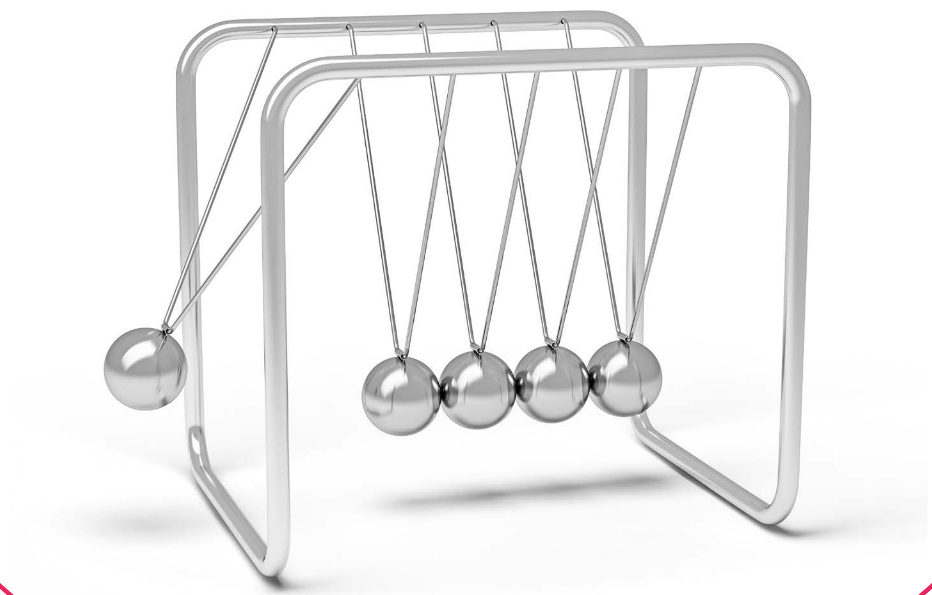
Cambridge Assessment International Education

Syllabus

Cambridge International AS & A Level Physics 9702

Use this syllabus for exams in 2022, 2023 and 2024.
Exams are available in the June and November series.
Exams are also available in the March series in India only.



Version 2

Cambridge Pathway

Why choose Cambridge International?

Cambridge International prepares school students for life, helping them develop an informed curiosity and a lasting passion for learning. We are part of the University of Cambridge.

Our Cambridge Pathway gives students a clear path for educational success from age 5 to 19. Schools can shape the curriculum around how they want students to learn – with a wide range of subjects and flexible ways to offer them. It helps students discover new abilities and a wider world, and gives them the skills they need for life, so they can achieve at school, university and work.

Our programmes and qualifications set the global standard for international education. They are created by subject experts, rooted in academic rigour and reflect the latest educational research. They provide a strong platform for students to progress from one stage to the next, and are well supported by teaching and learning resources.

We review all our syllabuses regularly, so they reflect the latest research evidence and professional teaching practice – and take account of the different national contexts in which they are taught.

We consult with teachers to help us design each syllabus around the needs of their learners. Consulting with leading universities has helped us make sure our syllabuses encourage students to master the key concepts in the subject and develop the skills necessary for success in higher education.

Our mission is to provide educational benefit through provision of international programmes and qualifications for school education and to be the world leader in this field. Together with schools, we develop Cambridge learners who are confident, responsible, reflective, innovative and engaged – equipped for success in the modern world.

Every year, nearly a million Cambridge students from 10 000 schools in 160 countries prepare for their future with the Cambridge Pathway.

‘We think the Cambridge curriculum is superb preparation for university.’

Christoph Guttentag, Dean of Undergraduate Admissions, Duke University, USA

Quality management

Cambridge International is committed to providing exceptional quality. In line with this commitment, our quality management system for the provision of international qualifications and education programmes for students aged 5 to 19 is independently certified as meeting the internationally recognised standard, ISO 9001:2015. Learn more at **www.cambridgeinternational.org/ISO9001**

Contents

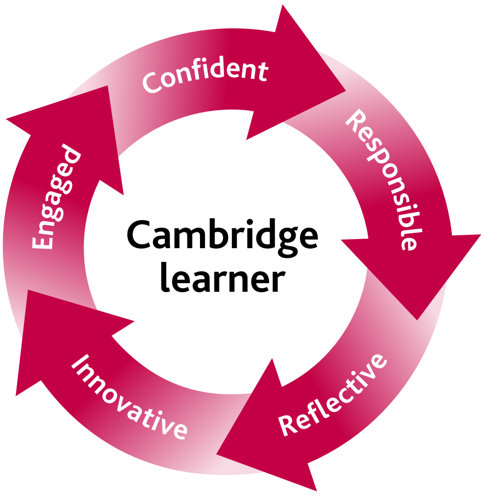
Changes to this syllabus

For information about changes to this syllabus for 2022, 2023 and 2024, go to page 60.

1 Why choose this syllabus?

Key benefits

The best motivation for a student is a real passion for the subject they're learning. By offering students a variety of Cambridge International AS & A Levels, you can give them the greatest chance of finding the path of education they most want to follow. With over 50 subjects to choose from, students can select the ones they love and that they're best at, which helps motivate them throughout their studies.



Following a Cambridge International AS & A Level programme helps students develop abilities which universities value highly, including:

- a deep understanding of their subjects
- higher order thinking skills – analysis, critical thinking, problem solving
- presenting ordered and coherent arguments
- independent learning and research.

Cambridge International AS & A Level Physics develops a set of transferable skills including handling data, practical problem-solving, and applying the scientific method. Learners develop relevant attitudes, such as concern for accuracy and precision, objectivity, integrity, enquiry, initiative and inventiveness. They acquire the essential scientific skills required for progression to further studies or employment.

Our approach in Cambridge International AS & A Level Physics encourages learners to be:

confident, secure in their knowledge, keen to explore further and able to communicate effectively through the language of science

responsible, developing efficient and safe scientific practices and working collaboratively with others

reflective, able to evaluate evidence to draw informed and appropriate conclusions and recognising that the applications of science have the potential to affect the individual, the community and the environment

innovative, applying problem-solving skills to novel situations and engaging with new tools and techniques, including information technology, to develop successful approaches

engaged, developing an enquiring mind, keen to apply scientific skills in everyday life.

'Cambridge students develop a deep understanding of subjects and independent thinking skills.'

Principal, Rockledge High School, USA

Key concepts

Key concepts are essential ideas that help students develop a deep understanding of their subject and make links between different aspects. Key concepts may open up new ways of thinking about, understanding or interpreting the important things to be learned.

Good teaching and learning will incorporate and reinforce a subject's key concepts to help students gain:

- a greater depth as well as breadth of subject knowledge
- confidence, especially in applying knowledge and skills in new situations
- the vocabulary to discuss their subject conceptually and show how different aspects link together
- a level of mastery of their subject to help them enter higher education.

The key concepts identified below, carefully introduced and developed, will help to underpin the course you will teach. You may identify additional key concepts which will also enrich teaching and learning.

The key concepts for Cambridge International AS & A Level Physics are:

- Models of physical systems
  Physics is the science that seeks to understand the behaviour of the Universe. The development of models of physical systems is central to physics. Models simplify, explain and predict how physical systems behave.
- Testing predictions against evidence
  Physical models are usually based on prior observations, and their predictions are tested to check that they are consistent with the behaviour of the real world. This testing requires evidence, often obtained from experiments.
- Mathematics as a language, and problem-solving tool
  Mathematics is integral to physics, as it is the language that is used to express physical principles and models. It is also a tool to analyse theoretical models, solve quantitative problems and produce predictions.
- Matter, energy and waves
  Everything in the Universe comprises matter and/or energy. Waves are a key mechanism for the transfer of energy and are essential to many modern applications of physics.
- Forces and fields
  The way that matter and energy interact is through forces and fields. The behaviour of the Universe is governed by fundamental forces with different magnitudes that interact over different distances. Physics involves study of these interactions across distances ranging from the very small (quantum and particle physics) to the very large (astronomy and cosmology).

International recognition and acceptance

Our expertise in curriculum, teaching and learning, and assessment is the basis for the recognition of our programmes and qualifications around the world. Every year thousands of students with Cambridge International AS & A Levels gain places at leading universities worldwide. They are valued by top universities around the world including those in the UK, US (including Ivy League universities), Europe, Australia, Canada and New Zealand.

UK NARIC, the national agency in the UK for the recognition and comparison of international qualifications and skills, has carried out an independent benchmarking study of Cambridge International AS & A Level and found it to be comparable to the standard of AS & A Level in the UK. This means students can be confident that their Cambridge International AS & A Level qualifications are accepted as equivalent, grade for grade, to UK AS & A Levels by leading universities worldwide.

Cambridge International AS Level Physics makes up the first half of the Cambridge International A Level course in physics and provides a foundation for the study of physics at Cambridge International A Level. Depending on local university entrance requirements, students may be able to use it to progress directly to university courses in physics or some other subjects. It is also suitable as part of a course of general education.

Cambridge International A Level Physics provides a foundation for the study of physics or related courses in higher education. Equally it is suitable as part of a course of general education.

For more information about the relationship between the Cambridge International AS Level and Cambridge International A Level see the ‘Assessment overview’ section of the Syllabus overview.

We recommend learners check the Cambridge recognitions database and the university websites to find the most up-to-date entry requirements for courses they wish to study.

Learn more at **www.cambridgeinternational.org/recognition**

Cambridge Assessment International Education is an education organisation and politically neutral. The content of this syllabus, examination papers and associated materials do not endorse any political view. We endeavour to treat all aspects of the exam process neutrally.

‘The depth of knowledge displayed by the best A Level students makes them prime targets for America’s Ivy League universities’

Yale University, USA

Supporting teachers

We provide a wide range of practical resources, detailed guidance, and innovative training and professional development so that you can give your students the best possible preparation for Cambridge International AS & A Level.

Support for Cambridge International AS & A Level

Teaching resources

- School Support Hub **www.cambridgeinternational.org/support**
- Syllabuses
- Schemes of work
- Learner guides
- Discussion forums
- Endorsed resources

Exam preparation resources

- Question papers
- Mark schemes
- Example candidate responses to understand what examiners are looking for at key grades
- Examiner reports to improve future teaching

Training

- Introductory – face-to-face or online
- Extension – face-to-face or online
- Enrichment – face-to-face or online
- Coursework – online
- Cambridge Professional Development Qualifications

Find out more at **www.cambridgeinternational.org/profdev**

Community

You can find useful information, as well as share your ideas and experiences with other teachers, on our social media channels and community forums.

Find out more at **www.cambridgeinternational.org/social-media**

'Cambridge International AS & A Levels prepare students well for university because they've learnt to go into a subject in considerable depth. There's that ability to really understand the depth and richness and the detail of a subject. It's a wonderful preparation for what they are going to face at university.'

