CAMBRIDGE
International Examinations

Cambridge
Pre-U

SYLLABUS

Cambridge International Level 3
Pre-U Certificate in
Physics (Principal)

9792

For examination in 2016, 2017 and 2018

QN: 500/3684/1

Cambridge Advanced

Support

Cambridge provides a wide range of support for Pre-U syllabuses, which includes recommended Resource Lists, Teacher Guides and Example Candidate Response booklets. Teachers can access these support materials at Teacher Support **http://teachers.cie.org.uk**

Changes to syllabus for 2016, 2017 and 2018

This syllabus has been updated. Significant changes to the syllabus are indicated by black vertical lines either side of the text.

New content (2016 references)

1(m); 1(n); 4(c); 12(g); 12(h); 12(i); 15(h)*; 17(p)
Mathematics: A29; A30

Clarified content (2016 references)

6(j); 15(e)*, 15(f)*; 15(g)*; 15(h)*; 19(f)*

Deleted content (2015 references)

5.7 Deduce using numerical methods the maximum power transfer from a source of emf is achieved when the load resistance is equal to the internal resistance

7.6 Understand amplitude modulation as an example of superposition and use the terms signal and carrier wave

14.10 Explain how electric and magnetic fields are used as a velocity selector in a mass spectrometer and derive, recall and use $v = \frac{E}{B}$

19.3 *Recognise and use … $\Delta E \Delta t \geq \frac{h}{2\pi}$ as a form of the Heisenberg uncertainty principle and interpret it

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

If there are any further changes to this syllabus, Cambridge will write to Centres to inform them. This syllabus is also on the Cambridge website **www.cie.org.uk/cambridgepreu**. The version of the syllabus on the website should always be considered as the definitive version.

*Learning outcomes assessed in Section 2 of Paper 3, Written Paper.

Copies of Cambridge Pre-U syllabuses can be downloaded from our website
www.cie.org.uk/cambridgepreu

Contents

Introduction

Why choose Cambridge Pre-U?

Cambridge Pre-U is designed to equip learners with the skills required to make a success of their studies at university. Schools can choose from a wide range of subjects.

Cambridge Pre-U is built on a core set of educational aims to prepare learners for university admission, and also for success in higher education and beyond:

- to support independent and self-directed learning
- to encourage learners to think laterally, critically and creatively, and to acquire good problem-solving skills
- to promote comprehensive understanding of the subject through depth and rigour.

Cambridge Pre-U Principal Subjects are linear. A candidate must take all the components together at the end of the course in one examination series. Cambridge Pre-U Principal Subjects are assessed at the end of a two-year programme of study.

The Cambridge Pre-U nine-point grade set recognises the full range of learner ability.

Guided learning hours

Cambridge Pre-U syllabuses are designed on the assumption that learners have around 380 guided learning hours per Principal Subject over the duration of the course, but this is for guidance only. The number of hours may vary according to curricular practice and the learners' prior experience of the subject.

Why choose Cambridge Pre-U Physics?

Cambridge Pre-U Physics enables learners to appreciate the role of physics in the real world by illustrating its use in medicine, biophysics, engineering, space exploration, transport, robotics, communications, global energy solutions, and environmental issues.

Cambridge Pre-U Physics provides learners with the opportunity to develop a sound understanding of the subject through rigorous mathematical reasoning, while at the same time fostering a historical and philosophical perspective in physics.

The syllabus will allow learners to acquire and develop problem-solving techniques in order to reach solutions to mathematical problems. Multi-step problem solving will be particularly useful for learners intending to go on to study engineering and more advanced physics courses.

To complement the mathematical rigour of the syllabus, Cambridge Pre-U Physics allows learners to reflect on the development and impact of philosophical, historical and ethical ideas in physics. These contrasting approaches to physics are designed to appeal to a wide range of learners; the mathematically competent learners who will find it satisfying to develop their understanding of philosophical approaches and key physical concepts, as well as those learners who strongly prefer mathematical analysis to problem solving.

Examination questions allow learners to apply their knowledge and understanding to novel contexts. Optional questions allow candidates an element of choice between questions with a strong mathematical flavour and those which are more discursive and reflective.

The linear assessment structure in which learners are tested at the end of the two-year course allows learners time to develop their knowledge, understanding and skills, and make links between different topics.

The Personal Investigation enables learners to develop experimental skills by carrying out an extended independent practical investigation into a topic which engages their interest. The development of practical skills is fundamental to the subject, and the investigation gives learners the opportunity to develop skills such as sound experimental methods and techniques for analysing data.

Prior learning

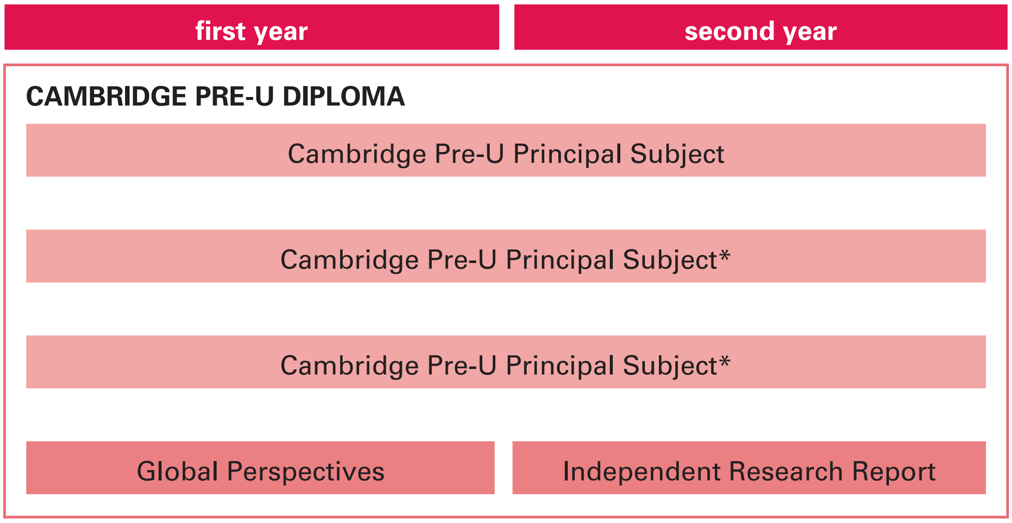
Cambridge Pre-U Physics builds on the knowledge, understanding and skills typically gained by candidates achieving Level 2 qualifications (equivalent to GCSE at grades A* to C) in physics or other comparable qualifications, including IGCSE Physics, IGCSE Co-ordinated Science and GCSE Science plus GCSE Additional Science.

Progression

Cambridge Pre-U is considered to be an excellent preparation for university and employment. It helps to develop the in-depth subject knowledge and understanding which are so important to universities and employers. Cambridge Pre-U Physics equips learners with a coherent theoretical and practical base of transferable skills and key knowledge for future study and employment in physics and related fields (e.g. medicine, engineering and applied sciences), while providing thought-provoking material to appeal to those who do not wish to pursue a scientific career.

Cambridge Pre-U Diploma

If learners choose, they can combine Cambridge Pre-U qualifications to achieve the Cambridge Pre-U Diploma; this comprises three Cambridge Pre-U Principal Subjects* together with Global Perspectives and Research (GPR). The Cambridge Pre-U Diploma, therefore, provides the opportunity for interdisciplinary study informed by an international perspective and includes an independent research project.



* Up to two A Levels, Scottish Advanced Highers or IB Diploma programme courses at higher level can be substituted for Principal Subjects.

Learn more about the Cambridge Pre-U Diploma at **www.cie.org.uk/cambridgepreu**

Syllabus aims

The aims of the syllabus, listed below, are the same for all candidates, and are to:

- equip learners with the principles with which they can make sense of the large body of physics knowledge
- develop learners' skills in solving physical problems and rationalising unfamiliar material
- enable learners to use mathematical reasoning to help them understand phenomena and solve problems
- enable learners to develop an understanding of key physics concepts
- enable learners to acquire a sound knowledge and understanding of some of the historical and philosophical developments in particular aspects of physics
- develop learners' understanding of the link between theory and experiment and foster the development of skills required for the design and execution of experiments
- instil in learners a sense of safe laboratory practice and equip them with the necessary laboratory skills to pursue the subject beyond this course
- foster the development of attitudes relevant to science such as concern for accuracy and precision, objectivity, integrity and the skills of enquiry, initiative and inventiveness
- promote an awareness of the use and development of scientific models
- provide the tools for learners to analyse independently, and to develop an informed interest in major scientific issues
- develop transferable skills applicable to the study and communication of science
- develop an understanding of the links between physics and other scientific and technological subjects
- promote an awareness that physics is a co-operative and cumulative activity, subject to technological, economic, historical, cultural, social and ethical factors
- promote the value of physics to society and stimulate interest in, and care for, the environment in relation to the impact of physics and its applications.

Scheme of assessment

For Cambridge Pre-U Physics, candidates take all four components.

