GCE

AS and A Level Specification

Physics A

For exams from June 2014 onwards
For certification from June 2014 onwards

Contents

Vertical black lines indicate a significant change or addition to the previous version of this specification.

1 Introduction

1.1 Why choose AQA?

It's a fact that AQA is the UK's favourite exam board and more students receive their academic qualifications from AQA than from any other board. But why does AQA continue to be so popular?

- **Specifications**
  Ours are designed to the highest standards, so teachers, students and their parents can be confident that an AQA award provides an accurate measure of a student's achievements. And the assessment structures have been designed to achieve a balance between rigour, reliability and demands on candidates.

- **Support**
  AQA runs the most extensive programme of support meetings; free of charge in the first years of a new specification and at a very reasonable cost thereafter. These support meetings explain the specification and suggest practical teaching strategies and approaches that really work.

- **Service**
  We are committed to providing an efficient and effective service and we are at the end of the phone when you need to speak to a person about an important issue. We will always try to resolve issues the first time you contact us but, should that not be possible, we will always come back to you (by telephone, email or letter) and keep working with you to find the solution.

- **Ethics**
  AQA is a registered charity. We have no shareholders to pay. We exist solely for the good of education in the UK. Any surplus income is ploughed back into educational research and our service to you, our customers. We don't profit from education, you do.

If you are an existing customer then we thank you for your support. If you are thinking of moving to AQA then we look forward to welcoming you.

1.2 Why choose Physics A?

- Physics A provides a seamless transition to A Level from previous studies and develops students' interest and enthusiasm for physics.
- The AS provides different starting points so teachers can choose to start the course with topics familiar or new topics.
- The A2 builds on AS and covers essential topics for progression to post A Level course in physics. It also includes optional topics from the former specification A course.
- The specification thus provides a smooth pathway from GCSE and a route to university courses in physics and other subjects in which physics is a key component.
- Physics A reflects the popular elements of both predecessor specifications, allowing teachers to adapt existing schemes of work and resources with minimum difficulty.
- Internal assessment of practical work is a key feature of the specification. There are two routes to the internal assessment.
  - Route T provides continuity in style and format from AQA's GCSE physics assessment model. This is achieved through assessment of practical skills (PSA) and an individual skills assessment (ISA) at AS level through Unit 3 and at A2 through Unit 6.
  - Route X provides a scheme of internal assessment through a verification of practical skills undertaken throughout the course and an externally marked practical test.
- The specification provides a wide range of opportunities to develop How Science Works by linking the general criteria on the nature of science to specific topics throughout the specification. Internal assessment gives students a deep awareness of how science in practice works.

1.3 How do I start using this specification?

Already using the existing AQA GCE Physics specifications?

- Register to receive further information, such as mark schemes, past question papers, details of teacher support meetings, etc, at **http://www.aqa.org.uk/rn/askaqa.php**. Information will be available electronically or in print, for your convenience.
- Tell us that you intend to enter candidates. Then we can make sure that you receive all the material you need for the examinations. This is particularly important where examination material is issued before the final entry deadline. You can let us know by completing the appropriate Intention to Enter and Estimated Entry forms. We will send copies to your Exams Officer and they are also available on our website **http://www.aqa.org.uk/exams-administration/entries/early-entry-information**

Not using the AQA specifications currently?

- Almost all centres in England and Wales use AQA or have used AQA in the past and are approved AQA centres. A small minority are not. If your centre is new to AQA, please contact our centre approval team at **centreapproval@aqa.org.uk**

1.4 How can I find out more?

Ask AQA

You have 24-hour access to useful information and answers to the most commonly-asked questions at **http://www.aqa.org.uk/rn/askaqa.php**

If the answer to your question is not available, you can submit a query for our team. Our target response time is one day.

Teacher Support

Details of the full range of current Teacher Support and CPD courses are available on our website at **http://web.aqa.org.uk/qual/cpd/index.php**

There is also a link to our fast and convenient online booking system for all of our courses at **http://events.aqa.org.uk/ebooking/**

Latest information online

You can find out more, including the latest news, how to register to use Enhanced Results Analysis, support and downloadable resources, on our website at **http://www.aqa.org.uk/**

2 Specification at a Glance

AS Examination

AS Award 1451

Unit 1 – PHYA1 **Particles, quantum phenomena and electricity**
Written Examination – (70 marks/120 UMS), 6 or 7 structured questions
1¼ hours
40% of the total AS marks
20% of the total A Level marks Available June only

Unit 2 – PHYA2 **Mechanics, materials and waves**
Written Examination – (70 marks/120 UMS), 6 or 7 structured questions
1¼ hours
40% of the total AS marks
20% of the total A Level marks Available June only

Unit 3 **Investigative and practical skills in AS Physics**

EITHER
PHA3T, Centre Marked Route T – 50 marks
Practical Skills Assignment (PSA – 9 raw marks)
Investigative Skills Assignment (ISA – 41 raw marks)
OR
PHA3X, Externally Marked Route X – 55 marks
Practical Skills Verification (PSV – teacher verification)
Externally Marked Practical Assignment (EMPA – 55 raw marks)
20% of the total AS marks
10% of the total A Level marks Available June only

A2 Examination

A Level Award 2451

Unit 4 – PHYA4 **Fields and further mechanics**
Written Examination – (75 marks/120 UMS)
1¾ hours
Section A is 25 multiple choice questions, each worth one mark.
Section B is a written paper of 4/5 structured questions and consists of 50 marks.
20% of the total A Level marks Available June only

Unit 5 – One of Units PHA5A, PHA5B, PHA5C, PHA5D
Written Examination – (75 marks/120 UMS)
1¾ hours
Section A: Nuclear and Thermal Physics – 40 marks – Compulsory section 4/5 structured questions
Section B: one of the following options.
Each paper has 4/5 structured questions and 35 marks.

Options:
A – Astrophysics
B – Medical Physics
C – Applied Physics
D – Turning Points in Physics

20% of the total A Level marks (Section A 10%, Section B 10%) Available June only

Unit 6 **Investigative and practical skills in A2 Physics**

EITHER
PHA6T, Centre Marked Route T – 50 marks
Practical Skills Assessment (PSA – 9 marks)
Investigative Skills Assignment (ISA – 41 marks)
OR
PHA6X, Externally Marked Route X – 55 marks
Practical Skills Verification (PSV – teacher verification)
Externally Marked Practical Assignment (EMPA – 55 raw marks)
10% of the total A Level marks Available June only

AS + A2 = A Level

3 Subject Content

Background information

The two AS theory units provide alternative starting points for the AS course.

Unit 1 invites teachers and students to start AS Physics by venturing into the field of Particle Physics and providing a new interest and dimension to their knowledge of the subject.

Unit 2 allows teachers to plan progression from GCSE and to develop topics already familiar to their students.

At A2, the two A2 theory units present a generally context-free approach to GCE level Physics, as at AS Level, leaving teachers to select the contexts and applications which bring the subject alive.

The first unit of the A2 course develops further the knowledge, understanding and applications of Mechanics and Fields.

Unit 5 covers Nuclear and Thermal Physics in Section A and provides a choice of optional topics from former Specification A in Section B.

3.1 Unit 1 PHYA1 Particles, Quantum Phenomena and Electricity

This unit involves two contrasting topics in physics: particle physics and electricity. Through the study of these topics, students should gain an awareness of the on-going development of new ideas in physics and of the application of in-depth knowledge of well-established topics such as electricity. Particle physics introduces students to the fundamental properties and nature of matter, radiation and quantum phenomena. In contrast, the study of electricity in this module builds on and develops previous GCSE studies and provides opportunities for practical work and looks into important applications.

3.1.1 Particles and Radiation

• Constituents of the atom

Proton, neutron, electron.

Their charge and mass in SI units and relative units. Specific charge of nuclei and of ions. Atomic mass unit is not required.

Proton number Z, nucleon number A, nuclide notation, isotopes

• Stable and unstable nuclei

The strong nuclear force; its role in keeping the nucleus stable; short-range attraction to about 3 fm, very-short range repulsion below about 0.5 fm.

Equations for alpha decay and β^- decay including the antineutrino.

• Particles, antiparticles and photons

Candidates should know that for every type of particle, there is a corresponding antiparticle. They should know that the positron, the antiproton, the antineutron and the antineutrino are the antiparticles of the electron, the proton, the neutron and the neutrino, respectively.

Comparison of particle and antiparticle masses, charge and rest energy in MeV

Photon model of electromagnetic radiation, the Planck constant,

$$E = hf = \frac{hc}{\lambda}$$

Knowledge of annihilation and pair production processes and the respective energies involved. The use of $E = mc^2$ is not required in calculations.

• Particle interactions

Concept of exchange particles to explain forces between elementary particles.

The electromagnetic force; virtual photons as the exchange particle.

The weak interaction limited β^-, β^+ decay, electron capture and electron-proton collisions; W^+ and W^- as the exchange particles.

Simple Feynman diagrams to represent the above reactions or interactions in terms of particles going in and out and exchange particles.

• Classification of particles

Hadrons: baryons (proton, neutron) and antibaryons (antiproton and antineutron) and mesons (pion, kaon).

Hadrons are subject to the strong nuclear force.

Candidates should know that the proton is the only stable baryon into which other baryons eventually decay; in particular, the decay of the neutron should be known.

Leptons: electron, muon, neutrino (electron and muon types).

Leptons are subject to the weak interaction.

Candidates will be expected to know baryon numbers for the hadrons. Lepton numbers for the leptons will be given in the data booklet.

- **Quarks and antiquarks**

  Up (u), down (d) and strange (s) quarks only.

  Properties of quarks: 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.

  Change of quark character in β^- and 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.

3.1.2 Electromagnetic Radiation and Quantum Phenomena

- **The photoelectric effect**

  Work function ϕ, threshold frequency f_o, photoelectric equation $hf = \phi + E_k$; the stopping potential experiment is not required.

- **Collisions of electrons with atoms**

  The electron volt.

  Ionisation and excitation; understanding of ionisation and excitation in the fluorescent tube.

- **Energy levels and photon emission**

  Line spectra (e.g. of atomic hydrogen) as evidence of transitions between discrete energy levels in atoms.

  $hf = E_1 - E_2$

- **Wave-particle duality**

  Candidates should know that electron diffraction suggests the wave nature of particles and the photoelectric effect suggests the particle nature of electromagnetic waves; details of particular methods of particle diffraction are not expected.

  de Broglie wavelength $\lambda = \dfrac{h}{mv}$,

  where mv is the momentum.

3.1.3 Current Electricity

- **Charge, current and potential difference**

  Electric current as the rate of flow of charge; potential difference as work done per unit charge.

  $$I = \frac{\Delta Q}{\Delta t} \text{ and } V = \frac{W}{Q}$$

  Resistance is defined by $R = \dfrac{V}{I}$

- **Current/voltage characteristics**

  For an ohmic conductor, a semiconductor diode and a filament lamp; candidates should have experience of the use of a current sensor and a voltage sensor with a data logger to capture data from which to determine $I - V$ curves.

  Ohm's law as a special case where $I \propto V$

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- ## Resistivity

$$\rho = \frac{RA}{L}$$

Description of the qualitative effect of temperature on the resistance of metal conductors and thermistors. Applications (e.g. temperature sensors).

Superconductivity as a property of certain materials which have zero resistivity at and below a critical temperature which depends on the material. Applications (e.g. very strong electromagnets, power cables).

- ## Circuits

Resistors in series; $R = R_1 + R_2 + R_3 + ...$

Resistors in parallel;

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

energy $E = I\,V\,t$, $P = IV$, $P = I^2R$; application, e.g. Understanding of high current requirement for a starter motor in a motor car.

Conservation of charge and energy in simple dc circuits.

The relationships between currents, voltages and resistances in series and parallel circuits, including cells in series and identical cells in parallel.

Questions will not be set which require the use of simultaneous equations to calculate currents or potential differences.

- ## Potential divider

The potential divider used to supply variable pd e.g. application as an audio 'volume' control.

Examples should include the use of variable resistors, thermistors and L.D.R.'s. The use of the potentiometer as a measuring instrument is not required.

- ## Electromotive force and internal resistance

$$\varepsilon = \frac{E}{Q} \qquad \varepsilon = I\,(R + r)$$

Applications; e.g. low internal resistance for a car battery.

- ## Alternating currents

Sinusoidal voltages and currents only; root mean square, peak and peak-to-peak values for sinusoidal waveforms only.

$$I_{rms} = \frac{I_0}{\sqrt{2}} \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$$

Application to calculation of mains electricity peak and peak-to-peak voltage values.

- ## Oscilloscope

Use of an oscilloscope as a dc and ac voltmeter, to measure time intervals and frequencies and to display a.c. waveforms. No details of the structure of the instrument is required but familiarity with the operation of the controls is expected.

3.2 Unit 2 PHYA2 Mechanics, Materials and Waves

This AS unit is about the principles and applications of mechanics, materials and waves. The first section introduces vectors and then develops knowledge and understanding of forces and energy from GCSE Additional Science. In the second section, materials are studied in terms of their bulk properties and tensile strength. The final section extends GCSE studies on waves by developing in-depth knowledge of the characteristics, properties and applications of waves, including refraction, diffraction, superposition and interference.

3.2.1 Mechanics

• Scalars and vectors

The addition of vectors by calculation or scale drawing. Calculations will be limited to two perpendicular vectors.

The resolution of vectors into two components at right angles to each other; examples should include the components of forces along and perpendicular to an inclined plane.

Conditions for equilibrium for two or three coplanar forces acting at a point; problems may be solved either by using resolved forces or by using a closed triangle.

