from historical and conceptual viewpoints, the significance of major paradigm shifts for the subject in the perspectives of experimentation and understanding. Many present-day technological industries are the consequence of these key developments and the topics in the option illustrate how unforeseen technologies can develop from new discoveries.

3.12.1 The discovery of the electron (A-level only)

3.12.1.1 Cathode rays (A-level only)

Content

Production of cathode rays in a discharge tube.

3.12.1.2 Thermionic emission of electrons (A-level only)

Content

The principle of thermionic emission.

Work done on an electron accelerated through a pd V ; $\frac{1}{2}mv^2 = eV$

3.12.1.3 Specific charge of the electron (A-level only)

Content

Determination of the specific charge of an electron, $\frac{e}{m_e}$, by any one method.

Significance of Thomson's determination of $\frac{e}{m_e}$

Comparison with the specific charge of the hydrogen ion.

3.12.1.4 Principle of Millikan's determination of the electronic charge, *e* (A-level only)

Content

Condition for holding a charged oil droplet, of charge Q, stationary between oppositely charged parallel plates.

$\frac{QV}{d} = mg$

Motion of a falling oil droplet with and without an electric field; terminal speed to determine the mass and the charge of the droplet.

Stokes' Law for the viscous force on an oil droplet used to calculate the droplet radius.

$F = 6\pi\eta rv$

Significance of Millikan's results.

Quantisation of electric charge.

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3.12.2 Wave-particle duality (A-level only)

3.12.2.1 Newton's corpuscular theory of light (A-level only)

Content

Comparison with Huygens' wave theory in general terms.

The reasons why Newton's theory was preferred.

3.12.2.2 Significance of Young's double slits experiment (A-level only)

Content

Explanation for fringes in general terms, no calculations are expected.

Delayed acceptance of Huygens' wave theory of light.

3.12.2.3 Electromagnetic waves (A-level only)

Content

Nature of electromagnetic waves.

Maxwell's formula for the speed of electromagnetic waves in a vacuum $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

where μ_0 is the permeability of free space and ε_0 is the permittivity of free space.

Students should appreciate that ε_0 relates to the electric field strength due to a charged object in free space and μ_0 relates to the magnetic flux density due to a current-carrying wire in free space.

Hertz's discovery of radio waves including measurements of the speed of radio waves.

Fizeau's determination of the speed of light and its implications.

3.12.2.4 The discovery of photoelectricity (A-level only)

Content

The ultraviolet catastrophe and black-body radiation.

Planck's interpretation in terms of quanta.

The failure of classical wave theory to explain observations on photoelectricity.

Einstein's explanation of photoelectricity and its significance in terms of the nature of electromagnetic radiation.

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3.12.2.5 Wave–particle duality (A-level only)

Content

de Broglie's hypothesis: $p = \frac{h}{\lambda}$;
$\lambda = \frac{h}{\sqrt{2meV}}$

Low-energy electron diffraction experiments; qualitative explanation of the effect of a change of electron speed on the diffraction pattern.

3.12.2.6 Electron microscopes (A-level only)

Content

Estimate of anode voltage needed to produce wavelengths of the order of the size of the atom.

Principle of operation of the transmission electron microscope (TEM).

Principle of operation of the scanning tunnelling microscope (STM).

3.12.3 Special relativity (A-level only)

3.12.3.1 The Michelson-Morley experiment (A-level only)

Content

Principle of the Michelson-Morley interferometer.

Outline of the experiment as a means of detecting absolute motion.

Significance of the failure to detect absolute motion.

The invariance of the speed of light.

3.12.3.2 Einstein's theory of special relativity (A-level only)

Content

The concept of an inertial frame of reference.

The two postulates of Einstein's theory of special relativity:

1 physical laws have the same form in all inertial frames

2 the speed of light in free space is invariant.

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3.12.3.3 Time dilation (A-level only)

Content

Proper time and time dilation as a consequence of special relativity.

Time dilation:

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Evidence for time dilation from muon decay.

3.12.3.4 Length contraction (A-level only)

Content

Length of an object having a speed v

$$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$$

3.12.3.5 Mass and energy (A-level only)

Content

Equivalence of mass and energy, $E = mc^2$; $E = \frac{m_0c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Graphs of variation of mass and kinetic energy with speed.

Bertozzi's experiment as direct evidence for the variation of kinetic energy with speed.

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3.13 Electronics (A-level only)

This option is designed for those who wish to learn more about modern electronic technologies as a development of their core work in electricity. A variety of discrete devices is introduced followed by discussions of both analogue and digital techniques ranging from the operational amplifier to digital signal processing. The option ends with a look at the issues surrounding data communication.

