Cambridge Pre-U Syllabus

Cambridge Pre-U

Cambridge International Level 3 Pre-U Certificate in **PHYSICS**

For examination in 2010, 2011 and 2012

UNIVERSITY *of* CAMBRIDGE
International Examinations

Cambridge Pre-U

Physics (9792)

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

For examination in 2010, 2011 and 2012

QAN 500/3684/1

Support

CIE provides comprehensive support for all its qualifications, including the Cambridge Pre-U. There are resources for teachers and candidates written by experts. CIE also endorses a range of materials from other publishers to give a choice of approach. More information on what is available for this particular syllabus can be found at www.cie.org.uk

Syllabus Updates

This syllabus is for teaching from 2008 and is valid for examination in 2010, 2011 and 2012.

If there are any changes to this syllabus CIE will write to Centres to inform them. This syllabus will also be published annually on the CIE website (www.cie.org.uk/cambridgepreu). The version of the syllabus on the website should always be considered as the definitive version.

Further copies of this, or any other Cambridge Pre-U syllabus, can be obtained by either downloading from our website www.cie.org.uk/cambridgepreu

or contacting:
Customer Services, University of Cambridge International Examinations,
1 Hills Road, Cambridge CB1 2EU
Telephone: +44 (0)1223 553554
Fax: +44 (0)1223 553558
E-mail: international@cie.org.uk

Cambridge International Level 3 Pre-U Certificate

Physics

9792

Contents

Introduction

Cambridge Pre-U syllabuses aim to equip candidates with the skills required to make a success of their subsequent studies at university, involving not only a solid grounding in each specialist subject at an appropriate level, but also the ability to undertake independent and self-directed learning and to think laterally, critically and creatively. The Cambridge Pre-U curriculum is underpinned by a core set of educational principles:

- A programme of study which supports the development of well-informed, open and independent-minded individuals capable of applying their skills to meet the demands of the world as they will find it and over which they may have influence.
- A curriculum which retains the integrity of subject specialisms and which can be efficiently, effectively and reliably assessed, graded and reported to meet the needs of universities.
- A curriculum which is designed to recognise a wide range of individual talents, interests and abilities and which provides the depth and rigour required for a university degree course.
- A curriculum which encourages the acquisition of specific skills and abilities, in particular the skills of problem solving, creativity, critical thinking, team working and effective communication.
- The encouragement of 'deep understanding' in learning – where that deep understanding is likely to involve higher order cognitive activities.
- The development of a perspective which equips young people to understand a range of different cultures and ideas and to respond successfully to the opportunity for international mobility.

Cambridge Pre-U syllabuses are linear. Candidates must take all the components together at the end of the course in one examination session.

Cambridge Pre-U Science syllabuses aim to develop and nurture in candidates a philosophy of evidence-based thinking and instil in them a notion of inquisitiveness and intellectual enjoyment in exploring a topic further on their own. The assessments foster practical approaches to problem-solving and engender an appreciation of the need for accuracy and precision when working with data.

The syllabuses are also designed to develop candidates' ability to communicate their understanding to a range of audiences, both orally and in written form; to encourage the articulation of informed opinions about science and technology issues, particularly controversial ones, and to enable them to participate in debate about such issues.

The Cambridge Pre-U Science suite should invoke in candidates an enthusiasm for Science, and encourage reflection on the nature, history and philosophy of scientific enquiry.

This syllabus derives from a desire to produce academic rigour in Physics while offering two enhancing viewpoints: a stress on mathematical reasoning while fostering an historical and philosophical perspective in Physics. The Assessment Objectives and assessment model allow appropriate progression from GCSE and IGCSE.

Key features of this Physics course include:

- examination questions set in novel contexts;
- can-do practical and research tasks which reduce the burden of assessment for the teacher and remove the constraints of assessment criteria on students;
- optional questions in the examination which reflect contrasting approaches to Physics;
- a genuinely worthwhile personal investigation for students to research and write up independently.

The Physics specified in this course will provide opportunities for illustrating its use in medicine, biophysics, engineering, space exploration, transport, architecture, robotics, communications, global energy solutions, environmental issues, geology and agriculture. However, although contexts do not drive the course, nor fragment the necessary conceptual development in teaching and learning, they will be emphasised in examination questions. This will help to ensure currency and relevance.

One of the main aims of this course is to allow some degree of choice and flexibility for the candidate. Choice is partly provided by an independent personal investigation chosen by the candidate in consultation with the teacher. Flexibility is also provided by allowing a candidate to opt for questions testing their preferred approach to the subject.

Multi-step mathematical problem solving is very important for more advanced Physics and engineering courses. However, these skills are not necessarily relevant for candidates who do not aim to go on to study these subjects at university. The course will allow mathematically competent candidates to enhance these vitally important skills in an intellectually satisfying, challenging and relevant way.

This course will also allow candidates to reflect on the development and impact of philosophical, historical, social and ethical ideas in Physics. The interpretation of quantum mechanics and the impact of our activities on the environment are two examples of what will be covered. The material will be assessed by questions that require knowledge of historical developments in key areas, good thinking skills, and clear communication linked to an accurate qualitative understanding of the relevant Physics and its context. These questions will have very little mathematical content, being concerned with the grand view, aesthetics and interpretations of physical theory. They will be intellectually rigorous and demanding, developing critical thinking, analysis and evaluation.

The provision of choice between questions with a strongly mathematical flavour, and those which are more discursive and reflective, will allow students to concentrate their work on the approach that suits them, and will allow teachers some flexibility to adapt the emphasis of their teaching to suit the needs of their students.

The course will equip candidates with a coherent theoretical and practical base of transferable skills and key knowledge suitable for future medics, engineers and scientists, whilst providing thought-provoking material that may appeal to those who do not wish to pursue a future scientific career. This approach serves the needs of those who wish to take analytical Physics further as engineers or professional scientists and those who wish to pursue undergraduate courses and careers in areas that do not depend so heavily on mathematics.

The course develops experimental competence through a series of can-do tasks that target a specified set of skills. Data-handling skills involving spreadsheets will be part of the can-do repertoire of first-year skills, which candidates are expected to complete as part of their normal lessons. Teachers simply record that these tasks have been completed. A written paper will assess some of the skills and analytical techniques in practical scenarios.

