UNIVERSITY *of* CAMBRIDGE
International Examinations

Cambridge
International
AS & A Level

SYLLABUS

Cambridge International AS and A Level Physics

9702

For examination in June and November 2014

Contents

1. Introduction

1.1 Why choose Cambridge?

University of Cambridge International Examinations is the world's largest provider of international education programmes and qualifications for 5 to 19 year olds. We are part of the University of Cambridge, trusted for excellence in education. Our qualifications are recognised by the world's universities and employers.

Recognition

A Cambridge International AS or A Level is recognised around the world by schools, universities and employers. The qualifications are accepted as proof of academic ability for entry to universities worldwide, though some courses do require specific subjects.

Cambridge International A Levels typically take two years to complete and offer a flexible course of study that gives students the freedom to select subjects that are right for them. Cambridge International AS Levels often represent the first half of an A Level course but may also be taken as a freestanding qualification. They are accepted in all UK universities and carry half the weighting of an A Level. University course credit and advanced standing is often available for Cambridge International A/AS Levels in countries such as the USA and Canada.

Learn more at **www.cie.org.uk/recognition**

Excellence in education

We understand education. We work with over 9000 schools in over 160 countries who offer our programmes and qualifications. Understanding learners' needs around the world means listening carefully to our community of schools, and we are pleased that 98 % of Cambridge schools say they would recommend us to other schools.

Our mission is to provide excellence in education, and our vision is that Cambridge learners become confident, responsible, innovative and engaged.

Cambridge programmes and qualifications help Cambridge learners to become:

- **confident** in working with information and ideas – their own and those of others
- **responsible** for themselves, responsive to and respectful of others
- **innovative** and equipped for new and future challenges
- **engaged** intellectually and socially, ready to make a difference.

Support in the classroom

We provide a world-class support service for Cambridge teachers and exams officers. We offer a wide range of teacher materials to Cambridge schools, plus teacher training (online and face-to-face), expert advice and learner-support materials. Exams officers can trust in reliable, efficient administration of exams entry and excellent, personal support from our customer services. Learn more at **www.cie.org.uk/teachers**

Not-for-profit, part of the University of Cambridge

We are a part of Cambridge Assessment, a department of the University of Cambridge and a not-for-profit organisation.

We invest constantly in research and development to improve our programmes and qualifications.

1.2   Why choose Cambridge International AS and A Level?

Cambridge International AS and A Levels have a proven reputation for preparing students well for university, employment and life. They help develop the in-depth subject knowledge and understanding which are so important to universities and employers.

You can offer almost any combination of 55 subjects. Students can specialise or study a range of subjects, ensuring breadth. Giving students the power to choose helps motivate them throughout their studies.

Cambridge International AS and A Level gives you building blocks to build an individualised curriculum that develops your learners' knowledge, understanding and skills in:

*   in-depth subject content
*   independent thinking
*   applying knowledge and understanding to new as well as familiar situations
*   handling and evaluating different types of information sources
*   thinking logically and presenting ordered and coherent arguments
*   making judgements, recommendations and decisions
*   presenting reasoned explanations, understanding implications and communicating them clearly and logically
*   working and communicating in English.

The syllabuses are international in outlook, but retain a local relevance. They have been created specifically for an international student body with content to suit a wide variety of schools and avoid cultural bias.

1.3   Why choose Cambridge International AS and A Level Physics?

Cambridge International AS and A Level Physics qualifications are accepted by universities and employers as proof of essential knowledge and ability.

This syllabus is designed:

*   to give a thorough introduction to the study of Physics and scientific methods
*   to develop skills and abilities that are relevant to the safe practice of science and to everyday life: concern for accuracy and precision, objectivity, integrity, the skills of enquiry, initiative and inventiveness
*   to emphasise the understanding and application of scientific concepts and principles, rather than the recall of factual material
*   to enable candidates to become confident citizens in a technological world and to take an informed interest in matters of scientific importance
*   to promote the use of IT as an aid to experiments and as a tool for the interpretation of experimental and theoretical results.

Physics is one of a number of science syllabuses that Cambridge offers – for details of other syllabuses at Cambridge IGCSE, Cambridge O Level and Cambridge International AS and A Level visit the Cambridge website at **www.cie.org.uk**

1.4 Cambridge AICE (Advanced International Certificate of Education) Diploma

Cambridge AICE (Advanced International Certificate of Education) Diploma is the group award of Cambridge International AS and A Level.

Cambridge AICE Diploma involves the selection of subjects from three curriculum groups – Mathematics and Science; Languages; Arts and Humanities.

A Cambridge International A Level counts as a double-credit qualification and a Cambridge International AS Level as a single-credit qualification within the Cambridge AICE Diploma award framework.

To be considered for an AICE Diploma, a candidate must earn the equivalent of six credits by passing a combination of examinations at either double credit or single credit, with at least one course coming from each of the three curriculum areas.

The AICE Diploma is comprised of examinations administered in May/June and October/November series each year.

Physics (9702) falls into Group 1, Mathematics and Science.

Learn more about the AICE Diploma at **http://www.cie.org.uk/qualifications/academic/uppersec/aice**

1.5 How can I find out more?

If you are already a Cambridge school

You can make entries for this qualification through your usual channels. If you have any questions, please contact us at **international@cie.org.uk**

If you are not yet a Cambridge school

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

2.   Assessment at a glance

- Candidates for Advanced Subsidiary (AS) certification will take Papers 1, 2 and 3 (either Advanced Practical Skills 1 or Advanced Practical Skills 2) in a single examination series.
- Candidates who, having received AS certification, wish to continue their studies to the full Advanced Level qualification may carry their AS marks forward and take just Papers 4 and 5 in the examination series in which they require certification.
- Candidates taking the complete Advanced Level qualification at the end of the course take all five papers in a single examination series.

Candidates may only enter for the papers in the combinations indicated above.

Candidates may not enter for single papers either on the first occasion or for re-sit purposes.

This syllabus is for:

- candidates for **AS certification only** in either 2013 or 2014,
- candidates carrying forward AS marks and taking Papers 4 and 5 to certificate their full Advanced Level qualification in 2014,
- candidates taking the complete Advanced Level qualification at the end of their course in 2014.

Paper	Type of Paper	Duration	Marks	Weighting	
				AS Level	A Level
1	Multiple Choice	1 hour	40	31%	15%
2	AS Structured Questions	1 hour	60	46%	23%
3	Advanced Practical Skills 1/2	2 hours	40	23%	12%
4	A2 Structured Questions	2 hours	100		38%
5	Planning, Analysis and Evaluation	1 hour 15 min	30		12%

Paper 1

The paper will consist of 40 questions, all of the direct choice type with four options. All questions will be based on the AS syllabus. Candidates will answer all questions.

Paper 2

This paper will consist of a variable number of structured questions of variable mark value. All questions will be based on the AS syllabus. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 3 – Advanced Practical Skills 1/2

In some examination sessions, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. In other sessions, only Advanced Practical Skills 1 will be available. These papers will be equivalent and each candidate will be required to take only one of them. This is to allow large Centres to split candidates into two groups: one group will take Advanced Practical Skills 1; the other group will take Advanced Practical Skills 2. Each of these papers will be timetabled on a different day.

Each paper will consist of two experiments drawn from different areas of Physics. Candidates will be allowed to use the apparatus for each experiment for a maximum of 1 hour. The examiners will not be restricted by the subject content. Candidates will answer all questions. Candidates will answer on the question paper.

See the Practical Assessment section of the syllabus for full details.

Paper 4

This paper will consist of two sections:

- **Section A (70 marks)** will consist of questions based on the A2 core, but may include material first encountered in the AS syllabus.
- **Section B (30 marks)** will consist of questions based on Applications of Physics, but may include material first encountered in the core (AS and A2) syllabus.

Both sections will consist of a variable number of structured questions of variable mark value. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 5

This paper will consist of two questions of equal mark value based on the practical skills of planning, analysis and evaluation. The examiners will not be restricted by the subject content. Candidates will answer all questions. Candidates will answer on the question paper.

Availability

This syllabus is examined in the May/June examination series and the October/November examination series.

This syllabus is available to private candidates. However it is expected that private candidates learn in an environment where practical work is an integral part of the course. Candidates will not be able to perform well in this assessment or successfully progress to further study without this necessary and important aspect of science education.

Centres in the UK that receive government funding are advised to consult the Cambridge website **www.cie.org.uk** for the latest information before beginning to teach this syllabus.

Combining this with other syllabuses

Candidates can combine this syllabus in an examination series with any other Cambridge syllabus, except:

- syllabuses with the same title at the same level
- 8780 Cambridge International AS Level Physical Science.

3. Syllabus aims and objectives

3.1 Aims

These are not listed in order of priority. The aims of a course based on this syllabus should be to:

1. provide, through well-designed studies of experimental and practical science, a worthwhile educational experience for all students, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to

    1.1 become confident citizens in a technological world and be able to take or develop an informed interest in scientific matters

    1.2 recognise the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life

    1.3 be suitably prepared for studies beyond Cambridge International A Level in Physics, in Engineering or in Physics-dependent vocational courses.

2. develop abilities and skills that

    2.1 are relevant to the study and practice of science

    2.2 are useful in everyday life

    2.3 encourage efficient and safe practice

    2.4 encourage effective communication.

3. develop attitudes relevant to science such as

    3.1 concern for accuracy and precision

    3.2 objectivity

    3.3 integrity

    3.4 the skills of enquiry

    3.5 initiative

    3.6 inventiveness.

4. stimulate interest in, and care for, the environment in relation to the environmental impact of Physics and its applications.

5. promote an awareness

    5.1 that the study and practice of Physics are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations

    5.2 that the implications of Physics may be both beneficial and detrimental to the individual, the community and the environment

    5.3 of the importance of the use of IT for communication, as an aid to experiments and as a tool for the interpretation of experimental and theoretical results.

6. stimulate students and create a sustained interest in Physics so that the study of the subject is enjoyable and satisfying.

3.2   Assessment objectives

The assessment objectives listed below reflect those parts of the Aims that will be assessed in the examination.

A   Knowledge with understanding

Candidates should be able to demonstrate knowledge and understanding of:

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

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define, state, describe*, or *explain* (see Glossary of terms).

