

SYLLABUS

**Cambridge International AS & A Level
Physics**

9702

For examination in June and November 2019, 2020 and 2021.
Also available for examination in March 2019, 2020 and 2021
for India only.

Changes to the syllabus for 2019, 2020 and 2021

The latest syllabus is version 1, published September 2016.

There are no significant changes which affect teaching.

Any textbooks endorsed to support the syllabus for examination from 2016 are still suitable for use with this syllabus.

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

Cambridge International Examinations retains the copyright on all its publications. Registered Centres are permitted to copy material from this booklet for their own internal use. However, we cannot give permission to Centres to photocopy any material that is acknowledged to a third party even for internal use within a Centre.

® IGCSE is the registered trademark of Cambridge International Examinations

© Cambridge International Examinations 2016

Contents

Introduction	2
Welcome	
Why Cambridge International Examinations?	
Why Cambridge International AS & A Levels?	
Why Cambridge International AS & A Level Physics?	
Teacher support	
1 Syllabus overview	9
1.1 Content	
1.2 Assessment	
2 Syllabus aims and assessment objectives	12
2.1 Syllabus aims	
2.2 Assessment objectives	
2.3 Relationship between assessment objectives and components	
2.4 Relationship between assessment objectives and qualifications	
3 Syllabus content	15
3.1 Structure of the syllabus	
3.2 Subject content	
4 Practical assessment.....	47
4.1 Introduction	
4.2 Paper 3	
4.3 Paper 5	
5 General syllabus requirements and information	60
5.1 Mathematical requirements	
5.2 Summary of key quantities, symbols and units	
5.3 Glossary of command words	
5.4 Data and formulae	
5.5 Circuit symbols	
6 Other information	70
Equality and inclusion	
Language	
Grading and reporting	
Entry option codes	

Welcome

Cambridge International AS & A Level Physics encourages learners to explore their subject in depth. The syllabus has been designed, in consultation with teachers and universities, to help learners develop not only subject knowledge, but also a strong understanding of some of the key concepts that are critical to mastering the subject.

All our syllabuses are reviewed and updated regularly so that they reflect the latest thinking of international experts and practitioners, and take account of the different national contexts in which they are taught. Consultation is an important part of the way we develop our syllabuses.

Consulting teachers

Teachers at Cambridge schools worldwide help us to shape our Cambridge International AS & A Level syllabuses. The feedback contributes to the development of syllabus content, assessments and support materials. Consulting teachers ensures that our materials are designed carefully around their needs and the needs of their learners.

Consulting universities

Like teachers, universities help to shape our Cambridge International AS & A Level syllabuses. We consult with leading higher education institutions to make sure the syllabuses encourage learners to get a firm grasp of the subject's key concepts and develop the skills necessary for success at university.

Key concepts

Key concepts are essential ideas, theories, principles or mental tools that help learners to develop a deep understanding of their subject and make links between the different topics. The key concepts that this syllabus is designed to develop are detailed on page 5.

Teacher support

Our comprehensive teacher support will help you deliver the syllabus confidently and effectively. The support includes resources for teaching and learning as well as exam preparation. The teaching support package helps teachers integrate the key concepts into their teaching, showing how they fit into the overall syllabus and suggesting ways to teach them with each topic. Learn more on page 8.

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

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

Why choose Cambridge International Examinations?

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

Our international qualifications are recognised by the world's best universities and employers, giving students a wide range of options in their education and career. As a not-for-profit organisation, we devote our resources to delivering high-quality educational programmes that can unlock learners' potential.

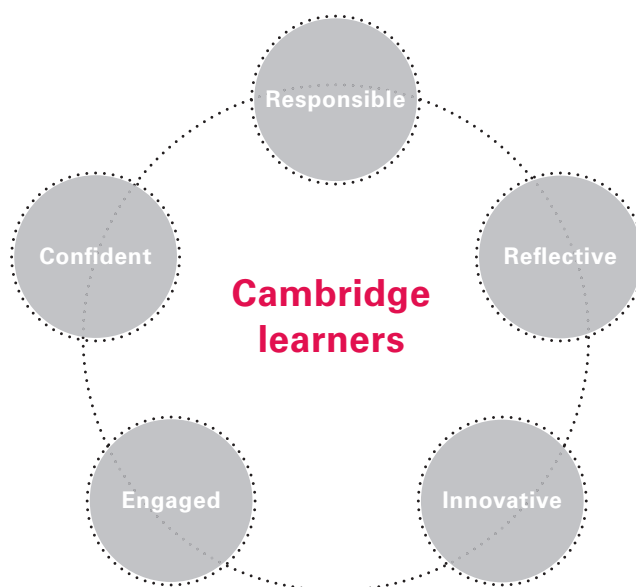
Our programmes and qualifications set the global standard for international education. They are created by subject experts, rooted in academic rigour and reflect the latest educational research. They provide a strong platform for learners to progress from one stage to the next, and are well supported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

Every year, nearly a million Cambridge learners from 10 000 schools in 160 countries prepare for their future with an international education from Cambridge.

Cambridge learners

Our mission is to provide educational benefit through provision of international programmes and qualifications for school education and to be the world leader in this field. Together with schools, we develop Cambridge learners who are:

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



Learn more about the Cambridge learner attributes in Chapter 2 of our *Implementing the curriculum with Cambridge* guide at www.cie.org.uk/curriculumguide