Components	Weighting
Paper 1 Multiple Choice **1 hour 30 minutes** Candidates answer 40 multiple-choice questions based on Parts A and B of the syllabus content. 40 marks Externally assessed	20%
Paper 2 Written Paper **2 hours** Section 1: Candidates answer structured questions based on Part A of the syllabus content. Section 2: Candidates answer structured questions related to pre-released material. The pre-released material may be linked to any part of the syllabus and may introduce new concepts upon which questions are based. 100 marks Externally assessed	30%
Paper 3 Written Paper **3 hours** Section 1: Candidates answer structured questions requiring short answers or calculations and some longer answers. The questions are focused on Part B of the syllabus content, but may also draw on Part A. Section 2: Candidates answer three questions from a choice of six. Three questions will have a strong mathematical focus and three questions will focus on philosophical issues and/or physics concepts. Learning outcomes marked with an asterisk (*) will only be assessed in this section. 140 marks Externally assessed	35%
Personal Investigation **20 hours** Candidates plan and carry out an investigtion of a practical problem of their own choosing. Candidates are assessed on their ability to: plan; make detailed observations of measurements; use a range of measuring instruments; use appropriate physics principles; and produce a well-organised report. Candidates are allowed a maximum of 20 hours to complete this investigation, including planning and writing up. 30 marks Internally marked and externally moderated	15%

Availability

This syllabus is examined in the June examination series.

The syllabus is available to private candidates with the exception of Component 4 (Personal Investigation), which may be carried forward from a previous examination series.

Combining this with other syllabuses

Candidates can combine this syllabus in any examination series with any other Cambridge syllabus, except syllabuses with the same title at the same level.

Assessment objectives

AO1	**Knowledge with understanding** Candidates will be expected to demonstrate knowledge and understanding in relation to: • scientific phenomena, facts, laws, definitions, quantities, principles, concepts and theories, and the relationships and models used to explain them • scientific vocabulary, terminology and conventions (including symbols, quantities and units) • scientific instruments, apparatus and methods, and their uses • scientific developments and the methodology used to develop knowledge. The content of the syllabus defines the actual knowledge that candidates may be required to recall and explain.	**40%**
AO2	**Application of knowledge and problem solving** Candidates will be expected to: • select, organise, interpret and present scientific information • translate information from one form to another (including manipulating numerical and other data) • analyse scientific information by identifying and explaining patterns and trends, drawing inferences and conclusions, and constructing arguments • evaluate scientific information in terms of validity, accuracy and precision • apply and synthesise scientific skills, knowledge and understanding to solve problems and explain phenomena. This assessment objective relates primarily to unfamiliar data, phenomena or situations which, by definition, cannot be listed in the content of the syllabus.	**40%**
AO3	**Experimental and investigative skills** Candidates will be expected to: • plan scientific investigations (including constructing and testing hypotheses and predictions) • research information from secondary sources (including books, journals and the internet) • use scientific apparatus, methods and techniques skilfully and safely • make, record and communicate observations, measurements and methods methodically with appropriate clarity, precision and accuracy • manipulate, present and analyse raw data provided or from scientific experiments and investigations (including identifying mathematical relationships, where appropriate) • report findings and conclusions, supported by evidence (including secondary sources, where appropriate) • evaluate experimental methods, techniques, raw data and conclusions; identify limitations and suggest improvements.	**20%**

Relationship between scheme of assessment and assessment objectives

The approximate weightings allocated to each of the assessment objectives are summarised below. The table shows the assessment objectives (AOs) as a percentage of each component and as a percentage of the overall Cambridge Pre-U Physics qualification.

Component	AO1	AO2	AO3	Total	Weighting of component in overall qualification
1 (Paper 1)	45%	55%	0%	100%	20%
2 (Paper 2)	50%	46%	4%	100%	30%
3 (Paper 3)	46%	43%	11%	100%	35%
4 (Personal Investigation)	0%	0%	100%	100%	15%
Weighting of AO in overall qualification	40%	40%	20%	–	

Grading and reporting

Cambridge International Level 3 Pre-U Certificates (Principal Subjects and Short Courses) are qualifications in their own right. Each individual Principal Subject and Short Course is graded separately on a scale of nine grades: Distinction 1, Distinction 2, Distinction 3, Merit 1, Merit 2, Merit 3, Pass 1, Pass 2 and Pass 3.

Grading Cambridge Pre-U Principal Subjects and Short Courses

Distinction	1
	2
	3
Merit	1
	2
	3
Pass	1
	2
	3

Grade descriptions

The following grade descriptions indicate the level of attainment characteristic of the middle of the given grade band. They give a general indication of the required standard at each specified grade. The descriptions should be interpreted in relation to the content outlined in the syllabus; they are not designed to define that content.

The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives overall. Shortcomings in some aspects of the examination may be balanced by better performance in others.

Distinction (D2)

Candidates recall and use knowledge of physics from the whole syllabus with few omissions and show good understanding of many of the most demanding principles and concepts in the syllabus. They select appropriate information from which to construct arguments or techniques with which to solve problems. In the solution of problems, candidates are usually able to bring together fundamental principles from different content areas of the syllabus and demonstrate a clear understanding of the relationships between them.

Candidates apply knowledge and principles of physics contained within the syllabus in both familiar and unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate good understanding of the underlying relationships between physical quantities involved and carry out all elements of extended calculations correctly in situations where little or no guidance is given. They are often successful in questions which require a combination of applying demanding concepts to unfamiliar contexts, extended problem solving and synthesis of ideas from different areas of physics.

In experimental activities, candidates identify a problem, formulate a clear and effective plan using knowledge and understanding of physics, and use a range of relevant techniques with care and skill. They are organised and methodical in the way they carry out their work and present their results. They make and record measurements which are sufficient and with a precision which is appropriate to the task. They interpret and explain their results with sound use of principles of physics and evaluate critically the reliability of their methods.

Merit (M2)

Candidates recall and use knowledge of physics from most parts of the syllabus with some omissions and show good understanding of many of the principles and concepts within it. They select appropriate information from which to solve problems, including some problems in unfamiliar contexts. Candidates show some signs of an ability to bring together fundamental principles from different content areas of the syllabus, but do not do so consistently. They usually make good use of the concepts and terminology of physics in communicating their answers.

Candidates apply knowledge and principles of physics contained within the syllabus in familiar and some unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate some understanding of the underlying relationships between physical quantities involved and are usually aware of the magnitudes of common physical quantities. Candidates are usually successful in calculations where some structure is provided and can carry out some elements of extended calculations correctly.

In experimental activities, candidates are usually able to identify a problem and to formulate a plan, many aspects of which are realistic and practicable. They use a range of relevant techniques with care and skill. They make and record measurements, usually with a precision which is appropriate to the task. They interpret and explain their results using principles of physics and make some critical evaluation of their methods.

Pass (P2)

Candidates recall and use knowledge of physics from many parts of the syllabus and demonstrate some understanding of a number of the main principles and concepts within it. Their level of knowledge and understanding may vary significantly across major areas of the syllabus. They select discrete items of knowledge and make some use of information that is presented in familiar ways to solve problems. They make some use of the concepts and terminology of physics in communicating their answers.

Candidates apply knowledge and principles of physics contained within the syllabus to material presented in a familiar or closely related context. They show some understanding of the magnitudes of common physical quantities when carrying out numerical work. Candidates carry out straightforward calculations in most areas of physics correctly when these calculations are of a familiar kind and when structure is provided, usually using correct units.

In experimental activities, candidates are able to plan some aspects of the solution to a practical problem. They make and record appropriate measurements and show some awareness of the need for precision. They usually offer an interpretation of their experimental results making some use of fundamental principles of physics.

Description of components

Component 1: Paper 1 Multiple Choice

This paper consists of 40 multiple-choice questions, all of the direct choice type. Questions will be based on Part A and Part B of the syllabus content, but not on the learning outcomes marked with an asterisk (*).

Component 2: Paper 2 Written Paper

This paper consists of two sections:

- **Section 1**: Structured questions. This section consists of compulsory structured questions of variable mark value. All questions will be based on Part A of the syllabus content. This section will contain 75 marks and candidates will be advised to spend about one and a half hours on the section.
- **Section 2**: Questions based on pre-released material. This section consists of one compulsory 25 mark question relating to material released to candidates prior to the examination. The material will draw on the physics concepts from Part A or Part B of the syllabus content and will show how these concepts are applied in broad areas of physics. Candidates are advised to spend about 30 minutes on the section. Learning outcomes marked with an asterisk (*) will not be assessed in this paper. The pre-released material will be made available to Centres by the date indicated in the *Cambridge Administrative Guide (UK)*. It will not be sent to Centres in hard copy. For the examination, the pre-released material will be supplied to all candidates as an Insert in the question paper. Candidates must not bring their own copies of the pre-released material into the examination room.

Component 3: Paper 3 Written Paper

This paper consists of two sections:

- **Section 1**: Compulsory questions. This section consists of a number of compulsory questions of variable mark value. These questions will focus on Part B of the syllabus content although some questions may also draw on content from Part A. Learning outcomes marked with an asterisk (*) will not be assessed in this section. The questions will primarily be structured questions, but there may also be an unstructured question requiring candidates to perform extended calculations and/or a question requiring the analysis of experimental data. This section contains 80 marks and candidates are advised to spend about one and a half hours on the section.
- **Section 2**: This section will consist of six questions, of which candidates answer three. Three questions will have a strong mathematical focus and three will require discussion of philosophical issues and/or physics concepts met in the course. The questions may assess content from any part of the syllabus and may have a problem-solving focus. The mathematical requirements and learning outcomes marked with an asterisk (*) will only be assessed in this section. Candidates are advised to spend about 30 minutes on each question in this section.