B   Handling, applying and evaluating information

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:

1.   locate, select, organise and present information from a variety of sources
2.   translate information from one form to another
3.   manipulate numerical and other data
4.   use information to identify patterns, report trends, draw inferences and report conclusions
5.   present reasoned explanations for phenomena, patterns and relationships
6.   make predictions and put forward hypotheses
7.   apply knowledge, including principles, to new situations
8.   evaluate information and hypotheses
9.   demonstrate an awareness of the limitations of physical theories and models.

These assessment objectives cannot be precisely specified in the syllabus content because questions testing such skills may be based on information that is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a new situation. Questions testing these objectives will often begin with one of the following words: *predict, suggest, deduce, calculate* or *determine* (see Glossary of terms).

C Experimental skills and investigations

Candidates should be able to:

1. follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively
2. make observations and measurements with due regard for precision and accuracy
3. interpret and evaluate observations and experimental data
4. identify a problem; design and plan investigations; evaluate methods and techniques; suggest possible improvement
5. record observations, measurements, methods and techniques with due regard for precision, accuracy and units.

3.3 Weighting of assessment objectives

The table below gives a general idea of the allocation of marks to the assessment objectives, though the balance on each paper may vary slightly.

Assessment objective	Weighting (%)	Assessment components
A: Knowledge with understanding	37	Papers 1, 2 and 4
B: Handling information and solving problems	40	Papers 1, 2 and 4
C: Experimental skills and investigations	23	Papers 3 and 5

Teachers should note that there is a greater weighting of 63% for skills (including handling information, solving problems, practical, experimental and investigative skills) compared to the 37% for knowledge and understanding. Teachers' schemes of work and the sequence of learning activities should reflect this balance so that the aims of the syllabus are met and the candidates prepared for the assessment.

3.4 Additional information

Symbols, signs and abbreviations used in examination papers will follow the recommendations made in the ASE publication *Signs, Symbols and Systematics* (2000).

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

The units kW h, atmosphere, eV and unified atomic mass unit (u) may be used in examination papers without further explanation.

4.   Syllabus content

4.1   Structure of the syllabus

The subject content of the syllabus is divided into:

• AS and A2 Core (sections I–VI)

• Applications of Physics (section VII).

The table below shows which parts of the syllabus contain AS material and/or A2 material.

Section		AS	A2
I General Physics	1. Physical quantities and units	✓	✓
	2. Measurement techniques	✓	✓
II Newtonian mechanics	3. Kinematics	✓	
	4. Dynamics	✓	
	5. Forces	✓	
	6. Work, energy, power	✓	
	7. Motion in a circle		✓
	8. Gravitational field		✓
III Matter	9. Phases of matter	✓	
	10. Deformation of solids	✓	
	11. Ideal gases		✓
	12. Temperature		✓
	13. Thermal properties of materials		✓
IV Oscillations and waves	14. Oscillations		✓
	15. Waves	✓	
	16. Superposition	✓	

V Electricity and magnetism	17. Electric fields	✓	✓
	18. Capacitance		✓
	19. Current of electricity	✓	
	20. D.C. circuits	✓	
	21. Magnetic fields		✓
	22. Electromagnetism		✓
	23. Electromagnetic induction		✓
	24. Alternating currents		✓
VI Modern Physics	25. Charged particles		✓
	26. Quantum physics		✓
	27. Nuclear physics	✓	✓
VII Gathering and communicating information	28. Direct sensing		✓
	29. Remote sensing		✓
	30. Communicating information		✓

4.2   Subject content

Teachers should incorporate the social, environmental, economic and technological aspects of Physics, wherever possible, throughout the syllabus (see Aims 4 and 5). Some examples are included in the syllabus and candidates should be encouraged to apply the principles of these examples to other situations introduced in the course. Further examples have not been included in the syllabus, as this would merely increase the amount of factual recall required.

The A2 parts of the syllabus, which will be examined only in the full Advanced Level qualification, are indicated in bold type throughout the subject content.

The Applications of Physics section occupies about 12% of the full Advanced Level course. A separate booklet covering this section is available from Cambridge Publications.

Aim 5.3 emphasises the importance of Information technology (IT) in this Physics course. Candidates should make full use of IT techniques in their practical work. Teachers may also use IT in demonstrations and simulations. Advice on the use of IT in Cambridge International A Level Physics is printed at the back of the syllabus.

The table of subject content is neither intended to be used as a teaching syllabus, nor to represent a teaching order.

4.2.1 AS and A2 Core: Sections I–VI inclusive

Section I: General physics

Recommended prior knowledge
Candidates should be aware of the nature of a physical measurement, in terms of a magnitude and a unit. They should have experience of making and recording such measurements in the laboratory.

1. Physical quantities and units

Content

1.1 Physical quantities

1.2 SI Units

1.3 The Avogadro constant

1.4 Scalars and vectors

Learning outcomes

Candidates should be able to:

(a) show an understanding that all physical quantities consist of a numerical magnitude and a unit

(b) recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), **amount of substance** (**mol**)

(c) express derived units as products or quotients of the SI base units and use the named units listed in this syllabus as appropriate

(d) use SI base units to check the homogeneity of physical equations

(e) show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000)

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

(g) make reasonable estimates of physical quantities included within the syllabus

(h) **show an understanding that the Avogadro constant is the number of atoms in 0.012 kg of carbon-12**

(i) **use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant**

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

(k) add and subtract coplanar vectors

(l) represent a vector as two perpendicular components.

2. Measurement techniques

Content

2.1 Measurements

2.2 Errors and uncertainties

Learning outcomes

Candidates should be able to:

(a) use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus.

In particular, candidates should be able to:

- measure lengths using a ruler, vernier scale and micrometer
- measure weight and hence mass using spring and lever balances
- measure an angle using a protractor
- measure time intervals using clocks, stopwatches and the calibrated time-base of a cathode-ray oscilloscope (c.r.o.)
- measure temperature using a thermometer as a sensor
- use ammeters and voltmeters with appropriate scales
- use a galvanometer in null methods
- use a cathode-ray oscilloscope (c.r.o.)
- **use a calibrated Hall probe**

(b) use both analogue scales and digital displays

(c) use calibration curves

(d) show an understanding of the distinction between systematic errors (including zero errors) and random errors

(e) show an understanding of the distinction between precision and accuracy

(f) assess the uncertainty in a derived quantity by simple addition of actual, fractional or percentage uncertainties (a rigorous statistical treatment is not required).

Section II: Newtonian mechanics

Recommended prior knowledge
Candidates should be able to describe the action of a force on a body.

They should be able to describe the motion of a body and recognise acceleration and constant speed.
They should be able to use the relationship *average speed = distance / time.*

3. Kinematics

Content

3.1 Linear motion

3.2 Non-linear motion

Learning outcomes

Candidates should be able to:

(a) define displacement, speed, velocity and acceleration

(b) use graphical methods to represent displacement, speed, velocity and acceleration

(c) find displacement from the area under a velocity-time graph

(d) use the slope of a displacement-time graph to find velocity

(e) use the slope of a velocity-time graph to find acceleration

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

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

(h) recall that the weight of a body is equal to the product of its mass and the acceleration of free fall

(i) describe an experiment to determine the acceleration of free fall using a falling body

(j) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance

(k) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

4. Dynamics

Content	Learning outcomes

4.1 Newton's laws of motion

4.2 Linear momentum and its conservation

Candidates should be able to:

(a) state each of Newton's laws of motion

(b) show an understanding that mass is the property of a body that resists change in motion

(c) describe and use the concept of weight as the effect of a gravitational field on a mass

(d) define linear momentum as the product of mass and velocity

(e) define force as rate of change of momentum

(f) recall and solve problems using the relationship $F = ma$, appreciating that acceleration and force are always in the same direction

(g) state the principle of conservation of momentum

(h) apply the principle of conservation of momentum to solve simple problems including elastic and inelastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required)

(i) recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation

(j) show an understanding that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

5. Forces

Content

5.1 Types of force

5.2 Equilibrium of forces

5.3 Centre of gravity

5.4 Turning effects of forces

Learning outcomes

Candidates should be able to:

(a) describe the forces on mass and charge in uniform gravitational and electric fields, as appropriate

(b) show an understanding of the origin of the upthrust acting on a body in a fluid

(c) show a qualitative understanding of frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required)

(d) use a vector triangle to represent forces in equilibrium

(e) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity

(f) show an understanding that a couple is a pair of forces that tends to produce rotation only

(g) define and apply the moment of a force and the torque of a couple

(h) show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium

(i) apply the principle of moments.

6. Work, energy, power

Content

6.1 Energy conversion and conservation

6.2 Work

6.3 Potential energy, kinetic energy and internal energy

6.4 Power

Learning outcomes

Candidates should be able to:

(a) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation to simple examples

(b) show an understanding of the concept of work in terms of the product of a force and displacement in the direction of the force

(c) calculate the work done in a number of situations including the work done by a gas that is expanding against a constant external pressure: $W = p\,\Delta V$

(d) derive, from the equations of motion, the formula $E_k = \frac{1}{2}mv^2$

(e) recall and apply the formula $E_k = \frac{1}{2}mv^2$

(f) distinguish between gravitational potential energy, electric potential energy and elastic potential energy

(g) show an understanding and use the relationship between force and potential energy in a uniform field to solve problems

(h) derive, from the defining equation $W = Fs$, the formula $E_p = mgh$ for potential energy changes near the Earth's surface

(i) recall and use the formula $E_p = mgh$ for potential energy changes near the Earth's surface

(j) show an understanding of the concept of internal energy

(k) recall and understand that the efficiency of a system is the ratio of useful work done by the system to the total energy input

(l) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems

(m) define power as work done per unit time and derive power as the product of force and velocity

(n) solve problems using the relationships $P = \dfrac{W}{t}$ and $P = Fv$.