3.13.1 Discrete semiconductor devices (A-level only)

3.13.1.1 MOSFET (metal-oxide semiconducting field-effect transistor) (A-level only)

Content
Simplified structure, behaviour and characteristics.
Drain, source and gate.
V_{DS}, V_{GS}, I_{DSS}, and V_{th}
Use as a switch, use as a device with a very high input resistance.
Use in N-channel, enhancement mode only is required.

3.13.1.2 Zener diode (A-level only)

Content
Characteristic curve showing zener breakdown voltage and typical minimum operating current.
Anode and cathode.
Use with a resistor as a constant voltage source.
Use to provide a reference voltage.
Use as a stabiliser is not required.

3.13.1.3 Photodiode (A-level only)

Content
Characteristic curves and spectral response curves.
Use in photo-conductive mode as a detector in optical systems.
Use with scintillator to detect atomic particles.

3.13.1.4 Hall effect sensor (A-level only)

Content
Use as magnetic field sensor to monitor attitude.
Use in tachometer.
Principles of operation are not required.

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3.13.2 Analogue and digital signals (A-level only)

3.13.2.1 Difference between analogue and digital signals (A-level only)

Content

Bits, bytes.

Analogue-to-digital conversion:

- sampling audio signals for transmission in digital form
- conversion of analogue signals into digital data using two voltage levels
- quantisation
- sampling rate
- effect of sampling rate and number of bits per sample on quality of conversion
- advantages and disadvantages of digital sampling
- process of recovery of original data from noisy signal
- effect of noise in communication systems.

Pulse code modulation.

Students should appreciate the use of a variety of sensors to collect analogue data.

The ability to carry out binary arithmetic is not required. Knowledge of binary numbers 1 to 10 is adequate.

3.13.3 Analogue signal processing (A-level only)

3.13.3.1 LC resonance filters (A-level only)

Content

Resonant frequency, $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Only parallel resonance arrangements are required.

Analogy between LC circuit and mass–spring system.

Inductance as mass analogy.

Capacitance as spring analogy.

Derivation of the equation is not required.

Energy (voltage) response curve.

The response curve for current is not required.

Q factor, $Q = \frac{f_0}{f_B}$

f_B is the bandwidth of the filter at the 50% energy points.

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3.13.3.2 The ideal operational amplifier (A-level only)

Content

Operation and characteristics of an ideal operational amplifier:

- power supply and signal connections
- infinite open-loop gain
- infinite input resistance.

Open-loop transfer function for a real operational amplifier, $V_{out} = A_{OL}(V_+ - V_-)$

Use as a comparator.

The operational amplifier should be treated as an important system building block.

3.13.4 Operational amplifier in:

3.13.4.1 Inverting amplifier configuration (A-level only)

Content

Derivation of $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$, calculations.

Meaning of virtual earth, virtual-earth analysis.

3.13.4.2 Non-inverting amplifier configuration (A-level only)

Content

$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

Derivation is not required.

3.13.4.3 Summing amplifier configuration (A-level only)

Content

$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots\right)$

Difference amplifier configuration.

Derivation is not required.

$V_{out} = (V_+ - V_-)\frac{R_f}{R_1}$

Derivation is not required.

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3.13.4.4 Real operational amplifiers (A-level only)

Content

Limitations of real operational amplifiers.

Frequency response curve.

$gain \times bandwidth = constant$ for a given device.

3.13.5 Digital signal processing (A-level only)

3.13.5.1 Combinational logic (A-level only)

Content

Use of Boolean algebra related to truth tables and logic gates.

$\overline{A}$ = **not** A

$A \cdot B$ = A **and** B

$A + B$ = A **or** B

Identification and use of AND, NAND, OR, NOR, NOT and EOR gates in combination in logic circuits.

Construction and deduction of a logic circuit from a truth table.

The gates should be treated as building blocks. The internal structure or circuit of the gates is not required.

3.13.5.2 Sequential logic (A-level only)

Content

Counting circuits:

- Binary counter
- BCD counter
- Johnson counter.

Inputs to the circuits, clock, reset, up/down.

Outputs from the circuits.

Modulo-n counter from basic counter with the logic driving a reset pin.

The gates should be treated as building blocks. The internal structure or circuit of the gates is not required.

3.13.5.3 Astables (A-level only)

Content

The astable as an oscillator to provide a clock pulse.

Clock (pulse) rate (frequency), pulse width, period, duty cycle, mark-to-space ratio.