• Moments

Moment of a force about a point defined as force x perpendicular distance from the point to the line of action of the force; torque.

Couple of a pair of equal and opposite forces defined as force x perpendicular distance between the lines of action of the forces.

The principle of moments and its applications in simple balanced situations.

Centre of mass; calculations of the position of the centre of mass of a regular lamina are not expected.

• Motion along a straight line

Displacement, speed, velocity and acceleration.

$$v = \frac{\Delta s}{\Delta t}, \qquad a = \frac{\Delta v}{\Delta t}$$

Representation by graphical methods of uniform and non-uniform acceleration; interpretation of velocity-time and displacement-time graphs for uniform and non-uniform acceleration; significance of areas and gradients.

Equations for uniform acceleration;

$$v = u + at, \qquad s = \left(\frac{u+v}{2}\right) t$$

$$s = ut + \frac{at^2}{2}, \qquad v^2 = u^2 + 2as$$

Acceleration due to gravity, *g*; detailed experimental methods of measuring *g* are not required.

Terminal speed.

• Projectile motion

Independence of vertical and horizontal motion; problems will be solvable from first principles. The memorising of projectile equations is not required.

• Newton's laws of motion

Knowledge and application of the three laws of motion in appropriate situations.

For constant mass, $F = ma$.

- ### Work, energy and power

$W = Fs \cos\theta$

$$P = \frac{\Delta W}{\Delta t}$$

$P = Fv$

$$\text{efficiency} = \frac{\text{useful output power}}{\text{input power}}$$

- ### Conservation of energy

Principle of conservation of energy, applied to examples involving gravitational potential energy, kinetic energy and work done against resistive forces.

$\Delta E_p = mg\Delta h$

$E_k = \frac{1}{2}mv^2$

3.2.2 Materials

- ### Bulk properties of solids

Density $\rho = \frac{m}{V}$

Hooke's law, elastic limit, experimental investigations.

$F = k\Delta L$

Tensile strain and tensile stress.

Elastic strain energy, breaking stress.

Derivation of $energy\ stored = \frac{1}{2} F\ \Delta L$

Description of plastic behaviour, fracture and brittleness; interpretation of simple stress-strain curves.

- ### The Young modulus

$$\text{The Young modulus} = \frac{tensile\ \ stress}{tensile\ \ strain} = \frac{FL}{A\ \Delta L}$$

One simple method of measurement.

Use of stress-strain graphs to find the Young modulus.

3.2.3 Waves

- ### Progressive Waves

Oscillation of the particles of the medium; amplitude, frequency, wavelength, speed, phase, path difference.

$c = f\lambda$

- ### Longitudinal and transverse waves

Characteristics and examples, including sound and electromagnetic waves.

Polarisation as evidence for the nature of transverse waves; applications e.g. Polaroid sunglasses, aerial alignment for transmitter and receiver.

- ## Refraction at a plane surface

Refractive index of a substance s, $n = \frac{c}{c_s}$

Candidates are not expected to recall methods for determining refractive indices.

Law of refraction for a boundary between two different substances of refractive indices n_1 and n_2 in the form

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Total internal reflection including calculations of the critical angle at a boundary between a substance of refractive index n_1 and a substance of lesser refractive index n_2 or air;

$$\sin\theta_c = \frac{n_2}{n_1}$$

Simple treatment of fibre optics including function of the cladding with lower refractive index around central core limited to step index only; application to communications.

- ## Superposition of waves, stationary waves

The formation of stationary waves by two waves of the same frequency travelling in opposite directions; the formula for fundamental frequency in terms of tension and mass per unit length is not required.

Simple graphical representation of stationary waves, nodes and antinodes on strings.

- ## Interference

The concept of path difference and coherence.

The laser as a source of coherent monochromatic light used to demonstrate interference and diffraction; comparison with non-laser light; awareness of safety issues.

Candidates will not be required to describe how a laser works.

Requirements of two source and single source double-slit systems for the production of fringes.

The appearance of the interference fringes produced by a double-slit system,

fringe spacing $w = \frac{\lambda D}{s}$,

where s is the slit separation.

- ## Diffraction

Appearance of the diffraction pattern from a single slit.

The plane transmission diffraction grating at normal incidence; optical details of the spectrometer will not be required.

Derivation of $d \sin\theta = n\lambda$,

where n is the order number.

Applications; e.g. to spectral analysis of light from stars.

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3.3 Unit 3 Investigative and Practical Skills in AS Physics

Candidates should carry out experimental and investigative activities in order to develop their practical skills. Experimental and investigative activities should be set in contexts appropriate to, and reflect the demand of, the AS content. These activities should allow candidates to use their knowledge and understanding of Physics in planning, carrying out, analysing and evaluating their work.

The specifications for Units 1 and 2 provide a range of different practical topics which may be used for experimental and investigative skills. The experience of dealing with such activities will develop the skills required for the assessment of these skills in the Unit. Examples of suitable experiments that could be considered throughout the course will be provided in the Teaching and learning resources web page.

The investigative and practical skills will be internally assessed through two routes;

- Route T – Investigative and Practical skills (Teacher assessed)
- Route X – Investigative and Practical skills (Externally Marked).

Route T – Investigative and Practical skills (Teacher assessed)

The assessment in this route is through two methods;

- Practical Skills Assessment (PSA)
- Investigative Skills Assignment (ISA).

The PSA will be based around a centre assessment throughout the AS course of the candidate's ability to follow and undertake certain standard practical activities.

The ISA will require candidates to undertake practical work, collect and process data and use it to answer questions in a written test (ISA test). See Section 3.8 for PSA and ISA details.

It is expected that candidates will be able to use and be familiar with 'standard' laboratory equipment which is deemed suitable at AS level, throughout their experiences of carrying out their practical activities.

This equipment might include:

Electric meters (analogue or digital), metre rule, set squares, protractors, vernier callipers, micrometer screwgauge (zero errors), an electronic balance, stopclock or stopwatch, thermometer (digital or liquid-in-glass), newtonmeters.

Candidates will not be expected to recall details of experiments they have undertaken in the written units 1 and 2. However, questions in the ISA may be set in experimental contexts based on the units, in which case full details of the context will be given.

Route X – Investigative and Practical skills (Externally Marked)

The assessment in this route is through a one off opportunity of a practical activity.

The first element of this route is that candidates should undertake five short AQA set practical exercises throughout the course, to be timed at the discretion of the centre. Details of the five exercises will be supplied by AQA at the start of the course. The purpose of these set exercises is to ensure that candidates have some competency in using the standard equipment which is deemed suitable at this level. No assessment will be made but centres will have to verify that these exercises will be completed.

The formal assessment will be through a longer practical activity. The activity will require candidates to undertake practical work, collect and process data and use it to answer questions in a written test. The activity will be made up of two tasks, followed by a written test. Only one activity will be provided every year.

Across both routes, it is also expected that in their course of study, candidates will develop their ability to use IT skills in data capture, data processing and when writing reports. When using data capture packages, they should appreciate the limitations of the packages that are used. Candidates should be encouraged to use graphics calculators, spreadsheets or other IT packages for data analysis and again be aware of any limitations of the hardware and software. However, they will not be required to use any such software in their assessments through either route.

The skills developed in course of their practical activities are elaborated further in the How Science Works section of this specification (see section 3.7).

In the course of their experimental work candidates should learn to:

- demonstrate and describe ethical, safe and skilful practical techniques
- process and select appropriate qualitative and quantitative methods
- make, record and communicate reliable and valid observations
- make measurements with appropriate precision and accuracy
- analyse, interpret, explain and evaluate the methodology, results and impact of their own and others experimental and investigative activities in a variety of ways.

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3.4 Unit 4 PHYA4 Fields and Further Mechanics

This is the first A2 unit, building on the key ideas and knowledge covered in AS Physics. The first section advances the study of momentum and introduces circular and oscillatory motion and covers gravitation. Electric and magnetic fields are covered, together with basic electromagnetic induction. Electric fields leads into capacitors and how quickly they charge and discharge through a resistor. Magnetic fields leads into the generation and transmission of alternating current.

3.4.1 Further Mechanics

- #### Momentum concepts

Force as the rate of change of momentum

$$F = \frac{\Delta(mv)}{\Delta t}$$

Impulse $F\Delta t = \Delta(mv)$

Significance of area under a force-time graph.

Principle of conservation of linear momentum applied to problems in one dimension.

Elastic and inelastic collisions; explosions.

- #### Circular motion

Motion in a circular path at constant speed implies there is an acceleration and requires a centripetal force.

Angular speed $\omega = \frac{v}{r} = 2\pi f$

Centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

Centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$

The derivation of $a = v^2/r$ will not be examined.

- #### Simple harmonic motion

Characteristic features of simple harmonic motion.

Condition for shm: $a = -(2\pi f)^2 x$

$$x = A\cos 2\pi ft \quad \text{and} \quad v = \pm 2\pi f\sqrt{A^2 - x^2}$$

Graphical representations linking x, v, a and t.

Velocity as gradient of displacement-time graph.

Maximum speed = $2\pi fA$

Maximum acceleration = $(2\pi f)^2 A$

- #### Simple harmonic systems

Study of mass-spring system.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Study of simple pendulum.

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Variation of E_k, E_p and total energy with displacement, and with time.

- **Forced vibrations and resonance**

  Qualitative treatment of free and forced vibrations.
  Resonance and the effects of damping on the sharpness of resonance.
  Phase difference between driver and driven displacements.
  Examples of these effects in mechanical systems and stationary wave situations.

3.4.2 Gravitation

- **Newton's law**

  Gravity as a universal attractive force acting between all matter.
  Force between point masses

  $$F = \frac{Gm_1 m_2}{r^2},$$

  where G is the gravitational constant.

- **Gravitational field strength**

  Concept of a force field as a region in which a body experiences a force.
  Representation by gravitational field lines.

  g as force per unit mass defined by $g = \frac{F}{m}$

  Magnitude of g in a radial field given by $g = \frac{GM}{r^2}$

- **Gravitational potential**

  Understanding of the definition of gravitational potential, including zero value at infinity, and of gravitational potential difference.
  Work done in moving mass m given by

  $$\Delta W = m\,\Delta V$$

  Gravitational potential V in a radial field given by

  $$V = -\frac{GM}{r}$$

  Graphical representations of variations of g and V with r.

  V related to g by $g = -\frac{\Delta V}{\Delta r}$

- **Orbits of planets and satellites**

  Orbital period and speed related to radius of circular orbit.
  Energy considerations for an orbiting satellite.
  Significance of a geosynchronous orbit.

3.4.3 Electric Fields

- **Coulomb's law**

  Force between point charges in a vacuum

  $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2},$$

  where ε_0 is the permittivity of free space.

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- **Electric field strength**

  E as force per unit charge defined by $E = \frac{F}{Q}$

  Representation by electric field lines.

  Magnitude of E in a radial field given by

  $$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

  Magnitude of E in a uniform field given by

  $$E = \frac{V}{d}$$

- **Electric potential**

  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

  $$\Delta W = Q\,\Delta V$$

  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.

- **Comparison of electric and gravitational fields**

  Similarities; inverse square law fields having many characteristics in common.

  Differences; masses always attract but charges may attract or repel.

3.4.4 Capacitance

- **Capacitance**

  Definition of capacitance;

  $$C = \frac{Q}{V}$$

- **Energy stored by a capacitor**

  Derivation of $E = \frac{1}{2}\,Q\,V$ and interpretation of area under a graph of charge against pd

  $$E = \tfrac{1}{2}\,Q\,V = \tfrac{1}{2}\,C\,V^2 = \tfrac{1}{2}\,Q^2/C$$

- **Capacitor discharge**

  Graphical representation of charging and discharging of capacitors through resistors

  Time constant = RC

  Calculation of time constants including their determination from graphical data.

  Quantitative treatment of capacitor discharge

  $$Q = Q_o\,e^{-t/RC}$$

  Candidates should have experience of the use of a voltage sensor and datalogger to plot discharge curves for a capacitor.

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3.4.5 Magnetic Fields

- ### Magnetic flux density
  Force on a current-carrying wire in a magnetic field.
  $F = B I l$, when field is perpendicular to current.
  Fleming's left hand rule.
  Magnetic flux density B and definition of the tesla.

- ### Moving charges in a magnetic field
  Force on charged particles moving in a magnetic field.
  $F = B Q v$, when the field is perpendicular to velocity.
  Circular path of particles; application in devices such as the cyclotron.

- ### Magnetic flux and flux linkage
  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 $N\Phi = BAN \cos\theta$ where θ is the angle between the normal to the plane of the coil and the magnetic field.

- ### Electromagnetic induction
  Simple experimental phenomena.
  Faraday's and Lenz's laws.
  Magnitude of induced emf = rate of change of flux linkage = $N\dfrac{\Delta\phi}{\Delta t}$

  Applications such as a moving straight conductor.
  Emf induced in a coil rotating uniformly in a magnetic field:

  $E = BAN\omega \sin \omega t$
  The operation of a transformer;

  The transformer equation = $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

  Transformer efficiency = $I_s V_s / I_p V_p$
  Causes of inefficiency of a transformer.
  Transmission of electrical power at high voltage.

3

3.5 Unit 5 PHA5A-5D Nuclear Physics, Thermal Physics and an Optional Topic

This unit consists of two sections. The first part of Section A 'Nuclear and Thermal Physics' looks at the characteristics of the nucleus, the properties of unstable nuclei and how energy is obtained from the nucleus. In the second part of Section A, the thermal properties of materials and the properties and nature of gases are studied in depth.

Section B offers an opportunity to study one of the following optional topics to gain deeper understanding and awareness of a selected branch of physics:

A Astronomy and cosmology

B Medical Physics

C Applied Physics

D Turning Points in Physics.