7. Motion in a circle

Content

7.1 Kinematics of uniform circular motion

7.2 Centripetal acceleration

7.3 Centripetal force

Learning outcomes

Candidates should be able to:

(a) **express angular displacement in radians**

(b) **understand and use the concept of angular velocity to solve problems**

(c) **recall and use $v = r\omega$ to solve problems**

(d) **describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle**

(e) **recall and use centripetal acceleration $a = r\omega^2$, $a = \dfrac{v^2}{r}$**

(f) **recall and use centripetal force $F = mr\omega^2$, $F = \dfrac{mv^2}{r}$**

8. Gravitational field

Content	**Learning outcomes**

8.1 Gravitational field

8.2 Force between point masses

8.3 Field of a point mass

8.4 Field near to the surface of the Earth

8.5 Gravitational potential

Candidates should be able to:

(a) show an understanding of the concept of a gravitational field as an example of field of force and define gravitational field strength as force per unit mass

(b) recall and use Newton's law of gravitation in the form $F = \dfrac{Gm_1m_2}{r^2}$

(c) derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass

(d) recall and solve problems using the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass

(e) show an appreciation that on the surface of the Earth g is approximately constant and is called the acceleration of free fall

(f) define potential at a point as the work done in bringing unit mass from infinity to the point

(g) solve problems using the equation $\phi = -\dfrac{GM}{r}$ for the potential in the field of a point mass

(h) recognise the analogy between certain qualitative and quantitative aspects of gravitational field and electric field

(i) analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes

(j) show an understanding of geostationary orbits and their application.

Section III: Matter

Recommended prior knowledge
Candidates should be able to describe matter in terms of particles, with a qualitative understanding of their behaviour.

9. Phases of matter

Content	**Learning outcomes**

Content

9.1 Density

9.2 Solids, liquids, gases

9.3 Pressure in fluids

9.4 Change of phase

Learning outcomes

Candidates should be able to:

(a) define the term density

(b) relate the difference in the structures and densities of solids, liquids and gases to simple ideas of the spacing, ordering and motion of molecules

(c) describe a simple kinetic model for solids, liquids and gases

(d) describe an experiment that demonstrates Brownian motion and appreciate the evidence for the movement of molecules provided by such an experiment

(e) distinguish between the structure of crystalline and non-crystalline solids with particular reference to metals, polymers and amorphous materials

(f) define the term pressure and use the kinetic model to explain the pressure exerted by gases

(g) derive, from the definitions of pressure and density, the equation $p = \rho gh$

(h) use the equation $p = \rho gh$

(i) distinguish between the processes of melting, boiling and evaporation.

10. Deformation of solids

Content	Learning outcomes
10.1 Stress, strain	Candidates should be able to:
10.2 Elastic and plastic behaviour	(a) appreciate that deformation is caused by a force and that, in one dimension, the deformation can be tensile or compressive
	(b) describe the behaviour of springs in terms of load, extension, elastic limit, Hooke's law and the spring constant (i.e. force per unit extension)
	(c) define and use the terms stress, strain and the Young modulus
	(d) describe an experiment to determine the Young modulus of a metal in the form of a wire
	(e) distinguish between elastic and plastic deformation of a material
	(f) deduce the strain energy in a deformed material from the area under the force-extension graph
	(g) demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials, including an understanding of ultimate tensile stress.

11. Ideal gases

Content	Learning outcomes
11.1 Equation of state	Candidates should be able to:
11.2 Kinetic theory of gases	(a) recall and solve problems using the equation of state for an ideal gas expressed as $pV = nRT$ (n = number of moles)
11.3 Pressure of a gas	(b) infer from a Brownian motion experiment the evidence for the movement of molecules
11.4 Kinetic energy of a molecule	(c) state the basic assumptions of the kinetic theory of gases
	(d) explain how molecular movement causes the pressure exerted by a gas and hence deduce the relationship $p = \frac{1}{3}\frac{Nm}{V}<c^2>$ (N = number of molecules) [a rigorous derivation is not required]
	(e) compare $pV = \frac{1}{3}Nm<c^2>$ with $pV = NkT$ and hence deduce that the average translational kinetic energy of a molecule is proportional to T.

12. Temperature

Content	Learning outcomes
12.1 Thermal equilibrium	Candidates should be able to:
12.2 Temperature scales	*(a)* **show an appreciation that thermal energy is transferred from a region of higher temperature to a region of lower temperature**
12.3 Practical thermometers	*(b)* **show an understanding that regions of equal temperature are in thermal equilibrium**

(c) **show an understanding that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties**

(d) **compare the relative advantages and disadvantages of resistance and thermocouple thermometers as previously calibrated instruments**

(e) **show an understanding that there is an absolute scale of temperature that does not depend on the property of any particular substance (i.e. the thermodynamic scale and the concept of absolute zero)**

(f) **convert temperatures measured in kelvin to degrees Celsius and recall that T / K = T / °C + 273.15.**

13. Thermal properties of materials

Content	Learning outcomes
13.1 Specific heat capacity	Candidates should be able to:
13.2 Specific latent heat	*(a)* **explain using a simple kinetic model for matter why**
13.3 Internal energy	
13.4 First law of thermodynamics	

(a) **explain using a simple kinetic model for matter why**

- **melting and boiling take place without a change in temperature**
- **the specific latent heat of vaporisation is higher than specific latent heat of fusion for the same substance**
- **a cooling effect accompanies evaporation**

(b) **define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods**

(c) **define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods**

(d) **relate a rise in temperature of a body to an increase in its internal energy**

(e) **show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system**

(f) **recall and use the first law of thermodynamics expressed in terms of the increase in internal energy, the heating of the system and the work done on the system.**

Section IV: Oscillations and waves

Recommended prior knowledge
Candidates should be able to describe basic wave behaviour, gained through a study of optics. They should be aware of the basic ideas of reflection and refraction in light.

14. Oscillations

Content	Learning outcomes
14.1 Simple harmonic motion	Candidates should be able to:
	(a) describe simple examples of free oscillations
14.2 Energy in simple harmonic motion	*(b)* investigate the motion of an oscillator using experimental and graphical methods
14.3 Damped and forced oscillations: resonance	*(c)* understand and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency
	(d) recognise and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion
	(e) recall and use $x = x_0 \sin \omega t$ as a solution to the equation $a = -\omega^2 x$
	(f) recognise and use $v = v_0 \cos \omega t$, $v = \pm\,\omega\sqrt{(x_0^{\,2} - x^2)}$
	(g) describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion
	(h) describe the interchange between kinetic and potential energy during simple harmonic motion
	(i) describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and the importance of critical damping in cases such as a car suspension system
	(j) describe practical examples of forced oscillations and resonance
	(k) describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system, and understand qualitatively the factors that determine the frequency response and sharpness of the resonance
	(l) show an appreciation that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided.

15. Waves

Content	Learning outcomes

15.1 Progressive waves

15.2 Transverse and longitudinal waves

15.3 Polarisation

15.4 Determination of speed, frequency and wavelength

15.5 Electromagnetic spectrum

Learning outcomes

Candidates should be able to:

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

(b) show an understanding of and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed

(c) deduce, from the definitions of speed, frequency and wavelength, the equation $v = f\lambda$

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

(e) show an understanding that energy is transferred by a progressive wave

(f) recall and use the relationship *intensity* $\propto$ (*amplitude*)^2

(g) compare transverse and longitudinal waves

(h) analyse and interpret graphical representations of transverse and longitudinal waves

(i) show an understanding that polarisation is a phenomenon associated with transverse waves

(j) determine the frequency of sound using a calibrated c.r.o.

(k) determine the wavelength of sound using stationary waves

(l) state that all electromagnetic waves travel with the same speed in free space and recall the orders of magnitude of the wavelengths of the principal radiations from radio waves to γ-rays.

16. Superposition

Content

16.1 Stationary waves

16.2 Diffraction

16.3 Interference

16.4 Two-source interference patterns

16.5 Diffraction grating

Learning outcomes

Candidates should be able to:

(a) explain and use the principle of superposition in simple applications

(b) show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columns

(c) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes

(d) explain the meaning of the term diffraction

(e) show an understanding of experiments that demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap

(f) show an understanding of the terms interference and coherence

(g) show an understanding of experiments that demonstrate two-source interference using water, light and microwaves

(h) show an understanding of the conditions required if two-source interference fringes are to be observed

(i) recall and solve problems using the equation $\lambda = \dfrac{ax}{D}$ for double-slit interference using light

(j) recall and solve problems using the formula $d \sin \theta = n\lambda$ and describe the use of a diffraction grating to determine the wavelength of light (the structure and use of the spectrometer are not included).

Section V: Electricity and magnetism

Recommended prior knowledge
Candidates should be aware of the two types of charge, charging by friction and by induction. They should be able to distinguish between conductors and insulators using a simple electron model.

17. Electric fields

Content	**Learning outcomes**

Content

17.1 Concept of an electric field

17.2 Uniform electric fields

17.3 Force between point charges

17.4 Electric field of a point charge

17.5 Electric potential

Learning outcomes

Candidates should be able to:

(a) show an understanding of the concept of an electric field as an example of a field of force and define electric field strength as force per unit positive charge acting on a stationary point charge

(b) represent an electric field by means of field lines

(c) recall and use $E = \dfrac{V}{d}$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation

(d) calculate the forces on charges in uniform electric fields

(e) describe the effect of a uniform electric field on the motion of charged particles

(f) **recall and use Coulomb's law in the form $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ for the force between two point charges in free space or air**

(g) **recall and use $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ for the field strength of a point charge in free space or air**

(h) **define potential at a point in terms of the work done in bringing unit positive charge from infinity to the point**

(i) **state that the field strength of the field at a point is equal to the negative of potential gradient at that point**

(j) **use the equation $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ for the potential in the field of a point charge**

(k) **recognise the analogy between certain qualitative and quantitative aspects of electric fields and gravitational fields.**

18. Capacitance

Content	**Learning outcomes**
18.1 Capacitors and capacitance	Candidates should be able to:
	(a) **show an understanding of the function of capacitors in simple circuits**
18.2 Energy stored in a capacitor	*(b)* **define capacitance and the farad**
	(c) **recall and solve problems using $C = \dfrac{Q}{V}$**
	(d) **derive, using the formula $C = \dfrac{Q}{V}$, conservation of charge and the addition of p.d.s, formulae for capacitors in series and in parallel**
	(e) **solve problems using formulae for capacitors in series and in parallel**
	(f) **deduce, from the area under a potential-charge graph, the equation $W = \dfrac{1}{2}QV$ and hence $W = \dfrac{1}{2}CV^2$.**