The course also gives candidates an opportunity to develop their interests and communication skills through researching a topic and delivering a presentation to their peers. The topic for the talk is to be chosen by the candidate and teacher in consultation. The presentation should be recorded when completed simply as a can-do task, with no mark. This will reduce the burden of assessment by the teacher and allow creative students to be unhindered by marking criteria.

The assessment for Cambridge Pre-U Physics employs the skills developed in the course to tackle an extended independent investigation which is assessed by teachers and externally moderated.

This syllabus builds on the knowledge, understanding and skills typically gained by candidates taking Level 2 qualifications in Physics, Additional Science or double-award Science. It is recommended that candidates should have attained communication and literacy skills at a level equivalent to IGCSE/GCSE Grade C in English and numeracy skills at a level equivalent to IGCSE/GCSE Grade C in Mathematics.

Aims

The purpose of this syllabus is to enable Centres to develop courses that will:

- develop an understanding of the link between theory and experiment and foster the development of skills in the design and execution of experiments;
- develop attitudes relevant to science such as concern for accuracy and precision, objectivity, integrity, the skills of enquiry, initiative and inventiveness;
- provide the tools for students to learn and analyse independently and to develop an informed interest in major scientific issues;
- use mathematical reasoning at an appropriate level for each student to help them understand phenomena and solve problems;
- develop an understanding of the links between Physics, Chemistry and Biology and to develop transferable skills;
- enable students to acquire a sound knowledge and understanding of some of the historical and philosophical developments in particular aspects of Physics;
- promote an awareness of the use and development of scientific models;
- promote an awareness that Physics is a cooperative human endeavour which is affected by historical, technological, economic, cultural, social and ethical factors;
- stimulate interest in and care for the environment in relation to the environmental impact of Physics and its applications.

Assessment Objectives

AO1	**Knowledge with understanding** Candidates will be expected to demonstrate knowledge and understanding in relation to: • physical phenomena, principles, concepts, laws, theories, models, relationships, facts, quantities and definitions; • Physics vocabulary, terminology, conventions, symbols and units; • Physics laboratory apparatus and its use; • the development of Physics through hypotheses, predictions, developments of theories, laws and models and through experimental work; • the cultural, historical and other contextual influences on developments in Physics; • scientific and technological applications of Physics including their social, economic and environmental implications. The curriculum content of the syllabus defines the factual knowledge that candidates may be required to recall and explain.
AO2	**Handling, applying and evaluating information** Candidates will be expected to: • interpret unfamiliar information; • select and organise information from a variety of sources; • translate information from one form into another; • identify patterns, report trends, draw inferences, and report conclusions from unfamiliar data; • apply knowledge and understanding of Physics to novel situations or to explain phenomena, patterns, trends or relationships; • evaluate information and hypotheses; • show an awareness of the limitations of physical theories and models. This assessment objective relates primarily to unfamiliar data, phenomena or situations which, by definition, cannot be listed in the curriculum content of the syllabus.
AO3	**Experimental and investigative skills** Candidates will be expected to: • plan investigations; • research information from a variety of sources including books, journals and the internet; • use laboratory apparatus and/or techniques appropriately, safely and effectively; • make and record observations methodically and with due regard for precision, accuracy and units; • plot and analyse graphs to identify mathematical relationships; • evaluate methods and techniques and suggest improvements; • communicate the method and findings of an investigation in a truthful, clear and concise way.

Scheme of Assessment

For the Cambridge Pre-U qualification in Physics, candidates take three written examination papers and submit a personal investigation in the same examination session. Candidates must also have completed all the Matriculation can-do tasks.

Component	Component Name	Duration	Weighting (%)	Type of Assessment
0	Compulsory Matriculation	–	*	School-based can-do tasks
1	Part A Multiple Choice	1 hour 15 minutes	20	Multiple choice paper, externally set and marked
2	Part A Written Paper	2 hours	30	Written paper, externally set and marked
3	Part B Written Paper	3 hours	35	Written paper, externally set and marked
4	Personal Investigation	(20 hours)	15	Project report, internally marked and externally moderated

* Although there is no weighting associated with the Compulsory Matriculation can-do tasks, these must have been completed in order for CIE to be able to make the Cambridge Pre-U award.

Weighting of Assessment Objectives

The table below shows the approximate weighting given to each assessment objective.

	Paper 1 (marks)	Paper 2 (marks)	Paper 3 (marks)	Paper 4 (marks)	Whole assessment (%)
AO1: Knowledge with understanding	18	50	65	0	40
AO2: Handling, applying and evaluating information	22	50	75	0	45
AO3: Experimental and investigative skills	0	0	0	30	15

Description of Papers

Contexts for questions on written papers

Questions on 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.

Component 0: Compulsory Matriculation

This compulsory component consists of can-do tasks which candidates must complete in order to be eligible to enter for the examination. These can-do tasks help to practise skills later tested in the written examinations. There are two categories of task:

- **Practical skills**: Practical work throughout the year must develop at least the full range of skills listed in Appendix 2 of this syllabus. These skills should be demonstrated in the context of meaningful experiments rather than as isolated exercises. The experiments will be set by the teacher. The number of experiments required to develop the full range of skills is at the discretion of the teacher.
- **Communication task**: A mini presentation is to be given, on any topic researched by the candidate. Topics for research are to be chosen by the candidate and teacher in consultation. The topic should be appropriate to a candidate's interest and ability. It may be inspired by a physics visit (e.g. to a hospital, a nuclear power station or a wind farm) or by the media or by an article from a science journal. The presentation should be recorded simply as a can-do exercise and may be taken at any time during the course.

From time to time, CIE may require Centres to provide evidence that these tasks have been completed. If this evidence is not provided then candidates will not be certificated in the written examinations.

Paper 1: Part A Multiple Choice

This paper consists of 40 multiple choice questions, all of the direct choice type. All questions will be based on Part A of the curriculum content.