Variation of running frequency using an external RC network.

Knowledge of a particular circuit or a specific device (eg 555 chip) will not be required.

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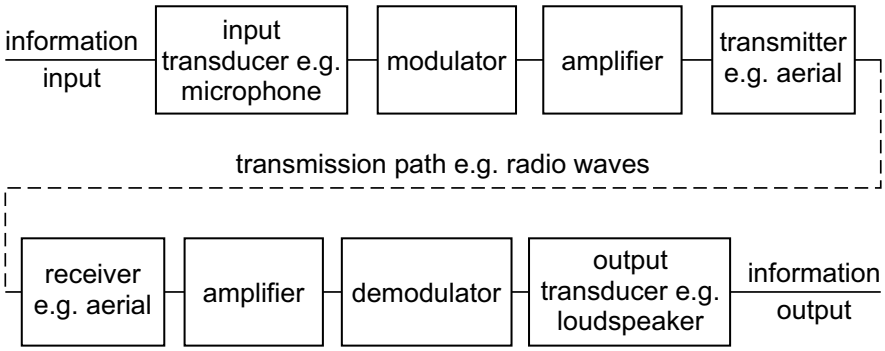
3.13.6 Data communication systems (A-level only)

3.13.6.1 Principles of communication systems (A-level only)

Content

Communication systems, block diagram of 'real time' communication system.



Only the purpose of each stage is required.

3.13.6.2 Transmission media (A-level only)

Content

Transmission-path media: metal wire, optic fibre, electromagnetic (radio, microwave).

Ground wave, refraction and reflection of sky waves, diffraction of long-wavelength radiation around the Earth's surface.

Satellite systems and typical transmission frequencies.

Students should recognise that up-links and down-links require different frequencies so that the receivers are not de-sensed.

Advantages and disadvantages of various transmission media. Students should consider data transmission rate, cost, and security issues.

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3.13.6.3 Time-division multiplexing (A-level only)

Content

Basic principles of time-division multiplexing.

3.13.6.4 Amplitude (AM) and frequency modulation (FM) techniques (A-level only)

Content

Principles of modulation; bandwidth.

Carrier wave and information signal.

Details of modulation circuits for modulating a carrier signal with the information signal will not be required.

Graphical representation of both AM and FM modulated signals.

A detailed mathematical treatment is not required.

Students will be expected to identify the carrier frequency and the information frequency from a graph of the variation of signal voltage with time.

Bandwidth requirements of simple AM and FM:

$bandwidth = 2f_{\mathrm{M}}$ for AM

$bandwidth = 2(\Delta f + f_{\mathrm{M}})$ for FM

Data capacity of a channel.

Comparison of bandwidth availability for various media.

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4 Scheme of assessment

Find past papers and mark schemes, and specimen papers for new courses, on our website at aqa.org.uk/pastpapers

The AS specification is designed to be taken over one or two years with all assessments taken at the end of the course. The A-level specification is designed to be taken over two years with all assessments taken at the end of the course.

Assessments and certification for the AS specification are available for the first time in May/June 2016 and then every May/June for the life of the specification.

Assessments and certification for the A-level specification are available for the first time in May/June 2017 and then every May/June for the life of the specification.

These are linear qualifications. In order to achieve the award, students must complete all exams in May/June in a single year. All assessments must be taken in the same series.

Questions for these specifications will be set which require students to demonstrate:

- their knowledge and understanding of the content developed in one section or topic, including the associated mathematical and practical skills or
- the ability to apply mathematical and practical skills to areas of content they are not normally developed in or
- the ability to draw together different areas of knowledge and understanding within one answer.

A range of question types will be used, including those that require extended responses. Extended response questions will allow students to demonstrate their ability to construct and develop a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. Extended responses may be in written English, extended calculations, or a combination of both, as appropriate to the question.

All materials are available in English only.

4.1 Aims

Courses based on these specifications should encourage students to:

- develop their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- develop essential knowledge and understanding of different areas of the subject and how they relate to each other
- develop and demonstrate a deep appreciation of the skills, knowledge and understanding of scientific methods
- develop competence and confidence in a variety of practical, mathematical and problem solving skills
- understand how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society
- use theories, models and ideas to develop scientific explanations
- use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
- use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems

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- carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- analyse and interpret data to provide evidence, recognising correlations and causal relationships
- evaluate methodology, evidence and data, and resolve conflicting evidence
- know that scientific knowledge and understanding develops over time
- communicate information and ideas in appropriate ways using appropriate terminology
- consider applications and implications of science and evaluate their associated benefits and risks
- consider ethical issues in the treatment of humans, other organisms and the environment
- evaluate the role of the scientific community in validating new knowledge and ensuring integrity
- evaluate the ways in which society uses science to inform decision making.