Contexts for questions in written papers

Questions in the written papers will, where possible, be set in novel contexts to show applications of physics. Contexts may include medicine, biophysics, engineering, space exploration, transport, structures and buildings, robotics, communications, global energy solutions, environmental issues, geology and agriculture. Some questions may be set in the context of the latest pieces of research. Historical and sociological scenarios may also be used. Some questions will enable candidates to demonstrate experimental techniques and others, problem-solving skills. Candidates will be provided with a data and formulae list for all written papers (see pages 34 and 35).

Component 4: Personal Investigation

Candidates will be required to perform an individual investigation of a practical problem of their own choosing which has been agreed by the teacher.

The work should be carried out in normal lesson time under the supervision of the teacher. Candidates will be allowed a maximum of 20 hours to complete the project, including planning and writing up. It is envisaged that after a brief period of trialling ideas and developing project ideas, the bulk of the work will be completed in two weeks of normal lesson time and homework. Teachers will monitor the progress of the work on a frequent basis throughout the two weeks of practical work to ensure that candidates are writing up their work as they go along.

The entire 20 hours of the project should be completed within four weeks.

Candidates will be assessed on their ability to:

- produce a detailed plan
- make detailed records of observations, measurements and methods
- use a range of different instruments to obtain accurate and precise results
- use appropriate physics principles to interpret results
- communicate raw and processed data to support conclusions
- produce a well organised, detailed and structured project report.

Teachers will be required to assess the candidate's organisation during the project, and to mark the candidate's report according to the assessment criteria listed in this syllabus. The marking will be sampled and externally moderated.

Nomenclature and units

Candidates are expected to be familiar with the nomenclature used in the syllabus. The proposals in *Signs, Symbols and Systematics* (The Association for Science Education Companion to 16–19 Science, 2000) will generally be adopted.

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 **http://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 are 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.

Syllabus content

The syllabus consists of the following topic areas:

Part A

1. Mechanics
2. Gravitational fields
3. Deformation of solids
4. Energy concepts
5. Electricity
6. Waves
7. Superposition
8. Atomic and nuclear processes
9. Quantum ideas

Part B

10. Rotational mechanics
11. Oscillations
12. Electric fields
13. Gravitation
14. Electromagnetism
15. Special relativity
16. Molecular kinetic theory
17. Nuclear physics
18. The quantum atom
19. Interpreting quantum theory
20. Astronomy and cosmology

The sequence in which the syllabus content is listed is not intended to represent a teaching order. There is no requirement to teach Part A of the syllabus content before Part B.

The topic areas listed in Part B contain some learning outcomes that will only be assessed in Section 2 of Paper 3 Written Paper. These learning outcomes are marked with an asterisk (*) in the following detailed content.

Part A

1 Mechanics

Content

- scalars and vectors
- moment of a force
- kinematics
- Newton’s laws of motion
- conservation of linear momentum
- density
- pressure

Candidates should be able to:

(a) distinguish between scalar and vector quantities and give examples of each

(b) resolve a vector into two components at right angles to each other by drawing and by calculation

(c) combine any number of coplanar vectors at any angle to each other by drawing

(d) calculate the moment of a force and use the conditions for equilibrium to solve problems (restricted to coplanar forces)

(e) construct displacement-time and velocity-time graphs for uniformly accelerated motion

(f) identify and use the physical quantities derived from the gradients of displacement-time and areas and gradients of velocity-time graphs, including cases of non-uniform acceleration

(g) recall and use:

$$v = \frac{\Delta x}{\Delta t}$$

$$a = \frac{\Delta v}{\Delta t}$$

(h) recognise and use the kinematic equations for motion in one dimension with constant acceleration:

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

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

(i) recognise and make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity

(j) recognise that internal forces on a collection of objects sum to zero vectorially

(k) recall and interpret statements of Newton’s laws of motion

(l) recall and use $F = ma$ in situations where mass is constant

(m) understand the effect of kinetic friction and static friction

(n) use $F_k = \mu_k N$ and $F_s = \mu_s N$, where N is the normal contact force and μ_k and μ_s are the coefficients of kinetic friction and static friction, respectively

(o) recall and use the independent effects of perpendicular components of a force

(p) recall and use $p = mv$ and apply the principle of conservation of linear momentum to problems in one dimension

(q) distinguish between elastic and inelastic collisions

(r) relate resultant force to rate of change of momentum in situations where mass is constant and recall and use $F = \frac{\Delta p}{\Delta t}$

(s) recall and use the relationship impulse = change in momentum

(t) recall and use the fact that the area under a force-time graph is equal to the impulse

(u) apply the principle of conservation of linear momentum to problems in two dimensions

(v) recall and use density $= \frac{\text{mass}}{\text{volume}}$

(w) recall and use pressure $= \frac{\text{normal force}}{\text{area}}$

(x) recall and use $p = \rho g h$ for pressure due to a liquid.

2 Gravitational fields

Content

- gravitational field strength
- centre of gravity

Candidates should be able to:

(a) recall and use the fact that the gravitational field strength g is equal to the force per unit mass and hence that weight $W = mg$

(b) recall that the weight of a body appears to act from its centre of gravity

(c) sketch the field lines for a uniform gravitational field (such as near the surface of the Earth)

(d) explain the distinction between gravitational field strength and force and explain the concept that a field has independent properties.

3 Deformation of solids

Content

- elastic and plastic behaviour
- stress and strain

Candidates should be able to:

(a) distinguish between elastic and plastic deformation of a material

(b) recall the terms brittle, ductile, hard, malleable, stiff, strong and tough, explain their meaning and give examples of materials exhibiting such behaviour

(c) explain the meaning of, use and calculate tensile/compressive stress, tensile/compressive strain, spring constant, strength, breaking stress, stiffness and Young modulus

(d) draw force-extension, force-compression and tensile/compressive stress-strain graphs, and explain the meaning of the limit of proportionality, elastic limit, yield point, breaking force and breaking stress

(e) state Hooke's law and identify situations in which it is obeyed

(f) account for the stress-strain graphs of metals and polymers in terms of the microstructure of the material.

4 Energy concepts

Content

- work
- power
- potential and kinetic energy
- energy conversion and conservation
- specific latent heat
- specific heat capacity

Candidates should be able to:

(a) understand and use the concept of work in terms of the product of a force and a displacement in the direction of that force, including situations where the force is not along the line of motion

(b) calculate the work done in situations where the force is a function of displacement using the area under a force-displacement graph

(c) understand that a heat engine is a device that is supplied with thermal energy and converts some of this energy into useful work

(d) calculate power from the rate at which work is done or energy is transferred

(e) recall and use $P = Fv$

(f) recall and use $\Delta E = mg\Delta \mathrm{h}$ for the gravitational potential energy transferred near the Earth's surface

(g) recall and use $g\Delta h$ as change in gravitational potential

(h) recall and use $E = \frac{1}{2}Fx$ for the elastic strain energy in a deformed material sample obeying Hooke's law

(i) use the area under a force-extension graph to determine elastic strain energy

(j) derive, recall and use $E = \frac{1}{2}kx^2$

(k) derive, recall and use $E = \frac{1}{2}mv^2$ for the kinetic energy of a body

(l) apply the principle of conservation of energy to solve problems

(m) recall and use $\%\ \text{efficiency} = \dfrac{\text{useful energy (or power) out}}{\text{total energy (or power) in}} \times 100$

(n) recognise and use $\Delta E = mc\Delta\theta$, where c is the specific heat capacity

(o) recognise and use $\Delta E = mL$, where L is the specific latent heat of fusion or of vaporisation.

5. Electricity

Content

- electric current
- potential difference and electromotive force (emf)
- resistance and resistivity
- conservation of charge and energy

Candidates should be able to:

(a) discuss electrical phenomena in terms of electric charge

(b) describe electric current as the rate of flow of charge and recall and use $I = \frac{\Delta Q}{\Delta t}$

(c) understand potential difference in terms of energy transfer and recall and use $V = \frac{W}{Q}$

(d) recall and use the fact that resistance is defined by $R = \frac{V}{I}$ and use this to calculate resistance variation for a variety of voltage-current characteristics

(e) define and use the concepts of emf and internal resistance and distinguish between emf and terminal potential difference

(f) derive, recall and use $E = I(R + r)$ and $E = V + Ir$

(g) recall and use $P = VI$ and $W = VIt$, and derive and use $P = I^2R$

(h) recall and use $R = \frac{\rho l}{A}$

(i) recall the formula for the combined resistance of two or more resistors in series and use it to solve problems $R_T = R_1 + R_2 + \ldots$

(j) recall the formula for the combined resistance of two or more resistors in parallel and use it to solve problems $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

(k) recall Kirchhoff's first and second laws and apply them to circuits containing no more than two supply components and no more than two linked loops

(l) appreciate that Kirchhoff's first and second laws are a consequence of the conservation of charge and energy, respectively

(m) use the idea of the potential divider to calculate potential differences and resistances.

6 Waves

Content

- progressive waves
- longitudinal and transverse waves
- electromagnetic spectrum
- polarisation
- refraction

Candidates should be able to:

(a) understand and use the terms displacement, amplitude, intensity, frequency, period, speed and wavelength

(b) recall and apply $f = \frac{1}{T}$ to a variety of situations not limited to waves

(c) recall and use the wave equation $v = f\lambda$

(d) recall that a sound wave is a longitudinal wave which can be described in terms of the displacement of molecules or changes in pressure

(e) recall that light waves are transverse electromagnetic waves, and that all electromagnetic waves travel at the same speed in a vacuum

(f) recall the major divisions of the electromagnetic spectrum in order of wavelength, and the range of wavelengths of the visible spectrum

(g) recall that the intensity of a wave is directly proportional to the square of its amplitude

(h) use graphs to represent transverse and longitudinal waves, including standing waves

(i) explain what is meant by a plane-polarised wave

(j) recall Malus' law (intensity $\propto \cos^2\theta$) and use it to calculate the amplitude and intensity of transmission through a polarising filter

(k) recognise and use the expression for refractive index $n = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$

(l) derive and recall $\sin c = \frac{1}{n}$ and use it to solve problems

(m) recall that optical fibres use total internal reflection to transmit signals

(n) recall that, in general, waves are partially transmitted and partially reflected at an interface between media.