Nuclear and Thermal Physics

3.5.1 Radioactivity

- **Evidence for the nucleus**

  Qualitative study of Rutherford scattering.

- **α, β and γ radiation**

  Their properties and experimental identification using simple absorption experiments; applications e.g. to relative hazards of exposure to humans.

  The inverse square law for γ radiation, $I = \dfrac{k}{x^2}$

  including its experimental verification; applications, e.g. to safe handling of radioactive sources.

  Background radiation; examples of its origins and experimental elimination from calculations.

- **Radioactive decay**

  Random nature of radioactive decay; constant decay probability of a given nucleus;

  $$\frac{\Delta N}{\Delta t} = -\lambda N, \quad N = N_0 e^{-\lambda t}$$

  Use of activity $A = \lambda N$

  Half life, $T_{1/2} = \dfrac{\ln 2}{\lambda}$; determination from

  graphical decay data including decay curves and log graphs; applications e.g. relevance to storage of radioactive waste, radioactive dating.

- **Nuclear instability**

  Graph of N against Z for stable nuclei.

  Possible decay modes of unstable nuclei including α, β^+, β^- and electron capture.

  Changes of N and Z caused by radioactive decay and representation in simple decay equations.

  Existence of nuclear excited states; γ ray emission; application e.g. use of technetium-99m as a γ source in medical diagnosis.

- **Nuclear radius**

  Estimate of radius from closest approach of alpha particles and determination of radius from electron diffraction; knowledge of typical values.

  Dependence of radius on nucleon number

  $R = r_0 A^{1/3}$

  derived from experimental data.

  Calculation of nuclear density.

3.5.2 Nuclear Energy

- **Mass and energy**

  Appreciation that $E = mc^2$ applies to all energy changes.

  Simple calculations on mass difference and binding energy.

  Atomic mass unit, u; conversion of units;

  $1 \text{ u} = 931.3 \text{ MeV}$

  Graph of average binding energy per nucleon against nucleon number.

  Fission and fusion processes.

  Simple calculations from nuclear masses of energy released in fission and fusion reactions.

- **Induced fission**

  Induced fission by thermal neutrons; possibility of a chain reaction; critical mass.

  The functions of the moderator, the control rods and the coolant in a thermal nuclear reactor; factors affecting the choice of materials for the moderator, the control rods and the coolant and examples of materials used; details of particular reactors are not required.

- **Safety aspects**

  Fuel used, shielding, emergency shut-down.

  Production, handling and storage of radioactive waste materials.

3.5.3 Thermal Physics

- **Thermal energy**

  Calculations involving change of energy.

  For a change of temperature; $Q = mc\Delta T$, where c is specific heat capacity.

  For a change of state; $Q = m\,l$, where l is specific latent heat.

- **Ideal gases**

  Gas laws as experimental relationships between p, V, T and mass.

  Concept of absolute zero of temperature.

  Ideal gas equation as $pV = nRT$ for n moles and as $pV = NkT$ for N molecules.

  Avogadro constant N_A, molar gas constant R, Boltzmann constant k.

  Molar mass and molecular mass.

- ## Molecular kinetic theory model

  Explanation of relationships between p, V and T in terms of a simple molecular model.

  Assumptions leading to and derivation of

  $$pV = \frac{1}{3} N m (c_{rms})^2$$

  Average molecular kinetic energy

  $$\frac{1}{2} m (c_{rms})^2 = \frac{3}{2} kT = \frac{3RT}{2 N_A}$$

3.5 Options

Unit 5A Astrophysics

In this option, fundamental physical principles are applied to the study and interpretation of the Universe. Candidates will 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 optical and other devices used are covered and some indication is given of the new information gained by the use of radio astronomy. Details of particular sources and their mechanisms are not required.

A.1.1 Lenses and Optical Telescopes

- **Lenses**

  Principal focus, focal length of converging lens.

  Formation of images by a converging lens.

  Ray diagrams.

  $$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

- **Astronomical telescope consisting of two converging lenses**

  Ray diagram to show the image formation in normal adjustment.

  Angular magnification in normal adjustment.

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

  Focal lengths of the lenses.

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

- **Reflecting telescopes**

  Focal point of concave mirror.

  Cassegrain arrangement *using a parabolic concave primary mirror and convex secondary mirror*, ray diagram to show path of rays through the telescope as far as the eyepiece.

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

- **Resolving power**

  Appreciation of diffraction pattern produced by circular aperture.

  Resolving power of telescope, Rayleigh criterion,

  $$\theta \approx \frac{\lambda}{D}$$

- **Charge coupled device**

  Use of CCD to capture images.

  Structure and operation of the charge coupled device:

  A CCD is a silicon chip divided into picture elements (pixels).

  Incident photons cause electrons to be released.

  The number of electrons liberated is proportional to the intensity of the light.

  These electrons are trapped in 'potential wells' in the CCD.

  An electron pattern is built up which is identical to the image formed on the CCD.

When exposure is complete, the charge is processed to give an image.

Quantum efficiency of pixel > 70%.

A.1.2 Non-optical Telescopes

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

  Similarities and differences compared to optical telescopes including structure, positioning and use, including comparisons of resolving and collecting powers.

A.1.3 Classification of Stars

- ### Classification by luminosity

  Relation between brightness and apparent magnitude.

- ### Apparent magnitude, *m*

  Relation between intensity and apparent magnitude.

  Measurement of m from photographic plates and distinction between photographic and visual magnitude not required.

- ### Absolute magnitude, *M*

  Parsec and light year.

  Definition of M, relation to m

  $$m - M = 5 \log \frac{d}{10}$$

- ### Classification by temperature, black body radiation

  Stefan's law and Wien's displacement law.

  General shape of black body curves, experimental verification is not required.

  Use of Wien's displacement law to estimate black-body temperature of sources

  $$\lambda_{max} T = \text{constant} = 2.9 \times 10^{-3} \text{ mK.}$$

  Inverse square law, assumptions in its application.

  Use of Stefan's law to estimate area needed for sources to have same power output as the Sun.

  $$P = \sigma A T^4$$

  Assumption that a star is a black body.

- ### Principles of the use of stellar spectral classes

  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) ionised metals
F	White	6 000 – 7 500	ionised metals
G	yellow-white	5 000 – 6 000	ionised & 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: need for atoms in $n = 2$ state.

- ### The Hertzsprung-Russell diagram

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).

Stellar evolution: path of a star similar to our Sun on the Hertzsprung-Russell diagram from formation to white dwarf.

- ### Supernovae, neutron stars and black holes

Defining properties: rapid increase in absolute magnitude of supernovae; composition and density of neutron stars; escape velocity > c for black holes.

Use of supernovae as standard candles to determine distances. Controversy concerning accelerating Universe and dark energy.

Supermassive black holes at the centre of galaxies.

Calculation of the radius of the event horizon for a black hole Schwarzschild radius (R_s)

$$R_s = \frac{2GM}{c^2}$$

A.1.4 Cosmology

- ### Doppler effect

$$z = \frac{\Delta f}{f} = \frac{v}{c} \text{ and } \frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$$

For $v << c$ applied to optical and radio frequencies.

Calculations on binary stars viewed in the plane of orbit, galaxies and quasars.

- ### Hubble's law

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 H and He.

- ### Quasars

Quasars as the most distant measurable objects.

Discovery as bright radio sources.

Quasars show large optical red shifts; estimation of distance.

Unit 5B Medical Physics

This option offers an opportunity for students with an interest in biological and medical topics to study some of the applications of physical principles and techniques in medicine.

B.2.1 Physics of the Eye

- **Physics of vision**
  Simple structure of the eye.
  The eye as an optical refracting system, including ray diagrams of image formation.

- **Sensitivity of the eye**
  Spectral response as a photodetector.

- **Spatial resolution**
  Explanation in terms of the behaviour of rods and cones.

- **Persistence of vision**
  Excluding a physiological explanation.

- **Lenses**
  Properties of converging and diverging lenses; principal focus, focal length and power,

$$\text{power} = \frac{1}{f} \quad , \quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad \text{and} \quad m = \frac{v}{u}$$

- **Ray diagrams**
  Image formation.

- **Defects of vision**
  Myopia, hypermetropia and astigmatism.

- **Correction of defects of vision using lenses**
  Ray diagrams and calculations of powers (in dioptres) of correcting lenses for myopia and hypermetropia.
  The format of prescriptions for astigmatism.

B.2.2 Physics of the Ear

- **The ear as a sound detection system**
  Simple structure of the ear, transmission processes.

- **Sensitivity and frequency response**
  Production and interception of equal loudness curves.
  Human perception of relative intensity levels and the need for a logarithmic scale to reflect this.

- **Relative intensity levels of sounds**
  Measurement of sound intensity levels and the use of dB and dBA scales.
  Definition of intensity.

- ### The threshold of hearing

$$I_0 = 1.0 \times 10^{-12}\ \mathrm{Wm}^{-2}$$

$$\textit{intensity level} = 10 \log \frac{I}{I_0}$$

Defects of hearing

The effect on equal loudness curves and the changes experienced in terms of hearing loss of:

injury resulting from exposure to excessive noise;

deterioration with age (excluding physiological changes).

B.2.3 Biological Measurement

- ### Basic structure of the heart

The heart as a double pump with identified valves.

- ### Electrical signals and their detection; action potentials

The biological generation and conduction of electrical signals; action potential of a nerve cell; methods of detection of electrical signals at the skin surface.

The response of the heart to the action potential originating at the sino-atrial node; action potential of heart muscle.

- ### Simple ECG machines and the normal ECG waveform

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

B.2.4 Non-Ionising Imaging

- ### Ultrasound imaging

Reflection and transmission characteristics of sound waves at tissue boundaries, acoustic impedance, 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-scan and B-scan

Examples of applications.

- ### Fibre optics and Endoscopy

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.

- ### MR Scanner

Basic principles of MR scanner; cross-section of patient scanned using magnetic fields: hydrogen nuclei excited during the scan emit radio frequency (RF) signals as they de-excite: RF signals detected and processed by a computer to produce a visual image.

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

B.2.5 X-ray Imaging

- **X-rays**
  The physics of diagnostic X-rays.

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

- **Differential tissue absorption of X-rays**
  Excluding details of the absorption processes.

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

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

- **Image contrast enhancement**
  Use of X-ray opaque material as illustrated by the barium meal technique.

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

- **CT scanner**
  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. Candidates will not be asked about the construction or operation of the detectors.
  Comparisons of ultrasound, CT and MR scans; advantages and disadvantages limited to image resolution, cost and safety issues.

Unit 5C Applied Physics

The option offers opportunities for students to reinforce and extend the work of units PHYA1, PHYA2, PHYA4 and PHYA5 section A of the specification by considering applications in areas of engineering and technology. It embraces rotational dynamics and thermodynamics.

The emphasis should be on an understanding of the concepts and the application of Physics. Questions may be set in novel or unfamiliar contexts, but in all such cases the scene will be set and all relevant information will be given.

C.3.1 Rotational dynamics

- #### Concept of moment of inertia

  $I = \sum mr^2$

  Expressions for moment of inertia will be given where necessary.

- #### Rotational kinetic energy

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

  Factors affecting the energy storage capacity of a flywheel.

  Use of flywheels in machines.

- #### Angular displacement, velocity and acceleration

  Equations for uniformly accelerated motion:

  $\omega_2 = \omega_1 + \alpha t$

  $\theta = \omega_1 t + \frac{1}{2} \alpha t^2$

  $\omega_2^2 = \omega_1^2 + 2\alpha\theta$

  $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

- #### Torque and angular acceleration

  $T = I\alpha$

- #### Angular momentum

  angular momentum = $I\omega$

  Conservation of angular momentum.

- #### Power

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

  Awareness that, in rotating machinery, frictional couples have to be taken into account.

C.3.2 Thermodynamics and Engines

- #### First law of thermodynamics

  $Q = \Delta U + W$,

  where Q is heat entering the system, ΔU is increase in internal energy and W is work done by the system.

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- ## Non-flow processes

Isothermal, adiabatic, constant pressure and constant volume changes

$pV = nRT$

adiabatic: pV^{γ} = constant

isothermal: pV = constant

at constant pressure $W = p\Delta V$

Application of first law of thermodynamics to the above processes.

- ## The p – V diagram

Representation of processes on *p* – *V* diagram.

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

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

Extension to cyclic processes:

work done per cycle = area of loop.

- ## Engine cycles

Understanding of a four-stroke petrol cycle and a Diesel engine cycle, and of the corresponding indicator diagrams; comparison with the theoretical diagrams for these cycles; a knowledge of engine constructional details is not required; where questions are set on other cycles, they will be interpretative and all essential information will be given; indicator diagrams predicting and measuring power and efficiency

input power = calorific value x fuel flow rate.

Indicated power as

(area of p – V loop) x (no. of cycles/s) x (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 = brake power/input power.

Thermal efficiency = indicated power/input power.

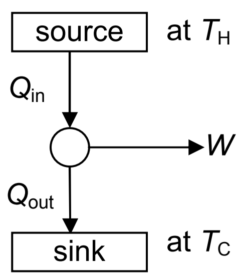
Mechanical efficiency = brake power/indicated power.

- ## Second Law and engines

Need for an engine to operate between a source and a sink

efficiency = $\dfrac{W}{Q_{\text{in}}} = \dfrac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$

maximum theoretical efficiency = $\dfrac{T_{\text{H}} - T_{\text{C}}}{T_{\text{H}}}$

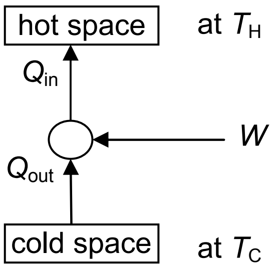


Reasons for the lower efficiencies of practical engines.