4.2 Assessment objectives

Assessment objectives (AOs) are set by Ofqual and are the same across all AS and A-level Physics specifications and all exam boards.

The exams will measure how students have achieved the following assessment objectives.

- AO1: Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures.
- AO2: Apply knowledge and understanding of scientific ideas, processes, techniques and procedures:
  - in a theoretical context
  - in a practical context
  - when handling qualitative data
  - when handling quantitative data.
- AO3: Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to:
  - make judgements and reach conclusions
  - develop and refine practical design and procedures.

Weighting of assessment objectives for AS Physics

Assessment objectives (AOs)	Component weightings (approx %)		Overall weighting (approx %)
	Paper 1	Paper 2	
AO1	34	37	36
AO2	41	39	40
AO3	24	24	24
Overall weighting of components	50	50	100

40% of the overall assessment of AS Physics will contain mathematical skills equivalent to Level 2 or above.

At least 15% of the overall assessment of AS Physics will assess knowledge, skills and understanding in relation to practical work.

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Weighting of assessment objectives for A-level Physics

Assessment objectives (AOs)	Component weightings (approx %)			Overall weighting (approx %)
	Paper 1	Paper 2	Paper 3	
AO1	34	32	31	33
AO2	38	53	35	42
AO3	28	15	32	25
Overall weighting of components	34	34	32	100

40% of the overall assessment of A-level Physics will contain mathematical skills equivalent to Level 2 or above.

At least 15% of the overall assessment of A-level Physics will assess knowledge, skills and understanding in relation to practical work.

4.3 Assessment weightings

The marks awarded on the papers will be scaled to meet the weighting of the components. Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

AS

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	70	x1	70
Paper 2	70	x1	70
		Total scaled mark:	140

A-level

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	85	x1	85
Paper 2	85	x1	85
Paper 3: Section A	45	x1	45
Paper 3: Section B (Astrophysics – option)	35	x1	35
Paper 3: Section B (Medical physics – option)	35	x1	35
Paper 3: Section B (Engineering physics – option)	35	x1	35
Paper 3: Section B (Turning points in physics – option)	35	x1	35
Paper 3: Section B (Electronics – option)	35	x1	35
		Total scaled mark:	250

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5 General administration

You can find information about all aspects of administration, as well as all the forms you need, at aqa.org.uk/examsadmin

5.1 Entries and codes

You only need to make one entry for each qualification.

Every specification is given a national discount (classification) code by the Department for Education (DfE), which indicates its subject area.

If a student takes two specifications with the same discount code, Further and Higher Education providers are likely to take the view that they have only achieved one of the two qualifications. Please check this before your students start their course.

Qualification title	AQA entry code	DfE discount code
AQA Advanced Subsidiary GCE in Physics	7407	1210 (post-16), RC1 (KS4)
AQA Advanced Level GCE in Physics	7408A (Astrophysics)	1210
	7408B (Medical physics)	1210
	7408C (Engineering physics)	1210
	7408D (Turning points in physics)	1210
	7408E (Electronics)	1210

These specifications comply with Ofqual's:

- *General conditions of recognition* that apply to all regulated qualifications
- GCE qualification level conditions that apply to all GCEs
- GCE subject level conditions that apply to all GCEs in this subject
- all relevant regulatory documents.

Ofqual has accredited these specifications. The qualification accreditation number (QAN) for the AS is 601/4746/5. The QAN for the A-level is 601/4747/7.

5.2 Overlaps with other qualifications

There is overlapping content in the AS and A-level Physics specifications. This helps you teach the AS and A-level together.

5.3 Awarding grades and reporting results

The AS qualification will be graded on a five-point scale: A, B, C, D and E.

The A-level qualification will be graded on a six-point scale: A*, A, B, C, D and E.

Students who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate.

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5.4 Re-sits and shelf life

Students can re-sit these qualifications as many times as they wish, within the shelf life of the qualifications.

5.5 Previous learning and prerequisites

There are no previous learning requirements. Any requirements for entry to a course based on these specifications are at the discretion of schools and colleges.

However, we recommend that students should have the skills and knowledge associated with at least GCSE Science and Additional Science or GCSE Physics course or equivalent.

5.6 Access to assessment: diversity and inclusion

General qualifications are designed to prepare students for a wide range of occupations and further study. Therefore our qualifications must assess a wide range of competences.