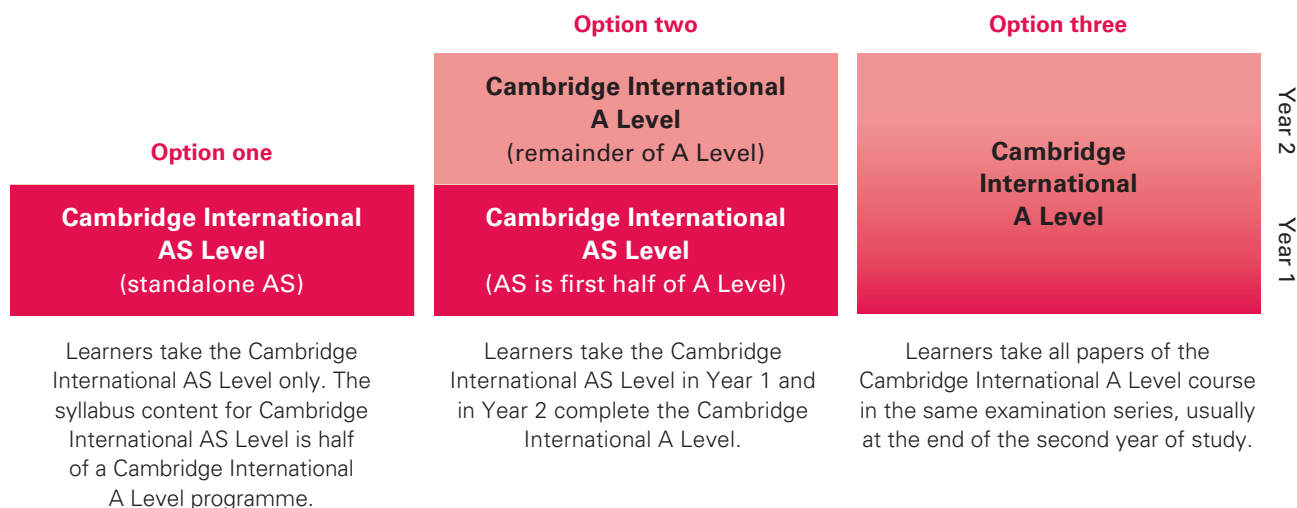
Why Cambridge International AS & A Levels?

Cambridge International AS & A Levels are international in outlook, but retain a local relevance. The syllabuses provide opportunities for contextualised learning and the content has been created to suit a wide variety of schools, avoid cultural bias and develop essential lifelong skills, including creative thinking and problem-solving.

Our aim is to balance knowledge, understanding and skills in our qualifications to enable students to become effective learners and to provide a solid foundation for their continuing educational journey. Cambridge International AS & A Levels give learners building blocks for an individualised curriculum that develops their knowledge, understanding and skills.

Cambridge International AS & A Level curricula are flexible. It is possible to offer almost any combination from a wide range of subjects. Cambridge International A Level is typically a two-year course, and Cambridge International AS Level is typically one year. Some subjects can be started as a Cambridge International AS Level and extended to a Cambridge International A Level.

There are three possible assessment approaches for Cambridge International AS & A Level:



Every year thousands of learners with Cambridge International AS & A Levels gain places at leading universities worldwide. Cambridge International AS & A Levels are accepted and valued by top universities around the world including those in the UK, US (including Ivy League universities), European nations, Australia, Canada and New Zealand. Learners should check the university website for specific entry requirements before applying.

Did you know?

In some countries universities accept Cambridge International AS Levels in their own right as qualifications counting towards entry to courses in the same or other related subjects. Many learners who take Cambridge International AS Levels also choose to progress to Cambridge International A Level.

Learn more

For more details go to www.cie.org.uk/recognition

Why Cambridge International AS & A Level Physics?

Universities value learners who have a thorough understanding of key concepts in physics, an in-depth knowledge of the most important themes in physics and strong practical skills. Cambridge International AS and A Level Physics helps learners develop the knowledge and skills that will prepare them for successful university study.

Our learners also develop lifelong skills of scientific enquiry, confidence in technology, and communication and teamwork skills.

Key concepts

The key concepts on which this syllabus is built are set out below. These key concepts can help teachers think about how to approach each syllabus topic in order to encourage learners to make links between topics and develop a deep overall understanding of the subject. The teaching support package gives teachers guidance on integrating the key concepts into their teaching. See page 8 for more information on our teacher support.

As a teacher, you will refer to these concepts again and again to help unify the subject and make sense of it. If mastered, learners can use the concepts to solve problems or to understand unfamiliar subject-related material.

- **Models of physical systems**

Physics is the science that seeks to understand the behaviour of the Universe. The development of models of physical systems is central to physics. Models simplify, explain and predict how physical systems behave.

- **Testing predictions against evidence**

Physical models are usually based on prior observations, and their predictions are tested to check that they are consistent with the behaviour of the real world. This testing requires evidence, often obtained from experiments.

- **Mathematics as a language and problem-solving tool**

Mathematics is integral to physics, as it is the language that is used to express physical principles and models. It is also a tool to analyse theoretical models, solve quantitative problems and produce predictions.

- **Matter, energy and waves**

Everything in the Universe comprises matter and/or energy. Waves are a key mechanism for the transfer of energy and are essential to many modern applications of physics.

- **Forces and fields**

The way that matter and energy interact is through forces and fields. The behaviour of the Universe is governed by fundamental forces that act over different length scales and magnitudes. These include the gravitational force and the electromagnetic force.

Guided learning hours

Guided learning hours give an indication of the amount of contact time teachers need to have with learners to deliver a particular course. Our syllabuses are designed around 180 guided learning hours for Cambridge International AS Level, and around 360 guided learning hours for Cambridge International A Level.

These figures are for guidance only. The number of hours needed to gain the qualification may vary depending on local practice and the learners' previous experience of the subject.

Prior learning

We recommend that learners who are beginning this course should have previously completed a Cambridge O Level or Cambridge IGCSE® course, or the equivalent, in Physics or Co-ordinated Science.

Progression

Cambridge International A Level Physics provides a suitable foundation for the study of physics or related courses in higher education. It is equally 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 is the first half of Cambridge International A Level Physics. Depending on local university entrance requirements, the qualification may permit or assist progression directly to university courses in physics or some other subjects.

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

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 info@cie.org.uk

If you are not yet a Cambridge school

Learn more about the benefits of becoming a Cambridge school from our website at www.cie.org.uk/startcambridge

Email us at info@cie.org.uk to find out how your organisation can register to become a Cambridge school.