US Higher Education Advisory Council

2 Syllabus overview

Aims

The aims describe the purposes of a course based on this syllabus.

The aims are to enable students to:

- acquire knowledge and understanding and develop practical skills, including efficient, accurate and safe scientific practices
- learn to apply the scientific method, while developing an awareness of the limitations of scientific theories and models
- develop skills in data analysis, evaluation and drawing conclusions, cultivating attitudes relevant to science such as objectivity, integrity, enquiry, initiative and inventiveness
- develop effective scientific communication skills, using appropriate terminology and scientific conventions
- understand their responsibility to others/society and to care for the environment
- enjoy science and develop an informed interest in the subject that may lead to further study.

Support for Cambridge International AS & A Level Physics

The School Support Hub is our secure online site for Cambridge teachers where you can find the resources you need to deliver our programmes, including schemes of work, past papers, mark schemes and examiner reports. You can also keep up to date with your subject and the global Cambridge community through our online discussion forums.

www.cambridgeinternational.org/support

Content overview

Candidates for Cambridge International AS Level Physics study the following topics:

1 Physical quantities and units
2 Kinematics
3 Dynamics
4 Forces, density and pressure
5 Work, energy and power
6 Deformation of solids
7 Waves
8 Superposition
9 Electricity
10 D.C. circuits
11 Particle physics

AS Level candidates also study practical skills.

Candidates for Cambridge International A Level Physics study the AS Level topics **and** the following topics:

12 Motion in a circle
13 Gravitational fields
14 Temperature
15 Ideal gases
16 Thermodynamics
17 Oscillations
18 Electric fields
19 Capacitance
20 Magnetic fields
21 Alternating currents
22 Quantum physics
23 Nuclear physics
24 Medical physics
25 Astronomy and cosmology

A level candidates also study practical skills.

Assessment overview

Paper 1

Multiple Choice — 1 hour 15 minutes

40 marks

40 multiple-choice questions

Questions are based on the AS Level syllabus content.

Externally assessed

31% of the AS Level

15.5% of the A Level

Paper 2

AS Level Structured Questions — 1 hour 15 minutes

60 marks

Structured questions

Questions are based on the AS Level syllabus content.

Externally assessed

46% of the AS Level

23% of the A Level

Paper 3

Advanced Practical Skills — 2 hours

40 marks

Practical work and structured questions

Questions are based on the experimental skills in the Practical assessment section of the syllabus. The context of the questions may be outside the syllabus content.

Externally assessed

23% of the AS Level

11.5% of the A Level

Paper 4

A Level Structured Questions — 2 hours

100 marks

Structured questions

Questions are based on the A Level syllabus content; knowledge of material from the AS Level syllabus content will be required.

Externally assessed

38.5% of the A Level

Paper 5

Planning, Analysis and Evaluation — 1 hour 15 minutes

30 marks

Candidates answer two compulsory questions.

Questions are based on the experimental skills in the Practical assessment section of the syllabus. The context of the questions may be outside the syllabus content.

Externally assessed

11.5% of the A Level

Information on availability is in the **Before you start** section.

There are three routes for Cambridge International AS & A Level Physics:

	Route	Paper 1	Paper 2	Paper 3	Paper 4	Paper 5
1	**AS Level only** (Candidates take all AS components in the same exam series)	✓	✓	✓		
2	**A Level** (staged over two years) Year 1 AS Level*	✓	✓	✓		
	Year 2 Complete the A Level				✓	✓
3	**A Level** (Candidates take all components in the same exam series)	✓	✓	✓	✓	✓

* Candidates carry forward their AS Level result subject to the rules and time limits described in the *Cambridge Handbook*.

Candidates following an AS Level route will be eligible for grades a–e. Candidates following an A Level route are eligible for grades A*–E.

Assessment objectives

The assessment objectives (AOs) are:

AO1 Knowledge and understanding

Candidates should be able to demonstrate knowledge and understanding of:

- scientific phenomena, facts, laws, definitions, concepts and theories
- scientific vocabulary, terminology and conventions (including symbols, quantities and units)
- scientific instruments and apparatus, including techniques of operation and aspects of safety
- scientific quantities and their determination
- scientific and technological applications with their social, economic and environmental implications.

AO2 Handling, applying and evaluating information

Candidates should be able to handle, apply and evaluate information in words or using other forms of presentation (e.g. symbols, graphical or numerical) to:

- locate, select, organise and present information from a variety of sources
- translate information from one form to another
- manipulate numerical and other data
- use information to identify patterns, report trends and draw conclusions
- give reasoned explanations for phenomena, patterns and relationships
- make predictions and construct arguments to support hypotheses
- make sense of new situations
- evaluate hypotheses
- demonstrate an awareness of the limitations of physical theories and models
- solve problems.

AO3 Experimental skills and investigations

Candidates should be able to:

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret experimental data to reach conclusions
- evaluate methods and quality of experimental data, and suggest improvements to experiments.

Weighting for assessment objectives

The approximate weightings allocated to each of the assessment objectives (AOs) are summarised below.

Assessment objectives as a percentage of each qualification

Assessment objective	Weighting in AS Level %	Weighting in A Level %
AO1 Knowledge and understanding	40	40
AO2 Handling, applying and evaluating information	40	40
AO3 Experimental skills and investigations	20	20
Total	100	100

Assessment objectives as a percentage of each component

Assessment objective	Weighting in components %				
	Paper 1	Paper 2	Paper 3	Paper 4	Paper 5
AO1 Knowledge and understanding	50	50	0	50	0
AO2 Handling, applying and evaluating information	50	50	0	50	0
AO3 Experimental skills and investigations	0	0	100	0	100
Total	100	100	100	100	100

3 Subject content

Introduction

Candidates for Cambridge International AS Level should study topics 1–11.

Candidates for Cambridge International A Level should study **all** topics.

The content of the AS Level learning outcomes is assumed knowledge for the A Level components.

Teachers should refer to the social, environmental, economic and technological aspects of physics wherever possible throughout the syllabus. Some examples are included in the syllabus and teachers should encourage learners to apply the principles of these examples to other situations introduced in the course.

The syllabus content for practical skills is in the Practical assessment section.

Teachers should ensure that candidates are prepared for the assessment of both theory learning outcomes and practical skills.

This syllabus gives you the flexibility to design a course that will interest, challenge and engage your learners. Where appropriate you are responsible for selecting suitable subject contexts, resources and examples to support your learners' study. These should be appropriate for the learners' age, cultural background and learning context as well as complying with your school policies and local legal requirements.

Support for teaching practical skills for these qualifications can be found on the School Support Hub **www.cambridgeinternational.org/support**

Data and formulae

Data and formulae will appear as page 2 in Papers 1 and 2 and pages 2 and 3 in Paper 4. The data and formulae are shown in section 6.

Decimal markers

In accordance with current ASE convention, decimal markers in examination papers will be a single dot on the line. Candidates are expected to follow this convention in their answers.

Units

In practical work, candidates will be expected to use SI units or, where appropriate, units approved by the BIPM for use with the SI (e.g. minute). A list of SI units and units approved for use with the SI may be found in the SI brochure at www.bipm.org. The use of imperial/customary units such as the inch and degree Fahrenheit is not acceptable and should be discouraged. In all examinations, where data is supplied for use in questions, candidates will be expected to use units that are consistent with the units supplied, and should not attempt conversion to other systems of units unless this is a requirement of the question.

AS Level subject content

1 Physical quantities and units

1.1 Physical quantities

Candidates should be able to:

1 understand that all physical quantities consist of a numerical magnitude and a unit

2 make reasonable estimates of physical quantities included within the syllabus

1.2 SI units

Candidates should be able to:

1 recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K)

2 express derived units as products or quotients of the SI base units and use the derived units for quantities listed in this syllabus as appropriate

3 use SI base units to check the homogeneity of physical equations

4 recall and use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)

1.3 Errors and uncertainties

Candidates should be able to:

1 understand and explain the effects of systematic errors (including zero errors) and random errors in measurements

2 understand the distinction between precision and accuracy

3 assess the uncertainty in a derived quantity by simple addition of absolute or percentage uncertainties

1.4 Scalars and vectors

Candidates should be able to:

1 understand the difference between scalar and vector quantities and give examples of scalar and vector quantities included in the syllabus

2 add and subtract coplanar vectors

3 represent a vector as two perpendicular components

2 Kinematics

2.1 Equations of motion

Candidates should be able to:

1 define and use distance, displacement, speed, velocity and acceleration

2 use graphical methods to represent distance, displacement, speed, velocity and acceleration

3 determine displacement from the area under a velocity–time graph

4 determine velocity using the gradient of a displacement–time graph

5 determine acceleration using the gradient of a velocity–time graph

6 derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line

7 solve problems using equations that represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance

8 describe an experiment to determine the acceleration of free fall using a falling object

9 describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction

3 Dynamics

An understanding of forces from Cambridge IGCSE/O Level Physics or equivalent is assumed.

3.1 Momentum and Newton's laws of motion

Candidates should be able to:

1 understand that mass is the property of an object that resists change in motion

2 recall $F = ma$ and solve problems using it, understanding that acceleration and resultant force are always in the same direction

3 define and use linear momentum as the product of mass and velocity

4 define and use force as rate of change of momentum

5 state and apply each of Newton's laws of motion

6 describe and use the concept of weight as the effect of a gravitational field on a mass and recall that the weight of an object is equal to the product of its mass and the acceleration of free fall

3.2 Non-uniform motion

Candidates should be able to:

1 show a qualitative understanding of frictional forces and viscous/drag forces including air resistance (no treatment of the coefficients of friction and viscosity is required, and a simple model of drag force increasing as speed increases is sufficient)

2 describe and explain qualitatively the motion of objects in a uniform gravitational field with air resistance

3 understand that objects moving against a resistive force may reach a terminal (constant) velocity

3.3 Linear momentum and its conservation

Candidates should be able to:

1 state the principle of conservation of momentum

2 apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between objects in both one and two dimensions (knowledge of the concept of coefficient of restitution is not required)

3 recall that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation

4 understand that, while momentum of a system is always conserved in interactions between objects, some change in kinetic energy may take place

4 Forces, density and pressure

4.1 Turning effects of forces

Candidates should be able to:

1 understand that the weight of an object may be taken as acting at a single point known as its centre of gravity

2 define and apply the moment of a force

3 understand that a couple is a pair of forces that acts to produce rotation only

4 define and apply the torque of a couple

4.2 Equilibrium of forces

Candidates should be able to:

1 state and apply the principle of moments

2 understand that, when there is no resultant force and no resultant torque, a system is in equilibrium

3 use a vector triangle to represent coplanar forces in equilibrium

4.3 Density and pressure

Candidates should be able to:

1 define and use density

2 define and use pressure

3 derive, from the definitions of pressure and density, the equation for hydrostatic pressure $\Delta p = \rho g \Delta h$

4 use the equation $\Delta p = \rho g \Delta h$

5 understand that the upthrust acting on an object in a fluid is due to a difference in hydrostatic pressure

6 calculate the upthrust acting on an object in a fluid using the equation $F = \rho g V$ (Archimedes' principle)

5 Work, energy and power

An understanding of the forms of energy and energy transfers from Cambridge IGCSE/O Level Physics or equivalent is assumed.