Maximising use of W and Q_{out} in combined heat and power schemes.

- ## Reversed heat engines

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



For a refrigerator: $COP_{ref} = \frac{Q_{out}}{W} = \frac{Q_{out}}{Q_{in} - Q_{out}}$

For a heat pump: $COP_{hp} = \frac{Q_{in}}{W} = \frac{Q_{in}}{Q_{in} - Q_{out}}$

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Unit 5D Turning Points in Physics

This option is intended to enable key developments in Physics to be studied in depth so that students can appreciate, from a historical viewpoint, the significance of major conceptual shifts in the subject both in terms of the understanding of the subject and in terms of its experimental basis. Many present day technological industries are the consequence of such key developments and the topics illustrate how unforeseen technologies develop from new discoveries.

D.4.1 The discovery of the Electron

- **Cathode rays**

  Production of cathode rays in a discharge tube.

- **Thermionic emission of electrons**

  The principle of thermionic emission.

  Work done on an electron accelerated through a pd

  $\frac{1}{2}mv^2 = eV$

- **Determination of the specific charge of an electron, *e/m*, by any one method**

  Significance of Thomson's determination of e/m.

  Comparison with the specific charge of the hydrogen ion.

  The use of equations

  $F = \frac{eV}{d}$ $F = Bev$ $r = \frac{mv}{Be}$

- **Principle of Millikan's determination of Q**

  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, 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.

D.4.2 Wave Particle Duality

- **Newton's corpuscular theory of light**

  Comparison with Huygens' wave theory in general terms.

  The reasons why Newton's theory was preferred.

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

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

  Delayed acceptance of Huygens' wave theory of light.

- **Electromagnetic waves**

  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.

  Candidates 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.

- **The discovery of photoelectricity**

  The failure of classical wave theory to explain observations on photoelectricity; the existence of the threshold frequency for the incident light and the variation of the stopping potential with frequency for different metals.

  Candidates should appreciate how the stopping potential is measured using a potential divider and a vacuum photocell.

  Candidates should also appreciate that photoelectric emission takes place almost instantaneously and that the maximum kinetic energy of the emitted photoelectrons is independent of the intensity of the incident light.

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

- **Wave particle duality**

  de Broglie's hypothesis supported by electron diffraction experiments

  $$p = \frac{h}{\lambda} \qquad \lambda = \frac{h}{\sqrt{2meV}}$$

- **Electron microscopes**

  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 (T.E.M.).

  Principle of operation of the scanning tunnelling microscope (S.T.M.).

D.4.3 Special Relativity

- **The Michelson-Morley experiment**

  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.

- **Einstein's theory of special relativity**

  The concept of an inertial frame of reference.

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

  (i) physical laws have the same form in all inertial frames,

  (ii) the speed of light in free space is invariant.

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- ## Time dilation

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

Time dilation

$$t = t_0\left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

Evidence for time dilation from muon decay.

- ## Length contraction

Length of an object having a speed v

$$l = l_0\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

- ## Mass and energy

Equivalence of mass and energy

$$E = mc^2 \qquad E = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

3.6 Unit 6 Investigative and Practical Skills in A2 Physics

Candidates should carry out experimental and investigative activities in order to develop their practical skills. Experimental and investigative activities should be set in contexts appropriate to, and reflect the demand of, the A2 content. These activities should allow candidates to use their knowledge and understanding of Physics in planning, carrying out, analysing and evaluating their work.

The specifications for Units 4 and 5 provide a range of different practical topics which may be used for experimental and investigative skills. The experience of dealing with such activities will develop the skills required for the assessment of these skills in the Unit. Examples of suitable experiments that could be considered throughout the course will be provided in the Teaching and learning resources web page.

The investigative and practical skills will be internally assessed through two routes:

- Route T – Investigative and Practical skills (Teacher assessed)
- Route X – Investigative and Practical skills (Externally Marked).

Route T – Investigative and Practical skills (Teacher assessed)

The investigative and practical skills will be centre assessed through two methods:

- Practical Skills Assessment (PSA)
- Investigative Skills Assignment (ISA).

The PSA will be based around a centre assessment throughout the A2 course of the candidate's ability to follow and undertake certain standard practical activities.

The ISA will require candidates to undertake practical work, collect and process data and use it to answer questions in a written test (ISA test). See Section 3.8 for PSA and ISA details.

It is expected that candidates will be able to use and be familiar with more 'complex' laboratory equipment or techniques which is deemed suitable at A2 level, throughout their experiences of carrying out their practical activities.

Reference made to more complex equipment/techniques might include:

Oscilloscope, travelling microscope, other vernier scales, spectrometer, data logger, variety of sensors, light gates for timing, ratemeter or scaler with GM tube, avoiding parallax errors, timing techniques (multiple oscillations).

Candidates will not be expected to recall details of experiments they have undertaken in the written units 4 and 5. However, questions in the ISA may be set in experimental contexts based on the units, in which case full details of the context will be given.

Route X – Investigative and Practical skills (Externally Marked)

The assessment in this route is through a one off opportunity of a practical activity.

The first element of this route is that candidates should undertake five short AQA set practical exercises throughout the course, to be timed at the discretion of the centre. Details of the five exercises will be supplied by AQA at the start of the course. The purpose of these set exercises is to ensure that candidates have some competency in using the standard equipment which is deemed suitable at this level. No assessment will be made but centres will have to verify that these exercises will be completed.

The formal assessment will be through a longer practical activity. The activity will require candidates to undertake practical work, collect and process data and use it to answer questions in a written test. The activity will be made up of two tasks, followed by a written test. Only one activity will be provided every year.

Across both routes, it is also expected that in their course of study, candidates will develop their ability to use IT skills in data capture, data processing and when writing reports. When using data capture packages, they should appreciate the limitations of the packages that are used. Candidates should be encouraged to use graphics calculators, spreadsheets or other IT packages for data analysis and again be aware of any limitations of the hardware and software. However, they will not be required to use any such software in their assessments through either route.

The skills developed in course of their practical activities are elaborated further in the How Science Works section of this specification (see section 3.7).

In the course of their experimental work candidates should learn to:

- demonstrate and describe ethical, safe and skilful practical techniques
- process and select appropriate qualitative and quantitative methods
- make, record and communicate reliable and valid observations
- make measurements with appropriate precision and accuracy
- analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.

3.7 How Science Works

How Science Works is an underpinning set of concepts and is the means whereby students come to understand how scientists investigate scientific phenomena in their attempts to explain the world about us. Moreover, How Science Works recognises the contribution scientists have made to their own disciplines and to the wider world.

Further, it recognises that scientists may be influenced by their own beliefs and that these can affect the way in which they approach their work. Also, it acknowledges that scientists can and must contribute to debates about the uses to which their work is put and how their work influences decision-making in society.

In general terms, it can be used to promote students' skills in solving scientific problems by developing an understanding of:

- the concepts, principles and theories that form the subject content
- the procedures associated with the valid testing of ideas and, in particular, the collection, interpretation and validation of evidence
- the role of the scientific community in validating evidence and also in resolving conflicting evidence.

As students become proficient in these aspects of How Science Works, they can also engage with the place and contribution of science in the wider world. In particular, students will begin to recognise:

- the contribution that scientists, as scientists, can make to decision-making and the formulation of policy
- the need for regulation of scientific enquiry and how this can be achieved
- how scientists can contribute legitimately in debates about those claims which are made in the name of science.

An understanding of How Science Works is a requirement for this specification and is set out in the following points which are taken directly from the GCE AS and A Level subject criteria for science subjects. Each point is expanded in the context of Physics. The specification references given illustrate where the example is relevant and could be incorporated.

A	**Use theories, models and ideas to develop and modify scientific explanations** Scientists use theories and models to attempt to explain observations. These theories or models can form the basis for scientific experimental work. Scientific progress is made when validated evidence is found that supports a new theory or model. Candidates should use historical examples of the way scientific theories and models have developed and how this changes our knowledge and understanding of the physical world. *Examples in this specification include:* • *Galileo deduced from his inclined plane experiment that falling objects accelerate. Newton later explained why and showed that freely-falling objects have the same acceleration. (AS Unit 2 §3.2.1)* • *The kinetic theory of gases explains the experimental gas laws. (A2 Unit 5 §3.5.3)*
B	**Use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas** Scientists use their knowledge and understanding when observing objects and events, in defining a scientific problem and when questioning their own explanations or those of other scientists. Scientific progress is made when scientists contribute to the development of new ideas, materials and theories. Candidates will learn that: • a hypothesis is an untested idea or theory based on observations • predictions from a hypothesis or a theory need to be tested by experiment • if a reliable experiment does not support a hypothesis or theory, the hypothesis or theory must be changed. *Examples in this specification include:* • *Many opportunities permeating throughout the Investigative and Practical Skills units (Unit 3 & 6)*
C	**Use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems** Observations ultimately lead to explanations in the form of hypotheses. In turn, these hypotheses lead to predictions that can be tested experimentally. Observations are one of the key links between the 'real world' and the abstract ideas of science. Once an experimental method has been validated, it becomes a protocol that is used by other scientists. ICT can be used to speed up, collect, record and analyse experimental data. Candidates will know how to: • plan or follow a given plan to carry out an investigation on topics relevant to the specification • identify the dependent and independent variables in an investigation and the control variables • select appropriate apparatus and methods, including ICT, to carry out reliable experiments relevant to topics in the specification • choose measuring instruments according to their sensitivity and precision. *Examples in this specification include:* • *Many opportunities permeating throughout the Investigative and Practical Skills units (Unit 3 & 6)*

D	**Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts** Scientists perform a range of experimental skills that include manual and data skills (tabulation, graphical skills etc). Scientists should select and use equipment that is appropriate when making accurate measurements and should record these measurements methodically. Scientists carry out experimental work in such a way as to minimise the risk to themselves, to others and to the materials, including organisms, used. Candidates will be able to: • follow appropriate experimental procedures in a sensible order • use appropriate apparatus and methods to make accurate and reliable measurements • identify and minimise significant sources of experimental error • identify and take account of risks in carrying out practical work. *Examples in this specification include:* • *Many opportunities permeating throughout the Investigative and Practical Skills units (Unit 3 & 6)*
E	**Analyse and interpret data to provide evidence, recognising correlations and causal relationships** Scientists look for patterns and trends in data as a first step in providing explanations of phenomena. The degree of uncertainty in any data will affect whether alternative explanations can be given for the data. Anomalous data are those measurements that fall outside the normal, or expected, range of measured values. Decisions on how to treat anomalous data should be made only after examination of the event. In searching for causal links between factors, scientists propose predictive theoretical models that can be tested experimentally. When experimental data confirm predictions from these theoretical models, scientists become confident that a causal relationship exists. Candidates will know how to: • tabulate and process measurement data • use equations and carry out appropriate calculations • plot and use appropriate graphs to establish or verify relationships between variables • relate the gradient and the intercepts of straight line graphs to appropriate linear equations. *Examples in this specification include:* • *Many opportunities permeating throughout the Investigative and Practical Skills units (Unit 3 & 6)*

F	**Evaluate methodology, evidence and data, and resolve conflicting evidence**
	The validity of new evidence, and the robustness of conclusions that stem from them, is constantly questioned by scientists. Experimental methods must be designed adequately to test predictions. Solutions to scientific problems are often developed when different research teams produce conflicting evidence. Such evidence is a stimulus for further scientific investigation, which involves refinements of experimental technique or development of new hypotheses. Candidates will be able to: • distinguish between systematic and random errors • make reasonable estimates of the errors in all measurements • use data, graphs and other evidence from experiments to draw conclusions • use the most significant error estimates to assess the reliability of conclusions drawn.
	Examples in this specification include: • *Many opportunities permeating throughout the Investigative and Practical Skills units (Unit 3 & 6)*
G	**Appreciate the tentative nature of scientific knowledge**
	Scientific explanations are those that are based on experimental evidence which is supported by the scientific community. Scientific knowledge changes when new evidence provides a better explanation of scientific observations. Candidates will be able to understand that scientific knowledge is founded on experimental evidence and that such evidence must be shown to be reliable and reproducible. If such evidence does not support a theory the theory must be modified or replaced with a different theory. Just as previous scientific theories have been proved inadequate or incorrect, our present theories may also be flawed.
	Examples in this specification include: • *Antiparticles were predicted before they were discovered. (AS Unit 1 §3.1.1)* • *Rutherford's alpha scattering experiment led to the nuclear model of the atom even though it was carried out to test Thompson's model of the atom. (A2 Unit 5 §3.5.1)*
H	**Communicate information and ideas in appropriate ways using appropriate terminology**
	By sharing the findings of their research, scientists provide the scientific community with opportunities to replicate and further test their work, thus either confirming new explanations or refuting them. Scientific terminology avoids confusion amongst the scientific community, enabling better understanding and testing of scientific explanations. Candidates will be able to provide explanations using correct scientific terms, and support arguments with equations, diagrams and clear sketch graphs when appropriate. The need for answers to be expressed in such a way pervades the written papers and the ISA. Furthermore, questions requiring extended writing will be set in which marks may be reserved for demonstrating this skill.
	Examples in this specification include: • *Many opportunities through the assessment of questions requiring extended prose which are evident throughout each of the assessment units in the specification.*