Cambridge AICE

Cambridge AICE Diploma is the group award of the Cambridge International AS & A Level. It gives schools the opportunity to benefit from offering a broad and balanced curriculum by recognising the achievements of candidates who pass examinations from different curriculum groups.

Learn more

For more details go to www.cie.org.uk/aice

“ Our research has shown that students who came to the university with a Cambridge AICE background performed better than anyone else that came to the university. That really wasn't surprising considering the emphasis they have on critical research and analysis, and that's what we require at university. ”

John Barnhill, Assistant Vice President for Enrollment Management, Florida State University, USA

Teacher support

We offer a wide range of practical and innovative support to help teachers plan and deliver our programmes and qualifications confidently.

The support package for our Cambridge International AS & A Levels will help teachers integrate key concepts into their teaching, showing how they fit into the overall syllabus and suggesting ways to teach them within each topic. It also gives teachers access to a worldwide teaching community enabling them to connect with other teachers, swap ideas and share best practice.

Teaching and learning

- Support materials provide teachers with ideas and planning resources for their lessons.
- Endorsed textbooks, ebooks and digital resources are produced by leading publishers. We have quality checked these materials to make sure they provide a high level of support for teachers and learners.
- Resource lists to help support teaching, including textbooks and websites.

Exam preparation

- Past question papers and mark schemes so teachers can give learners the opportunity to practise answering different questions.
- Example candidate responses help teachers understand exactly what examiners are looking for.
- Principal examiner reports describing learners' overall performance on each part of the papers. The reports give insight into common misconceptions shown by learners, which teachers can address in lessons.

Cambridge International AS & A Level support for teachers

Professional development

Face-to-face training

We hold workshops around the world to support teachers in delivering Cambridge syllabuses and developing their skills.

Online training

We offer self-study and tutor-led online training courses via our virtual learning environment. A wide range of syllabus-specific courses and skills courses is available. We also offer training via video conference and webinars.

Qualifications

We offer a wide range of practice-based qualifications at Certificate and Diploma level, providing a framework for continuing professional development.

Learn more

Find out more about support for this syllabus at www.cie.org.uk/alevel

Visit our online resource bank and community forum at <https://teachers.cie.org.uk>

Useful links

Customer Services www.cie.org.uk/help

LinkedIn <http://linkd.in/cambridgeteacher>

Twitter [@cie_education](https://twitter.com/cie_education)

Facebook www.facebook.com/cie.org.uk

1 Syllabus overview

1.1 Content

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

- Physical quantities and units
- Measurement techniques
- Kinematics
- Dynamics
- Forces, density and pressure
- Work, energy and power
- Deformation of solids
- Waves
- Superposition
- Electric fields
- Current of electricity
- D.C. circuits
- Particle and nuclear physics

Candidates for Cambridge International A Level Physics study the AS Level topics, including some topics in further detail, and additionally study the following topics:

- Motion in a circle
- Gravitational fields
- Ideal gases
- Temperature
- Thermal properties of materials
- Oscillations
- Communication
- Capacitance
- Electronics
- Magnetic fields
- Electromagnetic induction
- Alternating currents
- Quantum physics

All candidates study practical skills.

1.2 Assessment

Candidates for Advanced Subsidiary (AS) certification 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 Papers 4 and 5 in the examination series in which they require certification.

Candidates taking the full 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 resit purposes.

All components are externally assessed.

Component	Weighting	
	AS Level	A Level
Paper 1 Multiple Choice 1 hour 15 minutes This paper consists of 40 multiple choice questions, all with four options. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on an answer sheet. [40 marks]	31%	15.5%
Paper 2 AS Level Structured Questions 1 hour 15 minutes This paper consists of a variable number of questions of variable mark value. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on the question paper. [60 marks]	46%	23%
Paper 3 Advanced Practical Skills 2 hours This paper requires candidates to carry out practical work in timed conditions. The paper will consist of two experiments drawn from different areas of physics. The experiments may be based on physics not included in the syllabus content, but candidates will be assessed on their practical skills rather than their knowledge of theory. Candidates will answer both questions. Candidates will answer on the question paper. [40 marks]	23%	11.5%
Paper 4 A Level Structured Questions 2 hours This paper consists of a variable number of questions of variable mark value. All questions will be based on the A Level syllabus but may require knowledge of material first encountered in the AS Level syllabus. Candidates will answer all questions. Candidates will answer on the question paper. [100 marks]	–	38.5%
Paper 5 Planning, Analysis and Evaluation 1 hour 15 minutes This paper consists of two questions of equal mark value based on the practical skills of planning, analysis and evaluation. The context of the questions may be outside the syllabus content, but candidates will be assessed on their practical skills of planning, analysis and evaluation rather than their knowledge of theory. Candidates will answer both questions. Candidates will answer on the question paper. [30 marks]	–	11.5%

Data and formulae

Data and formulae will appear as pages 2 and 3 in Papers 1, 2 and 4. The data and formulae are shown in Section 5.4.

Nomenclature

Symbols, signs and abbreviations used in examination papers will follow the recommendations made in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000).

Decimal markers

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

Units

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

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

Availability

This syllabus is examined in the June and November examination series. This syllabus is also available for examination in March for India only.

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 progress successfully to further study without this necessary and important aspect of science education.

Detailed timetables are available from www.cie.org.uk/timetables

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.

2 Syllabus aims and assessment objectives

2.1 Syllabus aims

The aims listed below are not 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 learners, 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:
 - become confident citizens in a technological world and be able to take or develop an informed interest in scientific matters
 - recognise the usefulness, and limitations, of scientific method and appreciate its applicability in other disciplines and in everyday life
 - 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:
 - are relevant to the study and practice of science
 - are useful in everyday life
 - encourage efficient and safe practice
 - encourage effective communication.
- 3 develop attitudes relevant to science such as:
 - a concern for accuracy and precision
 - objectivity
 - integrity
 - a spirit of enquiry
 - initiative
 - 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:
 - 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
 - that the applications of physics may be both beneficial and detrimental to the individual, the community and the environment
 - 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 learners and create a sustained interest in physics so that the study of the subject is enjoyable and satisfying.