5.1 Energy conservation

Candidates should be able to:

1 understand the concept of work, and recall and use *work done* = *force* × *displacement* in the direction of the force

2 recall and apply the principle of conservation of energy

3 recall and understand that the efficiency of a system is the ratio of useful energy output from the system to the total energy input

4 use the concept of efficiency to solve problems

5 define power as work done per unit time

6 solve problems using $P = W / t$

7 derive $P = Fv$ and use it to solve problems

5.2 Gravitational potential energy and kinetic energy

Candidates should be able to:

1 derive, using $W = Fs$, the formula $\Delta E_P = mg\Delta h$ for gravitational potential energy changes in a uniform gravitational field

2 recall and use the formula $\Delta E_P = mg\Delta h$ for gravitational potential energy changes in a uniform gravitational field

3 derive, using the equations of motion, the formula for kinetic energy $E_K = \frac{1}{2}mv^2$

4 recall and use $E_K = \frac{1}{2}mv^2$

6 Deformation of solids

6.1 Stress and strain

Candidates should be able to:

1 understand that deformation is caused by tensile or compressive forces (forces and deformations will be assumed to be in one dimension only)

2 understand and use the terms load, extension, compression and limit of proportionality

3 recall and use Hooke's law

4 recall and use the formula for the spring constant $k = F / x$

5 define and use the terms stress, strain and the Young modulus

6 describe an experiment to determine the Young modulus of a metal in the form of a wire

6.2 Elastic and plastic behaviour

Candidates should be able to:

1 understand and use the terms elastic deformation, plastic deformation and elastic limit

2 understand that the area under the force–extension graph represents the work done

3 determine the elastic potential energy of a material deformed within its limit of proportionality from the area under the force–extension graph

4 recall and use $E_p = \frac{1}{2}Fx = \frac{1}{2}kx^2$ for a material deformed within its limit of proportionality

7 Waves

An understanding of colour from Cambridge IGCSE/O Level Physics or equivalent is assumed.

7.1 Progressive waves

Candidates should be able to:

1 describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks

2 understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed

3 understand the use of the time-base and *y*-gain of a cathode-ray oscilloscope (CRO) to determine frequency and amplitude

4 derive, using the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$

5 recall and use $v = f\lambda$

6 understand that energy is transferred by a progressive wave

7 recall and use $intensity = power/area$ and $intensity \propto (amplitude)^2$ for a progressive wave

7.2 Transverse and longitudinal waves

Candidates should be able to:

1 compare transverse and longitudinal waves

2 analyse and interpret graphical representations of transverse and longitudinal waves

7.3 Doppler effect for sound waves

Candidates should be able to:

1 understand that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency (understanding of the Doppler effect for a stationary source and a moving observer is not required)

2 use the expression $f_o = f_s v / (v \pm v_s)$ for the observed frequency when a source of sound waves moves relative to a stationary observer

7.4 Electromagnetic spectrum

Candidates should be able to:

1 state that all electromagnetic waves are transverse waves that travel with the same speed *c* in free space

2 recall the approximate range of wavelengths in free space of the principal regions of the electromagnetic spectrum from radio waves to γ-rays

3 recall that wavelengths in the range 400–700 nm in free space are visible to the human eye

7.5 Polarisation

Candidates should be able to:

1 understand that polarisation is a phenomenon associated with transverse waves

2 recall and use Malus's law ($I = I_0 \cos^2\theta$) to calculate the intensity of a plane polarised electromagnetic wave after transmission through a polarising filter or a series of polarising filters

8 Superposition

8.1 Stationary waves

Candidates should be able to:

1 explain and use the principle of superposition

2 show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columns (it will be assumed that end corrections are negligible; knowledge of the concept of end corrections is not required)

3 explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes

4 understand how wavelength may be determined from the positions of nodes or antinodes of a stationary wave

8.2 Diffraction

Candidates should be able to:

1 explain the meaning of the term diffraction

2 show an understanding of experiments that demonstrate diffraction including the qualitative effect of the gap width relative to the wavelength of the wave; for example diffraction of water waves in a ripple tank

8.3 Interference

Candidates should be able to:

1 understand the terms interference and coherence

2 show an understanding of experiments that demonstrate two-source interference using water waves in a ripple tank, sound, light and microwaves

3 understand the conditions required if two-source interference fringes are to be observed

4 recall and use $\lambda = ax / D$ for double-slit interference using light

8.4 The diffraction grating

Candidates should be able to:

1 recall and use $d \sin \theta = n\lambda$

2 describe the use of a diffraction grating to determine the wavelength of light (the structure and use of the spectrometer are not included)

9 Electricity

9.1 Electric current

Candidates should be able to:

1 understand that an electric current is a flow of charge carriers

2 understand that the charge on charge carriers is quantised

3 recall and use $Q = It$

4 use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers

9.2 Potential difference and power

Candidates should be able to:

1 define the potential difference across a component as the energy transferred per unit charge

2 recall and use $V = W / Q$

3 recall and use $P = VI$, $P = I^2R$ and $P = V^2 / R$

9.3 Resistance and resistivity

Candidates should be able to:

1 define resistance

2 recall and use $V = IR$

3 sketch the I–V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp

4 explain that the resistance of a filament lamp increases as current increases because its temperature increases

5 state Ohm's law

6 recall and use $R = \rho L / A$

7 understand that the resistance of a light-dependent resistor (LDR) decreases as the light intensity increases

8 understand that the resistance of a thermistor decreases as the temperature increases (it will be assumed that thermistors have a negative temperature coefficient)

10 D.C. circuits

10.1 Practical circuits

Candidates should be able to:

1 recall and use the circuit symbols shown in section 6 of this syllabus

2 draw and interpret circuit diagrams containing the circuit symbols shown in section 6 of this syllabus

3 define and use the electromotive force (e.m.f.) of a source as energy transferred per unit charge in driving charge around a complete circuit

4 distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations

5 understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference

10.2 Kirchhoff's laws

Candidates should be able to:

1 recall Kirchhoff's first law and understand that it is a consequence of conservation of charge

2 recall Kirchhoff's second law and understand that it is a consequence of conservation of energy

3 derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series

4 use the formula for the combined resistance of two or more resistors in series

5 derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel

6 use the formula for the combined resistance of two or more resistors in parallel

7 use Kirchhoff's laws to solve simple circuit problems

10.3 Potential dividers

Candidates should be able to:

1 understand the principle of a potential divider circuit

2 recall and use the principle of the potentiometer as a means of comparing potential differences

3 understand the use of a galvanometer in null methods

4 explain the use of thermistors and light-dependent resistors in potential dividers to provide a potential difference that is dependent on temperature and light intensity

11 Particle physics

11.1 Atoms, nuclei and radiation

Candidates should be able to:

1 infer from the results of the α-particle scattering experiment the existence and small size of the nucleus

2 describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons

3 distinguish between nucleon number and proton number

4 understand that isotopes are forms of the same element with different numbers of neutrons in their nuclei

5 understand and use the notation $^{A}_{Z}X$ for the representation of nuclides

6 understand that nucleon number and charge are conserved in nuclear processes

7 describe the composition, mass and charge of α-, β- and γ-radiations (both β^- (electrons) and β^+ (positrons) are included)

8 understand that an antiparticle has the same mass but opposite charge to the corresponding particle, and that a positron is the antiparticle of an electron

9 state that (electron) antineutrinos are produced during β^- decay and (electron) neutrinos are produced during β^+ decay

10 understand that α-particles have discrete energies but that β-particles have a continuous range of energies because (anti)neutrinos are emitted in β-decay

11 represent α- and β-decay by a radioactive decay equation of the form $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$

12 use the unified atomic mass unit (u) as a unit of mass

11.2 Fundamental particles

Candidates should be able to:

1 understand that a quark is a fundamental particle and that there are six flavours (types) of quark: up, down, strange, charm, top and bottom

2 recall and use the charge of each flavour of quark and understand that its respective antiquark has the opposite charge (no knowledge of any other properties of quarks is required)

3 recall that protons and neutrons are not fundamental particles and describe protons and neutrons in terms of their quark composition

4 understand that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and one antiquark)

5 describe the changes to quark composition that take place during β^- and β^+ decay

6 recall that electrons and neutrinos are fundamental particles called leptons

A Level subject content

12 Motion in a circle

12.1 Kinematics of uniform circular motion

Candidates should be able to:

1 define the radian and express angular displacement in radians

2 understand and use the concept of angular speed

3 recall and use $\omega = 2\pi / T$ and $v = r\omega$

12.2 Centripetal acceleration

Candidates should be able to:

1 understand that a force of constant magnitude that is always perpendicular to the direction of motion causes centripetal acceleration

2 understand that centripetal acceleration causes circular motion with a constant angular speed

3 recall and use $a = r\omega^2$ and $a = v^2 / r$

4 recall and use $F = mr\omega^2$ and $F = mv^2 / r$

13 Gravitational fields

13.1 Gravitational field

Candidates should be able to:

1 understand that a gravitational field is an example of a field of force and define gravitational field as force per unit mass

2 represent a gravitational field by means of field lines

13.2 Gravitational force between point masses

Candidates should be able to:

1 understand that, for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its centre

2 recall and use Newton's law of gravitation $F = Gm_1m_2 / r^2$ for the force between two point masses

3 analyse circular orbits in gravitational fields by relating the gravitational force to the centripetal acceleration it causes

4 understand that a satellite in a geostationary orbit remains at the same point above the Earth's surface, with an orbital period of 24 hours, orbiting from west to east, directly above the Equator

13.3 Gravitational field of a point mass

Candidates should be able to:

1 derive, from Newton's law of gravitation and the definition of gravitational field, the equation $g = GM / r^2$ for the gravitational field strength due to a point mass

2 recall and use $g = GM / r^2$

3 understand why g is approximately constant for small changes in height near the Earth's surface

13.4 Gravitational potential

Candidates should be able to:

1 define gravitational potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point
2 use $\phi = -GM / r$ for the gravitational potential in the field due to a point mass
3 understand how the concept of gravitational potential leads to the gravitational potential energy of two point masses and use $E_p = -GMm / r$

14 Temperature

14.1 Thermal equilibrium

Candidates should be able to:

1 understand that (thermal) energy is transferred from a region of higher temperature to a region of lower temperature
2 understand that regions of equal temperature are in thermal equilibrium

14.2 Temperature scales

Candidates should be able to:

1 understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties, including the density of a liquid, volume of a gas at constant pressure, resistance of a metal, e.m.f. of a thermocouple
2 understand that the scale of thermodynamic temperature does not depend on the property of any particular substance
3 convert temperatures between kelvin and degrees Celsius and recall that $T / \mathrm{K} = \theta / {}^\circ\mathrm{C} + 273.15$
4 understand that the lowest possible temperature is zero kelvin on the thermodynamic temperature scale and that this is known as absolute zero

14.3 Specific heat capacity and specific latent heat

Candidates should be able to:

1 define and use specific heat capacity
2 define and use specific latent heat and distinguish between specific latent heat of fusion and specific latent heat of vaporisation

15 Ideal gases

15.1 The mole

Candidates should be able to:

1 understand that amount of substance is an SI base quantity with the base unit mol
2 use molar quantities where one mole of any substance is the amount containing a number of particles of that substance equal to the Avogadro constant N_A

15.2 Equation of state

Candidates should be able to:

1 understand that a gas obeying $pV \propto T$, where T is the thermodynamic temperature, is known as an ideal gas

2 recall and use the equation of state for an ideal gas expressed as $pV = nRT$, where n = amount of substance (number of moles) and as $pV = NkT$, where N = number of molecules

3 recall that the Boltzmann constant k is given by $k = R / N_A$

15.3 Kinetic theory of gases

Candidates should be able to:

1 state the basic assumptions of the kinetic theory of gases

2 explain how molecular movement causes the pressure exerted by a gas and derive and use the relationship $pV = \frac{1}{3}Nm\langle c^2\rangle$, where $\langle c^2\rangle$ is the mean-square speed (a simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3}\langle c^2\rangle = \langle c_x^{\,2}\rangle$ is sufficient)

3 understand that the root-mean-square speed $c_{\text{r.m.s.}}$ is given by $\sqrt{\langle c^2\rangle}$

4 compare $pV = \frac{1}{3}Nm\langle c^2\rangle$ with $pV = NkT$ to deduce that the average translational kinetic energy of a molecule is $\frac{3}{2}kT$

16 Thermodynamics

An understanding of energy from Cambridge IGCSE/O Level Physics or equivalent is assumed.

16.1 Internal energy

Candidates should be able to:

1 understand that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system

2 relate a rise in temperature of an object to an increase in its internal energy

16.2 The first law of thermodynamics

Candidates should be able to:

1 recall and use $W = p\Delta V$ for the work done when the volume of a gas changes at constant pressure and understand the difference between the work done by the gas and the work done on the gas

2 recall and use the first law of thermodynamics $\Delta U = q + W$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred to the system by heating) and the work done on the system

17 Oscillations

17.1 Simple harmonic oscillations

Candidates should be able to:

1. understand and use the terms displacement, amplitude, period, frequency, angular frequency and phase difference in the context of oscillations, and express the period in terms of both frequency and angular frequency
2. understand that simple harmonic motion occurs when acceleration is proportional to displacement from a fixed point and in the opposite direction
3. use $a = -\omega^2 x$ and recall and use, as a solution to this equation, $x = x_0 \sin \omega t$
4. use the equations $v = v_0 \cos \omega t$ and $v = \pm\omega\sqrt{(x_0^2 - x^2)}$
5. analyse and interpret graphical representations of the variations of displacement, velocity and acceleration for simple harmonic motion

17.2 Energy in simple harmonic motion

Candidates should be able to:

1. describe the interchange between kinetic and potential energy during simple harmonic motion
2. recall and use $E = \frac{1}{2}m\omega^2 x_0^2$ for the total energy of a system undergoing simple harmonic motion

17.3 Damped and forced oscillations, resonance

Candidates should be able to:

1. understand that a resistive force acting on an oscillating system causes damping
2. understand and use the terms light, critical and heavy damping and sketch displacement–time graphs illustrating these types of damping
3. understand that resonance involves a maximum amplitude of oscillations and that this occurs when an oscillating system is forced to oscillate at its natural frequency

18 Electric fields

18.1 Electric fields and field lines

Candidates should be able to:

1. understand that an electric field is an example of a field of force and define electric field as force per unit positive charge
2. recall and use $F = qE$ for the force on a charge in an electric field
3. represent an electric field by means of field lines

18.2 Uniform electric fields

Candidates should be able to:

1. recall and use $E = \Delta V / \Delta d$ to calculate the field strength of the uniform field between charged parallel plates
2. describe the effect of a uniform electric field on the motion of charged particles

18.3 Electric force between point charges

Candidates should be able to:

1 understand that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre

2 recall and use Coulomb's law $F = Q_1Q_2 / (4\pi\varepsilon_0 r^2)$ for the force between two point charges in free space

18.4 Electric field of a point charge

Candidates should be able to:

1 recall and use $E = Q / (4\pi\varepsilon_0 r^2)$ for the electric field strength due to a point charge in free space

18.5 Electric potential

Candidates should be able to:

1 define electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point

2 recall and use the fact that the electric field at a point is equal to the negative of potential gradient at that point

3 use $V = Q / (4\pi\varepsilon_0 r)$ for the electric potential in the field due to a point charge

4 understand how the concept of electric potential leads to the electric potential energy of two point charges and use $E_P = Qq / (4\pi\varepsilon_0 r)$

19 Capacitance

19.1 Capacitors and capacitance

Candidates should be able to:

1 define capacitance, as applied to both isolated spherical conductors and to parallel plate capacitors

2 recall and use $C = Q / V$

3 derive, using $C = Q / V$, formulae for the combined capacitance of capacitors in series and in parallel

4 use the capacitance formulae for capacitors in series and in parallel

19.2 Energy stored in a capacitor

Candidates should be able to:

1 determine the electric potential energy stored in a capacitor from the area under the potential–charge graph

2 recall and use $W = \frac{1}{2}QV = \frac{1}{2}CV^2$

19.3 Discharging a capacitor

Candidates should be able to:

1 analyse graphs of the variation with time of potential difference, charge and current for a capacitor discharging through a resistor

2 recall and use $\tau = RC$ for the time constant for a capacitor discharging through a resistor

3 use equations of the form $x = x_0 \, e^{-(t/RC)}$ where x could represent current, charge or potential difference for a capacitor discharging through a resistor

20 Magnetic fields

20.1 Concept of a magnetic field

Candidates should be able to:

1 understand that a magnetic field is an example of a field of force produced either by moving charges or by permanent magnets

2 represent a magnetic field by field lines

20.2 Force on a current-carrying conductor

Candidates should be able to:

1 understand that a force might act on a current-carrying conductor placed in a magnetic field

2 recall and use the equation $F = BIL \sin \theta$, with directions as interpreted by Fleming's left-hand rule

3 define magnetic flux density as the force acting per unit current per unit length on a wire placed at right-angles to the magnetic field

20.3 Force on a moving charge

Candidates should be able to:

1 determine the direction of the force on a charge moving in a magnetic field

2 recall and use $F = BQv \sin \theta$

3 understand the origin of the Hall voltage and derive and use the expression $V_H = BI / (ntq)$, where t = thickness

4 understand the use of a Hall probe to measure magnetic flux density

5 describe the motion of a charged particle moving in a uniform magnetic field perpendicular to the direction of motion of the particle

6 explain how electric and magnetic fields can be used in velocity selection

20.4 Magnetic fields due to currents

Candidates should be able to:

1 sketch magnetic field patterns due to the currents in a long straight wire, a flat circular coil and a long solenoid

2 understand that the magnetic field due to the current in a solenoid is increased by a ferrous core

3 explain the origin of the forces between current-carrying conductors and determine the direction of the forces

20.5 Electromagnetic induction

Candidates should be able to:

1 define magnetic flux as the product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density
2 recall and use $\Phi = BA$
3 understand and use the concept of magnetic flux linkage
4 understand and explain experiments that demonstrate:
- that a changing magnetic flux can induce an e.m.f. in a circuit
- that the induced e.m.f. is in such a direction as to oppose the change producing it
- the factors affecting the magnitude of the induced e.m.f.

5 recall and use Faraday's and Lenz's laws of electromagnetic induction

21 Alternating currents

An understanding of the practical and economic advantages of transmission of power by electricity from Cambridge IGCSE / O Level Physics or equivalent is assumed.

21.1 Characteristics of alternating currents

Candidates should be able to:

1 understand and use the terms period, frequency and peak value as applied to an alternating current or voltage
2 use equations of the form $x = x_0 \sin \omega t$ representing a sinusoidally alternating current or voltage
3 recall and use the fact that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current
4 distinguish between root-mean-square (r.m.s.) and peak values and recall and use $I_{\text{r.m.s.}} = I_0 / \sqrt{2}$ and $V_{\text{r.m.s.}} = V_0 / \sqrt{2}$ for a sinusoidal alternating current

21.2 Rectification and smoothing

Candidates should be able to:

1 distinguish graphically between half-wave and full-wave rectification
2 explain the use of a single diode for the half-wave rectification of an alternating current
3 explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current
4 analyse the effect of a single capacitor in smoothing, including the effect of the values of capacitance and the load resistance

22 Quantum physics

22.1 Energy and momentum of a photon

Candidates should be able to:

1 understand that electromagnetic radiation has a particulate nature
2 understand that a photon is a quantum of electromagnetic energy
3 recall and use $E = hf$
4 use the electronvolt (eV) as a unit of energy
5 understand that a photon has momentum and that the momentum is given by $p = E / c$

22.2 Photoelectric effect

Candidates should be able to:

1 understand that photoelectrons may be emitted from a metal surface when it is illuminated by electromagnetic radiation
2 understand and use the terms threshold frequency and threshold wavelength
3 explain photoelectric emission in terms of photon energy and work function energy
4 recall and use $hf = \Phi + \frac{1}{2}mv_{max}^2$
5 explain why the maximum kinetic energy of photoelectrons is independent of intensity, whereas the photoelectric current is proportional to intensity

22.3 Wave-particle duality

Candidates should be able to:

1 understand that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature
2 describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles
3 understand the de Broglie wavelength as the wavelength associated with a moving particle
4 recall and use $\lambda = h / p$

22.4 Energy levels in atoms and line spectra

Candidates should be able to:

1 understand that there are discrete electron energy levels in isolated atoms (e.g. atomic hydrogen)
2 understand the appearance and formation of emission and absorption line spectra
3 recall and use $hf = E_1 - E_2$

23 Nuclear physics

23.1 Mass defect and nuclear binding energy

Candidates should be able to:

1 understand the equivalence between energy and mass as represented by $E = mc^2$ and recall and use this equation
2 represent simple nuclear reactions by nuclear equations of the form ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$
3 define and use the terms mass defect and binding energy
4 sketch the variation of binding energy per nucleon with nucleon number
5 explain what is meant by nuclear fusion and nuclear fission
6 explain the relevance of binding energy per nucleon to nuclear reactions, including nuclear fusion and nuclear fission
7 calculate the energy released in nuclear reactions using $E = c^2\Delta m$