I	**Consider applications and implications of science and appreciate their associated benefits and risks**
	Scientific advances have greatly improved the quality of life for the majority of people. Developments in technology, medicine and materials continue to further these improvements at an increasing rate. Scientists can predict and report on some of the beneficial applications of their experimental findings. Scientists evaluate, and report on, the risks associated with the techniques they develop and applications of their findings. Candidates will be able to study how science has been applied to develop technologies that improve our lives but will also appreciate that the technologies themselves pose significant risks that have to be balanced against the benefits.
	Examples in this specification include: • *Superconductors are used to make very powerful magnets which are used in MRI scanners. (AS Unit 1 §3.1.3)* • *A nuclear reactor is a reliable source of electricity and does not emit greenhouse gases but its radioactive waste must be processed and stored securely for many years. (A2 Unit 5 §3.5.2)*
J	**Consider ethical issues in the treatment of humans, other organisms and the environment**
	Scientific research is funded by society, either through public funding or through private companies that obtain their income from commercial activities. Scientists have a duty to consider ethical issues associated with their findings. Individual scientists have ethical codes that are often based on humanistic, moral and religious beliefs. Scientists are self-regulating and contribute to decision making about what investigations and methodologies should be permitted. Candidates will be able to appreciate how science and society interact. They should examine how science has provided solutions to problems but that the solutions require society to form judgements as to whether the solution is acceptable in view of moral issues that result. Issues such as the effects on the planet, and the economic and physical well-being of the living things on it should be considered.
	Examples in this specification include: • *Secure transmission of data is important if people are to be confident that personal data cannot be intercepted in transmission. (AS Unit 2 §3.2.3)* • *In the Second World War, scientists on both sides were in a race to build the first atom bomb. (A2 Unit 5 §3.5.2)*

K	**Appreciate the role of the scientific community in validating new knowledge and ensuring integrity**
	The findings of scientists are subject to peer review before being accepted for publication in a reputable scientific journal. The interests of the organisations that fund scientific research can influence the direction of research. In some cases the validity of those claims may also be influenced. Candidates will understand that scientists need a common set of values and responsibilities. They should know that scientists undertake a peer-review of the work of others. They should know that scientists work with a common aim to progress scientific knowledge and understanding in a valid way and that accurate reporting of findings takes precedence over recognition of success of an individual. Similarly, the value of findings should be based on their intrinsic value and the credibility of the research.
	Examples in this specification include: • *The supposed discovery of cold fusion was rejected after other scientists were unable to reproduce the discovery. (A2 Unit 5 §3.5.2)* • *The experimental discovery of electron diffraction confirmed the dual nature of matter particles, first put forward by de Broglie as a hypothesis several years earlier. (AS Unit 1 §3.1.2)*
L	**Appreciate the ways in which society uses science to inform decision making**
	Scientific findings and technologies enable advances to be made that have potential benefit for humans. In practice, the scientific evidence available to decision makers may be incomplete. Decision makers are influenced in many ways, including by their prior beliefs, their vested interests, special interest groups, public opinion and the media, as well as by expert scientific evidence. Candidates will be able to appreciate that scientific evidence should be considered as a whole. They should realise that new scientific developments inform new technology. They should realise the media and pressure groups often select parts of scientific evidence that support a particular viewpoint and that this can influence public opinion which in turn may influence decision makers. Consequently, decision makers may make socially and politically acceptable decisions based on incomplete evidence.
	Examples in this specification include: • *Electric cars may replace petrol vehicles if batteries giving a greater range than at present are developed. Until then, car buyers are unlikely to be persuaded to buy electric cars. (AS Unit 1 §3.1.3)* • *Satellite tracking for purposes such as road pricing may be implemented without adequate trials because of pressure group influence. (A2 Unit 4 §3.4.2)*

3.8 Guidance on Centre Assessment

Introduction

The GCE Sciences share a common approach to centre assessment. This is based on the belief that assessment should encourage practical activity in science, and that practical activity should encompass a broad range of activities. This section must be read in conjunction with information in the Teaching and learning resources web pages.

Practical and Investigative Skills are assessed in the centre assessed units, Unit 3 and Unit 6 worth, respectively, 20% of the AS award (and 10% of the Advanced Level Award) and 10% of the full Advanced level award.

There are two routes for the assessment of Practical and Investigative Skills

Either

Route T: Practical Skills Assessment (PSA) + Investigative Skills Assignment (ISA) – Teacher-marked

Or

Route X: Practical Skills Verification (PSV) + Externally Marked Practical Assignment (EMPA) – AQA-marked.

Both routes to assessment are available at AS and A2.

Centres can not make entries for the same candidate for both assessment routes [T and X] in the same examination series.

3.8.1 Centre Assessed Route T (PSA/ISA)

Each centre assessed unit comprises:

- Practical Skills Assessment (PSA)
- Investigative Skills Assignment (ISA).

The PSA consists of the centre's assessment of the candidate's ability to demonstrate practical skills throughout the course; thus, candidates should be encouraged to carry out practical and investigative work throughout the course of their study. This work should cover the skills and knowledge of How Science Works (Section 3.7) and in Sections 3.3 and 3.6.

The ISA has two stages where candidates:

- undertake practical work, collect and process of data
- complete a written ISA test.

There are two windows of assessment for the ISA:

- one for the practical work (Stage 1)
- one for the written test (Stage 2).

Each stage of the ISA must be carried out

- under controlled conditions
- within the windows of assessment stipulated by AQA in the Instructions for Administration of the ISA.

All students at a centre must complete the written test in a single uninterrupted session on the same day.

The ISA is set externally by AQA, but internally marked, with marking guidelines provided by AQA. In a given academic year two ISAs at each of AS and A2 level will be provided.

Practical Skills Assessment (PSA)

Candidates are assessed throughout the course on practical skills, using a scale from 0-9. The mark submitted for practical skills should be judged by the teacher. Teachers may wish to use this section for formative assessment and should keep an ongoing record of each candidate's performance but the mark submitted should represent the candidate's practical abilities over the whole course. Please refer to section 3.8.3 for marking guidance and criteria.

3

The nature of the assessment

Since the skills in this section involve implementation they must be assessed while the candidate is carrying out practical work. Practical activities are not intended to be undertaken as formal tests and supervisors can provide the usual level of guidance that would normally be given during teaching. In order to provide appropriate opportunities to demonstrate the necessary skills, instructions provided must not be too prescriptive but should allow candidates to make decisions for themselves, particularly concerning the conduct of practical work, their organisation and the manner in which equipment is used.

The tasks

There are no specific tasks set by AQA in relation to the PSA. Centres should set up tasks in order for the candidates to be provided opportunities to use the equipment deemed appropriate at the given level. Further guidance can be provided by the Assessment Adviser attached to the centre. Details of the appropriateness of the equipment and techniques are provided in Unit 3 and Unit 6 (Section 3.3 and 3.6).

The assessment criteria

In the context of material specified in the relevant AS or A2 specification candidates will be assessed on the following skills:

- Following instructions
- Selecting and using equipment
- Organisation and safety.

Detailed descriptors for these three skills are provided in Section 3.8.3.

AQA may wish to ask for further supporting evidence from centres in relation to the marks awarded for the PSA. Centres should therefore keep records of their candidates' performances in their practical activities throughout the course. (For example, a laboratory diary, log or tick sheet.)

Further guidance for awarding of marks for the PSA will be provided in the Teaching and learning resources web page.

Use of ICT during PSA

Candidates are encouraged to use ICT where appropriate in the course of developing practical skills, for example in collecting and analysing data.

Investigative Skills Assignment (ISA)

The Investigative Skills Assignment carries 41 marks and has two stages.

Stage 1: Collection and Processing of data

Candidates carry out practical work following an AQA task sheet. Centres may use the task sheet, as described, or may make minor suitable modifications to materials or equipment following AQA guidelines. Any modifications made to the task sheet must be agreed in writing with the AQA Assessment Adviser. The task may be conducted in a normal timetabled lesson but must be under controlled conditions and during the window of assessment for practical work.

Candidates will be asked to collect data and represent it in a table of their own design. They will be instructed to process the data and draw an appropriate graph. The teacher must not instruct the candidates on the presentation of the data or on the choice of graph/chart. All the completed work must be handed to the teacher at the end of the session. The teacher assesses the candidates' work to AQA marking guidelines.

There is no specified time limit for this stage.

Stage 2: The ISA written test

The ISA test should be taken after completion of Stage 1, under controlled conditions and during the window of assessment for the written test. All students at a centre must complete the written test in a single uninterrupted session on the same day. Each candidate is provided with an ISA test and the candidate's completed material from Stage 1. The teacher uses the AQA marking guidelines to assess the ISA test.

The ISA test is in two Sections:

a) Section A

This consists of a number of questions relating to the candidate's own data.

b) Section B

This section will provide a further set of data related to the original experiment. A number of questions relating to analysis and evaluation of the data then follow.

The number of marks allocated to each section may vary slightly with each ISA test.

Use of ICT during ISA

ICT may be used during the ISA Stages 1 and 2 but teachers should note any restrictions in the ISA marking guidelines. Use of the internet is not permitted.

Candidates absent for the practical work

A candidate absent for the practical work (Stage 1) should be given an opportunity to carry out the practical work before they sit the ISA test. This may be with another group or at a different time. In extreme circumstances when such arrangements are not possible, the teacher can supply a candidate with class data. In this case candidates cannot be awarded marks for Stage 1, but can still be awarded marks for Stage 2 of the assessment.

Material from AQA

For each ISA, AQA will provide:

- Teachers' Notes
- Task sheet
- ISA written test
- Marking guidelines.

This material must be kept under secure conditions within the centre. The centre must ensure security of the materials.

Further details regarding this material will be provided.

Security of assignments

All ISA materials including marked ISAs should be treated like examination papers and kept under secure conditions until the publication of results.

General Information

Route T

Administration

In any year a candidate may attempt either or both of the two ISAs. AQA will stipulate windows of assessment during which the ISAs (task and test) must be completed.

For each candidate, the teacher should submit to AQA a total mark comprising:

- The PSA mark
- The better ISA mark (if two have been attempted).

The ISA component of this mark must come from one ISA only, i.e. the marks awarded for individual stages of different ISAs cannot be combined.

The total mark must be submitted to AQA by the due date in the academic year for which the ISA was published.

Candidates may make only one attempt at an ISA and redrafting is not permitted at any stage during the ISA.

Work to be submitted

For each candidate in the sample the following materials must be submitted to the moderator by the deadline issued by AQA:

- the candidate's data from Stage 1
- the ISA written test which includes the Candidate Record Form, showing the marks for the ISA and the PSA.

In addition each centre must provide:

- a Centre Declaration Sheet

- details of any agreed amendments to the task sheet, with information supporting the changes from the AQA Assessment Adviser.

Working in groups

For the PSA candidates may work in groups provided that any skills being assessed are the work of individual candidates. For the ISA further guidance will be provided in the Teacher Notes.

Other information

Section 6 of this specification outlines further guidance on the supervision and authentication of centre assessed units.

Section 6 also provides information in relation to the internal standardisation of marking for these units. Please note that the marking of both of the PSA and the ISA must be internally standardised, as stated in Section 6.4.

Further support

AQA support the centre assessed units in a number of ways:

- AQA hold annual standardising meetings on a regional basis for all internally assessed components. Section 6 of this specification provides further details about these meetings
- Teaching and learning resources web page which includes information and guidance
- Assessment Advisers are appointed by AQA to provide advice on centre assessed units. Every centre is allocated an Adviser. Details are sent to the Head of Department.

  The assessment advisers can provide guidance on:

  – issues relating to the carrying out of assignments for assessment

  – application of the marking guidelines.

Any amendments to the ISA task sheet must be discussed with the Assessment Adviser and confirmation of the amendments made must be submitted to the AQA moderator.

3.8.2 Externally Marked Route X (PSV/EMPA)

The practical and investigative skills will be assessed through:

- Practical Skills Verification (PSV) and
- Externally Marked Practical Assignment (EMPA).

The PSV requires teachers to verify their candidates' ability to demonstrate safe and skilful practical techniques and make valid and reliable observations.

The EMPA has two stages where candidates:

- Undertake a practical activity
- Complete a written EMPA test.

There are two windows of assessment for the EMPA:

- one for practical work (Section A: Task 1 and Task 2)
- one for the written test (Section B).

Each stage of the EMPA must be carried out

- under controlled conditions
- within the windows of assessment stipulated by AQA in the Instructions for Administration of the EMPA.

All students at a centre must complete the written test in a single uninterrupted session on the same day.

The EMPA is set and marked by AQA. Only one EMPA at each of AS and A2 will be provided in a given academic year.

Practical Skills Verification

Candidates following this route must undertake specific practical exercises. They will be required to work individually and carry out 5 short practical exercises under supervision in the laboratory during normal class time. The exercises will be set by AQA and may be undertaken at any stage during the course at the centre's discretion either as individual exercises or by organising more than one exercise to be taken at a said time. The candidates should be supervised during the practical work. They will not be expected to spend more than

3 hours in total of laboratory time in completing these exercises. The exercises will be typical of the normal practical work that would be expected to be covered as part of any AS or A2 physics course and should not add any additional burden to centres.

The teacher will confirm on the front cover of the written test, for each candidate that this requirement has been met. Failure to complete the tick box will lead to a mark of zero being awarded to the candidate for the whole of this unit. Knowledge and understanding of the skills shown in the tasks may be assessed of the EMPA written tests.

ICT

Candidates may use ICT where appropriate in the course of developing practical skills, for example in collecting and analysing data.

Externally Marked Practical Assignment (EMPA)

The Externally Marked Practical Assignment carries 55 marks and has two stages.