2.2 Assessment objectives

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

AO1 Knowledge with understanding

Candidates should be able to demonstrate knowledge and understanding of:

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

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these assessment objectives will often begin with one of the following words: *define*, *state*, *describe*, or *explain* (see Glossary of command words on page 65).

AO2 Handling, applying and evaluating information

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

- locate, select, organise and present information from a variety of sources
- translate information from one form to another
- manipulate numerical and other data
- use information to identify patterns, report trends, draw inferences and report conclusions
- present reasoned explanations for phenomena, patterns and relationships
- make predictions and put forward hypotheses
- apply knowledge, including principles, to new situations
- evaluate information and hypotheses
- 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 command words on page 65).

AO3 Experimental skills and investigations

Candidates should be able to:

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

2.3 Relationship between assessment objectives and components

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

The table shows the assessment objectives (AO) as a percentage of each component.

Component	AO1 %	AO2 %	AO3 %
Paper 1	48	52	0
Paper 2	48	52	0
Paper 3	0	0	100
Paper 4	48	52	0
Paper 5	0	0	100

2.4 Relationship between assessment objectives and qualifications

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

The table shows the assessment objectives (AO) as a percentage of each qualification.

Assessment objective	Weighting in AS Level %	Weighting in A Level %
AO1	37	37
AO2	40	40
AO3	23	23

Teachers should note that there is a greater weighting of 63 per cent for skills (including handling information, solving problems, practical, experimental and investigative skills) compared to the 37 per cent 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 Syllabus content

3.1 Structure of the syllabus

The table shows which parts of the syllabus contain AS Level material and which contain additional material that is examined only in the full A Level.

Topic	AS Level	A Level
1 Physical quantities and units	✓	✓
2 Measurement techniques	✓	✓
3 Kinematics	✓	
4 Dynamics	✓	
5 Forces, density and pressure	✓	
6 Work, energy and power	✓	
7 Motion in a circle		✓
8 Gravitational fields		✓
9 Deformation of solids	✓	
10 Ideal gases		✓
11 Temperature		✓
12 Thermal properties of materials		✓
13 Oscillations		✓
14 Waves	✓	✓
15 Superposition	✓	
16 Communication		✓
17 Electric fields	✓	✓
18 Capacitance		✓
19 Current of electricity	✓	✓
20 D.C. circuits	✓	✓
21 Electronics		✓
22 Magnetic fields		✓
23 Electromagnetic induction		✓
24 Alternating currents		✓
25 Quantum physics		✓
26 Particle and nuclear physics	✓	✓

3.2 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 learners should be encouraged to apply the principles of these examples to other situations introduced in the course.

The **additional** learning outcomes that will be assessed only in the full A Level qualification are shown in **bold** type.

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

1 Physical quantities and units

The measurement and recording of quantities is central to the whole of physics. The skills of estimating a physical quantity and having a feeling for which quantities are reasonable and which are unreasonable are very useful for any physicist.

This topic introduces the SI system of units, which provides a universal framework of measurement that is common to all scientists internationally.

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 measurements in the laboratory.

Learning outcomes

Candidates should be able to:

- | | |
|---------------------------|---|
| 1.1 Physical quantities | <ul style="list-style-type: none"> a) understand that all physical quantities consist of a numerical magnitude and a unit b) make reasonable estimates of physical quantities included within the syllabus |
| 1.2 SI units | <ul style="list-style-type: none"> a) recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol) b) express derived units as products or quotients of the SI base units and use the named units listed in this syllabus as appropriate c) use SI base units to check the homogeneity of physical equations d) use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T) e) understand and use the conventions for labelling graph axes and table columns as set out in the ASE publication <i>Signs, Symbols and Systematics</i> (<i>The ASE Companion to 16–19 Science</i>, 2000) |
| 1.3 The Avogadro constant | <ul style="list-style-type: none"> a) understand that the Avogadro constant N_A is the number of atoms in 0.012 kg of carbon-12 b) use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant N_A |
| 1.4 Scalars and vectors | <ul style="list-style-type: none"> a) distinguish between scalar and vector quantities and give examples of each b) add and subtract coplanar vectors c) represent a vector as two perpendicular components |

2 Measurement techniques

Measurement is essential to the study of physics. Physicists need to be familiar with a wide range of measuring instruments.

Measurements themselves may be misleading and result in inappropriate conclusions as a result of errors and uncertainties. This topic develops an understanding of errors and uncertainties in measured and derived physical quantities.

Learning outcomes

Candidates should be able to:

2.1 Measurements

- 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 rulers, calipers and micrometers
 - measure weight and hence mass using 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
 - 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

2.2 Errors and uncertainties

- a) understand and explain the effects of systematic errors (including zero errors) and random errors in measurements
 - b) understand the distinction between precision and accuracy
 - c) assess the uncertainty in a derived quantity by simple addition of absolute, fractional or percentage uncertainties (a rigorous statistical treatment is not required)
-

3 Kinematics

Kinematics is the study of motion. Movement is part of everyday experience, so it is important to be able to analyse and predict the way in which objects move.

The behaviour of moving objects is studied both graphically and through equations of motion.

Learning outcomes

Candidates should be able to:

-
- | | |
|--------------------------------|---|
| 3.1 Equations of motion | <ul style="list-style-type: none">a) define and use distance, displacement, speed, velocity and accelerationb) use graphical methods to represent distance, displacement, speed, velocity and accelerationc) determine displacement from the area under a velocity-time graphd) determine velocity using the gradient of a displacement-time graphe) determine acceleration using the gradient of a velocity-time graphf) derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight lineg) 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 resistanceh) describe an experiment to determine the acceleration of free fall using a falling bodyi) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction |
|--------------------------------|---|
-

4 Dynamics

The motion of any object is governed by forces that act on the object.