23.2 Radioactive decay

Candidates should be able to:

1. understand that fluctuations in count rate provide evidence for the random nature of radioactive decay
2. understand that radioactive decay is both spontaneous and random
3. define activity and decay constant, and recall and use $A = \lambda N$
4. define half-life
5. use $\lambda = 0.693 / t_{\frac{1}{2}}$
6. understand the exponential nature of radioactive decay, and sketch and use the relationship $x = x_0 e^{-\lambda t}$, where x could represent activity, number of undecayed nuclei or received count rate

24 Medical physics

24.1 Production and use of ultrasound

Candidates should be able to:

1. understand that a piezo-electric crystal changes shape when a p.d. is applied across it and that the crystal generates an e.m.f. when its shape changes
2. understand how ultrasound waves are generated and detected by a piezoelectric transducer
3. understand how the reflection of pulses of ultrasound at boundaries between tissues can be used to obtain diagnostic information about internal structures
4. define the specific acoustic impedance of a medium as $Z = \rho c$, where c is the speed of sound in the medium
5. use $I_R / I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ for the intensity reflection coefficient of a boundary between two media
6. recall and use $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter

24.2 Production and use of X-rays

Candidates should be able to:

1. explain that X-rays are produced by electron bombardment of a metal target and calculate the minimum wavelength of X-rays produced from the accelerating p.d.
2. understand the use of X-rays in imaging internal body structures, including an understanding of the term contrast in X-ray imaging
3. recall and use $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter
4. understand that computed tomography (CT) scanning produces a 3D image of an internal structure by first combining multiple X-ray images taken in the same section from different angles to obtain a 2D image of the section, then repeating this process along an axis and combining 2D images of multiple sections

24.3 PET scanning

Candidates should be able to:

1 understand that a tracer is a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied

2 recall that a tracer that decays by β^+ decay is used in positron emission tomography (PET scanning)

3 understand that annihilation occurs when a particle interacts with its antiparticle and that mass-energy and momentum are conserved in the process

4 explain that, in PET scanning, positrons emitted by the decay of the tracer annihilate when they interact with electrons in the tissue, producing a pair of gamma-ray photons travelling in opposite directions

5 calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair

6 understand that the gamma-ray photons from an annihilation event travel outside the body and can be detected, and an image of the tracer concentration in the tissue can be created by processing the arrival times of the gamma-ray photons

25 Astronomy and cosmology

25.1 Standard candles

Candidates should be able to:

1 understand the term luminosity as the total power of radiation emitted by a star

2 recall and use the inverse square law for radiant flux intensity F in terms of the luminosity L of the source $F = L / (4\pi d^2)$

3 understand that an object of known luminosity is called a standard candle

4 understand the use of standard candles to determine distances to galaxies

25.2 Stellar radii

Candidates should be able to:

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

2 use the Stefan–Boltzmann law $L = 4\pi\sigma r^2 T^4$

3 use Wien's displacement law and the Stefan–Boltzmann law to estimate the radius of a star

25.3 Hubble's law and the Big Bang theory

Candidates should be able to:

1 understand that the lines in the emission spectra from distant objects show an increase in wavelength from their known values

2 use $\Delta\lambda / \lambda \approx \Delta f / f \approx v / c$ for the redshift of electromagnetic radiation from a source moving relative to an observer

3 explain why redshift leads to the idea that the Universe is expanding

4 recall and use Hubble's law $v \approx H_0 d$ and explain how this leads to the Big Bang theory (candidates will only be required to use SI units)

4 Details of the assessment

Paper 1 Multiple Choice

Written paper, 1 hour 15 minutes, 40 marks

Forty multiple-choice items of the four-choice type testing assessment objectives AO1 and AO2. Questions are based on the AS Level syllabus content.

Paper 2 AS Level Structured Questions

Written paper, 1 hour 15 minutes, 60 marks

Structured questions testing assessment objectives AO1 and AO2. Questions are based on the AS Level syllabus content.

Paper 3 Advanced Practical Skills

Practical test, 2 hours, 40 marks

This paper tests assessment objective AO3 in a practical context.

Two questions assess the AS Level practical skills in the Practical assessment section of the syllabus. The content of the questions may be outside the syllabus content.

Paper 4 A Level Structured Questions

Written paper, 2 hours, 100 marks

Structured questions testing assessment objectives AO1 and AO2.

Questions are based on the A Level syllabus; knowledge of material from the AS Level syllabus content will be required.

Paper 5 Planning, Analysis and Evaluation

Written paper, 1 hour 15 minutes, 30 marks

Two questions testing assessment objective AO3.

Questions are based on the A Level practical skills of planning, analysis and evaluation but may require knowledge of practical skills from the AS Level syllabus. The content of the questions may be outside of the syllabus content.

Command words

Command words and their meanings help candidates know what is expected from them in the exam. The table below includes command words used in the assessment for this syllabus. The use of the command word will relate to the subject context.

Command word	What it means
Calculate	work out from given facts, figures or information
Comment	give an informed opinion
Compare	identify/comment on similarities and/or differences
Define	give precise meaning
Describe	state the points of a topic / give characteristics and main features
Determine	establish an answer using the information available
Explain	set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence
Give	produce an answer from a given source or recall/memory
Identify	name/select/recognise
Justify	support a case with evidence/argument
Predict	suggest what may happen based on available information
Show (that)	provide structured evidence that leads to a given result
Sketch	make a simple freehand drawing showing the key features
State	express in clear terms
Suggest	apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals

5 Practical assessment

Introduction

Teachers should ensure that learners practise experimental skills throughout their course of study. As a guide, learners should spend at least 20 per cent of their time doing practical work individually or in small groups. This 20 per cent does not include the time spent observing demonstrations of experiments.

The practical work that learners do during their course should aim to:

- provide learning opportunities so they develop the skills they need to carry out experimental and investigative work
- reinforce their learning of the theoretical subject content of the syllabus
- instil an understanding of the relationship between experimentation and theory in scientific method
- be enjoyable, contributing to the motivation of learners.

Candidates' experimental skills will be assessed in Paper 3 and Paper 5. In each of these papers, the questions may be based on physics not included in the syllabus content, but candidates will be assessed on their practical skills rather than their knowledge of theory. Where appropriate, candidates will be given any additional information that they need.

Paper 3 Advanced Practical Skills

Paper 3 is a timetabled, laboratory-based practical paper focusing on the experimental skills of:

- manipulation, measurement and observation
- presentation of data and observations
- analysis, conclusions and evaluation.

Centres should refer to the document 'How to manage your sciences practical exams' for advice on making entries and organisation of candidates for practical exams.

Paper 3 consists of two questions, each of 1 hour and each of 20 marks.

Question 1 will be an experiment requiring candidates to collect data, to plot a graph and to draw conclusions.

Question 2 will be an experiment requiring candidates to collect data and to draw conclusions, but may or may not include the plotting of a graph. In the second question, the experimental method to be followed will be inaccurate, and candidates will be required to evaluate the method and suggest improvements.

The two questions will be set in different areas of physics. No prior knowledge of the theory will be required.

Mark allocations for Paper 3

Marks will be allocated for Paper 3 according to the table below. The expectations for each skill are listed in the sections that follow.

Question 1		
Skill	**Breakdown of skills**	**Minimum mark allocation***
Manipulation, measurement and observation	Successful collection of data	7 marks
	Quality of data	
Presentation of data and observations	Table of results	6 marks
	Recording of data, observations and calculations	
	Graph	
Analysis, conclusions and evaluation	Interpretation of graph	4 marks
	Drawing conclusions	

*The remaining 3 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Question 2		
Skill	**Breakdown of skills**	**Minimum mark allocation***
Manipulation, measurement and observation	Successful collection of data	5 marks
	Quality of data	
Presentation of data and observations	Recording of data, observations and calculations	2 marks
Analysis, conclusions and evaluation	Drawing conclusions	10 marks
	Estimating uncertainties	
	Identifying limitations	
	Suggesting improvements	

* The remaining 3 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Expectations for each skill (Paper 3)

Manipulation, measurement and observation

Successful collection of data

Candidates should be able to:

- set up apparatus correctly without assistance from the supervisor
- follow instructions given in the form of written instructions and diagrams (including circuit diagrams)
- use their apparatus to collect an appropriate quantity of data
- repeat readings where appropriate
- make measurements using common laboratory apparatus, such as millimetre scales, protractors, top-pan balances, newton meters, analogue or digital electrical meters, measuring cylinders, calipers*, micrometer screw gauges and thermometers
- use a stop-watch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations
- use both analogue scales and digital displays.

* Where calipers are required in the examination, centres may provide either vernier or digital calipers. Candidates should be familiar with the type of calipers provided.

Some candidates will be unable to set up their apparatus without help and may ask for assistance from the supervisor. Supervisors will be given clear instructions on what assistance may be given to candidates, but this assistance should never go beyond the minimum necessary to enable candidates to take some readings: under no circumstances should help be given with the presentation of data, analysis or evaluation sections. All assistance must be reported to the Examiners by recording details of the help given on the supervisor's report, and candidates who require assistance will not be awarded full credit for the successful collection of data.

Quality of data

Candidates should be able to:

- make and record accurate measurements
- make measurements that span the largest possible range of values within the limits either of the equipment provided or of the instructions given.

Marks will be awarded for measured data in which the values obtained are reasonable. In some cases, the award of the mark will be based on the scatter of points on a graph; in other cases, the candidate's data may be compared with information supplied by the supervisor or known to the Examiners. The Examiners will only consider the extent to which the candidate has affected the quality of the data: allowances will be made where the quality of data is limited by the experimental method required or by the apparatus used.

Presentation of data and observations

Table of results

Candidates should be able to:

- present numerical data and values in a single table of results
- record all data in the table
- draw up the table in advance of taking readings so that they do not have to copy up their results
- include in the table of results columns for raw data and for values calculated from them
- use column headings that include both the quantity and the unit and that conform to accepted scientific conventions.

As an example of accepted scientific convention in column headings, if the quantity being measured is current in milliamperes, then 'I / mA' would be the usual way to write the column heading, but 'I in mA' or 'I (mA)' or 'current / mA' would be allowed. Headings such as 'I mA' or just 'mA' are not acceptable. The quantity or the unit or both may be written in words rather than symbols. Conventional symbols or abbreviations (such as p.d.) may be used without explanation.

Recording of data, observations and calculations

Candidates should be able to:

- record raw readings of a quantity to the same degree of precision
- calculate other quantities from their raw data
- show their working in calculations, and the key steps in their reasoning
- use and justify the correct number of significant figures in calculated quantities.

For example, if one measurement of length in a column of raw data is given to the nearest millimetre, then all the lengths in that column should be given to the nearest millimetre. The degree of precision used should be compatible with the measuring instrument used: it would be inappropriate to record a distance measured on a millimetre scale as either '2 cm' or '2.00 cm'.