7 Superposition

Content

- phase difference
- diffraction
- interference
- standing waves

Candidates should be able to:

(a) explain and use the concepts of coherence, path difference, superposition and phase

(b) understand the origin of phase difference and path difference, and calculate phase differences from path differences

(c) understand how the phase of a wave varies with time and position

(d) determine the resultant amplitude when two waves superpose, making use of phasor diagrams

(e) explain what is meant by a standing wave, how such a wave can be formed, and identify nodes and antinodes

(f) understand that a complex wave may be regarded as a superposition of sinusoidal waves of appropriate amplitudes, frequencies and phases

(g) recall that waves can be diffracted and that substantial diffraction occurs when the size of the gap or obstacle is comparable to the wavelength

(h) recall qualitatively the diffraction patterns for a slit, a circular hole and a straight edge

(i) recognise and use the equation $n\lambda = b\sin\theta$ to locate the positions of destructive superposition for single slit diffraction, where b is the width of the slit

(j) recognise and use the Rayleigh criterion $\theta \approx \frac{\lambda}{b}$ for resolving power of a single aperture, where b is the width of the aperture

(k) describe the superposition pattern for a diffraction grating and for a double slit and use the equation $d\sin\theta = n\lambda$ to calculate the angles of the principal maxima

(l) use the equation $\lambda = \frac{ax}{D}$ for double-slit interference using light.

8 Atomic and nuclear processes

Content

- the nucleus
- nuclear processes
- probability and radioactive decay
- fission and fusion

Candidates should be able to:

(a) understand the importance of the α-particle scattering experiment in determining the nuclear model

(b) describe atomic structure using the nuclear model

(c) show an awareness of the existence and main sources of background radiation

(d) recognise nuclear radiations (α, β^-, γ) from their penetrating power and ionising ability, and recall the nature of these radiations

(e) write and interpret balanced nuclear transformation equations using standard notation

(f) understand and use the terms nucleon number (mass number), proton number (atomic number), nuclide and isotope

(g) appreciate the spontaneous and random nature of nuclear decay

(h) define and use the concept of activity as the number of decays occurring per unit time

(i) understand qualitatively how a constant decay probability leads to the shape of a radioactive decay curve

(j) determine the number of nuclei remaining or the activity of a source after a time which is an integer number of half-lives

(k) understand the terms thermonuclear fusion, induced fission and chain reaction

(l) recall that thermonuclear fusion and the fission of uranium-235 and plutonium-239 release large amounts of energy.

9 Quantum ideas

Content

- the photoelectric effect
- the photon
- wave-particle duality

Candidates should be able to:

(a) recall that, for monochromatic light, the number of photoelectrons emitted per second is proportional to the light intensity and that emission occurs instantaneously

(b) recall that the kinetic energy of photoelectrons varies from zero to a maximum, and that the maximum kinetic energy depends on the frequency of the light, but not on its intensity

(c) recall that photoelectrons are not ejected when the light has a frequency lower than a certain threshold frequency which varies from metal to metal

(d) understand how the wave description of light fails to account for the observed features of the photoelectric effect and that the photon description is needed

(e) recall that the absorption of a photon of energy can result in the emission of a photoelectron

(f) recognise and use $E = hf$

(g) understand and use the terms threshold frequency and work function and recall and use $hf = \Phi + \frac{1}{2}mv_{\max}^2$

(h) understand the use of stopping potential to find the maximum kinetic energy of photoelectrons and convert energies between joules and electron-volts

(i) plot a graph of stopping potential against frequency to determine the Planck constant, work function and threshold frequency

(j) understand the need for a wave model to explain electron diffraction

(k) recognise and use $\lambda = \dfrac{h}{p}$ for the de Broglie wavelength.

Part B

Learning outcomes marked with an asterisk (*) will be assessed only in Section 2 of Paper 3 Written Paper.

10 Rotational mechanics

Content

- kinematics of uniform circular motion
- centripetal acceleration
- moment of inertia
- kinematics of rotational motion

Candidates should be able to:

(a) define and use the radian

(b) understand the concept of angular velocity, and recall and use the equations $v = \omega r$ and $T = \frac{2\pi}{\omega}$

(c) derive, recall and use the equations for centripetal acceleration $a = \frac{v^2}{r}$ and $a = r\omega^2$

(d) recall that $F = ma$ applied to circular motion gives resultant force $\frac{mv^2}{r}$

(e) describe qualitatively the motion of a rigid solid object under the influence of a single force in terms of linear acceleration and rotational acceleration

(f) *recall and use $I = \Sigma mr^2$ to calculate the moment of inertia of a body consisting of three or fewer point particles fixed together

(g) *use integration to calculate the moment of inertia of a ring, a disk and a rod

(h) *deduce equations for rotational motion by analogy with Newton's laws for linear motion, including $E = \frac{1}{2}I\omega^2$, $L = I\omega$ and $\Gamma = I\frac{d\omega}{dt}$

(i) *apply the laws of rotational motion to perform kinematic calculations regarding a rotating object when the moment of inertia is given.

11 Oscillations

Content

- simple harmonic motion
- energy in simple harmonic motion
- forced oscillations, damping and resonance

Candidates should be able to:

(a) recall the condition for simple harmonic motion and hence identify situations in which simple harmonic motion will occur

(b) *show that the condition for simple harmonic motion leads to a differential equation of the form $\frac{d^2x}{dt^2} = -\omega^2 x$ and that $x = A\cos\omega t$ is a solution to this equation

(c) *use differential calculus to derive the expressions $v = -A\omega \sin\omega t$ and $a = -A\omega^2\cos\omega t$ for simple harmonic motion

(d) *recognise and use the expressions $x = A\cos\omega t$, $v = -A\omega\sin\omega t$, $a = -A\omega^2\cos\omega t$ and $F = -m\omega^2 x$ to solve problems

(e) recall and use $T = \frac{2\pi}{\omega}$ as applied to a simple harmonic oscillator

(f) understand the phase differences between displacement, velocity and acceleration in simple harmonic motion

(g) *show that the total energy of an undamped simple harmonic system is given by $E = \frac{1}{2}mA^2\omega^2$ and recognise that this is a constant

(h) recognise and use $E = \frac{1}{2}mA^2\omega^2$ to solve problems

(i) distinguish between free, damped and forced oscillations

(j) recall how the amplitude of a forced oscillation changes at and around the natural frequency of a system and describe, qualitatively, how damping affects resonance.

12 Electric fields

Content

- concept of an electric field
- uniform electric fields
- capacitance
- electric potential
- electric field of a point charge

Candidates should be able to:

(a) explain what is meant by an electric field and recall and use $E = \frac{F}{Q}$ for electric field strength

(b) recall that applying a potential difference to two parallel plates stores charge on the plates and produces a uniform electric field in the central region between them

(c) derive and use the equations $Fd = QV$ and $E = \frac{V}{d}$ for a charge moving through a potential difference in a uniform electric field

(d) recall that the charge stored on parallel plates is proportional to the potential difference between them

(e) recall and use $C = \frac{Q}{V}$ for capacitance

(f) recognise and use $W = \frac{1}{2}QV$ for the energy stored by a capacitor, derive the equation from the area under a graph of charge stored against potential difference, and derive and use related equations such as $W = \frac{1}{2}CV^2$

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

(h) define and use the time constant of a discharging capacitor

(i) analyse the discharge of a capacitor using equations of the form $x = x_o e^{\frac{-t}{RC}}$

(j) understand that the direction and electric field strength of an electric field may be represented by field lines (lines of force), and recall the patterns of field lines that represent uniform and radial electric fields

(k) understand electric potential and equipotentials

(l) understand the relationship between electric field and potential gradient, and recall and use $E = -\frac{dV}{dX}$

(m) recognise and use $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ for point charges

(n) derive and use $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the electric field due to a point charge

(o) *use integration to derive $W = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ from $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ for point charges

(p) *recognise and use $W = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ for the electrostatic potential energy for point charges.

13 Gravitation

Content

- Kepler's laws
- Newton's law of gravity
- gravitational field
- gravitational potential energy

Candidates should be able to:

(a) state Kepler's laws of planetary motion:
  (i) planets move in elliptical orbits with the Sun at one focus
  (ii) the Sun-planet line sweeps out equal areas in equal times
  (iii) the orbital period squared of a planet is proportional to its mean distance from the Sun cubed

(b) recognise and use $F = -\dfrac{Gm_1 m_2}{r^2}$

(c) use Newton's law of gravity and centripetal force to derive $r^3 \propto T^2$ for a circular orbit

(d) understand energy transfer by analysis of the area under a gravitational force-distance graph

(e) derive and use $g = \dfrac{Gm}{r^2}$ for the magnitude of the gravitational field strength due to a point mass

(f) recall similarities and differences between electric and gravitational fields

(g) recognise and use the equation for gravitational potential energy for point masses $E = -\dfrac{Gm_1 m_2}{r}$

(h) calculate escape velocity using the ideas of gravitational potential energy (or area under a force-distance graph) and energy transfer

(i) calculate the distance from the centre of the Earth and the height above its surface required for a geostationary orbit.