This topic introduces Newton's laws of motion, which are fundamental to understanding the connection between forces and motion. The concept of momentum and the use of momentum conservation to analyse interactions are also studied.

Learning outcomes

Candidates should be able to:

4.1 Momentum and Newton's laws of motion

- a) understand that mass is the property of a body that resists change in motion
- b) recall the relationship $F = ma$ and solve problems using it, appreciating that acceleration and resultant force are always in the same direction
- c) define and use linear momentum as the product of mass and velocity
- d) define and use force as rate of change of momentum
- e) state and apply each of Newton's laws of motion

4.2 Non-uniform motion

- a) describe and use the concept of weight as the effect of a gravitational field on a mass and recall that the weight of a body is equal to the product of its mass and the acceleration of free fall
- b) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance

4.3 Linear momentum and its conservation

- a) state the principle of conservation of momentum
 - b) apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between bodies in both one and two dimensions (knowledge of the concept of coefficient of restitution is not required)
 - c) recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation
 - d) understand that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy may take place
-

5 Forces, density and pressure

In this topic, the natures of some different types of force are studied, including how forces give rise to both translational and rotational equilibrium.

The concept of pressure is introduced. This acts as a starting point for later work on pressure in gases.

Learning outcomes

Candidates should be able to:

- | | |
|-------------------------------|--|
| 5.1 Types of force | <ul style="list-style-type: none"> a) describe the force on a mass in a uniform gravitational field and on a charge in a uniform electric field b) understand 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) understand that the weight of a body may be taken as acting at a single point known as its centre of gravity |
| 5.2 Turning effects of forces | <ul style="list-style-type: none"> a) define and apply the moment of a force b) understand that a couple is a pair of forces that tends to produce rotation only c) define and apply the torque of a couple |
| 5.3 Equilibrium of forces | <ul style="list-style-type: none"> a) state and apply the principle of moments b) understand that, when there is no resultant force and no resultant torque, a system is in equilibrium c) use a vector triangle to represent coplanar forces in equilibrium |
| 5.4 Density and pressure | <ul style="list-style-type: none"> a) define and use density b) define and use pressure c) derive, from the definitions of pressure and density, the equation $\Delta p = \rho g \Delta h$ d) use the equation $\Delta p = \rho g \Delta h$ |

6 Work, energy and power

This topic introduces different forms of energy in both qualitative and quantitative terms. The concept of energy and its conservation provide useful accounting tools that help to understand the behaviour of physical systems.

The concepts of power and efficiency are also studied.

Learning outcomes

Candidates should be able to:

6.1 Energy conversion and conservation

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

6.2 Work and efficiency

- a) understand the concept of work in terms of the product of a force and displacement in the direction of the force
- b) calculate the work done in a number of situations including the work done by a gas that is expanding against a constant external pressure:
 $W = p\Delta V$
- c) recall and understand that the efficiency of a system is the ratio of useful energy output from the system to the total energy input
- d) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems

6.3 Potential energy and kinetic energy

- a) derive, from the equations of motion, the formula for kinetic energy
 $E_k = \frac{1}{2}mv^2$
- b) recall and apply the formula $E_k = \frac{1}{2}mv^2$
- c) distinguish between gravitational potential energy and elastic potential energy
- d) understand and use the relationship between force and potential energy in a uniform field to solve problems
- e) derive, from the defining equation $W = Fs$, the formula $\Delta E_p = mg\Delta h$ for potential energy changes near the Earth's surface
- f) recall and use the formula $\Delta E_p = mg\Delta h$ for potential energy changes near the Earth's surface

6.4 Power

- a) define power as work done per unit time and derive power as the product of force and velocity
- b) solve problems using the relationships $P = \frac{W}{t}$ and $P = Fv$

7 Motion in a circle

The turning effect of forces is introduced in Topic 5. In this topic, rotational motion, confined to motion in a circle, is studied.

Radian measure is introduced and equations for circular motion are developed, in terms of both angular and linear speeds.

Learning outcomes

Candidates should be able to:

7.1 Kinematics of uniform circular motion

- a) define the radian and express angular displacement in radians
- b) understand and use the concept of angular speed to solve problems
- c) recall and use $v = r\omega$ to solve problems

7.2 Centripetal acceleration and centripetal force

- a) 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
- b) recall and use centripetal acceleration equations $a = r\omega^2$ and $a = \frac{v^2}{r}$
- c) recall and use centripetal force equations $F = mr\omega^2$ and $F = \frac{mv^2}{r}$

8 Gravitational fields

Forces due to gravity are a familiar experience. These experiences are formalised in an understanding of the concept of a gravitational field and in Newton's law of gravitation.

Gravitational forces, along with gravitational potential, enable a study to be made of the circular orbits of planets and satellites.

Learning outcomes

Candidates should be able to:

8.1 Gravitational field	<p>a) understand the concept of a gravitational field as an example of a field of force and define gravitational field strength as force per unit mass</p>
8.2 Gravitational force between point masses	<p>a) understand that, for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its centre</p> <p>b) recall and use Newton's law of gravitation in the form $F = \frac{Gm_1 m_2}{r^2}$</p> <p>c) analyse circular orbits in inverse square law fields, including geostationary orbits, by relating the gravitational force to the centripetal acceleration it causes</p>
8.3 Gravitational field of a point mass	<p>a) derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass</p> <p>b) recall and solve problems using the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass</p> <p>c) show an appreciation that on the surface of the Earth g is approximately constant</p>
8.4 Gravitational potential	<p>a) define potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point</p> <p>b) solve problems using the equation $\phi = -\frac{GM}{r}$ for the potential in the field of a point mass</p>

9 Deformation of solids

Solids change their shape under the action of forces. This change may be large in the case of springs or hardly noticeable in some structures such as buildings.