When a value is calculated from measured quantities (except by addition or subtraction), the appropriate number of significant figures for the calculated value usually depends on the measured quantity with the least number of significant figures. If this quantity has n significant figures, then n or n+1 significant figures are appropriate for the calculated value.

For example, if values of a potential difference and of a current are measured to 2 and 4 significant figures respectively, then the corresponding resistance should be given to 2 or 3 significant figures, but not 1 or 4. The number of significant figures may, if necessary, vary down a column of values for a calculated quantity.

Graph: Layout

Candidates should be able to:

- clearly label graph axes with both the quantity and the unit, following accepted scientific conventions
- choose scales for graph axes such that the data points occupy at least half of the graph grid in both x- and y-directions
- use a false origin where appropriate
- choose scales for the graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 2 cm square
- place regularly-spaced numerical labels along the whole of each axis at least every 2 cm.

The accepted scientific conventions for labelling the axes of a graph are the same as for the column headings in a table of results.

Graph: Plotting of points

Candidates should be able to:

- plot all their data points on their graph grid to an accuracy of better than 1 mm.

Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; plotted points should have a diameter of less than 1 mm.

Graph: Trend line

Candidates should be able to:

- draw straight lines of best fit or curves to show the trend of a graph
- draw tangents to curved trend lines.

The trend line should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn, continuous, and with a thickness of less than 1 mm, and should not contain kinks. If necessary, candidates may identify one point as anomalous and ignore this point when drawing the line. The anomalous point must be identified, e.g. circled or labelled.

Analysis, conclusions and evaluation

Interpretation of graph

Candidates should be able to:

- relate straight-line graphs to equations of the form $y = mx + c$, and derive expressions that equate to the gradient and/or the y-intercept of their graphs
- read the coordinates of points on the trend line of a graph
- determine the gradient of a straight-line graph or of a tangent to a curve
- determine the y-intercept of a straight-line graph or of a tangent to a curve, including where these are on graphs with a false origin.

When a gradient is to be determined, the points on the line chosen for the calculation should be separated by more than half of the length of the line drawn.

In cases where the y-intercept cannot be read directly from the y-axis, it is expected that the coordinates of a point on the line and the gradient will be substituted into $y = mx + c$ to determine the y-intercept

Estimating uncertainties

Candidates should be able to:

- estimate the absolute uncertainty in measurements
- express the uncertainty in a measurement as an absolute or percentage uncertainty, and translate between these forms
- express the absolute uncertainty in a repeated measurement as half the range of the repeated readings, where this is appropriate.

Drawing conclusions

Candidates should be able to:

- draw conclusions from an experiment, including determining the values of constants
- explain whether experimental data supports a given hypothesis
- make predictions.

To determine whether a relationship containing a constant is supported by experimental data, candidates should:

- calculate the percentage difference between values of the constant
- compare this percentage difference with a given percentage uncertainty
- give a conclusion based on this comparison.

Identifying limitations

Candidates should be able to:

- identify and describe the limitations in an experimental procedure
- identify the most significant sources of uncertainty in an experiment.

For uncertainties in measured quantities, candidates should state the quantity being measured and a reason for the uncertainty.

Suggesting improvements

Candidates should be able to:

- suggest modifications to an experimental arrangement that will improve the accuracy of the experiment or to extend the investigation to answer a new question
- describe these modifications clearly in words or diagrams.

Candidates' suggestions should be realistic, so that in principle they are achievable in practice in a school laboratory. The suggestions may include the use of other apparatus or different procedures, but not a different experiment. The suggested modifications may relate to sources of uncertainty identified by the candidate. Improvements that could have been made with the apparatus provided while following the instructions in the question will not normally gain credit.

Administration of Paper 3

Detailed regulations on the administration of Cambridge International practical examinations are contained in the *Cambridge Handbook*.

Details of the specific requirements for apparatus and materials for a particular examination are given in the confidential instructions which are sent to centres several weeks prior to the examination. Centres should contact Cambridge International if they believe the confidential instructions have not been received.

It is the responsibility of centres to provide the apparatus for practical examinations. Cambridge is not able to supply apparatus directly or provide advice on local suppliers of apparatus.

Apparatus and materials

Below is a list of the items that are regularly used in Paper 3. The list is not exhaustive: other items are usually required, to allow for variety in the questions set.

cells: 1.5 V
connecting leads and crocodile clips
digital ammeter, minimum ranges 0–1 A reading to 0.01 A or better, 0–200 mA reading to 0.1 mA or better, 0–20 mA reading to 0.01 mA or better (digital multimeters are suitable)
digital voltmeter, minimum ranges 0–2 V reading to 0.001 V or better, 0–20 V reading to 0.01 V or better (digital multimeters are suitable)
lamp and holder: 6 V 60 mA; 2.5 V 0.3 A
power supply: variable up to 12 V d.c. (low resistance)
rheostat (with a maximum resistance of at least 8 Ω, capable of carrying a current of at least 4 A)
switch
wire: constantan 26, 28, 30, 32, 34, 36, 38 swg or similar metric sizes

long stem thermometer: –10 °C to 110 °C reading to 1 °C
means to heat water safely to boiling (e.g. an electric kettle)
plastic or polystyrene cup 200 cm^3
stirrer

adhesive putty (e.g. Blu-tack)
adhesive tape (e.g. Sellotape)
balance reading to 0.1 g (this item may often be shared between sets of apparatus)
bar magnet
bare copper wire: 18, 20, 26 swg or similar metric sizes
beaker: 100 cm^3, 200 cm^3 or 250 cm^3
card
expendable steel spring (spring constant approx. 25 $N\,m^{-1}$; unstretched length approx. 2 cm)
G-clamp
Magnadur ceramic magnets
mass hanger
micrometer screw gauge (this item may often be shared between sets of apparatus)
modelling clay (e.g. Plasticine)
newton meter (1 N, 10 N)
pendulum bob
protractor
pulley
rule with a millimetre scale (1 m, 0.5 m, 300 mm)
scissors
slotted masses (100 g, 50 g, 20 g, 10 g)
stand, boss and clamp
stop-watch (candidates may use their wristwatches), reading to 0.1 s or better
stout pin or round nail
string/thread/twine
vernier or digital calipers (this item may often be shared between sets of apparatus)
wire cutters

Safety in the laboratory

Responsibility for safety matters rests with centres.

The attention of centres is drawn to any local regulations relating to safety and first aid.

Paper 5 Planning, Analysis and Evaluation

Paper 5 will be a timetabled written paper, focusing on the higher-order experimental skills of planning, analysis and evaluation.

This examination will not require laboratory facilities.

To prepare candidates for this exam, it should be emphasised that candidates will need extensive experience of laboratory work of A Level standard. In particular, learners cannot be taught to plan experiments effectively unless, on a number of occasions, they are required to:

- plan an experiment
- perform the experiment according to their plan
- evaluate what they have done.

This requires many hours of laboratory-based work and careful supervision from teachers to ensure that experiments are performed safely.

Paper 5 will consist of two questions each of 15 marks.

Question 1 will be a planning question, in which candidates will be required to design an experimental investigation of a given problem. The question will not be highly structured: candidates will be expected to answer with a diagram and an extended piece of writing.

Question 2 will be an analysis, conclusions and evaluation question, in which candidates will be given an equation and some experimental data. From these they will be required to find the value of a constant. This question will be structured but candidates will be expected to decide for themselves what they need to do in order to reach an answer. They will also be required to estimate the uncertainty in their answer.

Some questions on this paper may be set in areas of physics that are difficult to investigate experimentally in school laboratories, either because of the cost of equipment or because of restrictions on the availability of materials (e.g. radioactive materials). No question will require knowledge of theory or equipment that is beyond the syllabus. Candidates will be given the necessary information for questions set on topics that do not form part of the syllabus.

Mark allocations for Paper 5

Marks will be allocated for Paper 5 according to the table below. The expectations for each skill are listed in the sections that follow.

Question 1		
Skill	**Breakdown of skills**	**Mark allocation**
Planning	Defining the problem	15 marks
	Methods of data collection	
	Method of analysis	
	Additional detail including safety considerations	

Question 2		
Skill	**Breakdown of skills**	**Mark allocation**
Analysis, conclusions and evaluation	Data analysis	15 marks
	Table of results	
	Graph	
	Conclusion	
	Treatment of uncertainties	

Expectations for each skill (Paper 5)

Planning

Defining the problem

Candidates should be able to:

- identify the independent variable in the experiment
- identify the dependent variable in the experiment
- identify the variables that are to be kept constant.

Methods of data collection

Candidates should be able to:

- describe the method to be used to vary the independent variable
- describe how the independent and dependent variables are to be measured
- describe how other variables are to be kept constant
- describe, with the aid of a clear labelled diagram, the arrangement of apparatus for the experiment and the procedures to be followed.

For full credit to be awarded in this section, the overall arrangement must be workable, that is, it should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. The measuring instruments chosen should be fit for purpose, in that they should measure the correct physical quantity to a suitable precision for the experiment.

Method of analysis

Candidates should be able to:

- describe how the data should be used in order to reach a conclusion, including details of derived quantities to be calculated from graphs.

Additional detail including safety considerations

Marks will be available for additional relevant detail including safety precautions.

How these marks are awarded will depend on the experiment that is to be planned, but they might, for example, include marks for describing how additional variables are to be kept constant, or for a diagram of a circuit needed to make a particular measurement or a description of initial experiments or an explanation of how to obtain calibration curves.

For safety considerations, candidates should be able to:

- assess the risks of their experiment
- describe precautions that should be taken to keep risks to a minimum.

Candidates should be able to:

- describe the use of an oscilloscope (or storage oscilloscope) to measure voltage, current, time and frequency
- describe how to use light gates connected to a data logger to determine time, velocity and acceleration
- describe how other sensors can be used with a data logger, e.g. motion sensor.

Analysis, conclusions and evaluation

Data analysis

Candidates should be able to:

- rearrange expressions into the forms $y = mx + c$, $y = ax^n$ and $y = ae^{kx}$
- understand how a graph of y against x is used to find the constants m and c in an equation of the form $y = mx + c$
- understand how a graph of log y against log x is used to find the constants a and n in an equation of the form $y = ax^n$
- understand how a graph of $\ln y$ against x is used to find the constants a and k in an equation of the form $y = ae^{kx}$
- decide what derived quantities to calculate from raw data in order to enable an appropriate graph to be plotted.

Table of results

Candidates should be able to:

- complete a table of results following the conventions required for Paper 3
- calculate other quantities from raw data and record them in a table
- use the correct number of significant figures for calculated quantities following the conventions required for Paper 3.

Where logarithms are required, units should be shown with the quantity whose logarithm is being taken, e.g. ln (*d* / cm). The logarithm itself does not have a unit.