The subject criteria have been assessed to see if any of the skills or knowledge required present any possible difficulty to any students, whatever their ethnic background, religion, sex, age, disability or sexuality. If any difficulties were encountered, the criteria were reviewed again to make sure that tests of specific competences were only included if they were important to the subject.

As members of the Joint Council for Qualifications (JCQ) we participate in the production of the JCQ document *Access Arrangements and Reasonable Adjustments: General and Vocational qualifications*. We follow these guidelines when assessing the needs of individual students who may require an access arrangement or reasonable adjustment. This document is published on the JCQ website at jcq.org.uk

Students with disabilities and special needs

We can make arrangements for disabled students and students with special needs to help them access the assessments, as long as the competences being tested are not changed. Access arrangements must be agreed **before** the assessment. For example, a Braille paper would be a reasonable adjustment for a Braille reader but not for a student who does not read Braille.

We are required by the Equality Act 2010 to make reasonable adjustments to remove or lessen any disadvantage that affects a disabled student.

If you have students who need access arrangements or reasonable adjustments, you can apply using the Access arrangements online service at aqa.org.uk/eaqa

Special consideration

We can give special consideration to students who have been disadvantaged at the time of the assessment through no fault of their own – for example a temporary illness, injury or serious problem such as the death of a relative. We can only do this **after** the assessment.

Your exams officer should apply online for special consideration at aqa.org.uk/eaqa

For more information and advice about access arrangements, reasonable adjustments and special consideration please see aqa.org.uk/access or email accessarrangementsqueries@aqa.org.uk

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5.7 Working with AQA for the first time

If your school or college has not previously offered any AQA specification, you need to register as an AQA centre to offer our specifications to your students. Find out how at aqa.org.uk/becomeacentre

If your school or college is new to these specifications, please let us know by completing an Intention to enter form. The easiest way to do this is via e-AQA at aqa.org.uk/eaqa

5.8 Private candidates

A private candidate is someone who enters for exams through an AQA-approved school or college but is not enrolled as a student there.

If you are a private candidate you may be self-taught, home-schooled or have private tuition, either with a tutor or through a distance learning organisation. You must be based in the UK.

If you have any queries as a private candidate, you can:

- speak to the exams officer at the school or college where you intend to take your exams
- visit our website at aqa.org.uk/examsadmin
- email: privatecandidates@aqa.org.uk

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6 Mathematical requirements and exemplifications

In order to be able to develop their skills, knowledge and understanding in physics, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics as indicated in the table of coverage below.

Overall, at least 40% of the marks in assessments for physics will require the use of mathematical skills. These skills will be applied in the context of physics A-level and will be at least the standard of higher tier GCSE Mathematics.

The following tables illustrate where these mathematical skills may be developed during teaching or could be assessed. Those shown in **bold type** would only be tested in the full A-level course.

This list of examples is not exhaustive. These skills could be developed or assessed in other areas of specification content. Other areas where these skills could be developed have been exemplified throughout the specifications.

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6.1 Arithmetic and numerical computation

	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 0.1	Recognise and make use of appropriate units in calculations	Students may be tested on their ability to: • identify the correct units for physical properties such as $\mathrm{m\ s^{-1}}$, the unit for velocity • convert between units with different prefixes eg $\mathrm{cm^3}$ to $\mathrm{m^3}$
MS 0.2	Recognise and use expressions in decimal and standard form	Students may be tested on their ability to: • use physical constants expressed in standard form such as $c = 3.00 \times 10^8 \mathrm{m\ s^{-1}}$
MS 0.3	Use ratios, fractions and percentages	Students may be tested on their ability to: • calculate efficiency of devices • calculate percentage uncertainties in measurements
MS 0.4	Estimate results	Students may be tested on their ability to: • estimate the effect of changing experimental parameters on measurable values
MS 0.5	Use calculators to find and use power, **exponential and logarithmic functions**	Students may be tested on their ability to: • **solve for unknowns in decay problems such as $N = N_0 e^{-\lambda t}$**
MS 0.6	Use calculators to handle sin x, cos x, tan x when x is expressed in degrees or radians	Students may be tested on their ability to: • calculate the direction of resultant vectors

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6.2 Handling data

	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 1.1	Use an appropriate number of significant figures	Students may be tested on their ability to: • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement
MS 1.2	Find arithmetic means	Students may be tested on their ability to: • calculate a mean value for repeated experimental readings
MS 1.3	Understand simple probability	Students may be tested on their ability to: • understand probability in the context of radioactive decay
MS 1.4	Make order of magnitude calculations	Students may be tested on their ability to: • evaluate equations with variables expressed in different orders of magnitude
MS 1.5	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers	Students may be tested on their ability to: • determine the uncertainty where two readings for length need to be added together