The study of the deformation of solids is an important aspect of engineering. This topic provides an introduction to both elastic and plastic deformation of materials.

Learning outcomes

Candidates should be able to:

9.1 Stress and strain

- 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

9.2 Elastic and plastic behaviour

- a) distinguish between elastic and plastic deformation of a material
 - b) understand that the area under the force-extension graph represents the work done
 - c) deduce the strain energy in a deformed material from the area under the force-extension graph
-

10 Ideal gases

Real gases have complex behaviour, but it is possible to make progress in understanding gases by developing a simplified model of a gas called an ideal gas.

A link between the behaviour of gas molecules and temperature can be established. This provides an introduction to the concept of thermodynamic temperature.

Learning outcomes

Candidates should be able to:

10.1 Equation of state

- a) recall and solve problems using the equation of state for an ideal gas expressed as $pV = nRT$, where n = amount of substance (number of moles)

10.2 Kinetic theory of gases

- a) infer from a Brownian motion experiment the evidence for the movement of molecules
b) state the basic assumptions of the kinetic theory of gases
c) explain how molecular movement causes the pressure exerted by a gas and hence deduce the relationship $pV = \frac{1}{3}Nm\langle c^2 \rangle$, where N = number of molecules
[A simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3}\langle c^2 \rangle = \langle c_x^2 \rangle$ is sufficient.]

10.3 Kinetic energy of a molecule

- a) recall that the Boltzmann constant k is given by the expression $k = \frac{R}{N_A}$
b) compare $pV = \frac{1}{3}Nm\langle c^2 \rangle$ with $pV = NkT$ and hence deduce that the average translational kinetic energy of a molecule is proportional to T

11 Temperature

A link between temperature and the behaviour of gas molecules was introduced in Topic 10. In this topic, the concept of temperature is explored in further detail.

Reference to two types of practical thermometer enable aspects of the measurement of temperature to be considered.

Learning outcomes

Candidates should be able to:

11.1 Thermal equilibrium

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

11.2 Temperature scales

- a) understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties
- b) understand 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)
- c) convert temperatures measured in kelvin to degrees Celsius and recall that $T/K = T/^{\circ}\text{C} + 273.15$

11.3 Practical thermometers

- a) compare the relative advantages and disadvantages of thermistor and thermocouple thermometers as previously calibrated instruments
-

12 Thermal properties of materials

A simple kinetic model of matter is used to study properties of the three states of matter, including melting and vaporisation.

This topic then introduces the concept of internal energy and the first law of thermodynamics.

Learning outcomes

Candidates should be able to:

12.1 Specific heat capacity and specific latent heat

- a) explain using a simple kinetic model for matter:
 - the structure of solids, liquids and gases
 - why melting and boiling take place without a change in temperature
 - why the specific latent heat of vaporisation is higher than specific latent heat of fusion for the same substance
 - why 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

12.2 Internal energy and the first law of thermodynamics

- a) understand that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system
 - b) relate a rise in temperature of a body to an increase in its internal energy
 - c) recall and use the first law of thermodynamics $\Delta U = q + w$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred to the system by heating) and the work done on the system
-

13 Oscillations

Oscillations arise in many physical systems, and can be observed at both the microscopic and macroscopic level.

The study of oscillations is confined to simple harmonic motion. Equations that describe simple harmonic oscillations are developed in this topic.

Damping and resonance are introduced, and consideration given to situations where this can be either an advantage or a disadvantage.

Learning outcomes

Candidates should be able to:

13.1 Simple harmonic oscillations

- a) describe simple examples of free oscillations
- b) investigate the motion of an oscillator using experimental and graphical methods
- 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 the equations $v = v_0 \cos \omega t$ and $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
- g) describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion

13.2 Energy in simple harmonic motion

- a) describe the interchange between kinetic and potential energy during simple harmonic motion

13.3 Damped and forced oscillations, resonance

- a) describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and the importance of critical damping
- b) describe practical examples of forced oscillations and resonance
- c) 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
- d) appreciate that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided

14 Waves

This topic introduces the basic properties of transverse and longitudinal progressive waves, including the determination of the frequency and speed of sound waves. The electromagnetic spectrum is also introduced.

These basic properties of waves are developed further into a study of the Doppler effect and of ultrasound for diagnostic purposes.

The ideas of simple wave behaviour, such as reflection and refraction of light, would be useful prior knowledge.

Learning outcomes

Candidates should be able to:

14.1 Progressive waves	<ul style="list-style-type: none"> a) describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks b) understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed c) deduce, from the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$ d) recall and use the equation $v = f\lambda$ e) understand that energy is transferred by a progressive wave f) recall and use the relationship $intensity \propto (amplitude)^2$
14.2 Transverse and longitudinal waves	<ul style="list-style-type: none"> a) compare transverse and longitudinal waves b) analyse and interpret graphical representations of transverse and longitudinal waves
14.3 Determination of frequency and wavelength of sound waves	<ul style="list-style-type: none"> a) determine the frequency of sound using a calibrated cathode-ray oscilloscope (c.r.o.) b) determine the wavelength of sound using stationary waves
14.4 Doppler effect	<ul style="list-style-type: none"> a) understand that when a source of waves moves relative to a stationary observer, there is a change in observed frequency b) use the expression $f_o = \frac{f_s v}{(v \pm v_s)}$ for the observed frequency when a source of sound waves moves relative to a stationary observer c) appreciate that Doppler shift is observed with all waves, including sound and light
14.5 Electromagnetic spectrum	<ul style="list-style-type: none"> a) 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

-
- | | |
|---|--|
| 14.6 Production and use of ultrasound in diagnosis | <ul style="list-style-type: none">a) explain the principles of the generation and detection of ultrasonic waves using piezo-electric transducersb) explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structuresc) understand the meaning of specific acoustic impedance and its importance to the intensity reflection coefficient at a boundaryd) recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter |
|---|--|
-

15 Superposition

Superposition is used to develop the concept of stationary waves.