14 Electromagnetism

Content

- concept of a magnetic field
- force on a current-carrying conductor
- force on a moving charge
- electromagnetic induction
- the Hall effect

Candidates should be able to:

(a) understand and use the terms magnetic flux density, flux and flux linkage

(b) understand that magnetic fields are created by electric current

(c) recognise and use $F = BIl \sin\theta$

(d) recognise and use $F = BQv \sin\theta$

(e) use Fleming's left-hand rule to solve problems

(f) explain qualitatively the factors affecting the emf induced across a coil when there is relative motion between the coil and a permanent magnet or when there is a change of current in a primary coil linked with it

(g) recognise and use $E = -\frac{d(N\Phi)}{dt}$ and explain how it is an expression of Faraday's and Lenz's laws

(h) derive, recall and use $r = \frac{mv}{BQ}$ for the radius of curvature of a deflected charged particle

(i) explain the Hall effect, and derive and use $V = Bvd$.

15 Special relativity

Content

- Einstein's special principle of relativity
- time dilation
- length contraction

Candidates should be able to:

(a) *recall that Maxwell's equations describe the electromagnetic field and predict the existence of electromagnetic waves that travel at the speed of light (Maxwell's equations are not required)

(b) *recall that analogies with mechanical wave motion led most physicists to assume that electromagnetic waves must be vibrations in an electromagnetic medium (the aether) filling absolute space

(c) *recall that experiments to measure variations in the speed of light caused by the Earth's motion through the ether gave null results

(d) *understand that Einstein's theory of special relativity dispensed with the aether and postulated that the speed of light is a universal constant

(e) *state the postulates of Einstein's special principle of relativity

(f) *explain how Einstein's postulates lead to the idea of time dilation and length contraction that undermines the idea of absolute time and space

(g) *recognise and use $t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$ and $l' = l\sqrt{1 - \frac{v^2}{c^2}}$

(h) *understand that two events which are simultaneous in one frame of reference may not be simultaneous in another; explain this in terms of the fundamental postulates of relativity and distinguish this from the phenomenon of time dilation.

16 Molecular kinetic theory

Content

- absolute scale of temperature
- equation of state
- kinetic theory of gases
- kinetic energy of a molecule
- first law of thermodynamics
- entropy
- second law of thermodynamics

Candidates should be able to:

(a) explain how empirical evidence leads to the gas laws and to the idea of an absolute scale of temperature

(b) use the units kelvin and degrees Celsius and convert from one to the other

(c) recognise and use the Avogadro number $N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$

(d) recall and use $pV = nRT$ as the equation of state for an ideal gas

(e) describe Brownian motion and explain it in terms of the particle model of matter

(f) understand that the kinetic theory model is based on the assumptions that the particles occupy no volume, that all collisions are elastic, and that there are no forces between particles until they collide

(g) understand that a model will begin to break down when the assumptions on which it is based are no longer valid, and explain why this applies to kinetic theory at very high pressures or very high or very low temperatures

(h) derive $pV = \frac{1}{3}Nm\langle c^2\rangle$ from first principles to illustrate how the microscopic particle model can account for macroscopic observations

(i) recognise and use $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

(j) understand and calculate the root mean square speed for particles in a gas

(k) understand the concept of internal energy as the sum of potential and kinetic energies of the molecules

(l) recall and use the first law of thermodynamics expressed in terms of the change in internal energy, the heating of the system and the work done on the system

(m) recognise and use $W = p\Delta V$ for the work done on or by a gas

(n) understand qualitatively how the random distribution of energies leads to the Boltzmann factor $e^{\frac{-E}{kT}}$ as a measure of the chance of a high energy

(o) apply the Boltzmann factor to activation processes including rate of reaction, current in a semiconductor and creep in a polymer

(p) *describe entropy qualitatively in terms of the dispersal of energy or particles and realise that entropy is related to the number of ways in which a particular macroscopic state can be realised

(q) *recall that the second law of thermodynamics states that the entropy of an isolated system cannot decrease and appreciate that this is related to probability

(r) *understand that the second law provides a thermodynamic arrow of time that distinguishes the future (higher entropy) from the past (lower entropy)

(s) *understand that systems in which entropy decreases (e.g. humans) are not isolated and that when their interactions with the environment are taken into account their net effect is to increase the entropy of the Universe

(t) *understand that the second law implies that the Universe started in a state of low entropy and that some physicists think that this implies it was in a state of extremely low probability.

17 Nuclear physics

Content

- equations of radioactive decay
- mass excess and nuclear binding energy
- antimatter
- the standard model

Candidates should be able to:

(a) show that the random nature of radioactive decay leads to the differential equation $\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$ and that $N = N_0 e^{-\lambda t}$ is a solution to this equation

(b) recall that activity $A = -\frac{\mathrm{d}N}{\mathrm{d}t}$ and show that $A = \lambda N$ and $A = A_0 e^{-\lambda t}$

(c) show that the half-life $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

(d) use the equations in (a), (b) and (c) to solve problems

(e) recognise and use the equation $I = I_0 e^{-\mu x}$ as applied to attenuation losses

(f) recall that radiation emitted from a point source and travelling through a non-absorbing material obeys an inverse square law and use this to solve problems

(g) estimate the size of a nucleus from the distance of closest approach of a charged particle

(h) understand the concept of nuclear binding energy, and recognise and use the equation $\Delta E = c^2 \Delta m$ (binding energy will be taken to be positive)

(i) recall, understand and explain the curve of binding energy per nucleon against nucleon number

(j) recall that antiparticles have the same mass but opposite charge and spin to their corresponding particles

(k) relate the equation $\Delta E = c^2 \Delta m$ to the creation or annihilation of particle-antiparticle pairs

(l) recall the quark model of the proton (uud) and the neutron (udd)

(m) understand how the conservation laws for energy, momentum and charge in beta-minus decay were used to predict the existence and properties of the antineutrino

(n) balance nuclear transformation equations for alpha, beta-minus and beta-plus emissions

(o) recall that the standard model classifies matter into three families: quarks (including up and down), leptons (including electrons and neutrinos) and force carriers (including photons and gluons)

(p) recall that matter is classified as baryons and leptons and that baryon numbers and lepton numbers are conserved in nuclear transformations.

18 The quantum atom

Content

- line spectra
- energy levels in the hydrogen atom

Candidates should be able to:

(a) explain atomic line spectra in terms of photon emission and transitions between discrete energy levels

(b) apply $E = hf$ to radiation emitted in a transition between energy levels

(c) show an understanding of the hydrogen line spectrum, photons and energy levels as represented by the Lyman, Balmer and Paschen series

(d) recognise and use the energy levels of the hydrogen atom as described by the empirical equation

$$E_n = \frac{-13.6\,\text{eV}}{n^2}$$

(e) *explain energy levels using the model of standing waves in a rectangular one-dimensional potential well

(f) *derive the hydrogen atom energy level equation $E_n = \frac{-13.6\,\text{eV}}{n^2}$ algebraically using the model of electron standing waves, the de Broglie relation and the quantisation of angular momentum.

19 Interpreting quantum theory

Content

- interpretations of the double-slit experiment
- Schrödinger’s cat paradox
- the Heisenberg uncertainty principle

Candidates should be able to:

(a) *interpret the double-slit experiment using the Copenhagen interpretation (and collapse of the wave-function), Feynman’s sum-over-histories and Everett’s many-worlds theory

(b) *describe and explain Schrödinger’s cat paradox and appreciate the use of a thought experiment to illustrate and argue about fundamental principles

(c) *recognise and use $\Delta p \Delta x \geqslant \frac{h}{2\pi}$ as a form of the Heisenberg uncertainty principle and interpret it

(d) *recognise that the Heisenberg uncertainty principle places limits on our ability to know the state of a system and hence to predict its future

(e) *recall that Newtonian physics is deterministic, but quantum theory is indeterministic

(f) *understand why Einstein thought that quantum theory undermined the nature of reality by being:
    (i) indeterministic (initial conditions do not uniquely determine the future)
    (ii) non-local (for example, wave-function collapse)
    (iii) incomplete (unable to predict precise values for properties of particles).

20 Astronomy and cosmology

Content

- standard candles
- stellar radii
- Hubble's law
- the Big Bang theory
- the age of the Universe

Candidates should be able to:

(a) understand the terms luminosity and luminous flux

(b) recall and use the inverse square law for flux $F = \dfrac{L}{4\pi d^2}$

(c) understand the need to use standard candles to help determine distances to galaxies

(d) recognise and use Wien's displacement law $\lambda_{\text{max}} \propto \dfrac{1}{T}$ to estimate the peak surface temperature of a star either graphically or algebraically

(e) recognise and use Stefan's law for a spherical body $L = 4\pi\sigma r^2 T^4$

(f) use Wien's displacement law and Stefan's law to estimate the radius of a star

(g) understand that the successful application of Newtonian mechanics and gravitation to the Solar System and beyond indicated that the laws of physics apply universally and not just on Earth

(h) recognise and use $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer

(i) state Hubble's law and explain why galactic redshift leads to the idea that the Universe is expanding and to the Big Bang theory

(j) explain how microwave background radiation provides empirical support for the Big Bang theory

(k) understand that the theory of the expanding Universe involves the expansion of space-time and does not imply a pre-existing empty space into which this expansion takes place or a time prior to the Big Bang

(l) recall and use the equation $v \approx H_0 d$ for objects at cosmological distances

(m) derive an estimate for the age of the Universe by recalling and using the Hubble time $t = \dfrac{1}{H_0}$.