Paper 2: Part A Written Paper

This paper will consist of two sections:

- **Section A**: Structured questions. This section will consist of a number of compulsory structured questions of variable mark value. All questions will be based on Part A of the curriculum content. This section will contain 75 marks and candidates will be advised to spend 1½ hours on the section.
- **Section B**: Questions on pre-release material. This section will consist of a number of compulsory structured questions of variable mark value. The questions will relate to material released to candidates prior to the examination. The material will draw on the Physics concepts from Part A of the curriculum content and will show how these concepts are applied in an area such as medical physics, telecommunications, or engineering. This section will contain 25 marks and candidates will be advised to spend 30 minutes on the section. The pre-release material will be posted on the CIE teacher support website https://teachers.cie.org.uk/ by 1 April in the year of the examination. It will not be sent to Centres in hard copy. For the examination, the pre-release material will be supplied to all candidates as an insert in the question paper. Candidates must **not** bring their own copies of the pre-release material into the examination room.

Paper 3: Part B Written Paper

This paper will consist of two sections:

- **Section A**: Compulsory questions. This section will consist of a number of compulsory questions. These questions will focus on Part B of the curriculum content although some questions may also draw on content from Part A. Learning outcomes marked with an asterisk (*) will not be assessed in Section A. The questions will primarily be structured questions but may also include an unstructured question requiring candidates to perform extended calculations and/or a question requiring the analysis of experimental data. This section will contain 80 marks and candidates will be advised to spend 1½ hours on the section.
- **Section B**: Optional questions. This section will consist of six half-hour questions of which candidates will answer three. Three questions will have a strong mathematical flavour and three will require discussion of philosophical issues raised in the course. Candidates may choose whether to answer all of the mathematical questions, all of the philosophical ones, or a mixture of the two types. The questions may assess content from any part of the syllabus. Each question will contain 20 marks and candidates will be advised to spend 1½ hours on the section.

Component 4: Personal Investigation

This coursework component will consist of a research project. Candidates will be required to perform an individual investigation of a practical problem of their own choosing and 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.

Teachers will be required to assess the candidate's organisation during the project, and to mark the candidate's report according to the marking criteria in Appendix 3. The marking will be sampled and externally moderated.

Curriculum Content

Learning outcomes marked with an asterisk (*) will be assessed only in the optional questions in Section B of Paper 3.

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

Part A

1. Mechanics

Content

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

Learning outcomes

Candidates should be able to:

1 distinguish between scalar and vector quantities and give examples of each
2 resolve a vector into two components at right angles to each other by drawing and by calculation
3 combine any number of coplanar vectors at any angle to each other by drawing
4 calculate the moment of a force and use the conditions for equilibrium to solve problems (restricted to coplanar forces)
5 construct displacement/time and velocity/time graphs for uniformly accelerated motion
6 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
7 recall and use the expressions

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

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

8 recognise and use the kinematic equations for motion in one dimension with constant acceleration:

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

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

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

9 recognise and make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity
10 recognise that internal forces on a collection of objects sum to zero vectorially

11 recall and interpret statements of Newton's laws of motion
12 recall and use the relationship $F = ma$ in situations where mass is constant
13 recall and use the independent effects of perpendicular components of a force
14 recall and use the expression $p = mv$ and apply the principle of conservation of linear momentum to problems in one dimension
15 relate net force to rate of change of momentum in situations where mass is constant and recall and use $F = \frac{\Delta p}{\Delta t}$
16 recall and use the relationship impulse = change in momentum
17 recall and use the fact that the area under a force-time graph is equal to the impulse
18 be able to apply the principle of conservation of linear momentum to problems in two dimensions
19 recall and use the relationship pressure = $\frac{\text{normal force}}{\text{area}}$
20 recall and use the relationship $p = \rho gh$ for pressure due to a liquid

2. Gravitational fields

Content

gravitational field strength
centre of gravity

Learning outcomes

Candidates should be able to:

1 recall and use the fact that the gravitational field strength g is equal to the force per unit mass and hence that weight $W = mg$
2 recall that the weight of a body appears to act from its centre of gravity
3 sketch the field lines for a uniform gravitational field (such as near the surface of the Earth)
4 explain the distinction between 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

Learning outcomes

Candidates should be able to:

1 distinguish between elastic and plastic deformation of a material
2 explain what is meant by the terms brittle, ductile, hard, malleable, stiff, strong and tough; use these terms; and give examples of materials exhibiting such behaviour
3 explain the meaning of, use and calculate tensile/compressive stress, tensile/compressive strain, spring constant, strength, breaking stress, stiffness and Young Modulus
4 draw force-extension, force-compression and tensile/compressive stress-strain graphs, and identify the limit of proportionality, elastic limit, yield point, breaking force and breaking stress
5 state Hooke's law and identify situations in which it is obeyed

6 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

Learning outcomes

Candidates should be able to:

1 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
2 calculate the work done in situations where the force is a function of displacement using the area under a force-displacement graph
3 calculate power from the rate at which work is done or energy is transferred
4 recall and use the relationship $\Delta E = mg\Delta h$ for the gravitational potential energy transferred near the Earth's surface
5 recall and use the expression $g\Delta h$ as change in gravitational potential
6 recall and use the expression $E = \frac{1}{2}Fx$ for the elastic strain energy in a deformed material sample obeying Hooke's law
7 use the area under a force-extension graph to determine elastic strain energy
8 derive, recall and use the expression $E = \frac{1}{2}kx^2$
9 derive, recall and use the relationship $E = \frac{1}{2}mv^2$ for the kinetic energy of a body
10 apply the principle of conservation of energy to solve problems
11 recall and use the expression $\%\ \text{efficiency} = \frac{\text{useful energy (or power) out}}{\text{total energy (or power) in}} \times 100\%$
12 recognise and use the expression $\Delta E = mc\Delta\theta$, where c is the specific heat capacity
13 recognise and use the expression $\Delta E = mL$, 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

Learning outcomes

Candidates should be able to:

1 discuss electrical phenomena in terms of electric charge

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

3 understand potential difference in terms of energy transfer and recall and use the expression $V = \frac{W}{Q}$

4 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

5 define and use the concepts of emf and internal resistance and distinguish between emf and terminal potential difference

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

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

8 recall and use the expressions $P = VI$ and $W = VIt$, and derive and use the related expression $P = I^2R$