Diffraction and interference are then studied, including two-source interference and the diffraction grating.

Learning outcomes

Candidates should be able to:

-
- | | |
|------------------------------|---|
| 15.1 Stationary waves | <ul style="list-style-type: none">a) explain and use the principle of superposition in simple applicationsb) show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columnsc) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes |
|------------------------------|---|
-
- | | |
|-------------------------|---|
| 15.2 Diffraction | <ul style="list-style-type: none">a) explain the meaning of the term diffractionb) 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 |
|-------------------------|---|
-
- | | |
|---|--|
| 15.3 Interference, two-source interference | <ul style="list-style-type: none">a) understand the terms interference and coherenceb) show an understanding of experiments that demonstrate two-source interference using water ripples, light and microwavesc) understand the conditions required if two-source interference fringes are to be observedd) recall and solve problems using the equation $\lambda = \frac{ax}{D}$ for double-slit interference using light |
|---|--|
-
- | | |
|----------------------------------|---|
| 15.4 Diffraction gratings | <ul style="list-style-type: none">a) recall and solve problems using the formula $d \sin \theta = n\lambda$b) describe the use of a diffraction grating to determine the wavelength of light (the structure and use of the spectrometer are not included) |
|----------------------------------|---|
-

16 Communication

Modern methods of communication rely heavily on waves. This topic introduces the idea of different channels of communication together with modulation of waves and digital communication.

Aspects of communication are studied through a comparison of the advantages and disadvantages of different channels of communication.

Learning outcomes

Candidates should be able to:

16.1 Communication channels

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

16.2 Modulation

- 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) recall the frequencies and wavelengths used in different channels of communication
- e) demonstrate an awareness of the relative advantages of AM and FM transmissions

16.3 Digital communication

- a) recall the advantages of the transmission of data in digital form, compared with the transmission of data in analogue form
- b) understand that the digital transmission of speech or music involves analogue-to-digital conversion (ADC) before transmission and digital-to-analogue conversion (DAC) after reception
- c) understand the effect of the sampling rate and the number of bits in each sample on the reproduction of an input signal

16.4 Relative merits of channels of communication

- a) discuss the relative advantages and disadvantages of channels of communication in terms of available bandwidth, noise, crosslinking, security, signal attenuation, repeaters and regeneration
- b) recall the relative merits of both geostationary and polar orbiting satellites for communicating information

16.5 Attenuation

- a) understand and use signal attenuation expressed in dB and dB per unit length
- b) recall and use the expression $number\ of\ dB = 10 \lg \left(\frac{P_1}{P_2} \right)$ for the ratio of two powers

17 Electric fields

In this topic, the concept of an electric field is introduced. This is further developed to study the field and potential energy of point charges.

Awareness of the two types of charge and the processes of charging by friction and by induction are useful prior knowledge.

Learning outcomes

Candidates should be able to:

17.1 Concept of an electric field	<ul style="list-style-type: none"> a) understand 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
17.2 Uniform electric fields	<ul style="list-style-type: none"> a) recall and use $E = \frac{\Delta V}{\Delta d}$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation b) calculate the forces on charges in uniform electric fields c) describe the effect of a uniform electric field on the motion of charged particles
17.3 Electric forces between point charges	<ul style="list-style-type: none"> a) understand that, for any point outside a spherical conductor, the charge on the sphere may be considered to act as a point charge at its centre b) recall and use Coulomb's law in the form $F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$ for the force between two point charges in free space or air
17.4 Electric field of a point charge	<ul style="list-style-type: none"> a) recall and use $E = \frac{Q}{4\pi\epsilon_0 r^2}$ for the field strength of a point charge in free space or air
17.5 Electric potential	<ul style="list-style-type: none"> a) define potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point b) state that the field strength of the field at a point is equal to the negative of potential gradient at that point c) use the equation $V = \frac{Q}{4\pi\epsilon_0 r}$ for the potential in the field of a point charge d) recognise the analogy between certain qualitative and quantitative aspects of electric fields and gravitational fields

18 Capacitance

This topic introduces the concept of capacitance, then describes the capacitor and its functions in simple circuits.

Learning outcomes

Candidates should be able to:

18.1 Capacitors and capacitance

- a) define capacitance and the farad, as applied to both isolated conductors and to parallel plate capacitors
- b) recall and use $C = \frac{Q}{V}$
- c) derive, using the formula $C = \frac{Q}{V}$, conservation of charge and the addition of potential differences, formulae for combined capacitance for capacitors in series and in parallel
- d) solve problems using the capacitance formulae for capacitors in series and in parallel

18.2 Energy stored in a capacitor

- a) deduce, from the area under a potential-charge graph, the equation $W = \frac{1}{2}QV$ and hence $W = \frac{1}{2}CV^2$
 - b) show an understanding of the functions of capacitors in simple circuits
-

19 Current of electricity

Electric current, potential difference, resistance and power in electrical circuits are introduced. The concept of resistivity is included.

Some electrical components may be used to sense environmental changes. Some such devices are introduced so that they may be studied, in Topics 20 and 21, in circuits.

Learning outcomes

Candidates should be able to:

19.1 Electric current	<ul style="list-style-type: none"> a) understand that electric current is a flow of charge carriers b) understand that the charge on charge carriers is quantised c) define the coulomb d) recall and use $Q = It$ e) derive and use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers
19.2 Potential difference and power	<ul style="list-style-type: none"> a) define potential difference and the volt b) recall and use $V = \frac{W}{Q}$ c) recall and use $P = VI$ and $P = I^2R$
19.3 Resistance and resistivity	<ul style="list-style-type: none"> a) define resistance and the ohm b) recall and use $V = IR$ c) sketch and discuss the I–V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp d) state Ohm's law e) recall and use $R = \frac{\rho L}{A}$
19.4 Sensing devices	<ul style="list-style-type: none"> a) show an understanding of the change in resistance with light intensity of a light-dependent resistor (LDR) b) sketch the temperature characteristic of a negative temperature coefficient thermistor c) show an understanding of the action of a piezo-electric transducer and its application in a simple microphone d) describe the structure of a metal-wire strain gauge e) relate extension of a strain gauge to change in resistance of the gauge

20 D.C. circuits

In this topic, practical circuits are considered. Circuit diagrams are studied with particular reference to Kirchhoff's laws and the consequences of internal resistance.