Mathematical requirements

Part A

Candidates should be able to:

1. make reasonable estimates of physical quantities included within the syllabus
2. recall and use the base units of the SI and appreciate the importance of basing other units upon these base units
3. express derived units as products or quotients of the base units
4. express measurements using scientific notation or prefixes with units
5. recall and use the prefixes milli, micro, nano, pico, femto, kilo, mega, giga, and tera
6. use a given conversion formula to convert a measurement from one system of units to another
7. apply dimensional analysis to predict the form of a relationship, such as the time period of a simple pendulum, using the standard dimension symbols M, L, T, $\boldsymbol{I}$, θ for mass, length, time, current and temperature respectively
8. use fractions or percentages to express ratios
9. recognise proportionality or inverse proportionality from data, and be able to predict other measurements numerically from the assumption of proportionality or inverse proportionality
10. use calculators to find and use x^n, $\frac{1}{x}$ and $\sqrt{x}$
11. use calculators to find and use sin$x$, cos$x$, tan$x$, where x is expressed in degrees and radians
12. make estimates for the order of magnitude of results from calculations
13. use an appropriate number of significant figures, and from this recognise when models are or are not in agreement with data within the uncertainties of the data
14. find arithmetic means and recognise their use in reducing the random uncertainties of the mean of a set of measurements, while acknowledging that this procedure is of no use in reducing systematic uncertainties
15. change the subject of an equation by manipulation of the terms, including the use of positive, negative, integer and fraction indices
16. solve simple algebraic equations and simultaneous equations
17. substitute numerical values into algebraic equations using appropriate units for physical quantities
18. understand and use the symbols $=$, $\approx$, $<$, , $<<$, $>>$, , $>$, $\propto$, Δ
19. calculate the areas of triangles, the circumferences and areas of circles, and the surface areas and volumes of rectangular blocks, cylinders and spheres
20. use Pythagoras' theorem and the angle sum of a triangle
21. use sines, cosines and tangents and their inverses in physical problems
22. translate information between graphical, numerical and algebraic forms
23. plot graphs of two variables from experimental or other data
24. determine the slope of and area under a graph by drawing and (in the case of a straight-line graph) by calculation
25. express quantities with a very large range using the logarithm to base 10 of those quantities
26. use the slope and intercept of a graph to analyse a physical situation where a relationship is of the form $y = mx + c$
27. use spreadsheets or modelling packages to solve physical problems
28. recognise that equations of the same form occur in different areas of physics and make analogies between them
29. show an understanding of systematic and random errors
30. show an understanding of precision and accuracy.

Part B

The mathematical requirements marked with an asterisk (*) will be assessed only in Section 2 of Paper 3 Written Paper.

Candidates should be able to:

1. use the exponential function e^{kx}
2. plot data on a logarithmic graph and hence determine whether they change exponentially
3. plot a log-log graph and hence decide whether data obey a power law and, if they do, determine the exponent
4. understand how differentiation is related to the slope of a graph and how integration is related to the area under a graph
5. differentiate and integrate power laws and functions of the form $y = e^{ax}$
6. differentiate functions of the form $y = \sin ax$ and $y = \cos ax$
7. recall and use the relationship $\ln(e^x) = x$
8. *recognise differential equations of the form $\frac{dx}{dt} = -\lambda x$, recall that these have solutions of the form $x = Ae^{-\lambda t}$, and verify this by substitution
9. *recognise differential equations of the form $\frac{d^2x}{dt^2} = -\omega^2 x$, recall that these have solutions of the form $x = A\cos\omega t$ or $x = A\sin\omega t$, and verify this by substitution
10. *use increments such as δx to set up integrals.

Data and formulae list

This list of data and formulae will be provided with every examination paper.

Data

gravitational field strength close to Earth's surface	$g = 9.81\,\mathrm{N\,kg^{-1}}$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
speed of light in vacuum	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Planck constant	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
electron mass	$m_\mathrm{e} = 9.11 \times 10^{-31}\,\mathrm{kg}$
proton mass	$m_\mathrm{p} = 1.67 \times 10^{-27}\,\mathrm{kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\mathrm{kg}$
molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Avogadro constant	$N_\mathrm{A} = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
	$s = \left(\frac{u+v}{2}\right)t$
heating	$\Delta E = mc\Delta\theta$
change of state	$\Delta E = mL$
refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$n = \frac{v_1}{v_2}$

diffraction	
single slit, minima	$n\lambda = b\sin\theta$
grating, maxima	$n\lambda = d\sin\theta$
double slit interference	$\lambda = \frac{ax}{D}$
Rayleigh criterion	$\theta \approx \frac{\lambda}{b}$
photon energy	$E = hf$
de Broglie wavelength	$\lambda = \frac{h}{p}$
simple harmonic motion	$x = A\cos\omega t$
	$v = -A\omega\sin\omega t$
	$a = -A\omega^2\cos\omega t$
	$F = -m\omega^2 x$
	$E = \frac{1}{2}mA^2\omega^2$
energy stored in a capacitor	$W = \frac{1}{2}QV$
capacitor discharge	$Q = Q_0 e^{-\frac{t}{RC}}$
electric force	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = -\frac{Gm_1 m_2}{r^2}$
gravitational potential energy	$E = -\frac{Gm_1 m_2}{r}$
magnetic force	$F = BIl\sin\theta$
	$F = BQv\sin\theta$
electromagnetic induction	$E = -\frac{\mathrm{d}(N\Phi)}{\mathrm{d}t}$
Hall effect	$V = Bvd$
time dilation	$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$
length contraction	$l' = l\sqrt{1-\frac{v^2}{c^2}}$
kinetic theory	$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
work done on/by a gas	$W = p\Delta V$
radioactive decay	$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$
	$N = N_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
attenuation losses	$I = I_0 e^{-\mu x}$
mass-energy equivalence	$\Delta E = c^2\Delta m$
hydrogen energy levels	$E_n = \frac{-13.6\,\mathrm{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \frac{h}{2\pi}$
Wien's displacement law	$\lambda_{\max} \propto \frac{1}{T}$
Stefan's law	$L = 4\pi\sigma r^2 T^4$
electromagnetic radiation from a moving source	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

Summary of key quantities, symbols and units

The following list illustrates the symbols and units which will be used in question papers. The list is in alphabetical order.

Candidates will be expected to assume that the acceleration of free fall is equal to the gravitational field strength, i.e. the effects of the rotation of the Earth may be ignored.

Electron volts (eV), atomic mass units (u) and degrees Celsius (°C) may be used in question papers without explanation, and candidates will be expected to convert between them and SI units.

Quantity	**Usual symbols**	**Usual unit**
absorption coefficient	μ	$\mathrm{m^{-1}}$
acceleration	a	$\mathrm{m\,s^{-2}}$
activity of a radioactive source	A	Bq
amount of substance	n	mol
amplitude	A	m
angular frequency	ω	$\mathrm{rad\,s^{-1}}$
angular momentum	L	$\mathrm{kg\,m^2\,s^{-1}}$
angular speed	ω	$\mathrm{rad\,s^{-1}}$
angular velocity	ω	$\mathrm{rad\,s^{-1}}$
area	A	$\mathrm{m^2}$
Avogadro constant	N_{A}	$\mathrm{mol^{-1}}$
Boltzmann constant	k	$\mathrm{J\,K^{-1}}$
capacitance	C	F
change in internal energy	ΔU	J
charge	Q	C
critical angle	c	rad, °
decay constant	λ	$\mathrm{s^{-1}}$
density	ρ	$\mathrm{kg\,m^{-3}}$
depth	h	m
displacement	s, x	m
distance	d, x	m
electric current	I	A
electric field strength	E	$\mathrm{N\,C^{-1}}$ or $\mathrm{V m^{-1}}$
electric potential	V	V
electromotive force	E	V
elementary charge	e	C
energy	E, W	J, eV
energy level	E_{n}	J, eV
extension	x	m
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
heating	Q	J

height	h	m
Hubble constant	H_0	$\mathrm{s^{-1}}$
intensity	I	$\mathrm{W\,m^{-2}}$
internal resistance	r	Ω
length	l, L	m
light flux	F, Φ	$\mathrm{W\,m^{-2}}$
luminosity	L	W
magnetic flux	Φ	Wb
magnetic flux density	B	T
mass	m	kg, u
molar gas constant	R	$\mathrm{J\,K^{-1}\,mol^{-1}}$
moment of a force	Γ	N m
moment of inertia	I	$\mathrm{kg\,m^{2}}$
momentum	p	$\mathrm{kg\,m\,s^{-1}}$
number	n, N	
period	T	s
permittivity of free space	ε_0	$\mathrm{F\,m^{-1}}$
Planck constant	h	J s
potential difference	V	V
power	P	W
pressure	p	Pa
radius	r	m
resistance	R	Ω
resistivity	ρ	$\Omega\,\mathrm{m}$
slit separation	d	m
slit width	b	m
specific heat capacity	c	$\mathrm{J\,kg^{-1}\,K^{-1}}$
specific latent heat of fusion	L	$\mathrm{J\,kg^{-1}}$
specific latent heat of vaporisation	L	$\mathrm{J\,kg^{-1}}$
speed	v	$\mathrm{m\,s^{-1}}$
speed of light in vacuum	c	$\mathrm{m\,s^{-1}}$
spring constant	k	$\mathrm{N\,m^{-1}}$
Stefan-Boltzmann constant	σ	$\mathrm{W\,m^{-2}\,K^{-4}}$
strain	ε	*no unit*
stress	σ	Pa
temperature	T, θ	K, °C
time	t	s
torque	Γ	N m
velocity	v, u	$\mathrm{m\,s^{-1}}$
volume	V	$\mathrm{m^{3}}$
wavelength	λ	m
weight	W	N
work	W	J, eV
work function energy	Φ	J, eV
Young modulus	E	Pa

Glossary of terms used in physics papers

It is hoped that this glossary will prove helpful to candidates as a guide, although it is not exhaustive. The glossary has been deliberately kept brief with respect not only to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context. They should also note that the number of marks allocated for any part of a question is a guide to the depth of treatment required for the answer.