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6.3 Algebra

	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 2.1	Understand and use the symbols: =, <, <<, >>, >, ∝, ≈, Δ	Students may be tested on their ability to: • recognise the significance of the symbols in the expression $F \propto \frac{\Delta p}{\Delta t}$
MS 2.2	Change the subject of an equation, including non-linear equations	Students may be tested on their ability to: • rearrange $E = mc^2$ to make m the subject
MS 2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Students may be tested on their ability to: • calculate the momentum p of an object by substituting the values for mass m and velocity v into the equation $p = mv$
MS 2.4	Solve algebraic equations, including quadratic equations	Students may be tested on their ability to: • solve kinematic equations for constant acceleration such as $v = u + at$ and $s = ut + ½ at^2$
MS 2.5	**Use logarithms in relation to quantities that range over several orders of magnitude**	Students may be tested on their ability to: • **recognise and interpret real world examples of logarithmic scales**

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6.4 Graphs

	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 3.1	Translate information between graphical, numerical and algebraic forms	Students may be tested on their ability to: • calculate Young modulus for materials using stress–strain graphs
MS 3.2	Plot two variables from experimental or other data	Students may be tested on their ability to: • plot graphs of extension of a wire against force applied
MS 3.3	Understand that $y = mx + c$ represents a linear relationship	Students may be tested on their ability to: • rearrange and compare $v = u + at$ with $y = mx + c$ for velocity–time graph in constant acceleration problems
MS 3.4	Determine the slope and intercept of a linear graph	Students may be tested on their ability to: • read off and interpret intercept point from a graph eg the initial velocity in a velocity–time graph
MS 3.5	Calculate rate of change from a graph showing a linear relationship	Students may be tested on their ability to: • calculate acceleration from a linear velocity–time graph
MS 3.6	Draw and use the slope of a tangent to a curve as a measure of rate of change	Students may be tested on their ability to: • draw a tangent to the curve of a displacement–time graph and use the gradient to approximate the velocity at a specific time
MS 3.7	Distinguish between instantaneous rate of change and average rate of change	Students may be tested on their ability to: • understand that the gradient of the tangent of a displacement–time graph gives the velocity at a point in time which is a different measure to the average velocity
MS 3.8	Understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or estimate it by graphical methods as appropriate	Students may be tested on their ability to: • recognise that for a capacitor the area under a voltage–charge graph is equivalent to the energy stored
MS 3.9	Apply the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, eg $\frac{\Delta x}{\Delta t} = -\lambda x$ using a graphical method or spreadsheet modelling	Students may be tested on their ability to: • determine g from distance-time plot for projectile motion
MS 3.10	Interpret logarithmic plots	Students may be tested on their ability to: • **obtain time constant for capacitor discharge by interpreting plot of log *V* against time**

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	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 3.11	**Use logarithmic plots to test exponential and power law variations**	Students may be tested on their ability to: • **use logarithmic plots with decay law of radioactivity / charging and discharging of a capacitor**
MS 3.12	Sketch relationships which are modelled by $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = kx$, $y = \sin x$, $y = \cos x$, **$y = e^{\pm x}$, and $y = \sin^2 x$, $y = \cos^2 x$ as applied to physical relationships**	Students may be tested on their ability to: • **sketch relationships between pressure and volume for an ideal gas**

6.5 Geometry and trigonometry

	Mathematical skills	Exemplification of mathematical skill in the context of A-level Physics
MS 4.1	Use angles in regular 2D and 3D structures	Students may be tested on their ability to: • interpret force diagrams to solve problems
MS 4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Students may be tested on their ability to: • draw force diagrams to solve mechanics problems
MS 4.3	Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres	Students may be tested on their ability to: • calculate the area of the cross–section to work out the resistance of a conductor given its length and resistivity
MS 4.4	Use Pythagoras' theorem, and the angle sum of a triangle	Students may be tested on their ability to: • calculate the magnitude of a resultant vector, resolving forces into components to solve problems
MS 4.5	Use sin, cos and tan in physical problems	Students may be tested on their ability to: • resolve forces into components
MS 4.6	Use of small angle approximations including $\sin\theta \approx \theta$, $\tan\theta \approx \theta$, $\cos\theta \approx 1$ for small θ where appropriate	Students may be tested on their ability to: • calculate fringe separations in interference patterns
MS 4.7	Understand the relationship between degrees and radians and translate from one to the other	Students may be tested on their ability to: • convert angle in degrees to angle in radians

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7 AS practical assessment

Practical work is at the heart of physics, so we have placed it at the heart of this specification.