19. Current of electricity

Content	**Learning outcomes**
19.1 Electric current	Candidates should be able to:
19.2 Potential difference	*(a)* show an understanding that electric current is the flow of charged particles
19.3 Resistance and resistivity	*(b)* define charge and the coulomb
	(c) recall and solve problems using the equation $Q = It$
19.4 Sources of electromotive force	*(d)* define potential difference and the volt
	(e) recall and solve problems using $V = \dfrac{W}{Q}$
	(f) recall and solve problems using $P = VI$, $P = I^2 R$
	(g) define resistance and the ohm
	(h) recall and solve problems using $V = IR$
	(i) sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp
	(j) sketch the temperature characteristic of a thermistor (thermistors will be assumed to be of the negative temperature coefficient type)
	(k) state Ohm's law
	(l) recall and solve problems using $R = \dfrac{\rho L}{A}$
	(m) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit
	(n) distinguish between e.m.f. and p.d. in terms of energy considerations
	(o) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

20. D.C. circuits

Content	Learning outcomes

Content

20.1 Practical circuits

20.2 Conservation of charge and energy

20.3 Balanced potentials

Learning outcomes

Candidates should be able to:

(a) recall and use appropriate circuit symbols as set out in the ASE publication *Signs*, *Symbols and Systematics*

(b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus

(c) recall Kirchhoff's first law and appreciate the link to conservation of charge

(d) recall Kirchhoff's second law and appreciate the link to conservation of energy

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

(f) solve problems using the formula for the combined resistance of two or more resistors in series

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

(h) solve problems using the formula for the combined resistance of two or more resistors in parallel

(i) apply Kirchhoff's laws to solve simple circuit problems

(j) show an understanding of the use of a potential divider circuit as a source of variable p.d.

(k) explain the use of thermistors and light-dependent resistors in potential dividers to provide a potential difference that is dependent on temperature and illumination respectively

(l) recall and solve problems using the principle of the potentiometer as a means of comparing potential differences.

21. Magnetic fields

Content	Learning outcomes

21.1 Concept of magnetic field

Candidates should be able to:

(a) **show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets**

(b) **represent a magnetic field by field lines**.

22. Electromagnetism

Content	Learning outcomes

22.1 Force on a current-carrying conductor

22.2 Force on a moving charge

22.3 Magnetic fields due to currents

22.4 Force between current-carrying conductors

Candidates should be able to:

(a) **show an appreciation that a force might act on a current-carrying conductor placed in a magnetic field**

(b) **recall, and solve problems using, the equation $F = BIl \sin\theta$, with directions as interpreted by Fleming's left-hand rule**

(c) **define magnetic flux density and the tesla**

(d) **show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance**

(e) **predict the direction of the force on a charge moving in a magnetic field**

(f) **recall and solve problems using $F = BQv \sin\theta$**

(g) **sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid**

(h) **show an understanding that the field due to a solenoid may be influenced by the presence of a ferrous core**

(i) **explain the forces between current-carrying conductors and predict the direction of the forces**

(j) **describe and compare the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate.**

23. Electromagnetic induction

Content	Learning outcomes

23.1 Laws of electromagnetic induction

Candidates should be able to:

(a) **define magnetic flux and the weber**

(b) **recall and solve problems using $\Phi = BA$**

(c) **define magnetic flux linkage**

(d) **infer from appropriate experiments on electromagnetic induction:**

- **that a changing magnetic flux can induce an e.m.f. in a circuit**
- **that the direction of the induced e.m.f. opposes the change producing it**
- **the factors affecting the magnitude of the induced e.m.f.**

(e) **recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law**

(f) **explain simple applications of electromagnetic induction.**

24. Alternating currents

Content

24.1 Characteristics of alternating currents

24.2 The transformer

24.3 Transmission of electrical energy

24.4 Rectification

Learning outcomes

Candidates should be able to:

(a) show an understanding of and use the terms period, frequency, peak value and root-mean-square value as applied to an alternating current or voltage

(b) deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current

(c) represent a sinusoidally alternating current or voltage by an equation of the form $x = x_0 \sin \omega t$

(d) distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for the sinusoidal case

(e) show an understanding of the principle of operation of a simple laminated iron-cored transformer and recall and solve problems using $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p} = \dfrac{I_p}{I_s}$ for an ideal transformer

(f) show an appreciation of the scientific and economic advantages of alternating current and of high voltages for the transmission of electrical energy

(g) distinguish graphically between half-wave and full-wave rectification

(h) explain the use of a single diode for the half-wave rectification of an alternating current

(i) explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current

(j) analyse the effect of a single capacitor in smoothing, including the effect of the value of capacitance in relation to the load resistance.

Section VI: Modern Physics

Recommended prior knowledge
Candidates should be able to describe matter in terms of atoms, with electrons orbiting a positively charged nucleus. Candidates should have studied some of the material in Section IV.

25. Charged particles

Content	Learning outcomes
25.1 Electrons	Candidates should be able to:
25.2 Beams of charged particles	*(a)* show an understanding of the main principles of determination of *e* by Millikan's experiment
	(b) summarise and interpret the experimental evidence for quantisation of charge
	(c) describe and analyse qualitatively the deflection of beams of charged particles by uniform electric and uniform magnetic fields
	(d) explain how electric and magnetic fields can be used in velocity selection
	(e) explain the main principles of one method for the determination of *v* and $\frac{e}{m_e}$ for electrons.

26. Quantum physics

| **Content** | **Learning outcomes** |

26.1 Energy of a photon

26.2 Photoelectric emission of electrons

26.3 Wave-particle duality

26.4 Energy levels in atoms

26.5 Line spectra

Learning outcomes

Candidates should be able to:

(a) **show an appreciation of the particulate nature of electromagnetic radiation**

(b) **recall and use $E = hf$**

(c) **show an understanding that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature**

(d) **recall the significance of threshold frequency**

(e) **explain photoelectric phenomena in terms of photon energy and work function energy**

(f) **explain why the maximum photoelectric energy is independent of intensity, whereas the photoelectric current is proportional to intensity**

(g) **recall, use and explain the significance of $hf = \Phi + \frac{1}{2}mv_{max}^2$**

(h) **describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles**

(i) **recall and use the relation for the de Broglie wavelength $\lambda = \dfrac{h}{p}$**

(j) **show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines**

(k) **distinguish between emission and absorption line spectra**

(l) **recall and solve problems using the relation $hf = E_1 - E_2$.**

27. Nuclear physics

Content	Learning outcomes

Content

27.1 The nucleus

27.2 Isotopes

27.3 Nuclear processes

27.4 Mass excess and nuclear binding energy

27.5 Radioactive decay

Learning outcomes

Candidates should be able to:

(a) infer from the results of the α-particle scattering experiment the existence and small size of the nucleus

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

(c) distinguish between nucleon number and proton number

(d) show an understanding that an element can exist in various isotopic forms, each with a different number of neutrons

(e) use the usual notation for the representation of nuclides

(f) appreciate that nucleon number, proton number, and mass-energy are all conserved in nuclear processes

(g) represent simple nuclear reactions by nuclear equations of the form

$$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + ^{1}_{1}\text{H}$$
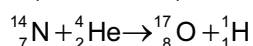
(h) show an appreciation of the spontaneous and random nature of nuclear decay

(i) show an understanding of the nature and properties of α-, β- and γ-radiations (β^+ is not included: β-radiation will be taken to refer to β^-)

(j) infer the random nature of radioactive decay from the fluctuations in count rate

(k) show an appreciation of the association between energy and mass as represented by $E = mc^2$ and recall and solve problems using this relationship

(l) sketch the variation of binding energy per nucleon with nucleon number

(m) explain what is meant by nuclear fusion and nuclear fission

(n) explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission

(o) define the terms activity and decay constant and recall and solve problems using $A = \lambda N$

(p) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_0 \exp(-\lambda t)$, where x could represent activity, number of undecayed particles or received count rate

(q) define half-life

(r) solve problems using the relation $\lambda = \dfrac{0.693}{t_{\frac{1}{2}}}$.

4.2.2 Applications of Physics: Section VII

Teachers will find it helpful to refer to Cambridge's *Applications of Physics* book when teaching this section. This is available from the Cambridge Teacher Support website and from Cambridge Publications, and provides a guide to the level of detail required. The Applications of Physics section of the syllabus forms approximately one-eighth of the A Level material examined.

Section VII: Gathering and communicating information

28. Direct sensing

Content	Learning outcomes
28.1 Sensing devices	Candidates should be able to:
28.2 The ideal operational amplifier	*(a)* **show an understanding that an electronic sensor consists of a sensing device and a circuit that provides an output voltage**
28.3 Operational amplifier circuits	*(b)* **show an understanding of the change in resistance with light intensity of a light-dependent resistor (LDR)**
28.4 Output devices	*(c)* **sketch the temperature characteristic of a negative temperature coefficient thermistor**

(d) **show an understanding of the action of a piezo-electric transducer and its application in a simple microphone**

(e) **describe the structure of a metal-wire strain gauge**

(f) **relate extension of a strain gauge to change in resistance of the gauge**

(g) **show an understanding that the output from sensing devices can be registered as a voltage**

(h) **recall the main properties of the ideal operational amplifier (op-amp)**

(i) **deduce, from the properties of an ideal operational amplifier, the use of an operational amplifier as a comparator**

(j) **show an understanding of the effects of negative feedback on the gain of an operational amplifier**

(k) **recall the circuit diagrams for both the inverting and the non-inverting amplifier for single signal input**

(l) **show an understanding of the virtual earth approximation and derive an expression for the gain of inverting amplifiers**

(m) **recall and use expressions for the voltage gain of inverting and of non-inverting amplifiers**

(n) **show an understanding of the use of relays in electronic circuits**

(o) **show an understanding of the use of light-emitting diodes (LEDs) as devices to indicate the state of the output of electronic circuits**

(p) **show an understanding of the need for calibration where digital or analogue meters are used as output devices.**