Stage 1: Collection and Processing of data

Candidates carry out practical work following AQA instructions. These will be laid out in Section A EMPA test answer booklet. The activity may be conducted in a normal timetabled lesson and at a time convenient to the centre but must be under controlled conditions and during the window of assessment for practical work. Candidates collect raw data and represent it in a table of their own design or make observations. The candidates' work must be handed to the teacher at the end of each session.

The activity will be made up of two tasks, centred around a particular area of physics. The tasks will assess the skills stipulated in the assessment objective AO3 (see section 4.2).

Centres will be guided how to set up the EMPA task by Teachers Notes which may be used, as described, or centres may make minor suitable modifications to materials or equipment following AQA guidelines. Any modifications made to the tasks must be indicated with the material sent to the examiner.

Candidates should work individually and be supervised throughout. The task will provide them with sufficient information to obtain reliable measurements which they will be required to identify, record, and process and eliminate possible anomalies and minimise measurement errors. They will be expected to then further analyse and evaluate their measurements in Stage 2. The questions in Section B of the EMPA will focus on both tasks.

There is no specified time limit for this stage.

Stage 2: The EMPA written test

The EMPA test should be taken under controlled conditions and during the window of assessment for the written test. All students at a centre must complete the written test in a single uninterrupted session on the same day. Each candidate is provided with a test paper (Section B of the EMPA) and the candidate's completed material written from Stage 1.

The test will be a duration of 1 hour 15 minutes.

Candidates will be required:

- to use their results and graph from Stage 1 to perform further analysis in order to arrive at a quantifiable outcome or conclusion
- to assess elements of the practical activity, such as the overall accuracy of the outcomes.

Use of ICT during the EMPA

ICT may be used during the EMPA Stages 1 and 2 but teachers should note any restrictions in the Teachers' Notes. Use of the internet is not permitted.

Candidates absent for the practical work

A candidate absent for the practical work (Stage 1) should be given an opportunity to carry out the practical work before they sit the EMPA written test. This may be with another group or at a different time. In extreme circumstances, when such arrangements are not possible the teacher can supply a candidate with class data. This must be noted on the Candidate Record Form, in this case the candidate cannot be awarded marks for Stage 1, but can still be awarded marks for Stage 2 of the assessment.

Material from AQA

For each EMPA AQA will provide:

- Teachers' Notes

- Section A and Section B papers of the EMPA test (Stage 1 and Stage 2 documentation).

When received, this material must be kept under secure conditions. Further details regarding this material will be provided.

Security of assignments

Completed EMPAs should be treated like examination papers and kept under secure conditions until sent to the AQA Examiner. All other EMPA materials should be kept under secure conditions until publication of results.

General Information

Route X

Administration

Only one EMPA will be available in any year at AS and at A2. AQA will stipulate a window of assessment during which the EMPA (task and test) must be completed.

Candidates may make only one attempt at a particular EMPA and redrafting is not permitted at any stage during the EMPA.

Work to be submitted

The material to be submitted to the examiner for each candidate consists of:

- the candidate's data in the Section A test papers (Stage 1 of the EMPA)
- the candidate's completed Section B test paper (Stage 2 of the EMPA) which includes the Candidate Record Form, including the PSV verification of the 5 practical exercises.

In addition each centre must provide:

- a Centre Declaration Sheet
- Details of any agreed amendments to the tasks, with information supporting the changes from the AQA Assessment Adviser.

Working in groups

For the PSV candidates may work in groups provided that any skills being assessed are the work of individual candidates. For the EMPA further guidance will be provided but the opportunity for group work will not be a common feature.

Other information

Section 6 of this specification outlines further guidance on the supervision and authentication of Internally assessed units.

Further support

AQA supports centres in a number of ways:

- A Teaching and learning resources web page which includes further information and guidance
- Assessment Advisers are appointed by AQA to provide advice on internally assessed units. Every centre is allocated an Assessment Adviser.

The Assessment Advisers can provide guidance on issues relating to the carrying out of tasks for assessment.

Any amendments to the EMPA task sheet must be discussed with the AQA Assessment Adviser and confirmation of the amendments made must be submitted to the AQA Examiner.

3.8.3 General Marking Guidance for each PSA

Centres should use the following marking grids in relation to the PSA assessment.

Each skill has a descriptor with a three point scale (0, 1, 2 or 3 marks). The descriptors are hierarchical and different for Unit 3 and Unit 6 to reflect the differing demand of the Units.

Candidates should be awarded marks which reflect their level of performance over the whole course.

Unit 3		
Following instructions and group work	**Selecting and using equipment**	**Organisation and safety**
1A Follows instructions in standard procedures but sometimes needs guidance.	1B Uses standard laboratory equipment with some guidance as to the appropriate instrument/ range.	1C Works in a safe and organised manner following guidance provided but needs reminders.
2A Follows instructions for standard procedures without guidance. Works with others making some contribution.	2B Uses standard laboratory equipment selecting the appropriate range.	2C Works in an organised manner with due regard to safety with only occasional guidance or reminders.
3A Follows instructions on complex tasks without guidance. Works with others making some contribution.	3B Selects and uses standard laboratory equipment with appropriate precision and recognises when it is appropriate to repeat measurements.	3C Works safely without supervision and guidance. (Will have effectively carried out own risk assessment.)
Total 3 marks	Total 3 marks	Total 3 marks

Unit 6		
Following instructions and group work	**Selecting and using equipment**	**Organisation and safety**
4A Plans and works with some guidance, selecting appropriate techniques and following instructions.	4B Selects and uses suitable equipment, including at least two complex instruments **or** techniques appropriate to the A2 course.	4C Demonstrates safe working practices in using a range of equipment appropriate to the A2 course.
5A Plans and works without guidance, selecting appropriate techniques and following instructions. Participates in group work.	5B Selects and uses suitable equipment, including more than two complex instruments **and** techniques appropriate to the A2 course.	5C Demonstrates safe working practices in some of the more complex procedures encountered on the A2 course.
6A Plans and works without guidance, selecting appropriate techniques and following complex instructions. Participates in group work.	6B Selects and uses suitable equipment with due regard to precision, including a **wide** range of at least 6 complex instruments and techniques appropriate to the A2 course.	6C Consistently demonstrates safe working practices in the more complex procedures encountered on the A2 course.
Total 3 marks	Total 3 marks	Total 3 marks

3.9 Mathematical Requirements

In order to develop their skills, knowledge and understanding in science, candidates need to have been taught, and to have acquired competence in, the appropriate areas of mathematics relevant to the subject as set out below.

	Candidates should be able to:
Arithmetic and computation	• recognise and use expressions in decimal and standard form • use ratios, fractions and percentages • use calculators to find and use x^n, $1/x$, $\sqrt{x}$, $\log_{10}x$, e^x, $\log_e x$ • use calculators to handle sin x, cos x, tan x when x is expressed in degrees or radians.
Handling data	• use an appropriate number of significant figures • find arithmetic means • make order of magnitude calculations.
Algebra	• understand and use the symbols: =, $<$, $\ll$, $\gg$, $>$, $\propto$, ~. • change the subject of an equation by manipulation of the terms, including positive, negative, integer and fractional indices • substitute numerical values into algebraic equations using appropriate units for physical quantities • solve simple algebraic equations.
Graphs	• translate information between graphical, numerical and algebraic forms • plot two variables from experimental or other data • understand that $y = mx + c$ represents a linear relationship • determine the slope and intercept of a linear graph • draw and use the slope of a tangent to a curve as a measure of rate of change • understand the possible physical significance of the area between a curve and the x -axis and be able to calculate it or measure it by counting squares as appropriate • use logarithmic plots to test exponential and power law variations • sketch simple functions including $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = \sin x$, $y = \cos x$, $y = e^{-kx}$
Geometry and trigonometry	• calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres • use Pythagoras' theorem, and the angle sum of a triangle • use sines, cosines and tangents in physical problems • understand the relationship between degrees and radians and translate from one to the other.

3

4 Scheme of Assessment

4.1 Aims

AS and A Level courses based on this specification should encourage candidates to:

a) develop their interest in, and enthusiasm for the subject, including developing an interest in further study and careers in the subject

b) appreciate how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society

c) develop and demonstrate a deeper appreciation of the skills, knowledge and understanding of How Science Works

d) develop essential knowledge and understanding of different areas of the subject and how they relate to each other.

4.2 Assessment Objectives (AOs)

The Assessment Objectives are common to AS and A Level. The assessment units will assess the following Assessment Objectives in the context of the content and skills set out in Section 3 (Subject Content).

These Assessment Objectives are the same for AS and A Level. They apply to the whole specification.

In the context of these Assessment Objectives, the following definitions apply:

- Knowledge: includes facts, specialist vocabulary, principles, concepts, theories, models, practical techniques, studies and methods
- Issues: include ethical, social, economic, environmental, cultural, political and technological
- Processes: include collecting evidence, explaining, theorising, modelling, validating, interpreting, planning to test an idea, peer reviewing.

AO1: Knowledge and understanding of science and of *How Science Works*

Candidates should be able to:

a) recognise, recall and show understanding of scientific knowledge

b) select, organise and communicate relevant information in a variety of forms.

AO2: Application of knowledge and understanding of science and of *How Science Works*

Candidates should be able to:

a) analyse and evaluate scientific knowledge and processes

b) apply scientific knowledge and processes to unfamiliar situations including those related to issues

c) assess the validity, reliability and credibility of scientific information.

AO3: *How Science Works* – Physics

Candidates should be able to:

a) demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods

b) make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy

c) analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.

Quality of Written Communication (QWC)

In GCE specifications which require candidates to produce written material in English, candidates must:

- ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

In this specification QWC will be assessed in PHYA1, PHYA2, PHYA4, and Section A of PHA5A- PHA5D.

Weighting of Assessment Objectives for AS

The table below shows the approximate weighting of each of the Assessment Objectives in the AS units.

Assessment Objectives	Unit Weightings (%)			Overall weighting of AOs (%)
	Unit 1	Unit 2	Unit 3	
AO1	19	19	2	40
AO2	19	19	2	40
AO3	2	2	16	20
Overall weighting of units (%)	40	40	20	100

Weighting of Assessment Objectives for A Level

The table below shows the approximate weighting of each of the Assessment Objectives in the AS and A2 units.

Assessment Objectives	Unit Weightings (%)						Overall weighting of AOs (%)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	
AO1	9.5	9.5	1	7	7	1	35
AO2	9.5	9.5	1	12	12	1	45
AO3	1	1	8	1	1	8	20
Overall weighting of units (%)	20	20	10	20	20	10	100

4.3 National Criteria

This specification complies with the following:

- The Subject Criteria for Science
- The Code of Practice for GCE
- The GCE AS and A Level Qualification Criteria
- The Arrangements for the Statutory Regulation of External Qualifications in England, Wales and Northern Ireland: Common Criteria

4.4 Prior Learning

There are no prior learning requirements. We recommend that candidates should have acquired the skills and knowledge associated with a GCSE Science (Additional) course or equivalent.

However, any requirements set for entry to a course following this specification are at the discretion of centres.

4.5 Synoptic Assessment and Stretch and Challenge

The definition of synoptic assessment in the context of science requires candidates to make and use connections within and between different areas of science, for example, by:

- applying knowledge and understanding of more than one area to a particular situation or context
- using knowledge and understanding of principles and concepts in experimental and investigative work and in the analysis and evaluation of data
- bringing together scientific knowledge and understanding from different areas of the subject and applying them.

There is a requirement to formally assess synopticity at A2. Synoptic assessment in Physics is assessed in all the A2 units through both the written papers (Unit 4 and Unit 5) and the Investigative and Practical skills unit (Unit 6).

The requirement that Stretch and Challenge is included at A2 will be met in the externally assessed units by:

- using a variety of stems in questions to avoid a formulaic approach through the use of such words as: analyse, evaluate, compare, discuss
- avoiding assessments being too atomistic, connections between areas of content being used where possible and appropriate
- having some requirement for extended writing
- using a range of question types to address different skills i.e. not just short answer/structured questions
- asking candidates to bring to bear knowledge and the other prescribed skills in answering questions rather than simply demonstrating a range of content coverage.

4.6 Access to Assessment for Disabled Students

AS/A Levels often require assessment of a broader range of competences. This is because they are general qualifications and, as such, prepare candidates for a wide range of occupations and higher level courses.

The revised AS/A Level qualification and subject criteria were reviewed to identify whether any of the competences required by the subject presented a potential barrier to any disabled candidates. If this were the case, the situation was reviewed again to ensure that such competences were included only where essential to the subject. The findings of this process were discussed with disability groups and with disabled people.

Reasonable adjustments are made for disabled candidates in order to enable them to access the assessments. For this reason, very few candidates will have a complete barrier to any part of the assessment.

Candidates who are still unable to access a significant part of the assessment, even after exploring all possibilities through reasonable adjustments, may still be able to receive an award. They would be given a grade on the parts of the assessment they have taken and there would be an indication on their certificate that not all the competences had been addressed. This will be kept under review and may be amended in the future.

5 Administration

5.1 Availability of Assessment Units and Certification

After June 2013, examinations and certification for this specification are available in June only.

5.2 Entries

Please refer to the current version of Entry Procedures and Codes for up-to-date entry procedures. You should use the following entry codes for the units and for certification.

Unit 1 – PHYA1

Unit 2 – PHYA2

Unit 3 – **either** PHA3T **or** PHA3X

Unit 4 – PHYA4

Unit 5 – PHA5A **or** PHA5B **or** PHA5C **or** PHA5D

Unit 6 – **either** PHA6T **or** PHA6X

Centres can not make entries for the same candidate for both assessment routes [T and X] in either Unit 3 or Unit 6 in the same examination series.