1. *Define* (*the term(s) ...*) is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, is required.
2. *What is meant by* ... normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment required should be interpreted in the light of the indicated mark value.
3. *Explain* may imply reasoning or some reference to theory, depending on the context.
4. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained by inspection.
5. *List* requires a number of points with no elaboration. Where a given number of points is specified, this should not be exceeded.
6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description required should be interpreted in the light of the indicated mark value.
7. *Discuss* requires candidates to give a critical account of the points involved in the topic.
8. *Deduce/Predict* implies that candidates are not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an earlier part of the question.
9. *Suggest* is used in two main contexts. It may either imply that there is no unique answer or that candidates are expected to apply their general knowledge to a novel situation, one that formally may not be in the syllabus.
10. *Calculate* is used when a numerical answer is required. In general, working should be shown.
11. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule; or angle, using a protractor.
12. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. the Young modulus, relative molecular mass.
13. *Show* is used where a candidate is expected to derive a given result. It is important that the terms being used by candidates are stated explicitly and that all stages in the derivation are stated clearly.
14. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.
15. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct. However, candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. On a sketch graph it is essential that candidates clearly indicate what is being plotted on each axis.
16. *Sketch*, when applied to diagrams, implies that a simple, freehand drawing is acceptable; nevertheless, care should be taken over proportions and the clear exposition of important details.
17. *Compare* requires candidates to provide both similarities and differences between things or concepts.

Guidance relating to practical assessment

Each candidate will carry out an individual open-ended investigation occupying at most 20 hours of teaching time and homework (including planning and writing up). The entire 20 hours of the project should be completed within four weeks.

The assessment of the Personal Investigation is in two parts:

1. a plan of the project handed in at the end of the first week
2. a written project report handed in at the end of the project.

The project report will be marked by the teacher and moderated externally.

Guidelines for suitable investigations

Each candidate must plan and carry out an individual investigation lasting (in total) no more than 20 hours spread over no more than four weeks. This time should be divided as follows.

- one week for planning and preliminary tests
- two weeks of intensive practical work, to be written up each day and checked frequently by the teacher
- one week for additional practical work (if required) and final writing up.

A short pause may be required after the preliminary tests to organise laboratories and build or modify apparatus, and for the teacher to approve the plan.

A good investigation will:

- allow the candidate to make a variety of measurements using a range of apparatus
- require some experimental design
- lead the candidate to new physics
- be sufficiently ‘open’ that the candidate does not know all the answers in advance
- involve a dialogue between experiment and analysis
- generate a significant amount of numerical data
- not involve unmanageable risks.

The plan

This is an investigation proposal written by the candidate. The plan should be a brief document, typically occupying about two sides of A4 paper. It must include:

- the working title of the investigation
- the aim of the investigation
- an outline of the initial experiments
- a list of required apparatus
- a diagram of the initial experimental arrangement
- a risk assessment
- a rough breakdown of how the two-week period of intensive practical work will be spent.

The plan must be agreed by the candidate’s teacher before work continues. In some cases, the teacher will need to suggest modifications to the plan for reasons of safety, or to keep the project within achievable limits, or because of resource implications. In such cases, the candidate’s original plan should be the one that is marked, but the modified and agreed plan should form the basis of the remainder of the project.

The two weeks of practical work

Candidates should write up their work regularly, ideally every day. This will involve tabulating results, graph plotting and analysis. It should also involve some further research of relevant physics or analytical techniques, using books, journals and/or the internet.

The regular writing up of the practical work, analysis and conclusions during the two weeks of work should be monitored by the candidate’s teacher. The teacher should sign that they have seen the project every two days. In this way, development can be monitored and candidates are encouraged to analyse their work frequently.

The report

The report should contain:

- a statement of aim
- a word-processed summary of approximately 300 words written after completing the project, including an outline of any changes from the original plan
- details of pilot experiments conducted, giving reasons why they helped in planning
- safety and risk assessments
- a day-by-day diary with interpretation, evaluation and conclusions for each experiment (which will usually be hand written)
- an evaluation of the whole project
- a glossary of all new technical words encountered and used in the project
- references to books, journals and websites (in the order in which they were used).

Use of apparatus

Candidates are expected to be familiar with the following apparatus:

- metre rule
- protractor
- stopwatch
- ammeter
- voltmeter
- multimeter (to measure resistance, voltage or current)
- oscilloscope (to measure time or voltage)
- vernier callipers
- micrometer screw gauge
- thermometer
- lux meter
- digital top-pan balance or other balance
- newton meter
- data logger

Practical techniques

Candidates are expected to be able to:

- identify and deal with zero errors
- avoid parallax
- calibrate a measuring instrument
- assess risks to themselves and others

Data processing

Candidates will be expected to:

- tabulate data (including units, decimal places and significant figures)
- repeat and average readings
- plot appropriate graphs
- estimate uncertainties in measured quantities
- determine the uncertainty in a final result
- identify the physical significance of the gradient or intercept of a graph
- process data using a spreadsheet

Assessment

The work of each candidate should be marked by the teacher using the following assessment criteria.

The assessment criteria should be used by matching the work produced by the candidate to the descriptions. A best-fit approach should be used; the marking should not be hierarchical.

For some of the assessment criteria, grade descriptions are only provided for even numbers of marks. The teacher should award an odd number of marks if the standard of the candidate's work falls between the standards described for the adjacent even numbers.

Fractions of marks should not be used.

The teacher must annotate the work to show where each mark has been awarded, and the marks should also be recorded on the Coursework Assessment Summary Form (see page 46).

Centres are required to deliver a programme of practical activities designed to develop experimental skills and good practice. The development of these skills is an end in itself but the practical work will also prepare candidates to tackle the Personal Investigation. Some of the skills and analytical techniques will also be assessed in the written papers.

Assessment criteria

Initial planning	**Marks**
The plan contains a clear title, aim and a number of clearly worded research questions. There is an outline of initial experiment(s) in a sensible sequence with substantial background physics that helps to interpret or develop the practical scenario. Some of the background physics has been researched and is novel to the candidate. There is a sensible risk assessment and written guidelines for maintaining safety (where relevant). Pilot experiment(s) are used to help develop the plan, for example in improving accuracy or precision or in checking a prediction. The plan contains experimental details and describes what will be measured and controlled, and uses clear diagrams. The apparatus chosen is suitable for every task. Some ingenuity has been shown, for example apparatus has been modified or new apparatus devised. There is a summary of how the practical work might develop, related to the research questions.	4
The plan contains a clear title and aim, with at least one research question. There is an outline of initial experiment(s) with some background physics that helps to interpret or develop the practical scenario. There is a sensible risk assessment (where relevant). At least one pilot experiment has been performed. Largely appropriate apparatus has been requested. There is a brief summary of how the investigation might develop.	2
The plan contains a title, a statement of the aim and an outline of initial experiment(s). There is little or no elaboration.	0
Maximum 4 marks	

Organisation during the two weeks of practical work	**Marks**
The work is written up at least every two days. Practical methods are described clearly. Records are clear, well organised and complete, making clear what work was completed each day and how the ideas evolved. The analysis of each experiment is completed (e.g. graphs are plotted and the mathematical relationships and uncertainties discussed) and results are interpreted (with the help of further research where necessary) before work on the next experiment begins. Where appropriate, the plans for later experiments are adapted in response to the results of earlier experiments.	2
The work is written up more than once a week. Records are largely complete so that it is possible to follow what was done each day. There is evidence that some analysis and interpretation of each experiment has taken place before work on the next experiment begins, but there is little evidence of further research to help interpret the results.	1
The work is written up only once a week or when the candidate is prompted. Notes of practical methods lack detail, records are generally incomplete, and the record of the work is poorly organised and difficult to follow. There is little evidence that the results of each experiment have been analysed and interpreted before work on the next experiment begins.	0
Maximum 2 marks	

Quality of physics	Marks
Wherever appropriate, principles of physics have been used to interpret results, perform calculations or make predictions. The physics is explained and goes beyond the requirements of the taught course. It includes some relevant quantitative arguments and is related to the project. Sound understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are no errors in calculations or in explanations.	6
In most cases where it is appropriate, principles of physics have been used to interpret results, perform calculations or make predictions. The physics is usually explained, draws on the content of the taught course, and is related to the project. Understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are some errors in calculations and in explanations.	4
There is some use of physics but there are omissions in its application to the interpretation of results. Some of it is copied and the references given, but it is put together with little coherence or direct reference to the research topic. Some calculations are performed successfully but there are some errors.	2
The physics used is mainly descriptive. Most of it is copied and is of limited relevance to the research topic. Some calculations are performed successfully but there are also many errors and the misuse of units is common.	0
Maximum 6 marks	

Use of measuring instruments	Marks
More than two experiments* are performed with a range of different instruments, some of which require checking of zero, calibration or selection of different ranges. Some of the apparatus is either of a sophisticated nature, e.g. signal generator, cathode ray oscilloscope, two place digital balance, data logger, micrometer, or involves a creative or ingenious technique in its use. In all experiments, apparatus has been set up and manipulated without assistance.	3
At least two experiments* are completed where at least two measuring instruments are used, at least one of which was zeroed or calibrated correctly to obtain accurate results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	2
At least one experiment* is completed where two measuring instruments are used to obtain results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	1
At least one experiment* is completed. There are some errors in using the apparatus, which make some of the readings unreliable. Some assistance in setting up or manipulating apparatus has been required.	0
Maximum 3 marks	

* For the purposes of these criteria, an experiment involves changing an independent variable in order to observe or measure the effect on a dependent variable. Two experiments may be considered to be different if one or both of the variables are different.