29. Remote sensing

Content	Learning outcomes

Content

29.1 Production and use of X-rays

29.2 Production and use of ultrasound

29.3 Use of magnetic resonance as an imaging technique

Learning outcomes

Candidates should be able to:

(a) **explain in simple terms the need for remote sensing (non-invasive techniques of diagnosis) in medicine**

(b) **explain the principles of the production of X-rays by electron bombardment of a metal target**

(c) **describe the main features of a modern X-ray tube, including control of the intensity and hardness of the X-ray beam**

(d) **show an understanding of the use of X-rays in imaging internal body structures, including a simple analysis of the causes of sharpness and contrast in X-ray imaging**

(e) **show an understanding of the purpose of computed tomography or CT scanning**

(f) **show an understanding of the principles of CT scanning**

(g) **show an understanding of how the image of an 8-voxel cube can be developed using CT scanning**

(h) **explain the principles of the generation and detection of ultrasonic waves using piezo-electric transducers**

(i) **explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structures**

(j) **show an understanding of the meaning of specific acoustic impedance and its importance to the intensity reflection coefficient at a boundary**

(k) **recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of X-rays and of ultrasound in matter**

(l) **explain the main principles behind the use of magnetic resonance to obtain diagnostic information about internal structures**

(m) **show an understanding of the function of the non-uniform magnetic field, superimposed on the large constant magnetic field, in diagnosis using magnetic resonance.**

30. Communicating information

Content

    30.1 Principles of modulation

30.2 Sidebands and bandwidth

30.3 Transmission of information by digital means

30.4 Different channels of communication

30.5 The mobile-phone network

Learning outcomes

Candidates should be able to:

(a) understand the term modulation and be able to distinguish between amplitude modulation (AM) and frequency modulation (FM)

(b) recall that a carrier wave, amplitude modulated by a single audio frequency, is equivalent to the carrier wave frequency together with two sideband frequencies

(c) understand the term bandwidth

(d) demonstrate an awareness of the relative advantages of AM and FM transmissions

(e) recall the advantages of the transmission of data in digital form, compared to the transmission of data in analogue form

(f) understand that the digital transmission of speech or music involves analogue-to-digital conversion (ADC) on transmission and digital-to-analogue conversion (DAC) on reception

(g) show an understanding of the effect of the sampling rate and the number of bits in each sample on the reproduction of an input signal

(h) appreciate that information may be carried by a number of different channels, including wire-pairs, coaxial cables, radio and microwave links and optic fibres

(i) discuss the relative advantages and disadvantages of channels of communication in terms of available bandwidth, noise, cross-linking, security, signal attenuation, repeaters and regeneration, cost and convenience

(j) describe the use of satellites in communication

(k) recall the relative merits of both geostationary and polar orbiting satellites for communicating information

(l) recall the frequencies and wavelengths used in different channels of communication

(m) understand and use signal attenuation expressed in dB and dB per unit length

(n) recall and use the expression *number of dB* $= 10 \lg \left(\dfrac{P_1}{P_2} \right)$ for the ratio of two powers

(o) understand that, in a mobile-phone system, the public switched telephone network (PSTN) is linked to base stations via a cellular exchange

(p) understand the need for an area to be divided into a number of cells, each cell served by a base station

q) understand the role of the base station and the cellular exchange during the making of a call from a mobile phone handset

(r) recall a simplified block diagram of a mobile phone handset and understand the function of each block.

5.   Practical assessment

5.1 Introduction

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

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

• provide learning opportunities so that candidates develop the skills they need to carry out experimental and investigative work

• reinforce the learning of the theoretical subject content of the syllabus

• instil an understanding of the interplay of experiment and theory in scientific method

• prove enjoyable, contributing to the motivation of candidates

Candidates' experimental skills will be assessed in Paper 3 (Advanced Practical Skills 1/2) and Paper 5. In each of these papers, the examiners will not be strictly bound by the subject content of the syllabus in setting questions. Where appropriate, candidates will be told exactly what to do and how to do it: only knowledge of theory and experimental skills within the syllabus will be expected.

5.2 Paper 3 – Advanced Practical Skills 1/2

In some examination sessions, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. These papers will contain different questions, but will be equivalent in the skills assessed and in the level of demand. Each candidate should take one of these papers.

Where two versions of the paper are offered, some schools may wish to divide their candidates so that some are entered for Advanced Practical Skills 1 and the others are entered for Advanced Practical Skills 2; other schools may wish to enter all of their candidates for the same paper.

Paper 3 (Advanced Practical Skills 1/2) will be a timetabled, laboratory-based practical paper, focusing on the following experimental skills:

• manipulation, measurement and observation

• presentation of data and observations

• analysis, conclusions and evaluation

Each paper will consist of two questions, each of 1 hour and each of 20 marks.

The first question will be an experiment requiring candidates to collect data, to plot a graph and to draw simple conclusions.

The second question will not require the plotting of a graph. In the second question, the experimental method to be followed will be inaccurate, and candidates will be required to evaluate the method and suggest improvements.

The two questions will be set in different areas of Physics. No prior knowledge of the theory will be required. The areas of Physics will not be confined to the AS subject content, and may relate to A2 topics.

5.2.1 Mark scheme for Paper 3 (Advanced Practical Skills 1/2)

Paper 3 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Question 1				
Skill			**Breakdown of marks**	
Manipulation, measurement and observation	9 marks		Successful collection of data	7 marks
			Range and distribution of values	1 mark
			Quality of data	1 mark
Presentation of data and observations	7 marks		Table of results: layout	1 mark
			Table of results: raw data	1 mark
			Table of results: calculated quantities	2 marks
			Graph: layout	1 mark
			Graph: plotting of points	1 mark
			Graph: trend line	1 mark
Analysis, conclusions and evaluation	4 marks		Interpretation of graph	2 marks
			Drawing conclusions	2 marks

Question 2				
Skill			**Breakdown of marks**	
Manipulation, measurement and observation	7 marks		Successful collection of data	6 marks
			Quality of data	1 mark
Presentation of data and observations	3 marks		Display of calculation and reasoning	3 marks
Analysis, conclusions and evaluation	10 marks		Drawing conclusions	1 mark
			Estimating uncertainties	1 mark
			Identifying limitations	4 marks
			Suggesting improvements	4 marks

5.2.2 Expectations for each mark category (Paper 3)

Manipulation, measurement and observation

Successful collection of data

Candidates should be able to:

- set up apparatus correctly without assistance from the Supervisor
- follow instructions given in the form of written instructions, diagrams or circuit diagrams
- use their apparatus to collect an appropriate quantity of data
- repeat readings where appropriate
- make measurements using common laboratory apparatus, such as millimetre scales, protractors, stopwatches, top-pan balances, newton-meters, analogue or digital electrical meters, measuring cylinders, vernier calipers, micrometer screw gauges and thermometers
- use both analogue scales and digital displays.

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

Range and distribution of values

Candidates should be able to:

- make measurements that span the largest possible range of values within the limits either of the equipment provided or of the instructions given
- make measurements whose values are appropriately distributed within this range.

In most experiments, including those involving straight-line graphs, a regularly-spaced set of measurements will be appropriate. For other experiments, such as those requiring the peak value of a curved graph to be determined, it may be appropriate for the measurements to be concentrated in one part of the range investigated. Candidates will be expected to be able to identify the most appropriate distribution of values.

Quality of data

Candidates should be able to:

- make and record accurate measurements.

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

Presentation of data and observations

Table of results: layout
Candidates should be able to:

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

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

Table of results: raw data
Candidates should be able to:

- record raw readings of a quantity to the same degree of precision.

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

Table of results: calculated quantities
Candidates should be able to:

- calculate other quantities from their raw data
- use the correct number of significant figures for these calculated quantities.

Except where they are produced by addition or subtraction, calculated quantities should be given to the same number of significant figures (or one more than) the measured quantity of least accuracy. For example, if values of a potential difference and of a current are measured to 2 and 4 significant figures respectively, then the corresponding resistance should be given to 2 or 3 significant figures, but not 1 or 4. The number of significant figures may, if necessary, vary down a column of values for a calculated quantity.

Graph: layout

Candidates should be able to:

- plot the independent variable on the *x*-axis and the dependent variable on the *y*-axis, except where the variables are conventionally plotted the other way around

- clearly label graph axes with both the quantity and the unit, following accepted scientific conventions

- choose scales for graph axes such that the data points occupy at least half of the graph grid in both *x*- and *y*-directions

- use a false origin where appropriate

- choose scales for the graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 2 cm square

- place regularly-spaced numerical labels along the whole of each axis.

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

Graph: plotting of points

Candidates should be able to:

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

Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; a thick pencil blob is not.

Graph: trend line

Candidates should be able to:

- identify when the trend of a graph is linear or curved

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

- draw tangents to curved trend lines.

The trend line should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn and should not contain kinks or breaks.

Display of calculation and reasoning

Candidates should be able to:

- show their working in calculations, and the key steps in their reasoning

- justify the number of significant figures in a calculated quantity.

Analysis, conclusions and evaluation

Interpretation of graph
Candidates should be able to:

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

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

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

Drawing conclusions
Candidates should be able to:

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

Estimating uncertainties
Candidates should be able to:

- estimate, quantitatively, the uncertainty in their measurements
- express the uncertainty in a measurement as an actual, fractional or percentage uncertainty, and translate between these forms.

Identifying limitations
Candidates should be able to:

- identify and describe the limitations in an experimental procedure
- identify the most significant sources of uncertainty in an experiment
- show an understanding of the distinction between systematic errors (including zero errors) and random errors.

Suggesting improvements
Candidates should be able to:

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

Candidates' suggestions should be realistic, so that in principle they are achievable in practice. The suggestions may relate either to the apparatus used or to the experimental procedure followed. Candidates may include improvements that they have actually made while carrying out the experiment. The suggested modifications may relate to sources of uncertainty identified by the candidate.

5.2.3 Administration of the practical test

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

A document called the *Confidential Instructions* will be despatched to Centres, usually about six weeks before the date of the examination. The *Confidential Instructions* will detail the apparatus that will be required and how it should be laid out for candidates. They will also contain sufficient details to allow testing of the apparatus. Centres should contact the Despatch Department at Cambridge if they believe the *Confidential Instructions* have not been received.