Assessment of practical skills in this AS specification will be by written exams only.

The practical endorsement does not apply to the AS specification. A rich diet of practical work is essential to develop students' manipulative skills and understanding of the processes of scientific investigation. It also contributes to teaching and learning of the concepts within this specification.

Questions in the papers have been written in the expectation that students have carried out at least the six required practical activities in Section 7.2.

15% of the marks in the papers will relate to practical work.

7.1 Use of apparatus and techniques

All students taking an A-level Physics qualification are expected to have carried out the required practical activities in Section 7.2. These develop skills in the use of many of the following apparatus and techniques. This list is a compulsory element of the full A-level course. It is reproduced here for reference and to aid co-teaching the AS and A-level specifications.

	Apparatus and techniques
ATa	use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings
ATb	use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass)
ATc	use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line
ATd	use stopwatch or light gates for timing
ATe	use calipers and micrometers for small distances, using digital or vernier scales
ATf	correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important
ATg	design, construct and check circuits using DC power supplies, cells, and a range of circuit components
ATh	use signal generator and oscilloscope, including volts/division and time-base
ATi	generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave / radio wave source
ATj	use laser or light source to investigate characteristics of light, including interference and diffraction
ATk	use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data
ATl	use ionising radiation, including detectors

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7.2 AS required practical activities

The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

	Required activity	Apparatus and technique reference
1	Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.	a, b, c, i
2	Investigation of interference effects to include the Young's slit experiment and interference by a diffraction grating.	a, j
3	Determination of g by a free-fall method.	a, c, d, k
4	Determination of the Young modulus by a simple method.	a, c, e
5	Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.	a, b, e, f
6	Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.	b, f, g

Teachers are encouraged to vary their approach to these practical activities. Some are more suitable for highly structured approaches that develop key techniques. Others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the six required practical activities. The explicit teaching of practical skills will build students' competence. Many teachers will also use practical approaches to the introduction of content knowledge in the course of their normal teaching.

7.3 Practical skills to be assessed in written papers

Overall, at least 15% of the marks for all AS level Physics courses will require the assessment of practical skills.

In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the table of coverage below.

7.3.1 Independent thinking

	Practical skill
PS1.1	Solve problems set in practical contexts
PS1.2	Apply scientific knowledge to practical contexts

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7.3.2 Use and application of scientific methods and practices

	Practical skill
PS2.1	Comment on experimental design and evaluate scientific methods
PS2.2	Present data in appropriate ways
PS2.3	Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS2.4	Identify variables including those that must be controlled

7.3.3 Numeracy and the application of mathematical concepts in a practical context

	Practical skill
PS3.1	Plot and interpret graphs
PS3.2	Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS3.3	Consider margins of error, accuracy and precision of data

7.3.4 Instruments and equipment

	Practical skill
PS4.1	Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

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8 A-level practical assessment

Practical work is at the heart of physics, so we have placed it at the heart of this specification.

Practical assessments have been divided into those that can be assessed in written exams and those that can only be directly assessed whilst students are carrying out experiments.

A-level grades will be based only on marks from written exams.

A separate endorsement of practical skills will be taken alongside the A-level. This will be assessed by teachers and will be based on direct observation of students' competency in a range of skills that are not assessable in written exams.

8.1 Use of apparatus and techniques

All students taking an A-level Physics qualification are expected to have had opportunities to use the following apparatus and develop and demonstrate these techniques. These apparatus and techniques are common to all A-level Physics specifications.

Carrying out the 12 required practicals in Section 8.2 means that students will have experienced use of each of these apparatus and techniques. However, teachers are encouraged to develop students' abilities by inclusion of other opportunities for skills development, as exemplified in the right hand column of the content section of this specification.