9 recall and use the relationship $R = \frac{\rho L}{A}$

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

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

12 recall Kirchoff's first and second laws and apply them to circuits containing no more than two supply components and no more than two linked loops

13 appreciate that Kirchoff's first and second laws are a consequence of the conservation of charge and energy respectively

14 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

Learning outcomes

Candidates should be able to:

1 understand and use the terms displacement, amplitude, intensity, frequency, period, speed and wavelength

2 recall and apply the equation $f = \frac{1}{T}$ to a variety of situations not limited to waves

3 recall and use the wave equation $v = f\lambda$
4 recall that a sound wave is a longitudinal wave which can be described in terms of the displacement of molecules or changes in pressure
5 recall that light waves are transverse electromagnetic waves, and that all electromagnetic waves travel at the same speed in vacuum
6 recall the major divisions of the electromagnetic spectrum in order of wavelength, and the range of wavelengths of the visible spectrum
7 recall that the intensity of a wave is directly proportional to the square of its amplitude
8 use graphs to represent transverse and longitudinal waves, including standing waves
9 explain what is meant by a plane polarised wave
10 use the components of amplitude perpendicular and parallel to the axis of a polarizing filter to determine the amplitude and intensity of transmission through a filter
11 recognise and use the expression for refractive index $n = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$
12 derive the equation $\sin c = \frac{1}{n}$, recall it, and use it to solve problems
13 recall that optical fibres use total internal reflection to transmit signals
14 recall that, in general, waves are partially transmitted and partially reflected at an interface between media

7. Superposition

Content

phase difference
diffraction
N-source interference
standing waves

Learning outcomes

Candidates should be able to:

1 explain and use the concepts of coherence, path difference, superposition and phase
2 understand the origin of phase difference and path difference, and calculate phase differences from path differences
3 understand how the phase of a wave varies with time and position
4 use a geometrical (phasor) or algebraic method to calculate the resultant amplitude when two waves superpose (limited to situations in which either the phase difference is a multiple of 90° or in which the two incident amplitudes are equal)
5 understand amplitude modulation as an example of superposition and use the terms signal and carrier wave
6 understand that a complex wave may be regarded as a superposition of sinusoidal waves of appropriate amplitudes, frequencies and phases
7 recall that waves can be diffracted and that substantial diffraction occurs when the size of the gap or obstacle is comparable with the wavelength
8 recall qualitatively the diffraction patterns for a slit, a circular hole and a straight edge
9 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

10 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
11 describe the N-source superposition pattern and use the equation $d \sin \theta = n\lambda$ to calculate the angles of the principal maxima for a diffraction grating and for a double slit
12 explain what is meant by a standing wave, how such a wave is formed, and identify nodes and antinodes

8. Atomic and nuclear

Content

the nucleus
nuclear processes
probability and radioactive decay
fission and fusion

Learning outcomes

Candidates should be able to:

1 understand the importance of the α-particle scattering experiment in determining the nuclear model
2 describe atomic structure using the nuclear model
3 show an awareness of the existence and main sources of background radiation
4 recognise nuclear radiations (α, β^-, γ) from their penetrating power and ionising ability, and recall the nature of these radiations
5 write and interpret balanced nuclear transformation equations using standard notation
6 understand and use the terms nucleon number (mass number), proton number (atomic number), nuclide and isotope
7 appreciate the spontaneous and random nature of nuclear decay
8 define and use the concept of activity as the number of decays occurring per unit time
9 understand qualitatively how a constant decay probability leads to the shape of a radioactive decay curve
10 determine the number of nuclei remaining or the activity of a source after a time which is an integer number of half-lives
11 understand the terms thermonuclear fusion, induced fission and chain reaction
12 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

Learning outcomes

Candidates should be able to:

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

2 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
3 recall that photoelectrons are not ejected when the light has a frequency lower than a certain threshold frequency which varies from metal to metal
4 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
5 recall that the absorption of a photon of energy can result in the emission of a photoelectron
6 recognise and use the expression $E = hf$
7 understand and use the terms threshold frequency and work function and recall and use the expression $hf = \Phi + \frac{1}{2}mv_{max}{}^2$
8 understand the use of stopping potential to find the maximum kinetic energy of photoelectrons and convert energies between joules and electron-volts
9 plot a graph of stopping potential against frequency to determine the Planck constant, work function and threshold frequency
10 understand the need for a wave model to explain electron diffraction
11 recognise and use the expression $\lambda = \frac{h}{p}$ for the de Broglie wavelength

Part B

10. Rotational mechanics

Content

kinematics of uniform circular motion
centripetal force
moment of inertia
kinematics of rotational motion

Learning outcomes

Candidates should be able to:
1 define and use the radian
2 understand the concept of angular velocity, and recall and use the relationships $v = \omega r$ and $T = \frac{2\pi}{\omega}$
3 recall and use the expression for centripetal force $F = \frac{mv^2}{r}$
4 derive, recall and use the expressions for centripetal acceleration $a = \frac{v^2}{r}$ and $a = r\omega^2$
5 describe qualitatively the motion of a rigid solid object under the influence of a single force in terms of linear acceleration and rotational acceleration
6 * use $I = \Sigma mr^2$ to calculate the moment of inertia of a body consisting of three or fewer point particles fixed together
7 * use integration to calculate the moment of inertia of a ring, a disk and a rod

8 * deduce laws for rotational motion by analogy with Newton's laws for linear motion, including

$E = \frac{1}{2}I\omega^2$, $L = I\omega$ and $\Gamma = I\frac{d\omega}{dt}$

9 * 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

Learning outcomes

Candidates should be able to:

1 recall the condition for simple harmonic motion and hence identify situations in which simple harmonic motion will occur

2 * 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

3 * 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

4 * 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

5 recall and use the expression $T = \frac{2\pi}{\omega}$ as applied to a simple harmonic oscillator

6 understand the phase differences between displacement, velocity and acceleration in simple harmonic motion

7 * 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

8 recognise and use the expression $E = \frac{1}{2} mA^2\omega^2$ to solve problems

9 distinguish between free, damped and forced oscillations

10 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

Learning outcomes

Candidates should be able to:

1 explain what is meant by an electric field and recall and use the expression electric field strength $E = \frac{F}{Q}$

2 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

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

4 recall that the charge stored on parallel plates is proportional to the potential difference between them

5 recall and use the expression for capacitance $C = \frac{Q}{V}$

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

7 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

8 understand electric potential and equipotentials

9 understand the relationship between electric field and potential gradient, and recall and use the equation $E = \frac{-\mathrm{d}V}{\mathrm{d}x}$

10 recognise and use the expression $F = \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}$ for point charges

11 derive and use the expression $E = \frac{Q}{4\pi\varepsilon_o r^2}$ for the electric field due to a point charge

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

13 * recognise and use the equation for electric potential energy for point charges $W = \frac{Q_1 Q_2}{4\pi\varepsilon_o r}$

13. Gravitation

Content

Kepler's laws
Newton's law of gravity
gravitational field of a point mass
gravitational potential energy

Learning outcomes

Candidates should be able to:

1 state Kepler's laws of planetary motion:
- Planets move in elliptical orbits with the Sun at one focus.
- The Sun-planet line sweeps out equal areas in equal times.
- The orbital period squared of a planet is proportional to its mean distance from the Sun cubed.

2 recognise and use the expression $F = \frac{-Gm_1m_2}{r^2}$

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

4 understand energy transfer by analysis of the area under a gravitational force-distance graph

5 derive and use the expression $g = \frac{Gm}{r^2}$ for the magnitude of the gravitational field strength due to a point mass

6 recall similarities and differences between electric and gravitational fields

7 recognise and use the equation for gravitational potential energy for point masses $E = \frac{-Gm_1m_2}{r}$

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

9 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 filed
force on a current-carrying conductor
force on a moving charge
electromagnetic induction
the Hall effect

Learning outcomes

Candidates should be able to:

1 understand and use the terms magnetic flux density, flux and flux linkage

2 understand that magnetic fields are created by electric current

3 recognise and use the expression $F = BIL \sin\theta$

4 recognise and use the expression $F = BQv \sin\theta$

5 use Fleming's left hand rule to solve problems

6 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

7 recognise and use the expression $E = \frac{-\mathrm{d}(N\Phi)}{\mathrm{d}t}$ and explain how it is an expression of Faraday's and Lenz's laws

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

9 explain the Hall effect, and derive and use the equation $V = Bvd$

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

15. Special relativity

Content

Einstein's special principle of relativity
time dilation

Learning outcomes

Candidates should be able to:

1 * 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)

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

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

4 * understand that Einstein's theory of special relativity dispensed with the ether and postulated that the speed of light is a universal constant

5 * state Einstein's special principle of relativity and recall that the constancy of the speed of light may be interpreted as a consequence of this

6 * explain how Einstein's postulate leads to the idea of time dilation expressed by the equation $t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$ and that this undermines the ideas of absolute space and time

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

Learning outcomes

Candidates should be able to:

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

2 use the units Kelvin and degrees Celsius and convert from one to the other

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

4 recall and use the expression $pV = nRT$ as the equation of state for an ideal gas

5 describe Brownian motion and explain it in terms of the particle model of matter

6 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

7 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

8 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

9 recognise and use the expression $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

10 understand and calculate the root mean square speed for particles in a gas

11 understand the concept of internal energy as the sum of potential and kinetic energies of the molecules

12 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

13 recognise and use the expression $W = p\Delta V$ for the work done on or by a gas

14 understand qualitatively how the random distribution of energies leads to the Boltzmann factor $e^{-E/kT}$ as a measure of the chance of a high energy

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

16 * 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

17 * 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

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

19 * 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

20 * 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

Learning outcomes

Candidates should be able to:

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

2 recall that activity $A = -\frac{dN}{dt}$ and show that $A = \lambda N$ and $A = A_0 e^{-\lambda t}$

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

4 use these equations to solve problems

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

6 recognise 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

7 estimate the size of a nucleus from the distance of closest approach of a charged particle

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

9 understand and explain the curve of binding energy per nucleon against nucleon number

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

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

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

13 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

14 balance nuclear transformation equations for alpha, beta minus and beta plus emissions

15 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)

18. The Quantum atom

Content

line spectra

energy levels in the hydrogen atom

Learning outcomes

Candidates should be able to:

1 explain atomic line spectra in terms of photon emission and transitions between discrete energy levels

2 apply the expression $E = hf$ to radiation emitted in a transition between energy levels

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

4 recognise and use the energy levels of the hydrogen atom as described by the empirical equation $E_n = \frac{-13.6\,\text{eV}}{n^2}$

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

6 * 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

Learning outcomes

Candidates should be able to:

1 * 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
2 * describe and explain Schrödinger's cat paradox and appreciate the use of a thought experiment to illustrate and argue about fundamental principles
3 * recognise and use $\Delta p\, \Delta x \geq \frac{h}{2\pi}$ and $\Delta E\, \Delta t \geq \frac{h}{2\pi}$ as forms of the Heisenberg uncertainty principle and interpret them
4 * recognise that the Heisenberg uncertainty principle places limits on our ability to know the state of a system and hence to predict its future
5 * recall that Newtonian Physics is deterministic but quantum theory is indeterministic
6 * explain why Einstein thought that quantum theory undermined the nature of reality

20. Astronomy and cosmology

Content

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

Learning outcomes

Candidates should be able to:

1 understand the terms luminosity and luminous flux
2 recall how flux reduces as an inverse square law $F = \frac{L}{4\pi d^2}$
3 understand the need to use standard candles to help determine distances to galaxies
4 recognise and use Wien's law $\lambda_{max} \propto \frac{1}{T}$ to estimate the peak surface temperature of a star either graphically or algebraically
5 recognise and use Stefan's law for a spherical body $L = 4\pi\sigma r^2\, T^4$
6 use Wien's displacement law and Stefan's law to estimate the radius of a star
7. 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
8 recognise and use $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer
9 state Hubble's law and explain why galactic redshift leads to the idea that the Universe is expanding and to the Big Bang theory

10 explain how microwave background radiation provides empirical support for the Big Bang theory

11 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

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

13 derive an estimate for the age of the Universe by recalling and using the Hubble time $t \approx \frac{1}{H_0}$

Appendix 1: 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 Système International 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, 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, $1/x$ and $\sqrt{x}$
11 use calculators to find and use sin x, cos x, tan x, where x is expressed in degrees
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 $=$, $\approx$, $<$, $\leqslant$, $<<$, $>>$, $\geqslant$, $>$, $\propto$, 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 and area of 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

Part B

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 $y = \cos aix$

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

Appendix 2: Matriculation Requirements

The Matriculation component consists of can-do tasks, that is, tasks which candidates must simply complete. There are no assessment criteria other than completion of the tasks, and there is no standard of performance that must be demonstrated. Candidates must complete all of the tasks in order to be eligible to enter for the examination. There are two categories of task.