Access to the question paper itself is not permitted in advance of the examination.

It is essential that absolute confidentiality be maintained in advance of the examination date: the contents of the *Confidential Instructions* must not be revealed either directly or indirectly to candidates.

The *Confidential Instructions* contain a Supervisor's Report Form. Centres must complete this form and enclose a copy in each envelope of scripts. A sample set of results may also be helpful to the examiners, especially if there was any local difficulty with apparatus. A missing report can delay the marking process.

If there is any doubt about the interpretation of *Confidential Instructions* document or the suitability of the apparatus available, enquiries should be sent to the Product Manager for Physics at Cambridge, using either e-mail (**international@cie.org.uk**) or fax (+44 1223 553558) or telephone (+44 1223 553554).

5.2.4 Apparatus that is used regularly

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

Ammeter: (digital or analogue) f.s.d. 100 mA and 1 A (digital multimeters are suitable)

Cells: 1.5 V

Lamp and holder: 6 V 60 mA; 2.5 V 0.3 A

Leads and crocodile clips

Power supply: variable up to 12 V d.c. (low resistance)

Rheostat (with a maximum resistance of at least 8 Ω, capable of carrying a current of at least 4A)

Switch

Voltmeter: (digital or analogue) f.s.d. 5 V, 10 V (digital multimeters are suitable)

Wire: constantan 26, 28, 30, 32, 34, 36, 38 s.w.g. or metric equivalents

Long stem thermometer: –10 °C to 110 °C × 1 °C

Means to heat water safely to boiling (e.g. an electric kettle)

Plastic or polystyrene cup 200 cm^3

Stirrer

Adhesive tape (e.g. Sellotape)

Balance to 0.1 g (this item may often be shared between sets of apparatus)

Bar magnet

Bare copper wire: 18, 26 s.w.g.

Beaker: 100 cm^3, 200 cm^3 or 250 cm^3

Blu-Tack

Card

Expendable steel spring (spring constant approx. $25\,N\,m^{-1}$; unstretched length approx. $2\,cm$)

G-clamp

Magnadur ceramic magnets

Mass hanger

Micrometer screw gauge (this item may often be shared between sets of apparatus)

Modelling clay (e.g. Plasticine)

Newton-meter (1 N, 10 N)

Pendulum bob

Protractor

Pulley

Rule with a millimetre scale (1 m, 0.5 m, 300 mm)

Scissors

Slotted masses (100 g, 50 g, 20 g, 10 g) or alternative

Spring

Stand, boss and clamp

Stopwatch (candidates may use their wristwatches), reading to 0.1 s or better

Stout pin or round nail

String/thread/twine

Vernier calipers (this item may often be shared between sets of apparatus)

Wire cutters

Wood or metal jaws

5.3 Paper 5

Paper 5 will be a timetabled written paper, focusing on the following higher-order experimental skills:

- planning
- analysis, conclusions and evaluation.

This examination paper will not require laboratory facilities.

It should be stressed that candidates cannot be adequately prepared for this paper without extensive laboratory work during their course of study.

In particular, candidates cannot be taught to plan experiments effectively unless, on a number of occasions, they are required:

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

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

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

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

The second question will be an analysis, conclusions and evaluation question, in which candidates will be given an equation and some experimental data. From these they will be required to find the value of a constant. This question also will not be highly structured: candidates will be expected to decide for themselves what they need to do in order to reach an answer. They will also be required to estimate the uncertainty in their answer.

Some questions on this paper may be set in areas of Physics that are difficult to investigate experimentally in school laboratories, either because of the cost of equipment or because of restrictions on the availability of materials (e.g. radioactive materials). No question will require prior knowledge of theory or equipment that is beyond the syllabus: candidates will be given all the information that they need.

5.3.1 Mark scheme for Paper 5

Paper 5 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Question 1			
Skill		**Breakdown of marks**	
Planning	15 marks	Defining the problem	3 marks
		Methods of data collection	5 marks
		Method of analysis	2 marks
		Safety considerations	1 mark
		Additional detail	4 marks

Question 2			
Skill		**Breakdown of marks**	
Analysis, conclusions and evaluation	15 marks	Approach to data analysis	1 mark
		Table of results	2 marks
		Graph	3 marks
		Conclusion	4 marks
		Treatment of uncertainties	5 marks

5.3.2 The expectations for each mark category (Paper 5)

Planning
Defining the problem Candidates should be able to: • identify the independent variable in the experiment • identify the dependent variable in the experiment • identify the variables that are to be kept constant.
Methods of data collection Candidates should be able to: • describe the method to be used to vary the independent variable • describe how the independent and dependent variables are to be measured • describe how other variables are to be kept constant • describe, with the aid of a clear labelled diagram, the arrangement of apparatus for the experiment and the procedures to be followed. For full marks to be scored in this section, the overall arrangement must be workable, that is, it should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. The measuring instruments chosen should be fit for purpose, in that they should measure the correct physical quantity to a suitable precision for the experiment.
Method of analysis Candidates should be able to: • describe how the data should be used in order to reach a conclusion, including details of derived quantities to be calculated and graphs to be drawn as appropriate.
Safety considerations Candidates should be able to: • assess the risks of their experiment • describe precautions that should be taken to keep risks to a minimum.
Additional detail Up to four marks will be available for additional relevant detail. How these marks are awarded will depend on the experiment that is to be planned, but they might, for example, include marks for describing how additional variables are to be kept constant, or for a diagram of a circuit needed to make a particular measurement, or for additional safety considerations.

Analysis, conclusions and evaluation

Approach to data analysis

Candidates should be able to:

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

Table of results

Candidates should be able to:

- complete a table of results following the conventions required for Paper 3

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

Graph

Candidates should be able to:

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

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

Conclusion

Candidates should be able to:

- determine the gradient and y-intercept of a straight-line graph
- derive expressions that equate to the gradient or the y-intercept of their straight lines of best fit
- draw the required conclusions from these expressions.

The conclusion required will normally be the value of a constant.

Treatment of uncertainties

Candidates should be able to:

- convert absolute uncertainty estimates into fractional or percentage uncertainty estimates and vice versa

- show uncertainty estimates, in absolute terms, beside every value in a table of results

- calculate uncertainty estimates in derived quantities

- show uncertainty estimates as error bars on a graph

- estimate the absolute uncertainty in the gradient of a graph by recalling that
  absolute uncertainty = gradient of line of best fit – gradient of worst acceptable line

- estimate the absolute uncertainty in the y-intercept of a graph by recalling that
  absolute uncertainty = y-intercept of line of best fit – y-intercept of worst acceptable line

- express a quantity as a value, an uncertainty estimate and a unit.

6. Appendix

6.1 Safety in the laboratory

Responsibility for safety matters rests with Centres.

Attention is drawn to the following UK publications:

(a) *The Control of Substances Hazardous to Health (COSHH) Regulations*, UK Parliament, 2002

(b) *Safe Practices in Chemical Laboratories*, Royal Society of Chemistry, 1989

(c) *Safety in Science Laboratories*, DES Safety Series, 2, HMSO, 1976

(d) *Hazards in the Chemical Laboratory*, ed. L. Bretherick, The Royal Society of Chemistry, 4th ed., 1986

(e) *Safeguards in the School Laboratory*, ASE, 9th edition, 1988

(f) Hazcards, as published by CLEAPSS Development Group, Brunel University, Uxbridge UB8 3PH

6.2 Mathematical requirements

Expectations shown in **bold** type are not required for the AS qualification.

Arithmetic
Candidates should be able to: • recognise and use expressions in decimal and standard form (scientific) notation • recognise and use binary notation • use appropriate calculating aids (electronic calculator or tables) for addition, subtraction, multiplication and division. Find arithmetic means, powers (including reciprocals and square roots), sines, cosines, tangents (and the inverse functions), **exponentials and logarithms (lg and ln)** • take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified • make approximate evaluations of numerical expressions (e.g. $\pi^2 \approx 10$) and use such approximations to check the magnitude of calculated results.

Algebra

Candidates should be able to:

- change the subject of an equation. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots
- solve simple algebraic equations. Most relevant equations are linear but some may involve inverse and inverse square relationships. Linear simultaneous equations and the use of the formula to obtain the solutions of quadratic equations are included
- substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations
- formulate simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models
- **recognise and use the logarithmic forms of expressions like ab, a/b, x^n, e^{kx} and understand the use of logarithms in relation to quantities with values that range over several orders of magnitude**
- express small changes or uncertainties as percentages and vice versa
- comprehend and use the symbols $<$, $>$, $\leqslant$, $\geqslant$, $\ll$, $\gg$, $\approx$, $/$, $\propto$, $<x>$ ($= \overline{x}$), Σ , Δx, δx, $\sqrt{}$

Geometry and trigonometry

Candidates should be able to:
- calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of rectangular blocks, cylinders and spheres
- use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle
- use sines, cosines and tangents (especially for 0°, 30°, 45°, 60°, 90°). **Use the trigonometric relationships for triangles:**

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \qquad\qquad a^2 = b^2 + c^2 - 2bc \cos A$$

- **use $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ ; $\sin^2\theta + \cos^2\theta = 1$**
- **understand the relationship between degrees and radians (defined as arc/radius), translate from one to the other and use the appropriate system in context.**

Vectors

Candidates should be able to:

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

Graphs

Candidates should be able to:

- translate information between graphical, numerical, algebraic and verbal forms
- select appropriate variables and scales for graph plotting
- for linear graphs, determine the slope, intercept and intersection
- choose, by inspection, a straight line which will serve as the line of best fit through a set of data points presented graphically
- draw a curved trend line through a set of data points presented graphically, when the arrangement of these data points is clearly indicative of a non-linear relationship
- recall standard linear form $y = mx + c$ and rearrange relationships into linear form where appropriate
- sketch and recognise the forms of plots of common simple expressions like $1/x$, x^2, $1/x^2$, $\sin x$, $\cos x$, e^{-x}
- **use logarithmic plots to test exponential and power law variations**
- **understand, draw and use the slope of a tangent to a curve as a means to obtain the gradient, and use notation in the form dy/dx for a rate of change**
- understand and use the area below a curve where the area has physical significance.