	Apparatus and techniques
ATa	use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings
ATb	use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass)
ATc	use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line
ATd	use stopwatch or light gates for timing
ATe	use calipers and micrometers for small distances, using digital or vernier scales
ATf	correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important
ATg	design, construct and check circuits using DC power supplies, cells, and a range of circuit components
ATh	use signal generator and oscilloscope, including volts/division and time-base
ATi	generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave / radio wave source
ATj	use laser or light source to investigate characteristics of light, including interference and diffraction
ATk	use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data
ATl	use ionising radiation, including detectors

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8.2 A-level required practical activities

The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

	Required activity	Apparatus and technique reference
1	Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.	a, b, c, i
2	Investigation of interference effects to include the Young's slit experiment and interference by a diffraction grating.	a, j
3	Determination of g by a free-fall method	a, c, d, k
4	Determination of the Young modulus by a simple method.	a, c, e
5	Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.	a, b, e, f
6	Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.	b, f, g
7	Investigation into simple harmonic motion using a mass-spring system and a simple pendulum.	a, b, c, h, i
8	Investigation of Boyle's (constant temperature) law and Charles's (constant pressure) law for a gas.	a
9	Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant RC.	b, f, g, h, k
10	Investigate how the force on a wire varies with flux density, current and length of wire using a top pan balance.	a, b, f
11	Investigate, using a search coil and oscilloscope, the effect on magnetic flux linkage of varying the angle between a search coil and magnetic field direction.	a, b, f, h
12	Investigation of the inverse-square law for gamma radiation.	a, b, k, l

Teachers are encouraged to vary their approach to these practical activities. Some are more suitable for highly structured approaches that develop key techniques. Others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the 12 required practical activities. The explicit teaching of practical skills will build students' competence. Many teachers will also use practical approaches to the introduction of content knowledge in the course of their normal teaching. Students' work in these activities can also contribute towards the endorsement of practical skills.

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8.3 Practical skills to be assessed in written papers

Overall, at least 15% of the marks for all A-level Physics courses will require the assessment of practical skills.

In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the table of coverage below.

8.3.1 Independent thinking

	Practical skill
PS1.1	Solve problems set in practical contexts
PS1.2	Apply scientific knowledge to practical contexts

8.3.2 Use and application of scientific methods and practices

	Practical skill
PS2.1	Comment on experimental design and evaluate scientific methods
PS2.2	Present data in appropriate ways
PS2.3	Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS2.4	Identify variables including those that must be controlled

8.3.3 Numeracy and the application of mathematical concepts in a practical context

	Practical skill
PS3.1	Plot and interpret graphs
PS3.2	Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS3.3	Consider margins of error, accuracy and precision of data

8.3.4 Instruments and equipment

	Practical skill
PS4.1	Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

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8.4 A-level practical skills to be assessed via endorsement

8.4.1 Cross-board statement on practical endorsement

The assessment of practical skills is a compulsory requirement of the course of study for A-level qualifications in biology, chemistry and physics. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills will be common to all awarding organisations. These arrangements will include:

- A minimum of 12 practical activities to be carried out by each student which, together, meet the requirements of Appendices 5b (Practical skills identified for direct assessment and developed through teaching and learning) and 5c (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education. The required practical activities will be defined by each awarding organisation.
- Teachers will assess students against Common Practical Assessment Criteria (CPAC) issued jointly by the awarding organisations. The CPAC (see below) are based on the requirements of Appendices 5b and 5c of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.
- Each student will keep an appropriate record of their practical work, including their assessed practical activities.
- Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade.
- There will be no separate assessment of practical skills for AS qualifications.
- Students will answer questions in the AS and A-level exam papers that assess the requirements of Appendix 5a (practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education. These questions may draw on, or range beyond, the practical activities included in the specification.

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8.4.2 Criteria for the assessment of practical competency in A-level Biology, Chemistry and Physics

Competency	Practical mastery
	In order to be awarded a Pass a Learner must, by the end of the practical science assessment, consistently and routinely meet the criteria in respect of each competency listed below. A Learner may demonstrate the competencies in any practical activity undertaken as part of that assessment throughout the course of study. Learners may undertake practical activities in groups. However, the evidence generated by each Learner must demonstrate that he or she independently meets the criteria outlined below in respect of each competency. Such evidence: (a) will comprise both the Learner's performance during each practical activity and his or her contemporaneous record of the work that he or she has undertaken during that activity, and (b) must include evidence of independent application of investigative approaches and methods to practical work.
1. Follows written procedures	(a) Correctly follows written instructions to carry out the experimental techniques or procedures.
2. Applies investigative approaches and methods when using instruments and equipment	(a) Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting. (b) Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments where necessary. (c) Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled. (d) Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.
3. Safely uses a range of practical equipment and materials	(a) Identifies hazards and assesses risks associated with those hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field. (b) Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.
4. Makes and records observations	(a) Makes accurate observations relevant to the experimental or investigative procedure. (b) Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.

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Competency	Practical mastery
5. Researches, references and reports	(a) Uses appropriate software and/or tools to process data, carry out research and report findings. (b) Cites sources of information demonstrating that research has taken place, supporting planning and conclusions.

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