- **Practical tasks**: Practical work throughout the first year must cover the full range of required practical skills listed in this appendix. Some of the skills require the use of spreadsheets. The tasks will be set by the teacher. The number of practical tasks required to develop the full range of skills is at the discretion of the teacher. Candidates are allowed to work in pairs or small groups on these tasks, but teachers should ensure that each candidate is given opportunities to develop each skill.
- **Communication task**: A 15 minute presentation by the candidate on any Physics topic researched by the candidate. The topic may be directly related to the curriculum content, but this is not a requirement. Topics for research are to be chosen by the candidate and teacher in consultation. The topic should be appropriate to a candidate's interest and ability.

From time to time, CIE may require Centres to provide evidence that these tasks have been completed. If this evidence is not provided, then candidates will not be certificated in the examination.

Practical tasks

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.

Candidates may be exempted from the practical tasks if they have disabilities that prevent them from carrying out the tasks.

Record of practical tasks

Schools will be required to keep a record of practical activities showing how the chosen activities give opportunities for each candidate to develop the required skills. The record may vary from class to class.

It is suggested that the record is laid out on a spreadsheet with a row for each of the required skills, a column for each of the practicals carried out by the candidates (in the correct sequence where possible), and ticks in the cells to indicate which skills were needed for the practical. The record may be in whatever format the school finds convenient.

The record only needs to be sent to CIE if requested. It may be sent in any format and in soft copy or in hard copy. In this way the administrative burden for schools is kept to a minimum.

Student practical notebooks

Each candidate will be required to keep a laboratory notebook to provide a record of their progress. The work in the notebooks should correspond to the school's record of practical activities (described above).

The notebooks only need to be sent to CIE if requested.

List of required practical skills

The practical tasks must allow candidates to demonstrate that they have used all of the following skills at least once.

Use of apparatus:

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

Practical techniques:

- identifying and dealing with zero errors
- avoiding parallax
- calibration of a measuring instrument
- assessing risks to themselves and others

Data processing

- tabulating data (including units, decimal places and significant figures)
- repetition and averaging of readings
- graph plotting
- estimating uncertainties in measured quantities
- determining the uncertainty in a final result
- identifying the physical significance of the gradient or y-intercept of a graph
- data processing using a spreadsheet

Communication Task

Candidates research a topic chosen in consultation with their teacher. The topic should be appropriate to the candidate's interests and ability. It may be directly related to the curriculum content, but candidates are encouraged to go beyond the syllabus. The topic for research may cover a contemporary aspect of Physics inspired by a Physics visit (e.g. to a hospital, a nuclear power station or a wind farm), a media report or an article in a science journal. Suitable journals include *Physics Review*, *New Scientist*, *Scientific American* and *Nature*.

The candidate should then deliver a 10 to 15 minute presentation on their research to their peers. The presentation may be oral or may use other suitable media. The presentation should be recorded simply as a can-do exercise, i.e. teachers are required to record that the presentation has been given but they are not required to make judgements on the standard of the work.

A record of the work should be kept. This may be in the form of a recording of the presentation, or in the form of a Microsoft PowerPoint presentation, or in the form of the candidate's notes. The record only needs to be sent to CIE if requested.

Appendix 3: Personal Investigation Requirements

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 might be divided as follows.

- 1 week for planning and preliminary tests
- a pause, to allow time to organise laboratories and build or modify apparatus, and for the teacher to approve the plan
- 2 weeks of intensive practical work, to be written up each day and checked frequently by the teacher
- 1 week for additional practical work (if required) and final writing up

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 apparatus requirements;
- a diagram of the initial experimental arrangement;
- a risk assessment;
- a rough breakdown of how the two week investigation period 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).

Marking Criteria

The work of each candidate should be marked by their teacher using the marking criteria below.

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

For some of the marking criteria, grade descriptors 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.

Criteria for Component 4 Personal Project	Marks
Initial Planning	
The plan contains a title, a statement of the aim and an outline of initial experiment(s). There is little or no elaboration.	0
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 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
Maximum mark 4	

Organisation during the two weeks of practical work	
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
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 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
Maximum mark 2	

Quality of Physics	
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
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
In most cases where it is appropriate, physics principles 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
Wherever appropriate, physics principles 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
Maximum mark 6	

Use of Measuring Instruments	
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
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 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
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 (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
Maximum mark 3	

* 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	
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
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 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 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
Maximum mark 3	

Data Processing	
Most data is 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
Data is 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
Data is 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 is 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
Maximum mark 6	

Communication	
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
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
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
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
Maximum mark 6	

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 CIE, the teacher is authenticating the work as the candidate's own.

External moderation

Marks for all candidates should be submitted to CIE no later than 30 April.

After the marks have been submitted, CIE 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 the candidates

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

For each candidate in the sample, the plan and the report should be sent to CIE. In addition, the completed Coursework Assessment Summary Form (see following page) and a copy of mark sheet MS1 (a computer-printed mark sheet sent from CIE) should be enclosed with the sample of work.

PHYSICS 9792

Coursework Assessment Summary Form

CAMBRIDGE PRE-U

Please read the instructions printed overleaf before completing this form.