Practical techniques	Marks
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. Anomalous measurements are correctly identified and are investigated further. There is awareness of the need to consider precision and sensitivity, and experiments are designed to maximise precision. Measurements are repeated where appropriate. Where it is appropriate, more than one measuring technique is used to help corroborate readings or inventive methods are used to help improve or check readings.	3
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. Anomalous measurements are correctly identified but in most cases they are not investigated further. There is awareness of the need to consider precision and sensitivity, and experiments are designed to maximise precision. Measurements are repeated where appropriate.	2
The number and range of measurements taken in most experiments is adequate. Some measurements are identified as anomalous but there is little attention paid to them. There is some awareness of the need to consider precision and sensitivity, and measurements are usually repeated where appropriate.	1
The number and range of measurements taken in some, but not all, experiments is adequate. There is no attention paid to anomalous measurements. There is some awareness of the need to consider precision and sensitivity, and some measurements are repeated.	0
Maximum 3 marks	

Data processing	Marks
Data are tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and relationships are successfully analysed. Some of the work is sophisticated and requires, for example, the plotting of logarithmic graphs to test for power laws or exponential trends. Error bars are shown wherever appropriate, and uncertainties are routinely calculated for derived quantities. Conclusions are well supported by the results.	6
Data are tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and linear relationships are successfully analysed. Error bars are shown, although not on all graphs and not always correctly, and there is some treatment of uncertainties. Conclusions are well supported by the results.	4
Data are tabulated correctly and graphs are plotted correctly. Calculations contain some errors but these are not major. Some conclusions are not well supported by the results.	2
Most data are tabulated correctly and graphs are mostly plotted correctly, with only a few minor errors. However, calculations contain some major errors and conclusions are not well supported by the results.	0
Maximum 6 marks	

Communication	**Marks**
The report is well organised with a clear structure, which details all the main findings clearly. Material is presented in a logical order and is easy to read and follow. Aims and conclusions are stated clearly for each practical and for any mathematical analysis. Ideas are linked together and clearly show development and feedback between experiment and analysis. There is a clear account of any changes from the original plan. Spelling and grammar are correct. Technical terms are used correctly and there is a glossary of all new technical words encountered and used in the project. There are references to books, journals and websites clearly showing the source of the information.	6
The report summarises most of the main findings clearly. It is easy to read and follow. Sub-headings are used. Spelling and grammar are largely correct. Technical terms are usually used correctly but there are occasional errors. Aims and conclusions are generally stated clearly. References identify sources clearly (for example by providing page numbers).	4
A report is produced. There is some attempt at organisation and layout so that the report provides a clear outline of the course of the project. Some of the aims and conclusions are stated fairly clearly for some of the practical work. References are included but these do not make the source clear (for example, page numbers are usually missing).	2
A report is produced but there are omissions in the account and a poor structure so that the report is not straightforward to follow. References are included but these do not make the source clear (for example, page numbers are missing).	0
Maximum 6 marks	

Internal standardisation

Where more than one teacher in a Centre has marked personal investigations, arrangements must be made within the Centre to ensure that all teachers interpret the marking criteria in the same way. The arrangements for internal standardisation should normally include:

- a standardisation meeting at the start of the marking period, at which the application of the marking criteria is discussed in detail using examples
- the mutual monitoring of marking during the marking period by all of the teachers involved.

It is essential that all candidates in the Centre are assessed to a common standard.

Authentication

The Personal Investigation must be entirely the candidate’s own work. By submitting the mark to Cambridge, the teacher is authenticating the work as the candidate’s own.

External moderation

Marks for all candidates, along with the coursework sample, should be submitted to Cambridge no later than the date indicated in the *Cambridge Administrative Guide (UK)*.

Cambridge will provide a list of candidates whose work is required for external moderation. The number of candidates in the sample will be as shown in the table below.

Number of candidates entered	Number of candidates whose work is required
1–10	all candidates
11–50	10
51–100	15
101–200	20
More than 200	10% of candidates

An additional sample of candidates' work may subsequently be requested by Cambridge if necessary.

For each candidate in the sample, the plan and the report should be sent to Cambridge. In addition, the completed Coursework Assessment Summary Form (which can be downloaded from Teacher Support **http://teachers.cie.org.uk**) and a copy of mark sheet MS1 (a computer-printed mark sheet sent from Cambridge) should be enclosed with the sample of work.

Additional information

Equality and inclusion

Cambridge has taken great care in the preparation of this syllabus and related assessment materials to avoid bias of any kind. To comply with the UK Equality Act (2010), Cambridge has designed this qualification with the aim of avoiding direct and indirect discrimination.

The standard assessment arrangements may present unnecessary barriers for candidates with disabilities or learning difficulties. Arrangements can be put in place for these candidates to enable them to access the assessments and receive recognition of their attainment. Access arrangements will not be agreed if they give candidates an unfair advantage over others or if they compromise the standards being assessed. Candidates who are unable to access the assessment of any component may be eligible to receive an award based on the parts of the assessment they have taken. Information on access arrangements is found in the *Cambridge Handbook (UK)*, for the relevant year, which can be downloaded from the website **www.cie.org.uk/examsofficers**

Entries

For entry information, please refer to the *Cambridge Administrative Guide (UK)*, for the relevant year, available from the website **www.cie.org.uk/examsofficers**

If you are not yet a Cambridge school

Learn about the benefits of becoming a Cambridge school at **www.cie.org.uk/startcambridge**. Email us at **info@cie.org.uk** to find out how your organisation can register to become a Cambridge school.

Language

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

Procedures and regulations

This syllabus complies with our *Code of Practice* and *Ofqual General Conditions of Recognition*.

Further information about the regulations for Cambridge Pre-U can be found in the *Cambridge Handbook (UK)*, for the relevant year. The *Cambridge Administrative Guide (UK)*, for the relevant year, gives details about the administration of Cambridge Pre-U syllabuses. Both of these documents can be downloaded from the website **www.cie.org.uk/examsofficers** or obtained by contacting **info@cie.org.uk**

Spiritual, moral, ethical, social, legislative, economic and cultural issues

The topic area Astronomy and cosmology will foster in candidates a sense of awe at the immensity and grandeur of the universe, and their work on the Big Bang theory and the second law of thermodynamics will shape their thought on the processes involved in its origin, allowing them to participate in informed debate. More generally, the syllabus aims to instil wonder at the elegance and simplicity of the laws of physics which describe the workings of the natural world. The sections on quantum theory offer candidates the opportunity to consider how views of determinism and the nature of reality and laws of physics have been challenged by modern physics.

Candidates' work across the syllabus will deepen their understanding of scientific method and of the essential place of integrity within it. The historical references within the syllabus will enable students to see that scientific advance is a co-operative and cumulative process and that cultural attitudes influence the directions of scientific effort and progress. The use of context in questions, in teaching and in the additional material for Section 2 of Paper 2 will show that physics has an impact on the lives of people and societies, that scientific developments open up new technological possibilities and new economic opportunities, and that the impact of science can be for good or ill.

There are no legislative issues in this syllabus.

Sustainable development, health and safety considerations and international developments

This syllabus includes work on radioactivity, including the ionising ability and penetrating power of the main types of radiations (topic area 8). The syllabus also requires candidates to consider the risks to themselves and others when carrying out laboratory work.

The syllabus includes work on the energy released during nuclear fission and fusion and, although not mentioned in the learning outcomes, ideas about the environmental impact of nuclear power and the sustainability of energy supplies could be drawn into the course.

Advances in physics have been made by scientists from a variety of national backgrounds, and the syllabus will encourage students to appreciate that science is an international endeavour. The names mentioned in the syllabus will make this clear: they include Newton, Young, Hooke, Kirchhoff, Rayleigh, de Broglie, Kepler, Faraday, Lenz, Hall, Maxwell, Einstein, Kelvin, Avogadro, Boltzmann, Lyman, Balmer, Paschen, Feynman, Everitt, Schrödinger, Heisenberg, Wien, Stefan and Hubble. European co-operation in joint scientific projects, such as JET, could be drawn into the course.

Cambridge has developed this syllabus in line with UK, European and International legislation and agreement.

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