For logarithmic quantities, the number of decimal places should correspond to the number of significant figures. For example, if *L* / cm is 76.5 (3 sf), then lg (*L* / cm) should be either 1.884 (3 dp) or 1.8837 (4 dp).

Graph

Candidates should be able to:

- plot a graph following the conventions required for Paper 3
- show error bars, in both directions where appropriate, for each point on the graph
- draw a straight line of best fit and a worst acceptable straight line through the points on the graph.

The worst acceptable line should be either the steepest possible line or the shallowest possible line that passes through the error bars of all the data points. It should be distinguished from the line of best fit either by being drawn as a broken line or by being clearly labelled.

Conclusion

Candidates should be able to:

- determine the gradient and *y*-intercept of a straight-line graph
- derive expressions that equate to the gradient or the *y*-intercept of their straight lines of best fit
- draw the required conclusions, with correct units and appropriate number of significant figures, from these expressions.

Treatment of uncertainties

Candidates should be able to:

- convert absolute uncertainty estimates into fractional or percentage uncertainty estimates and vice versa
- show uncertainty estimates, in absolute terms, beside every value in a table of results
- calculate uncertainty estimates in derived quantities
- estimate the absolute uncertainty in the gradient of a graph by recalling that
  absolute uncertainty = gradient of line of best fit – gradient of worst acceptable line
- estimate the absolute uncertainty in the *y*-intercept of a graph by recalling that
  absolute uncertainty = *y*-intercept of line of best fit – *y*-intercept of worst acceptable line
- express a quantity as a value, an uncertainty estimate and a unit.

6 Additional information

Mathematical requirements

We expect candidates to be able to use the following mathematical skills and knowledge in the assessment. Teaching the mathematical requirements should be included in the AS & A Level Physics course.

At AS Level and A Level

Arithmetic

Candidates should be able to:

- recognise and use expressions in decimal and standard form (scientific) notation
- use a calculator for addition, subtraction, multiplication and division, and find arithmetic means, powers (including reciprocals and *n*th-roots), sines, cosines, tangents (and the inverse functions)
- understand how to perform calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified
- use approximations to check the magnitude of calculated results.

Algebra

Candidates should be able to:

- change the subject of an equation (most relevant equations involve only the simpler operations but may include positive and negative indices and *n*th-roots)
- solve simple algebraic equations
- solve a system of two linear simultaneous equations
- recall and use the formula $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ to solve quadratic equations
- substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations
- set up simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models
- use percentages to express changes or uncertainties
- understand and use the symbols $<$, $>$, $\leqslant$, $\geqslant$, $\ll$, $\gg$, $\approx$, $\pm$, $/$, $\propto$, $\langle x \rangle$ $(= \bar{x})$, $\sum$, Δx, $\sqrt{\ }$, $\sqrt[n]{\ }$.

Geometry and trigonometry

Candidates should be able to:

- recall and use formulae for the area and perimeter/circumference of rectangles, circles, right-angled and isosceles triangles
- recall and use formulae for the volume and surface area of cuboids, cylinders and spheres
- recall and use Pythagoras' theorem in 2 and 3 dimensions
- use the similarity of triangles and the angle sum of a triangle
- understand and use the definitions of sin, cos and tan as applied to a right-angled triangle, and recall and use the relationship $\sin\theta / \cos\theta = \tan\theta$
- recall and use the trigonometric relationships for triangles $a/\sin A = b/\sin B = c/\sin C$ and $a^2 = b^2 + c^2 - 2bc \cos A$.

Vectors

Candidates should be able to:

- find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate
- obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate.

Graphs

Candidates should be able to:

- select appropriate variables and scales for graph plotting
- determine the gradient, intercept and intersection of linear graphs
- choose, by inspection, a straight line which will serve as the line of best fit through a set of data points presented graphically
- draw a curved trend line through a set of data points presented graphically, when the arrangement of these data points is clearly indicative of a non-linear relationship
- sketch and recognise the forms of plots of common simple expressions like $\frac{1}{x}$, x^2, $\frac{1}{x^2}$, $\sin x$, $\cos x$
- draw a tangent to a curve, and understand and use the gradient of the tangent as a means to obtain the gradient of the curve at a point
- understand and use the area below a curve where the area has physical significance.

Additional requirements for A level only

Geometry and trigonometry

Candidates should be able to:

- recall and use $\sin^2\theta + \cos^2\theta = 1$
- recall and use $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ
- understand the relationship between degrees and radians, convert from one to the other and use the appropriate system in context.

Exponentials and logarithms

Candidates should be able to:

- calculate exponentials and logarithms (lg and ln)
- recognise and use the logarithms of expressions like ab, $\frac{a}{b}$, x^n, e^{kx}
- sketch and recognise the form of a plot of e^{-x}
- use logarithmic plots to test exponential and power law variations

Summary of key quantities, symbols and units

The list below is intended as a guide to the more important quantities which might be encountered in teaching and used in question papers.

This list is for use in both AS Level and full A Level qualifications.

Quantity	Usual symbols	Usual unit
Base quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
acceleration	a	$\mathrm{m\,s^{-2}}$
acceleration of free fall	g	$\mathrm{m\,s^{-2}}$
activity of radioactive source	A	Bq
amplitude	x_0	m
angle	θ	°, rad
angular displacement	θ	°, rad
angular frequency	ω	$\mathrm{rad\,s^{-1}}$
angular speed	ω	$\mathrm{rad\,s^{-1}}$
angular velocity	ω	$\mathrm{rad\,s^{-1}}$
area	A	$\mathrm{m^2}$
atomic mass	m_a	kg, u
attenuation/absorption coefficient	μ	$\mathrm{m^{-1}}$
Avogadro constant	N_A	$\mathrm{mol^{-1}}$
Boltzmann constant	k	$\mathrm{J\,K^{-1}}$
capacitance	C	F
Celsius temperature	θ	°C
decay constant	λ	$\mathrm{s^{-1}}$
density	ρ	$\mathrm{kg\,m^{-3}}$
displacement	s, x	m
distance	d	m
efficiency	η	
electric charge	q, Q	C
electric field strength	E	$\mathrm{N\,C^{-1}}$, $\mathrm{V\,m^{-1}}$
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
electron mass	m_e	kg, u
elementary charge	e	C

Quantity	Usual symbols	Usual unit
energy	E, U, W	J
force	F	N
frequency	f	Hz
gravitational constant	G	$\mathrm{N\,m^2\,kg^{-2}}$
gravitational field strength	g	$\mathrm{N\,kg^{-1}}$
gravitational potential	ϕ	$\mathrm{J\,kg^{-1}}$
half-life	$t_{\frac{1}{2}}$	s
Hall voltage	V_H	V
heating	q, Q	J
Hubble constant	H_0	$\mathrm{s^{-1}}$
intensity	I	$\mathrm{W\,m^{-2}}$
internal energy change	ΔU	J
kinetic energy	E_K	J
luminosity	L	W
magnetic flux	Φ	Wb
magnetic flux density	B	T
mean-square speed	$\langle c^2 \rangle$	$\mathrm{m^2\,s^{-2}}$
molar gas constant	R	$\mathrm{J\,mol^{-1}\,K^{-1}}$
moment of force	T	N m
momentum	p	N s
neutron mass	m_n	kg, u
neutron number	N	
nucleon number	A	
number	N, n, m	
number density (number per unit volume)	n	$\mathrm{m^{-3}}$
period	T	s
permeability of free space	μ_0	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	$\mathrm{F\,m^{-1}}$
phase difference	ϕ	°, rad
Planck constant	h	J s
potential energy	E_P	J
power	P	W
pressure	p	Pa
proton mass	m_p	kg, u
proton number	Z	
radiant flux intensity	F	$\mathrm{W\,m^{-2}}$
resistance	R	Ω
resistivity	ρ	Ω m

Quantity	Usual symbols	Usual unit
specific acoustic impedance	Z	$kg\,m^{-2}\,s^{-1}$
specific heat capacity	c	$J\,kg^{-1}\,K^{-1}$
specific latent heat	L	$J\,kg^{-1}$
speed	u, v, w, c	$m\,s^{-1}$
speed of electromagnetic waves	c	$m\,s^{-1}$
spring constant	k	$N\,m^{-1}$
Stefan–Boltzmann constant	σ	$W\,m^{-2}\,K^{-4}$
strain	ε	
stress	σ	Pa
time constant	τ	s
torque	T	N m
velocity	u, v, w, c	$m\,s^{-1}$
volume	V, v	m^3
wavelength	λ	m
weight	W	N
work	w, W	J
work function energy	Φ	J
Young modulus	E	Pa

Data and formulae

The following data and formulae will appear on page 2 in Papers 1, 2 and 4.

Data

acceleration of free fall	$g = 9.81\,\text{m}\,\text{s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^{8}\,\text{m}\,\text{s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
unified atomic mass unit	$1\,\text{u} = 1.66 \times 10^{-27}\,\text{kg}$
rest mass of proton	$m_\text{p} = 1.67 \times 10^{-27}\,\text{kg}$
rest mass of electron	$m_\text{e} = 9.11 \times 10^{-31}\,\text{kg}$
Avogadro constant	$N_\text{A} = 6.02 \times 10^{23}\,\text{mol}^{-1}$
molar gas constant	$R = 8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\text{J}\,\text{K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\text{N}\,\text{m}^{2}\,\text{kg}^{-2}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F}\,\text{m}^{-1}$
	$(\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\text{m}\,\text{F}^{-1})$
Planck constant	$h = 6.63 \times 10^{-34}\,\text{J}\,\text{s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$

Formulae

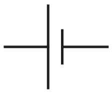
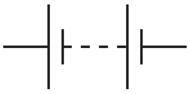
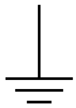
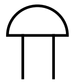
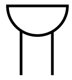
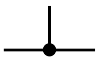
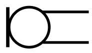
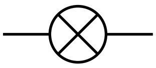
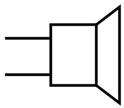
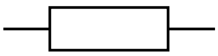
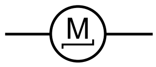
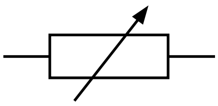
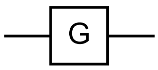
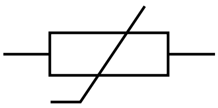
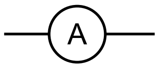
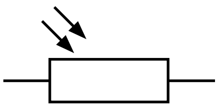
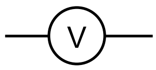
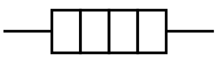
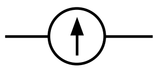
uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_o = \dfrac{f_s v}{v \pm v_s}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \ldots$

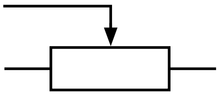
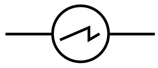
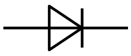
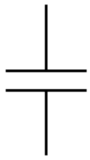
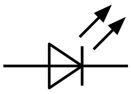
The following formulae will appear on page 3 in Paper 4.

gravitational potential	$\phi = -\dfrac{GM}{r}$
gravitational potential energy	$E_P = -\dfrac{GMm}{r}$
pressure of an ideal gas	$p = \tfrac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm\omega\sqrt{(x_0^2 - x^2)}$
electric potential	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
electrical potential energy	$E_P = \dfrac{Qq}{4\pi\varepsilon_0 r}$
capacitors in series	$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \dfrac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \dfrac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\dfrac{I_R}{I_0} = \dfrac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

Circuit symbols

The following table gives a guide to the circuit symbols that may be used in examination papers.

cell		switch	
battery of cells	 or 	earth	
power supply		electric bell	
a.c. power supply		buzzer	
junction of conductors		microphone	
lamp		loudspeaker	
fixed resistor		motor	
variable resistor		generator	
thermistor		ammeter	
light-dependent resistor		voltmeter	
heater		galvanometer	

potentiometer		oscilloscope	
diode		capacitor	
light-emitting diode			

7 What else you need to know

This section is an overview of other information you need to know about this syllabus. It will help to share the administrative information with your exams officer so they know when you will need their support. Find more information about our administrative processes at **www.cambridgeinternational.org/eoguide**

Before you start

Previous study

We recommend that learners starting this course should have completed a course in Physics or Co-ordinated Science equivalent to Cambridge IGCSE™ or Cambridge O Level.