6.3 Glossary of terms used in Physics papers

This glossary should prove helpful to candidates as a guide, although it is not exhaustive and it has deliberately been kept brief. Candidates should understand that the meaning of a term must depend in part on its context. The number of marks allocated for any part of a question is a guide to the depth required for the answer.

1. *Define (the term(s) ...)* is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, is required.

2. *What is meant by ...* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The number of marks indicated will suggest the amount of supplementary comment required.

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. If a specific number of points is requested, this number 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. For particular phenomena, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description intended is suggested by 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 new situation (one that may not, formally, 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 any necessary simplifying assumptions about points of principle and about the values of quantities not otherwise included in the question.

15. *Sketch* (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* (applied to diagrams) implies that a simple, freehand drawing is acceptable, though 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.

6.4 Summary of key quantities, symbols and units

The following list illustrates the symbols and units that will be used in question papers.
This list is for both AS and full A Level qualifications.

Quantity	Usual symbols	Usual unit
Base Quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol

Quantity	Usual symbols	Usual unit
Other Quantities		
distance	d	m
displacement	s, x	m
area	A	m^2
volume	V, v	m^3
density	ρ	$kg\,m^{-3}$
speed	u, v, w, c	$m\,s^{-1}$
velocity	u, v, w, c	$m\,s^{-1}$
acceleration	a	$m\,s^{-2}$
acceleration of free fall	g	$m\,s^{-2}$
force	F	N
weight	W	N
momentum	p	N s
work	w, W	J
energy	E, U, W	J
potential energy	E_p	J
kinetic energy	E_k	J
heating	q, Q	J
change of internal energy	ΔU	J
power	P	W
pressure	p	Pa
torque	T	N m
gravitational constant	G	$N\,kg^{-2}\,m^2$
gravitational field strength	g	$N\,kg^{-1}$
gravitational potential	ϕ	$J\,kg^{-1}$

angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	$rad\,s^{-1}$
angular velocity	ω	$rad\,s^{-1}$
period	T	s
frequency	f	Hz
angular frequency	ω	$rad\,s^{-1}$
wavelength	λ	m
phase difference	ϕ	°, rad
speed of electromagnetic waves	c	$m\,s^{-1}$
electric charge	q, Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	$\Omega\,m$
electric field strength	E	$N\,C^{-1}, V\,m^{-1}$
permittivity of free space	ε_0	$F\,m^{-1}$
capacitance	C	F
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_0	$H\,m^{-1}$
stress	σ	Pa
strain	ε	
spring constant	k	$N\,m^{-1}$
Young modulus	E	Pa
Celsius temperature	θ	°C
specific heat capacity	c	$J\,kg^{-1}\,K^{-1}$
molar heat capacity	C_m	$J\,mol^{-1}\,K^{-1}$
specific latent heat	L	$J\,kg^{-1}$
molar gas constant	R	$J\,mol^{-1}\,K^{-1}$
Boltzmann constant	k	$J\,K^{-1}$
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s

work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}
half-life	$t_{\frac{1}{2}}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	$kg\,mol^{-1}$
proton number	Z	
nucleon number	A	
neutron number	N	

6.5   Data and formulae

The following data and formulae will appear as pages 2 and 3 in Papers 1, 2 and 4.
Those in **bold** type are not required for the AS qualification.

Data		
speed of light in free space	c =	$3.00 \times 10^8\,m\,s^{-1}$
permeability of free space	μ_0 =	$4\pi \times 10^{-7}\,H\,m^{-1}$
permittivity of free space	ε_0 =	$8.85 \times 10^{-12}\,F\,m^{-1}$
	$(\dfrac{1}{4\pi\varepsilon_0}$ =	$8.99 \times 10^9\,m\,F^{-1})$
elementary charge	e =	$1.60 \times 10^{-19}\,C$
the Planck constant	h =	$6.63 \times 10^{-34}\,J\,s$
unified atomic mass constant	u =	$1.66 \times 10^{-27}\,kg$
rest mass of electron	m_e =	$9.11 \times 10^{-31}\,kg$
rest mass of proton	m_p =	$1.67 \times 10^{-27}\,kg$
molar gas constant	R =	$8.31\,J\,K^{-1}\,mol^{-1}$
the Avogadro constant	N_A =	$6.02 \times 10^{23}\,mol^{-1}$
the Boltzmann constant	k =	$1.38 \times 10^{-23}\,J\,K^{-1}$
gravitational constant	G =	$6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}$
acceleration of free fall	g =	$9.81\,m\,s^{-2}$

Formulae			
uniformly accelerated motion	s	$=$	$ut + \frac{1}{2}at^2$
	v^2	$=$	$u^2 + 2as$
work done on/by a gas	W	$=$	$p\,\Delta V$
gravitational potential	ϕ	$=$	$-\dfrac{Gm}{r}$
hydrostatic pressure	p	$=$	ρgh
pressure of an ideal gas	p	$=$	$\dfrac{1}{3}\dfrac{Nm}{V}<c^2>$
simple harmonic motion	a	$=$	$-\omega^2 x$
velocity of particle in s.h.m.	v	$=$	$v_0 \cos \omega t$
	v	$=$	$\pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	V	$=$	$\dfrac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C$	$=$	$1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	C	$=$	$C_1 + C_2 + \ldots.$
energy of charged capacitor	W	$=$	$\dfrac{1}{2}QV$
resistors in series	R	$=$	$R_1 + R_2 + \ldots.$
resistors in parallel	$1/R$	$=$	$1/R_1 + 1/R_2 + \ldots.$
alternating current/voltage	x	$=$	$x_0 \sin \omega t$
radioactive decay	x	$=$	$x_0 \exp(-\lambda t)$
decay constant	λ	$=$	$\dfrac{0.693}{t_{\frac{1}{2}}}$

6.6   IT usage in Cambridge International A Level Physics

Information Technology (IT) is a term used to cover a number of processes which have become an indispensable part of modern life. These processes are almost all based on the ability of the microprocessor chip to handle and manipulate large volumes of binary data in a short time. The use of IT is now an important factor in Physics education, and all Cambridge International A Level candidates should have the opportunity to experience each of the following five processes:

1. Data Capture (Hardware)

Sensors and data loggers can be used in any experiment to measure and store a number of physical quantities which vary with time. The sensor usually converts the quantity (e.g. temperature, light/sound intensity, position, count rate, magnetic flux density) into a voltage and the data logger samples this voltage at regular intervals, from a few microseconds to a few hours depending on the duration of the 'experiment'. Each sample is converted into a binary/digital number and then stored in memory. The number of samples that are taken and stored depends on the particular data logger in use, but it is usually several hundred. This large number has the effect that, when the stored data is subsequently plotted graphically, the data points are so close together that the physical quantity appears to vary continuously over the timescale of the experiment.

Sensors and data loggers are invaluable where the timescale of the experiment is either very long (e.g. the variation of temperature over several days) or very short (e.g. the microphone signal of a handclap).

Although most suppliers of sensors and data loggers will indicate the type of experiment in which they may be used, the following are some examples of their use in standard Cambridge International A Level Physics experiments:

- the variation of voltage in capacitor charge/discharge circuits
- the variation of temperature in a latent heat demonstration
- the variation of induced e.m.f. in a coil as a magnet falls through it
- the variation of count rate in radioactive half-life measurement
- the variation of the position of an oscillator in simple harmonic motion.

2. Data Analysis (Software)

Large collections of data may be easily stored and analysed using a spreadsheet program, such as Microsoft Excel, the free-of-charge OpenOffice.org Calc, or the free online Google Docs service. Numerical values may be entered into a spreadsheet using either data entry or with the aid of a data logger.

For example, a student might investigate the behaviour of a filament lamp by recording the current through the lamp when different potential differences (p.d.) are applied. This data could be recorded in a spreadsheet, with the first two columns containing the p.d. and current. A third column might contain a formula that determines the power P dissipated by the lamp by multiplying the p.d. and the current. Another column might calculate the resistance R of the lamp by dividing the p.d. by the current.

Spreadsheets also typically allow for the presentation of data in graphical form. For example, in the simple experiment outlined above, a line graph could be plotted to show the variation with resistance of power dissipated in the lamp. Relationships may be tested easily by graphical methods. For example, to test that P varies linearly with R^4, a column could be created containing R^4 and a scatter graph then plotted to look for a linear relationship. The spreadsheet program would be able to determine a straight line of best fit and give its gradient and intercept.

A spreadsheet may also be used to build mathematical models of physical situations by calculating and plotting the necessary data. For example, the dynamic model for the two-dimensional flight of a ball subject to air resistance may be examined without resorting to the calculus of differential equations. Here, the positions of the ball after successive increments of time would be calculated algebraically and added to successive cells in the spreadsheet. These positions can then be plotted and extrapolated to reveal the ball's trajectory.

3. Teaching Aids and Resources (Software)

Although classroom demonstrations and practicals are often the most engaging and effective ways to teach scientific concepts to students, time and resources do not always make this feasible. There also exist interactive demonstrations on the Internet — many of which may be used free of charge, by students and teachers alike. In addition, where Internet access is not available, there are many software packages available on CD-ROM or DVD-ROM, which can help to illustrate concepts from throughout the syllabus content. Examples of these websites and software packages are given in the Resource List, available on the Teacher Support Site. Further examples may be found elsewhere on the Internet, by searching for particular topics of interest.

Lastly, many educational suppliers produce videos (on VHS, on DVD and online) of examples of Physics being used in the real world — from nuclear power stations to bridge-building. These can help to inspire students to think of ways in which their knowledge may be used outside education. Science programmes and podcasts, produced both by national radio stations and international channels such as the BBC World Service, may also introduce students to applications of Physics that they had not previously considered.

4. World Wide Web (WWW)

The 'World Wide Web' allows teachers and students to share and interact with content created by users from across the world. Many websites contain tutorials, demonstrations, video clips, photographs and encyclopaedic information that can support students in their learning. For the teacher, many online communities of teachers exist to share lesson plans, practical ideas and test questions. For both student and teacher alike, discussion forums and e-mail provide ways to share ideas and consult with peers and subject experts.