AS certification – 1451

A Level certification – 2451

5.3 Private Candidates

This specification is available to private candidates under certain conditions. Because of the nature of the assessment of the practical skills, candidates must be attending an AQA centre which will supervise and assess the work. As we are no longer providing supplementary guidance in hard copy, see our website for guidance and information on taking exams and assessments as a private candidate:

www.aqa.org.uk/exams-administration/entries/private-candidates

Entries from private candidates can only be accepted where the candidate is registered with an AQA registered centre that will accept responsibility for:

- supervising the practical components of the PSA/ISA or PSV/EMPA
- supervising the written component of the ISA or EMPA
- prime marking the internally assessed work.

Candidates wishing to repeat or complete the AS and/or A2 components may only register as private candidates if they already have a previously moderated mark for Units 3 and 6, respectively, or if they can find a centre that will comply with the above requirements.

5.4 Access Arrangements and Special Consideration

We have taken note of Equality Act 2010 and the interests of minority groups in developing and administering this specification.

We follow the guidelines in the Joint Council for Qualifications (JCQ) document: *Access Arrangements, Reasonable Adjustments and Special Consideration.* This is published on the JCQ website (**http://www.jcq.org.uk**) or you can follow the link from our website (**http://www.aqa.org.uk**).

Section 2.14.5 of the above JCQ document states that "A practical assistant will not normally be allowed to carry out physical tasks or demonstrate physical abilities where they form part of the assessment objectives." However, in order that candidates may obtain experimental results that can be used in the ISA or EMPA, practical assistants may be used to carry out the manipulation under the candidate's instructions. An application for a practical assistant should be made via access arrangements online and cases will be considered individually.

Access Arrangements

We can make arrangements so that candidates with disabilities can access the assessment. These arrangements must be made **before** the examination. For example, we can produce a Braille paper for a candidate with a visual impairment.

Special Consideration

We can give special consideration to candidates who have had a temporary illness, injury or serious problem, such as death of a relative, at the time of the examination. We can only do this **after** the examination.

The Examinations Officer at the centre should apply online for access arrangements and special consideration by following the e-AQA link from our website (**www.aqa.org.uk**)

5.5 Language of Examinations

We will provide units in English only.

5.6 Qualification Titles

Qualifications based on this specification are:

- AQA Advanced Subsidiary GCE in Physics A, and
- AQA Advanced Level GCE in Physics A.

5.7 Awarding Grades and Reporting Results

The AS qualification will be graded on a five-point grade scale: A, B, C, D and E. The full A Level qualification will be graded on a six-point scale: A*, A, B, C, D and E. To be awarded an A*, candidates will need to achieve a grade A on the full A Level qualification and an A* on the aggregate of the A2 units.

For AS and A Level candidates who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate. Individual assessment unit results will be certificated.

5.8 Re-sits and Shelf-life of Unit Results

Unit results remain available to count towards certification, whether or not they have already been used, as long as the specification is still valid.

Each unit is available in June only. Candidates may re-sit a unit any number of times within the shelf-life of the specification. The best result for each unit will count towards the final qualification. Candidates who wish to repeat a qualification may do so by re-taking one or more units. The appropriate subject award entry, as well as the unit entry/entries, must be submitted in order to be awarded a new subject grade.

Candidates will be graded on the basis of the work submitted for assessment.

5

6 Administration of Internally Assessed Units: Route T and Route X

The Head of Centre is responsible to AQA for ensuring that Internally Assessed work is conducted in accordance with AQA's instructions and JCQ instructions.

Centres can not make entries for the same candidate for both assessment routes [T and X] in either Unit 3 or Unit 6 in the same examination series.

6.1 Supervision and Authentication of the Centre Assessed Units

The Code of Practice for GCE requires:

- **candidates to** sign the appropriate section on the front cover of the ISA or EMPA Written Test to confirm that the work submitted is their own, and
- **teachers/assessors** to confirm on the front cover of the ISA or EMPA Written Test that the work submitted is solely that of the candidate concerned and was conducted under the conditions laid down by the specification.

Candidates and teachers complete the front cover of the ISA or EMPA Written Test in place of the Candidate Record Form (CRF). Failure to sign the authentication statement may delay the processing of the candidates' results.

In all cases, direct supervision is necessary to ensure that the work submitted can be confidently authenticated as the candidate's own.

If teachers/assessors have reservations about signing the authentication statements, the following points of guidance should be followed:

- If it is believed that a candidate has received additional assistance and this is acceptable within the guidelines for the relevant specification, the teacher declaration should be signed and information given on the relevant form
- If the teacher/assessor is unable to sign the authentication statement for a particular candidate, then the candidate's work cannot be accepted for assessment
- If malpractice is suspected, the Examinations Officer should be consulted about the procedure to be followed.

Route T

All teachers who have assessed the work of any candidate entered for each unit must sign the declaration of authentication.

The practical work for the PSA and for the ISA should be carried out in normal lesson time with a degree of supervision appropriate for candidates working in a laboratory. The practical work for the ISA should be completed during the window of assessment for practical work. The processing of raw data and the ISA written test should be taken in normal lesson time under controlled conditions and during the window of assessment for the written test.

Redrafting of answers to any stage of the ISA is not permitted. Candidates must **not** take their work away from the laboratory.

Material to submit to moderator
For each candidate in the sample, the following material must be submitted to the moderator by the deadline issued by AQA:

- the candidate's data from Stage 1
- the ISA written test which includes the Candidate Record Form, showing the marks for the ISA and the PSA.

In addition each centre must provide:

- a Centre Declaration Sheet
- details of any amendments to the task sheet with the information supporting the changes from the Assessment Adviser, if there are any significant changes

Route X

The practical work for the PSV and Stage 1 of the EMPA should be carried out in normal lesson time with a degree of supervision appropriate for candidates working in a laboratory. The practical work for the EMPA should be completed during the window of assessment for practical work. The practical work for the EMPA should be completed during the window of assessment for practical work. The processing of raw data and the EMPA written test should be taken in normal lesson time under controlled conditions and during the window of assessment for the written test.

Redrafting of answers to any stage of the EMPA is not permitted. Candidates must **not** take their work away from the class.

Material to submit to examiner
For each candidate, the following material must be submitted to the examiner by the deadline issued by AQA:

- the candidate's data from Stage 1 Section A (Task 1 and Task 2)
- the EMPA written test (Section B) which includes the Candidate Record Form, including the PSV verification of safe and skilful practical techniques and reliable and valid observations.

In addition each centre must provide:

- a Centre Declaration Sheet
- details of any amendments to the task sheet with the information supporting the changes from the Assessment Adviser, if there are any significant changes.

6

6.2 Malpractice

Teachers should inform candidates of the AQA Regulations concerning malpractice.

Candidates must **not**:

- submit work which is not their own
- lend work to other candidates
- submit work typed or word-processed by a third person without acknowledgement.

These actions constitute malpractice, for which a penalty (e.g. disqualification from the examination) will be applied.

Route T

Where suspected malpractice in centre assessed work is identified by a centre after the candidate has signed the declaration of authentication, the Head of Centre must submit full details of the case to AQA at the earliest opportunity. The form JCQ/M1 should be used. Copies of the form can be found on the JCQ website (http://www.jcq.org.uk/).

Malpractice in centre assessed work discovered prior to the candidate signing the declaration of authentication need not be reported to AQA, but should be dealt with in accordance with the centre's internal procedures. AQA would expect centres to treat such cases very seriously. Details of any work which is not the candidate's own must be recorded on the Candidate Record Form or other appropriate place.

Route X

If the teacher administering the EMPA believes that a student is involved in malpractice, he/she should contact AQA.

If the examiner suspects malpractice with the EMPA, at any stage, he/she will raise the matter with the Irregularities Office at AQA. An investigation will be undertaken, in line with the JCQ's policies on Suspected Malpractice in Examinations and Assessments.

6.3 Teacher Standardisation (Route T only)

We will hold annual standardising meetings for teachers, usually in the autumn term, for the centre assessed units. At these meetings we will provide support in developing appropriate coursework tasks and using the marking criteria.

If your centre is new to this specification, you must send a representative to one of the meetings. If you have told us you are a new centre, either by submitting an estimate of entry or by contacting the subject team, we will contact you to invite you to a meeting.

We will also contact centres if:

- the moderation of centre assessed work from the previous year has identified a serious misinterpretation of the centre assessed requirements
- inappropriate tasks have been set, or
- a significant adjustment has been made to a centre's marks.

In these cases, centres will be expected to send a representative to one of the meetings. For all other centres, attendance is optional. If you are unable to attend and would like a copy of the materials used at the meeting, please contact the subject team at **physics-gce@aqa.org.uk**.

6.4 Internal Standardisation of Marking (Route T only)

Centres must standardise marking within the centre to make sure that all candidates at the centre have been marked to the same standard. One person must be responsible for internal standardisation. This person should sign the Centre Declaration Sheet to confirm that internal standardisation has taken place.

Internal standardisation involves:

- all teachers marking some trial pieces of work and identifying differences in marking standards
- discussing any differences in marking at a training meeting for all teachers involved in the assessment
- referring to reference and archive material such as previous work or examples from AQA's teacher standardising meetings.

6.5 Annotation of Centre Assessed Work (Route T only)

The Code of Practice for GCE states that the awarding body must require internal assessors to show clearly how the marks have been awarded in relation to the marking criteria defined in the specification and that the awarding body must provide guidance on how this is to be done.

The annotation will help the moderator to see as precisely as possible where the teacher considers that the candidates have met the criteria in the specification.

Work could be annotated by the following methods:

- key pieces of evidence flagged throughout the work by annotation either in the margin or in the text
- summative comments on the work, referencing precise sections in the work.

6.6 Submitting Marks and Sample Work for Moderation (Route T only)

The total mark for each candidate must be submitted to AQA and the moderator on the mark forms provided or by Electronic Data Interchange (EDI) by the specified date. Centres will be informed which candidates' work is required in the samples to be submitted to the moderator.

6.7 Factors Affecting Individual Candidates

Teachers should be able to accommodate the occasional absence of candidates by ensuring that the opportunity is given for them to make up missed assessments.

If work is lost, AQA should be notified immediately of the date of the loss, how it occurred, and who was responsible for the loss. Centres should use the JCQ form JCQ/LCW to inform AQA Candidate Services of the circumstances.

Where special help which goes beyond normal learning support is given, AQA must be informed through comments on the CRF so that such help can be taken into account when moderation takes place (see Section 6.1).

Candidates who move from one centre to another during the course sometimes present a problem for a scheme of internal assessment. Possible courses of action depend on the stage at which the move takes place. If the move occurs early in the course the new centre should take responsibility for assessment. If it occurs late in the course it may be possible to arrange for the moderator to assess the work through the 'Educated Elsewhere' procedure. Centres should contact AQA at the earliest possible stage for advice about appropriate arrangements in individual cases.

6.8 Retaining Evidence and Re-using Marks (Route T only)

The centre must retain the work of all candidates, with CRFs attached, under secure conditions, from the time it is assessed, to allow for the possibility of an enquiry about results. The work may be returned to candidates after the deadline for enquiries about results. If an enquiry about a result has been made, the work must remain under secure conditions in case it is required by AQA.

7 Moderation (Route T only)

7.1 Moderation Procedures

Moderation of the centre assessed work is by inspection of a sample of candidates' work, sent by post or electronically from the centre to a moderator appointed by AQA. The centre marks must be submitted to AQA and to the moderator by the specified deadline. **(http://www.aqa.org.uk/deadlines.php)**. We will let centres know which candidates' work will be required in the sample to be submitted for moderation.

Following the re-marking of the sample work, the moderator's marks are compared with the centre marks to determine whether any adjustment is needed in order to bring the centre's assessments into line with standards generally. In some cases it may be necessary for the moderator to call for the work of other candidates in the centre. In order to meet this possible request, centres must retain under secure conditions and have available, the centre assessed work and the CRF of every candidate entered for the examination and be prepared to submit it on demand. Mark adjustments will normally preserve the centre's order of merit but, where major discrepancies are found, we reserve the right to alter the order of merit.

7.2 Post-moderation Procedures

On publication of the AS/A level results, we will provide centres with details of the final marks for the centre assessed unit.

The candidates' work will be returned to the centre after moderation has taken place. The centre will receive a report, with, or soon after, the despatch of published results, giving feedback on the appropriateness of the tasks set, the accuracy of the assessments made, and the reasons for any adjustments to the marks.

We reserve the right to retain some candidates' work for archive or standardising purposes.

Appendices

A Performance Descriptions

These performance descriptions show the level of attainment characteristic of the grade boundaries at A Level. They give a general indication of the required learning outcomes at the A/B and E/U boundaries at AS and A2. The descriptions should be interpreted in relation to the content outlined in the specification; they are not designed to define that content.

The grade awarded will depend in practice upon the extent to which the candidate has met the Assessment Objectives (see Section 4) overall. Shortcomings in some aspects of the examination may be balanced by better performances in others.