Centre Number						Centre Name		June	2	0	1	0

Candidate Number	Candidate Name	Teaching Group	**Initial planning** (max 4)	**Organisation** (max 2)	**Quality of Physics** (max 6)	**Use of measuring instruments** (max 3)	**Practical techniques** (max 3)	**Data processing** (max 6)	**Communi-cation** (max 6)	**Total Mark** (max 30)

Name of teacher marking work		Signature		Date						

A INSTRUCTIONS FOR COMPLETING COURSEWORK ASSESSMENT SUMMARY FORMS

1. Complete the information at the head of the form.

2. List the candidates in an order that will allow ease of transfer of information to a computer-printed coursework mark sheet MS1 at a later stage (i.e. in candidate number order, where this is known: see item B.1 below). Show the teaching group for each candidate. The initials of the teacher may be used to indicate the teaching group.

3. Transfer each candidate's marks from his or her work to this form as follows:
   (a) Enter the marks awarded for each of the marking criteria in the appropriate column.
   (b) In the column headed 'Total Mark', enter the total mark awarded.

4. Check the form carefully and complete and sign the bottom portion.

5. Retain a copy of the form.

B PROCEDURES FOR EXTERNAL MODERATION

1. University of Cambridge International Examinations (CIE) sends a computer-printed coursework mark sheet MS1 to each Centre (in late March for the June examination) showing the names and candidate numbers of each candidate. Transfer the total mark for each candidate from the Coursework Assessment Summary Form to the computer-printed coursework mark sheet MS1.

2. The top copy of the computer-printed coursework mark sheet MS1 must be despatched in the specially provided envelope to arrive at CIE as soon as possible and no later than 30 April.

3. A sample of the candidates' work covering the full ability range should be selected for external moderation, as described in the syllabus. The sample of work, together with this Coursework Assessment Summary Form and the second copy of the computer-printed coursework mark sheet MS1, must be sent to CIE, arriving no later than 30 April.

Appendix 4: Some Suggested Reading

Candidates' performance in the philosophical and historical sections of the course will be considerably improved if they are encouraged to read around the subject. The following list of resources is intended to offer some help with these sections and is not exhaustive.

For candidates and teachers:

1. *The Character of Physical Law*, Richard Feynman
2. *QED*, Richard Feynman
3. *The New World of Mr Tompkins*, George Gamow and Russell Stannard
4. *The Evolution of Physics*, Albert Einstein and Leopold Infeld
5. *Copenhagen*, a play by Michael Frayn

And for teachers:

1. *Science in History*, vol 1, 2 and 3, J D Bernal, Pelican 1969
2. *Popper*, Bryan Magee, Fontana Modern Masters, 1973
3. *The Structure of Scientific Revolutions*, Thomas S Kuhn, University of Chicago Press
4. *The Aim and Structure of Physical Theory*, Pierre du Hen

Appendix 5: List of Data, Formulae and Relationships for use in Examinations

The list of data and formulae in this Appendix will be provided in every examination paper.

Data

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

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	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$n = \frac{v_1}{v_2}$
photon energy	$E = hf$

de Broglie wavelength	$\lambda = \dfrac{h}{p}$
simple harmonic motion	$x = A \cos \omega t$
	$v = -A\omega \sin \omega t$
	$a = -A\omega^2 \cos \omega t$
	$F = -m\omega^2 x$
	$E = \dfrac{1}{2} m A^2 \omega^2$
energy stored in a capacitor	$W = \dfrac{1}{2} QV$
electric force	$F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = \dfrac{-G m_1 m_2}{r^2}$
gravitational potential energy	$E = \dfrac{-G m_1 m_2}{r}$
magnetic force	$F = BIl \sin \theta$
	$F = BQv \sin \theta$
electromagnetic induction	$E = \dfrac{-\mathrm{d}(N\Phi)}{\mathrm{d}t}$
Hall effect	$V = Bvd$
time dilation	$t' = \dfrac{t}{\sqrt{1 - \dfrac{v^2}{c^2}}}$
kinetic theory	$\dfrac{1}{2} m\langle c^2\rangle = \dfrac{3}{2} kT$
work done on/by a gas	$W = p\Delta V$
radioactive decay	$\dfrac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$
	$N = N_0 \mathrm{e}^{-\lambda t}$
	$t_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$
attenuation losses	$I = I_0 \mathrm{e}^{-\mu x}$

mass-energy equivalence	$\Delta E = c^2 \Delta m$
hydrogen energy levels	$E_n = \dfrac{-13.6\text{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p \Delta x \geqslant \dfrac{h}{2\pi}$
	$\Delta E \Delta t \geqslant \dfrac{h}{2\pi}$
Wien's law	$\lambda_{max} \propto \dfrac{1}{T}$
Stefan's law	$L = 4\pi\sigma r^2 T^4$
electromagnetic radiation from a moving source	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

Appendix 6: 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	m^{-1}
acceleration	a	$m\ s^{-2}$
activity of a radioactive source	A	Bq
amount of substance	n	mol
amplitude	A	m
angular frequency	ω	$rad\ s^{-1}$
angular momentum	L	$kg\ m^2\ s^{-1}$
angular speed	ω	$rad\ s^{-1}$
angular velocity	ω	$rad\ s^{-1}$
area	A	m^2
Avogadro constant	N_A	mol^{-1}
Boltzmann constant	k	$J\ K^{-1}$
capacitance	C	F
change in internal energy	ΔU	J
charge	Q	C
critical angle	c	rad, °
decay constant	λ	s^{-1}
density	ρ	$kg\ m^{-3}$
depth	h	m
displacement	s, x	m
distance	d, x	m
electric current	I	A
electric field strength	E	$N\ C^{-1}$
electric potential	V	V
elementary charge	e	C
electromotive force	E	V
energy	E, W	J, eV
energy level	E_n	J, eV
extension	x	m
force	F	N
frequency	f	Hz
gravitational constant	G	$N\ m^2\ kg^{-2}$
gravitational field strength	g	$N\ kg^{-1}$
gravitational potential	φ	$J\ kg^{-1}$