Cambridge also encourages Physics teachers and heads of department to join our discussion group for people teaching Cambridge Physics syllabuses. Further information can be found on our Teacher Support Site, at **http://teachers.cie.org.uk/**

5. Presentation Technologies

The communication of scientific concepts, both to other scientists and to people unfamiliar with science, is an important skill. Where possible, students should be encouraged to use software packages such as OpenOffice.org or Microsoft Office in order to produce clear and engaging written or oral presentations. Information may also be communicated through websites, podcasts or video clips; students may find these and other technologies an engaging way to interact with a wide audience.

Learning Outcomes

Finally, students must develop an awareness of the many possible applications and limitations of IT. They should be able to judge when to use IT to collect, handle and analyse scientific investigation. Students must be aware of the need to be critical of information produced using IT and that the results may be affected by the use of inaccurate data or careless entry. Most importantly, students will, in the process, learn to adopt a critical and creative approach to problem solving that would enable them to meet the challenges of the new knowledge-based economy.

A brief commentary follows on some parts of the syllabus where IT can be applied. In some cases, software is available commercially; in others, teachers may be able to develop their own.

Syllabus section	IT application
2. **Measurement techniques**	Learning outcomes in this section introduce candidates to the presentation of data in analogue and digital forms. Data-capture techniques may be used in the measurement of magnetic flux density. The treatment of uncertainties may be illustrated using IT simulation methods.
3. **Kinematics**	Teaching of this section offers an opportunity to use computer programs to simulate particle motion, and to demonstrate how quantities such as displacement, velocity and acceleration are related. Data-capture techniques may also be used in practical work on kinematics.
4. **Dynamics**	Examples of the application of Newton's second law may be presented through computer simulations. Likewise, collision problems may be presented very effectively using IT simulations. Experimental investigations of collisions lend themselves to data-capture techniques.
6. **Work, energy, power**	The concepts of force, energy and power may be demonstrated using simulation methods.
7. **Motion in a circle**	Computer simulation techniques may be used effectively in the analysis of circular orbits.
8. **Gravitational field**	Theoretical predictions from Newton's law of gravitation and the concept of gravitational potential may be presented through computer simulations. Information on the orbits of planets in the Solar System could be stored on a spreadsheet.
12. **Temperature**	Data-capture methods may be used with certain types of thermometer.
14. **Oscillations**	The relations between acceleration, velocity and displacement in simple harmonic motion and in damped and forced oscillation may be demonstrated using computer simulations.
15. **Waves**	The graphical representation of transverse and longitudinal waves may be illustrated using computer simulations. Data capture may be applied in the measurement of the frequency and wavelength of sound.

16. Superposition	Computer simulations may be used to help students to model the concept of superposition and to investigate stationary waves.
17. Electric fields	Theoretical predictions from Coulomb's law and the concept of electric potential may be presented through computer simulations.
19. Current of electricity	The current-voltage characteristics of a number of devices may be presented through computer simulations and data-capture.
20. D.C. circuits	The characteristics of thermistors and light-dependent resistors may be presented using computer simulation techniques and data-capture.
23. Electromagnetic induction	Computer simulations may be used to illustrate the phenomena of electromagnetic induction.
24. Alternating currents	Computer simulations, or demonstrations using a cathode-ray oscilloscope, are powerful methods of demonstrating alternating currents.
25. Charged particles	The classic experiments on the determination of e and e/m_e may be presented through computer simulations. Theoretical predictions of the motion of charged particles in electric and magnetic fields may also be presented in this way.
26. Quantum physics	Important concepts of the quantum theory may be presented using simulation techniques, and theoretical predictions may be demonstrated. The relation of spectral lines to systems of discrete electron energy levels may also be presented in this way.
27. Nuclear physics	Computer simulations of an α-particle scattering experiment may be very effective. Simple models of the nuclear atom may be presented using computer simulations. Data-capture methods may be used in experiments on radioactive decay.

7. Additional information

7.1 Guided learning hours

Cambridge International A Level syllabuses are designed on the assumption that candidates have about 360 guided learning hours per subject over the duration of the course. Cambridge International AS Level syllabuses are designed on the assumption that candidates have about 180 guided learning hours per subject over the duration of the course. ('Guided learning hours' include direct teaching and any other supervised or directed study time. They do not include private study by the candidate.)

However, these figures are for guidance only, and the number of hours required may vary according to local curricular practice and the candidates' prior experience of the subject.

7.2 Recommended prior learning

We recommend that candidates who are beginning this course should have previously completed a Cambridge O Level or Cambridge IGCSE course, or the equivalent, in Physics or in Coordinated Science.

7.3 Progression

Cambridge International A Level Physics provides a suitable foundation for the study of Physics or related courses in higher education. Equally it is suitable for candidates intending to pursue careers or further study in Physics or Engineering, or as part of a course of general education.

Cambridge International AS Level Physics constitutes the first half of the Cambridge International A Level course in Physics and therefore provides a suitable foundation for the study of Physics at Cambridge International A Level and thence for related courses in higher education. Depending on local university entrance requirements, it may permit or assist progression directly to university courses in Physics or some other subjects. It is also suitable for candidates intending to pursue careers or further study in Physics, or as part of a course of general education.

7.4 Component codes

Because of local variations, in some cases component codes will be different in instructions about making entries for examinations and timetables from those printed in this syllabus, but the component names will be unchanged to make identification straightforward.

7.5   Grading and reporting

Cambridge International A Level results are shown by one of the grades A*, A, B, C, D or E indicating the standard achieved, Grade A* being the highest and Grade E the lowest. 'Ungraded' indicates that the candidate has failed to reach the standard required for a pass at either Cambridge International AS Level or A Level. 'Ungraded' will be reported on the statement of results but not on the certificate.

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

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

For languages other than English, Cambridge also reports separate speaking endorsement grades (Distinction, Merit and Pass), for candidates who satisfy the conditions stated in the syllabus.

Percentage uniform marks are also provided on each candidate's statement of results to supplement their grade for a syllabus. They are determined in this way:

- A candidate who obtains…
    … the minimum mark necessary for a Grade A* obtains a percentage uniform mark of 90%.
    … the minimum mark necessary for a Grade A obtains a percentage uniform mark of 80%.
    … the minimum mark necessary for a Grade B obtains a percentage uniform mark of 70%.
    … the minimum mark necessary for a Grade C obtains a percentage uniform mark of 60%.
    … the minimum mark necessary for a Grade D obtains a percentage uniform mark of 50%.
    … the minimum mark necessary for a Grade E obtains a percentage uniform mark of 40%.
    … no marks receives a percentage uniform mark of 0%.

Candidates whose mark is none of the above receive a percentage mark in between those stated according to the position of their mark in relation to the grade 'thresholds' (i.e. the minimum mark for obtaining a grade). For example, a candidate whose mark is halfway between the minimum for a Grade C and the minimum for a Grade D (and whose grade is therefore D) receives a percentage uniform mark of 55%.

The percentage uniform mark is stated at syllabus level only. It is not the same as the 'raw' mark obtained by the candidate, since it depends on the position of the grade thresholds (which may vary from one series to another and from one subject to another) and it has been turned into a percentage.

Cambridge International AS Level results are shown by one of the grades a, b, c, d or e indicating the standard achieved, Grade a being the highest and Grade e the lowest. 'Ungraded' indicates that the candidate has failed to reach the standard required for a pass at Cambridge International AS Level. 'Ungraded' will be reported on the statement of results but not on the certificate.

For languages other than English, Cambridge will also report separate speaking endorsement grades (Distinction, Merit and Pass) for candidates who satisfy the conditions stated in the syllabus.

The content and difficulty of a Cambridge International AS Level examination is equivalent to the first half of a corresponding Cambridge International A Level.

Percentage uniform marks are also provided on each candidate's statement of results to supplement their grade for a syllabus. They are determined in this way:

- A candidate who obtains…
    … the minimum mark necessary for a Grade a obtains a percentage uniform mark of 80%.
    … the minimum mark necessary for a Grade b obtains a percentage uniform mark of 70%.
    … the minimum mark necessary for a Grade c obtains a percentage uniform mark of 60%.
    … the minimum mark necessary for a Grade d obtains a percentage uniform mark of 50%.
    … the minimum mark necessary for a Grade e obtains a percentage uniform mark of 40%.
    … no marks receives a percentage uniform mark of 0%.

Candidates whose mark is none of the above receive a percentage mark in between those stated according to the position of their mark in relation to the grade 'thresholds' (i.e. the minimum mark for obtaining a grade). For example, a candidate whose mark is halfway between the minimum for a Grade c and the minimum for a Grade d (and whose grade is therefore d) receives a percentage uniform mark of 55%.

The percentage uniform mark is stated at syllabus level only. It is not the same as the 'raw' mark obtained by the candidate, since it depends on the position of the grade thresholds (which may vary from one series to another and from one subject to another) and it has been turned into a percentage.

7.6   Access

Reasonable adjustments are made for disabled candidates in order to enable them to access the assessments and to demonstrate what they know and what they can do. For this reason, very few candidates will have a complete barrier to the assessment. Information on reasonable adjustments is found in the *Cambridge Handbook* which can be downloaded from the website **www.cie.org.uk**

Candidates who are unable to access part of the assessment, even after exploring all possibilities through reasonable adjustments, may still be able to receive an award based on the parts of the assessment they have taken.

7.7   Resources

Copies of syllabuses, the most recent question papers and Principal Examiners' reports for teachers are on the Syllabus and Support Materials CD-ROM, which we send to all Cambridge International Schools. They are also on our public website – go to **www.cie.org.uk/alevel**. Click the Subjects tab and choose your subject. For resources, click 'Resource List'.

You can use the 'Filter by' list to show all resources or only resources categorised as 'Endorsed by Cambridge'. Endorsed resources are written to align closely with the syllabus they support. They have been through a detailed quality-assurance process. As new resources are published, we review them against the syllabus and publish their details on the relevant resource list section of the website.

Additional syllabus-specific support is available from our secure Teacher Support website **http://teachers.cie.org.uk** which is available to teachers at registered Cambridge schools. It provides past question papers and examiner reports on previous examinations, as well as any extra resources such as schemes of work or examples of candidate responses. You can also find a range of subject communities on the Teacher Support website, where Cambridge teachers can share their own materials and join discussion groups.

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