AS Performance Descriptions – Physics

	Assessment Objective 1	Assessment Objective 2	Assessment Objective 3
Assessment Objectives	**Knowledge and understanding of science and of *How Science Works*** Candidates should be able to: • recognise, recall and show understanding of scientific knowledge • select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of *How Science Works*** Candidates should be able to: • analyse and evaluate scientific knowledge and processes • apply scientific knowledge and processes to unfamiliar situations including those related to issues • assess the validity, reliability and credibility of scientific information.	***How Science Works*** Candidates should be able to: • demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods • make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy • analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.
A/B boundary	Candidates characteristically: a) demonstrate knowledge of most principles, concepts and facts from the AS specification b) show understanding of most principles, concepts and facts from the AS specification c) select relevant information from the AS specification d) organise and present information clearly in appropriate forms using scientific terminology.	Candidates characteristically: a) apply principles and concepts in familiar and new contexts involving only a few steps in the argument b) describe significant trends and patterns shown by data presented in tabular or graphical form and interpret phenomena with few errors c) explain and interpret phenomena with few errors and present arguments and evaluations clearly d) carry out structured calculations with few errors and demonstrate good understanding of the underlying relationships between physical quantities.	Candidates characteristically: a) devise and plan experimental and investigative activities, selecting appropriate techniques b) demonstrate safe and skilful practical techniques c) make observations and measurements with appropriate precision and record these methodically d) interpret, explain, evaluate and communicate the results of their own and others' experimental and investigative activities, in appropriate contexts.
E/U boundary	Candidates characteristically: a) demonstrate knowledge of some principles and facts from the AS specification b) show understanding of some principles and facts from the AS specification c) select some relevant information from the AS specification d) present information using basic terminology from the AS specification.	Candidates characteristically: a) apply a given principle to material presented in familiar or closely related contexts involving only a few steps in the argument b) describe some trends or patterns shown by data presented in tabular or graphical form c) provide basic explanations and interpretations of some phenomena, presenting very limited evaluations d) carry out some steps within calculations.	Candidates characteristically: a) devise and plan some aspects of experimental and investigative activities b) demonstrate safe practical techniques c) make observations and measurements, and record them d) interpret, explain and communicate some aspects of the results of their own and others' experimental and investigative activities, in appropriate contexts.

A2 Performance Descriptions – Physics

	Assessment Objective 1	Assessment Objective 2	Assessment Objective 3
Assessment Objectives	**Knowledge and understanding of science and of *How Science Works*** Candidates should be able to: • recognise, recall and show understanding of scientific knowledge • select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of *How Science Works*** Candidates should be able to: • analyse and evaluate scientific knowledge and processes • apply scientific knowledge and processes to unfamiliar situations including those related to issues • assess the validity, reliability and credibility of scientific information.	***How Science Works*** Candidates should be able to: • demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods • make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy • analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.
A/B boundary performance descriptions	Candidates characteristically: a) demonstrate detailed knowledge of most principles, concepts and facts from the A2 specification b) show understanding of most principles, concepts and facts from the A2 specification c) select relevant information from the A2 specification d) organise and present information clearly in appropriate forms using scientific terminology.	Candidates characteristically: a) apply principles and concepts in familiar and new contexts involving several steps in the argument b) describe significant trends and patterns shown by complex data presented in tabular or graphical form, interpret phenomena with few errors,and present arguments and evaluations clearly and logically c) explain and interpret phenomena effectively, presenting arguments and evaluations d) carry out extended calculations, with little or no guidance, and demonstrate good understanding of the underlying relationships between physical quantities e) select a wide range of facts, principles and concepts from both AS and A2 specifications f) link together appropriate facts principles and concepts from different areas of the specification.	Candidates characteristically: a) devise and plan experimental and investigative activities, selecting appropriate techniques b) demonstrate safe and skilful practical techniques c) make observations and measurements with appropriate precision and record these methodically d) interpret, explain, evaluate and communicate the results of their own and others' experimental and investigative activities, in appropriate contexts.

(cont.)

A2 Performance Descriptions – Physics (cont.)

	Assessment Objective 1	Assessment Objective 2	Assessment Objective 3
E/U boundary performance descriptions	Candidates characteristically: a) demonstrate knowledge of some principles and facts from the A2 specification b) show understanding of some principles and facts from the A2 specification c) select some relevant information from the A2 specification d) present information using basic terminology from the A2 specification.	Candidates characteristically: a) apply given principles or concepts in familiar and new contexts involving a few steps in the argument b) describe, and provide a limited explanation of, trends or patterns shown by complex data presented in tabular or graphical form c) provide basic explanations and interpretations of some phenomena, presenting very limited arguments and evaluations d) carry out routine calculations, where guidance is given e) select some facts, principles and concepts from both AS and A2 specifications f) put together some facts, principles and concepts from different areas of the specification.	Candidates characteristically: a) devise and plan some aspects of experimental and investigative activities b) demonstrate safe practical techniques c) make observations and measurements, and record them d) interpret, explain and communicate some aspects of the results of their own and others' experimental and investigative activities, in appropriate contexts.

A

B Spiritual, Moral, Ethical, Social and other Issues

Moral, Ethical, Social and Cultural Issues

It is clear that Physics plays a major part in the development of the modern world. This specification is keenly aware of the implications of this development. The general philosophy of the subject is rooted in How Science Works (see Section 3.7). This section of the specification makes full references to the moral, ethical, social and cultural issues that permeate physics and science in general at this level.

European Dimension

AQA has taken account of the 1988 Resolution of the Council of the European Community in preparing this specification and associated specimen units. The specification is designed to improve candidates' knowledge and understanding of the international debates surrounding developments in Physics and to foster responsible attitudes towards them.

Environmental Education

AQA has taken account of the 1988 Resolution of the Council of the European Community and the Report "Environmental Responsibility: An Agenda for Further and Higher Education" 1993 in preparing this specification and associated specimen units. The study of physics as described in this specification can encourage a responsible attitude towards the environment.

Avoidance of Bias

AQA has taken great care in the preparation of this specification and specimen units to avoid bias of any kind.

Health and Safety

AQA recognises the need for safe practice in laboratories and tries to ensure that experimental work required for this specification and associated practical work complies with up-to-date safety recommendations.

Nevertheless, centres are primarily responsible for the safety of candidates and teachers should carry out their own risk assessment.

Candidates should make every effort to make themselves aware of any safety hazards involved in their work. As part of their coursework they will be expected to undertake risk assessments to ensure their own safety and the safety of associated workers, the components and test equipment.

C Overlaps with other Qualifications

The AQA GCE Physics Specification A overlaps with many of the Science specifications. The nature of Physics and Electronics means that there are significant overlaps with the AS content in Unit 1 and AQA GCE Electronics. There is more marginal overlap with GCE specifications in Chemistry and Biology, as well as AQA GCE Science in Society and Environmental Studies.

The overlap with GCE Mathematics rests only on the use and application of the formulae and equations given in Section 3.9.

D Key Skills

Key Skills qualifications have been phased out and replaced by Functional Skills qualifications in English, Mathematics and ICT from September 2010.

E Data and Formulae Booklet

GCE Physics Specification A
Data and Formulae Booklet

DATA
FUNDAMENTAL CONSTANTS AND VALUES

Quantity	*Symbol*	*Value*	*Units*
speed of light in vacuo	c	3.00×10^{8}	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ε_0	8.85×10^{-12}	F m^{-1}
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	N m^{2} kg^{-2}
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	J K^{-1} mol^{-1}
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	W m^{-2} K^{-4}
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	e/m_p	9.58×10^{7}	C kg^{-1}
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

ASTRONOMICAL DATA

Body	*Mass/kg*	*Mean radius/m*
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.98×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
surface area of cylinder	$= 2\pi rh$
volume of cylinder	$= \pi r^2 h$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

E

AS FORMULAE

PARTICLE PHYSICS

Rest energy values

class	*name*	*symbol*	*rest energy /MeV*
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks
antiquarks have opposite signs

type	*charge*	*baryon number*	*strangeness*
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of leptons

	lepton number
particles : $e^-, \nu_e; \mu^-, \nu_\mu$	+1
antiparticles : $e^+, \overline{\nu_e}; \mu^+, \overline{\nu_\mu}$	−1

Photons and Energy Levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{K\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

ELECTRICITY

current and pd $I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$

emf $\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

resistors in series $R = R_1 + R_2 + R_3 + \ldots$

resistors in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

resistivity $\rho = \frac{RA}{L}$

power $P = VI = I^2R = \frac{V^2}{R}$

alternating current $I_{rms} = \frac{I_0}{\sqrt{2}}$ $V_{rms} = \frac{V_0}{\sqrt{2}}$

MECHANICS

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \frac{(u+v)}{2}t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

work, energy and power $W = Fs\cos\theta$

$E_K = ½\, m\, v^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{\text{useful output power}}{\text{input power}}$

MATERIALS

density $\rho = \frac{m}{V}$ Hooke's law $F = k\,\Delta L$

Young modulus $= \frac{\text{tensile stress}}{\text{tensile strain}}$ tensile stress $= \frac{F}{A}$ tensile strain $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

WAVES

wave speed $c = f\lambda$ *period* $T = \frac{1}{f}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d\sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1\sin\theta_1 = n_2\sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

E

A2 FORMULAE

MOMENTUN

force	$F = \frac{\Delta(mv)}{\Delta t}$
impulse	$F\,\Delta t = \Delta(mv)$

CIRCULAR MOTION

angular velocity	$\omega = \frac{v}{r}$
	$\omega = 2\pi f$
centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r$
centripetal force	$F = \frac{mv^2}{r} = m\omega^2 r$

OSCILLATIONS

acceleration	$a = -(2\pi f)^2 x$
displacement	$x = A\cos(2\pi f t)$
speed	$v = \pm 2\pi f\sqrt{A^2 - x^2}$
maximum speed	$v_{max} = 2\pi f A$
maximum acceleration	$a_{max} = (2\pi f)^2 A$
for a mass-spring system	$T = 2\pi\sqrt{\frac{m}{k}}$
for a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$

GRAVITATIONAL FIELDS

force between two masses	$F = \frac{G m_1 m_2}{r^2}$
gravitational field strength	$g = \frac{F}{m}$
magnitude of gravitational field strength in a radial field	$g = \frac{GM}{r^2}$
gravitational potential	$\Delta W = m\Delta V$
	$V = -\frac{GM}{r}$ $\quad g = -\frac{\Delta V}{\Delta r}$

ELECTRIC FIELDS AND CAPACITORS

force between two point charges	$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
force on a charge	$F = EQ$
field strength for a uniform field	$E = \frac{V}{d}$
field strength for a radial field	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$
electric potential	$\Delta W = Q\Delta V$
	$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
capacitance	$C = \frac{Q}{V}$
decay of charge	$Q = Q_0 e^{-t/RC}$
time constant	RC
capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

MAGNETIC FIELDS

force on a current	$F = BIl$
force on a moving charge	$F = BQv$
magnetic flux	$\Phi = BA$
magnetic flux linkage	$N\Phi = BAN$
magnitude of induced emf	$\varepsilon = N\frac{\Delta\Phi}{\Delta t}$
emf induced in a rotating coil	$N\Phi = BAN\cos\theta$
	$\varepsilon = BAN\omega\sin\omega t$
transformer equations	$\frac{N_s}{N_p} = \frac{V_s}{V_p}$
	efficiency $= \frac{I_s V_s}{I_p V_p}$

RADIOACTIVITY AND NUCLEAR PHYSICS

the inverse square law for γ radiation	$I = \frac{k}{x^2}$
radioactive decay	$\frac{\Delta N}{\Delta t} = -\lambda N$ $\quad N = N_0 e^{-\lambda t}$
activity	$A = \lambda N$
half-life	$T_{½} = \frac{\ln 2}{\lambda}$
nuclear radius	$R = r_0 A^{1/3}$
energy-mass equation	$E = mc^2$

GASES AND THERMAL PHYSICS

gas law	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3}Nm(c_{rms})^2$
kinetic energy of gas molecule	$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$
energy to change temperature	$Q = mc\Delta T$
energy to change state	$Q = ml$

E

OPTIONS FORMULAE

ASTROPHYSICS

1 astronomical unit $= 1.50 \times 10^{11}$ m

1 light year $= 9.46 \times 10^{15}$ m

1 parsec $= 206265$ AU $= 3.08 \times 10^{16}$ m $= 3.26$ lyr

Hubble constant, $H = 65$ km s^{-1} Mpc^{-1}

lens equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

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

in normal adjustment $M = \frac{f_0}{f_e}$

resolving power $\theta \approx \frac{\lambda}{D}$

magnitude equation $m - M = 5 \log \frac{d}{10}$

Wien's law $\lambda_{max} T = 0.0029$ m K

Hubble's law $v = H d$

Stefan's law $P = \sigma A T^4$

Doppler shift for v << c $z = \frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$

Schwarzschild radius $R_s = \frac{2GM}{c^2}$

MEDICAL PHYSICS

lens equations $P = \frac{1}{f}$

$m = \frac{v}{u}$

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

intensity level intensity level $= 10 \log \frac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \frac{\mu}{\rho}$

APPLIED PHYSICS

moment of inertia $I = \Sigma m r^2$

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

equations of angular motion $\omega_2 = \omega_1 + \alpha t$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\theta = ½ (\omega_1 + \omega_2) t$

torque $T = I \alpha$

angular momentum angular momentum $= I\omega$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

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

isothermal change $pV =$ constant

heat engines

efficiency $= \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$

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

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power = (area of p-V loop) × (no. of cycles per second) × number of cylinders

output of brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

refrigerator: $COP_{ref} = \frac{Q_{out}}{W} = \frac{Q_{out}}{Q_{in} - Q_{out}}$

heat pump: $COP_{hp} = \frac{Q_{in}}{W} = \frac{Q_{in}}{Q_{in} - Q_{out}}$

TURNING POINTS IN PHYSICS

electrons in fields $F = \frac{eV}{d}$

$F = Bev$

$r = \frac{mv}{Be}$

$½ mv^2 = eV$

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

$F = 6\pi \eta r v$

wave particle duality $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

special relativity $E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$

$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$ $t = t_0 \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$

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GCE Physics A (2450) For exams from June 2014 onwards

Qualification Accreditation Number: AS 500/2569/7 - A Level 500/2615/X

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