Guided learning hours

We design Cambridge International AS & A Level syllabuses based on learners having about 180 guided learning hours for each Cambridge International AS Level and about 360 guided learning hours for a Cambridge International A Level. The number of hours a learner needs to achieve the qualification may vary according to local practice and their previous experience of the subject.

Availability and timetables

All Cambridge schools are allocated to one of six administrative zones. Each zone has a specific timetable.

You can view the timetable for your administrative zone at **www.cambridgeinternational.org/timetables**

You can enter candidates in the June and November exam series. If your school is in India, you can also enter your candidates in the March exam series.

Check you are using the syllabus for the year the candidate is taking the exam.

Private candidates can enter for this syllabus. However, it is expected that private candidates learn in an environment where practical work is an integral part of the course. Candidates will not be able to perform well in this assessment or progress successfully to further study without this necessary and important aspect of science education. For more information, please refer to the *Cambridge Guide to Making Entries*.

Combining with other syllabuses

Candidates can take this syllabus alongside other Cambridge International syllabuses in a single exam series. The only exceptions are:

- syllabuses with the same title at the same level.

Group awards: Cambridge AICE

Cambridge AICE (Advanced International Certificate of Education) is a group award for Cambridge International AS & A Level. It allows schools to offer a broad and balanced curriculum by recognising the achievements of learners who pass examinations in a range of different subjects.

Learn more about Cambridge AICE at **www.cambridgeinternational.org/aice**

Making entries

Exams officers are responsible for submitting entries to Cambridge International. We encourage them to work closely with you to make sure they enter the right number of candidates for the right combination of syllabus components. Entry option codes and instructions for submitting entries are in the *Cambridge Guide to Making Entries*. Your exams officer has a copy of this guide.

Exam administration

To keep our exams secure, we produce question papers for different areas of the world, known as administrative zones. We allocate all Cambridge schools to one administrative zone determined by their location. Each zone has a specific timetable. Some of our syllabuses offer candidates different assessment options. An entry option code is used to identify the components the candidate will take relevant to the administrative zone and the available assessment options.

Support for exams officers

We know how important exams officers are to the successful running of exams. We provide them with the support they need to make your entries on time. Your exams officer will find this support, and guidance for all other phases of the Cambridge Exams Cycle, at **www.cambridgeinternational.org/eoguide**

Retakes

Candidates can retake Cambridge International AS Level and Cambridge International A Level as many times as they want to. To confirm what entry options are available for this syllabus, refer to the *Cambridge Guide to Making Entries* for the relevant series.

Candidates can carry forward the result of their Cambridge International AS Level assessment from one series to complete the Cambridge International A Level in a following series, subject to the rules and time limits described in the *Cambridge Handbook*.

Equality and inclusion

We have taken great care to avoid bias of any kind in the preparation of this syllabus and related assessment materials. In compliance with the UK Equality Act (2010) we have designed this qualification to avoid any direct and indirect discrimination.

The standard assessment arrangements may present unnecessary barriers for candidates with disabilities or learning difficulties. We can put arrangements in place for these candidates to enable them to access the assessments and receive recognition of their attainment. We do not agree access arrangements if they give candidates an unfair advantage over others or if they compromise the standards being assessed.

Candidates who cannot access the assessment of any component may be able to receive an award based on the parts of the assessment they have completed.

Information on access arrangements is in the *Cambridge Handbook* at **www.cambridgeinternational.org/eoguide**

Language

This syllabus and the related assessment materials are available in English only.

After the exam

Grading and reporting

Grades A*, A, B, C, D or E indicate the standard a candidate achieved at Cambridge International A Level, with A* being the highest grade.

Grades a, b, c, d or e indicate the standard a candidate achieved at Cambridge International AS Level, with 'a' being the highest grade.

'Ungraded' means that the candidate's performance did not meet the standard required for the lowest grade (E or e). 'Ungraded' is reported on the statement of results but not on the certificate. In specific circumstances your candidates may see one of the following letters on their statement of results:

- Q (pending)
- X (no result)
- Y (to be issued).

These letters do not appear on the certificate.

If a candidate takes a Cambridge International A Level and fails to achieve grade E or higher, a Cambridge International AS Level grade will be awarded if both of the following apply:

- the components taken for the Cambridge International A Level by the candidate in that series included all the components making up a Cambridge International AS Level
- the candidate's performance on the AS Level components was sufficient to merit the award of a Cambridge International AS Level grade.

On the statement of results and certificates, Cambridge International AS & A Levels are shown as General Certificates of Education, GCE Advanced Subsidiary Level (GCE AS Level) and GCE Advanced Level (GCE A Level).

'Cambridge International A Levels are the 'gold standard' qualification. They are based on rigorous, academic syllabuses that are accessible to students from a wide range of abilities yet have the capacity to stretch our most able.'

Director of Studies, Auckland Grammar School, New Zealand

How students, teachers and higher education can use the grades

Cambridge International A Level

Assessment at Cambridge International A Level has two purposes:

- to measure learning and achievement
  The assessment:
  – confirms achievement and performance in relation to the knowledge, understanding and skills specified in the syllabus, to the levels described in the grade descriptions.

- to show likely future success
  The outcomes:
  – help predict which students are well prepared for a particular course or career and/or which students are more likely to be successful
  – help students choose the most suitable course or career.

Cambridge International AS Level

Assessment at Cambridge International AS Level has two purposes:

- to measure learning and achievement
  The assessment:
  – confirms achievement and performance in relation to the knowledge, understanding and skills specified in the syllabus.

- to show likely future success
  The outcomes:
  – help predict which students are well prepared for a particular course or career and/or which students are more likely to be successful
  – help students choose the most suitable course or career
  – help decide whether students part way through a Cambridge International A Level course are making enough progress to continue
  – guide teaching and learning in the next stages of the Cambridge International A Level course.

Grade descriptions

Grade descriptions are provided to give an indication of the standards of achievement candidates awarded particular grades are likely to show. Weakness in one aspect of the examination may be balanced by a better performance in some other aspect.

Grade descriptions for Cambridge International A Level Physics will be published after the first assessment of the A Level in 2022. Find more information at **www.cambridgeinternational.org/alevel**

Changes to this syllabus for 2022, 2023 and 2024

The syllabus has been updated. The latest version is version 2, published June 2020. The changes are indicated by vertical black lines.

The syllabus has been reviewed and revised for first examination in 2022.

You are strongly advised to read the whole syllabus before planning your teaching programme.

From 2022, the A Level components will assume knowledge of the **revised** AS Level content. All candidates should therefore be familiar with the AS Level content in this syllabus.

Changes to version 2, published June 2020

Changes to syllabus	• The wording in learning outcome 3.1.6 and 4.1.1 has been updated. The meaning of these learning outcomes has not changed. • The list of command words has been updated on page 34. • The heading of 14.3 has been corrected to Specific Heat Capacity on page 24.

Changes to version 1, published September 2019

Changes to syllabus content	• The learner attributes have been updated. • Small changes have been made to the key concepts to better reflect the overarching ideas that run throughout physics. • The structure of the subject content has changed so that the AS Level and A Level content is now split into separate sections. This makes the distinction between the AS Level and A Level content clearer. • The wording in the learning outcomes has been updated to provide clarity to what depth each topic should be taught. Although the wording will look different in many places, the content to teach remains largely the same. • There has been a limited amount of change to topics: some topics have been removed and others added, and some content has moved from AS Level to A Level and vice versa; but the teaching time still falls within the recommended guided learning hours. • Two topics 'Communication' and 'Electronics' have been removed from the A Level. • A new topic 'Astronomy and cosmology' has been added to the A Level. • The AS Level content on electric fields has been moved to the A Level. • The sub-topics 'NMRI' and 'Band theory' have been removed from the A Level. • The new sub-topics 'PET scanning' and 'Discharging a capacitor' have been added to the A Level. • The new sub-topic 'Polarisation' has been added to the AS Level. • Content on 'LDRs (light-dependent resistors)' and 'thermistors' has been moved from the A Level to the AS Level. • The topic 'Measurement techniques' is covered under practical skills. • The learning outcomes have been numbered, rather than listed by letters.

Changes to syllabus content continued	• The Practical assessment section has been updated and further explanation has been provided. • The Mathematical requirements have been updated. • The Summary of key quantities, symbols and units section has been updated. • The Data and formulae have been updated. Separate formulae are provided for AS Level and A Level. • The Circuit symbols have been updated. • The list of command words has been updated.
Changes to assessment (including changes to specimen papers)	• The syllabus aims have been updated to improve the clarity of wording and the consistency between AS & A Level Biology, Chemistry and Physics. • The wording of the assessment objectives (AOs) has been updated to ensure consistency across AS & A Level Biology, Chemistry and Physics. The assessment objectives still test the same knowledge and skills as previously. • The weightings of the AOs are now given as an approximate weighting. Please see section 2 Syllabus overview for details.

In addition to reading the syllabus, you should refer to the updated specimen papers. The specimen papers will help your students become familiar with exam requirements and command words in questions. The specimen mark schemes explain how students should answer questions to meet the assessment objectives.

Any textbooks endorsed to support the syllabus for examination from 2022 are suitable for use with this syllabus.

‘While studying Cambridge IGCSE and Cambridge International A Levels, students broaden their horizons through a global perspective and develop a lasting passion for learning.’

Zhai Xiaoning, Deputy Principal, The High School Affiliated to Renmin University of China

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