half-life	$t_{½}$	s
heating	Q	J
height	h	m
Hubble constant	H_0	s^{-1}
intensity	I	$W\ m^{-2}$
internal resistance	r	Ω
length	l, L	m
light flux	F	$W\ m^{-2}$
luminosity	L	W
magnetic flux	Φ	Wb
magnetic flux density	B	T
mass	m	kg, u
molar gas constant	R	$J\ K^{-1}\ mol^{-1}$
moment of a force	Γ	N m
moment of inertia	I	$kg\ m^2$
momentum	p	$kg\ m\ s^{-1}$
number	n, N	
period	T	s
permittivity of free space	ε_0	$F\ m^{-1}$
Planck constant	h	J s
potential difference	V	V
power	P	W
pressure	p	Pa
radius	r	m
resistance	R	Ω
resistivity	ρ	Ω m
slit separation	d	m
slit width	b	m
specific heat capacity	c	$J\ kg^{-1}\ K^{-1}$
specific latent heat of fusion	L	$J\ kg^{-1}$
specific latent heat of vaporisation	L	$J\ kg^{-1}$
speed	v	$m\ s^{-1}$
speed of light in vacuum	c	$m\ s^{-1}$
spring constant	k	$N\ m^{-1}$
Stefan-Boltzmann constant	σ	$W\ m^{-2}\ K^{-4}$
strain	ε	
stress	σ	Pa
temperature	T, θ	K, °C
time	t	s
torque	Γ	N m
velocity	v, u	$m\ s^{-1}$
volume	V	m^3
wavelength	λ	m
weight	W	N
work	W	J, eV
work function energy	Φ	J, eV
Young modulus	E	Pa

Appendix 7: Glossary of Terms Used in Physics Papers

It is hoped that the 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, being 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 intended 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 intended 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.

Appendix 8: Grade Descriptors

The following grade descriptors indicate the level of attainment characteristic of the given grade. They give a general indication of the required standard at each specified grade. The descriptors 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 these.

Candidates apply knowledge and physical principles 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 on 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 physical principles 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 physical principles 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.

Appendix 9: Additional Information

Guided Learning Hours

It is intended that each Principal subject should be delivered through 380 hours of guided learning. This is a notional measure of the substance of the qualification. It includes an estimate of the time that might be allocated to direct teaching or instruction, together with other structured learning time such as directed assignments or supported individual study and practice. It excludes learner-initiated private study.

Certification Title

This qualification is shown on a certificate as:
- Cambridge International Level 3 Pre-U Certificate in **Physics (Principal)**

The qualification is accredited at Level 3 of the UK National Qualifications Framework and provides a solid grounding for students to pursue a variety of progression pathways.

Entries

For Entry information please refer to the *Pre-U E3 Booklet*.

Grading and Reporting

The Cambridge International Level 3 Pre-U Certificates in the Principal Subjects are qualifications in their own right. They are acceptable as an alternative to A Level (or other Level 3 qualifications) for entry into Higher Education or employment. Each individual Principal Subject 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, Pass 3.

Subjects can also be combined with two core components to meet the requirements for eligibility for the Cambridge International Level 3 Pre-U Diploma. More details about the Diploma requirements and the core components can be found in a separate Diploma syllabus. The results of the individual Principal Subjects are reported on a separate certificate to the Diploma result.

Classification Code for UK Centres

In the UK, every syllabus is assigned to a national classification code that indicates the subject area to which it belongs. UK Centres should be aware that candidates who enter for more than one qualification with the same classification code will have only one grade (the highest) counted for the purpose of the School and College Performance Tables.

The classification code for this syllabus is **1210**.

Language

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

Procedures and Regulations

This syllabus complies with the *CIE Code of Practice* and *The Statutory Regulation of External Qualifications 2004*.

Further information about the administration of Cambridge Pre-U qualifications can be found in the CIE *Handbook for Cambridge Pre-U Centres* available from CIE Publications or by contacting international@cie.org.uk

Spiritual, Moral, Ethical, Social, Economic and Cultural Issues

The section Astronomy and Cosmology will foster in candidates a sense of awe at the immensity and grandeur of creation, and their work on the Big Bang theory and the second law of thermodynamics will shape their thought on the processes of creation. More generally, the syllabus aims to instil wonder at the elegance and simplicity of the physical laws which describe the workings of the natural world. The sections on quantum theory offer candidates the opportunity to consider the scope within Physics for an understanding of providence.

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 and in teaching and the additional material for Section B of Paper 2 will show that Physics impacts 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.

Health and Safety Issues

This syllabus includes work on radioactivity, including the ionising ability and penetrating power of the main types of radiations (Section 8). The course also requires candidates to consider the risks to themselves and others when carrying out laboratory work (Appendix 2 and Appendix 3).

Environmental Education and Sustainable Development

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.

European and International Dimension

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.

Avoidance of Bias

CIE has taken great care in the preparation of this syllabus and assessment materials to avoid bias of any kind.

Key Skills

This syllabus provides opportunities for the development of evidence for the Key Skills of: *Communication*, *Application of Number*, *Information Technology*, *Working with Others*, *Improving Own Learning and Performance* and *Problem Solving* at Levels 2 and/or 3. However, the extent to which this evidence fulfils the Key Skills criteria at these levels will be totally dependent on the style of teaching and learning adopted for each section.

The Key Skills awarding bodies and the regulatory authorities have produced a suite of example portfolios that will help to give candidates and practitioners a clear understanding of the requirements for the Key Skills portfolio. These are available on the QCA Key Skills website (www.qca.org.uk/keyskills). Full details of the requirements for certification can be obtained from the awarding bodies that are approved to offer Key Skills. For further information about Key Skills assessment, including the current standards, please see the document *The Key Skills Qualifications Standards and Guidance* published by the Qualifications and Curriculum Authority 2004 (ISBN 1 85838 548 2).

The following table indicates where opportunities may exist for at least some coverage of the various Key Skills criteria at Levels 2 and/or 3 for each section.

Paper	Communication	Application of Number	IT	Working with Others	Improving own Learning and Performance	Problem Solving
Part A	✓	✓	✓	✓	✓	✓
Part B	✓	✓	✓	✓	✓	✓
Personal Investigation	✓	✓	✓		✓	✓

University of Cambridge International Examinations
1 Hills Road, Cambridge, CB1 2EU, United Kingdom
Tel: +44 1223 553554 Fax: +44 1223 553558
Email: international@cie.org.uk Website: www.cie.org.uk