The use of potential divider circuits for monitoring environmental conditions is studied.

Learning outcomes

Candidates should be able to:

- | | |
|-------------------------|--|
| 20.1 Practical circuits | <ul style="list-style-type: none"> a) recall and use appropriate circuit symbols as set out in the ASE publication <i>Signs, Symbols and Systematics</i> (example circuit symbols are given in Section 5.5.) 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) define electromotive force (e.m.f.) in terms of the energy transferred by a source in driving unit charge round a complete circuit d) distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations e) understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference |
| 20.2 Kirchhoff's laws | <ul style="list-style-type: none"> a) recall Kirchhoff's first law and appreciate the link to conservation of charge b) recall Kirchhoff's second law and appreciate the link to conservation of energy c) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series d) solve problems using the formula for the combined resistance of two or more resistors in series e) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel f) solve problems using the formula for the combined resistance of two or more resistors in parallel g) apply Kirchhoff's laws to solve simple circuit problems |
| 20.3 Potential dividers | <ul style="list-style-type: none"> a) understand the principle of a potential divider circuit as a source of variable p.d. b) recall and solve problems using the principle of the potentiometer as a means of comparing potential differences c) understand that an electronic sensor consists of a sensing device and a circuit that provides an output that can be registered as a voltage d) explain the use of thermistors, light-dependent resistors and strain gauges in potential dividers to provide a potential difference that is dependent on temperature, illumination and strain respectively |

21 Electronics

An introduction to electronics is provided in this topic through the study of amplifier circuits incorporating an ideal operational amplifier. In particular, emphasis is placed on sensing circuits for changes in environmental conditions.

The use of feedback to control gain is considered together with some output devices.

Learning outcomes

Candidates should be able to:

21.1 The ideal operational amplifier

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

21.2 Operational amplifier circuits

- a) deduce, from the properties of an ideal operational amplifier, the use of an operational amplifier as a comparator
- b) understand the effects of negative feedback on the gain of an operational amplifier
- c) recall the circuit diagrams for both the inverting and the non-inverting amplifier for single signal input
- d) understand the virtual earth approximation and derive an expression for the gain of inverting amplifiers
- e) recall and use expressions for the voltage gain of inverting and of non-inverting amplifiers

21.3 Output devices

- a) understand that an output device may be required to monitor the output of an op-amp circuit
 - b) understand the use of relays in electronic circuits
 - c) understand the use of light-emitting diodes (LEDs) as devices to indicate the state of the output of electronic circuits
 - d) understand the need for calibration where digital or analogue meters are used as output devices
-

22 Magnetic fields

The concept of a magnetic field is developed by studying the force on current-carrying conductors and on charged particles in magnetic fields.

The Hall effect and nuclear magnetic resonance imaging are studied as examples of the use of magnetic fields.

Learning outcomes

Candidates should be able to:

22.1 Concept of magnetic field

- a) understand 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

22.2 Force on a current-carrying conductor

- a) appreciate 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) understand how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance

22.3 Force on a moving charge

- a) predict the direction of the force on a charge moving in a magnetic field
- b) recall and solve problems using $F = BQv \sin \theta$
- c) derive the expression $V_H = \frac{BI}{ntq}$ for the Hall voltage, where t = thickness
- d) describe and analyse qualitatively the deflection of beams of charged particles by uniform electric and uniform magnetic fields
- e) explain how electric and magnetic fields can be used in velocity selection
- f) explain the main principles of one method for the determination of v and $\frac{e}{m_e}$ for electrons

22.4 Magnetic fields due to currents

- a) sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid
- b) understand that the field due to a solenoid is influenced by the presence of a ferrous core
- c) explain the forces between current-carrying conductors and predict the direction of the forces
- d) describe and compare the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate

-
- | | |
|--|--|
| 22.5 Nuclear magnetic resonance imaging | <ul style="list-style-type: none">a) explain the main principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain diagnostic information about internal structuresb) understand the function of the non-uniform magnetic field, superimposed on the large constant magnetic field, in diagnosis using NMRI |
|--|--|
-

23 Electromagnetic induction

Electromagnetic induction provides the basis of an important means of generating electrical power. In this topic, the laws of electromagnetic induction are developed.

Learning outcomes

Candidates should be able to:

23.1 Laws of electromagnetic induction

- a) define magnetic flux and the weber
 - b) recall and use $\Phi = BA$
 - 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

In many countries, electrical energy is supplied in the form of an alternating voltage supply. The basic terms used to describe alternating currents are introduced.

Transformers are studied, together their use in the transmission of electrical energy. Rectification and smoothing are also included.

Learning outcomes

Candidates should be able to:

24.1 Characteristics of alternating currents

- understand and use the terms period, frequency, peak value and root-mean-square value as applied to an alternating current or voltage
- deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current
- represent a sinusoidally alternating current or voltage by an equation of the form $x = x_0 \sin \omega t$
- distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{\text{r.m.s.}} = \frac{I_0}{\sqrt{2}}$ for the sinusoidal case

24.2 The transformer

- understand the principle of operation of a simple laminated iron-cored transformer and recall and solve problems using $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$ for an ideal transformer
- understand the sources of energy loss in a practical transformer

24.3 Transmission of electrical energy

- appreciate the practical and economic advantages of alternating current and of high voltages for the transmission of electrical energy

24.4 Rectification

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

25 Quantum physics

Quantum physics is the name given to studies involving an appreciation that some quantities are found only in discrete amounts.

The concept of a photon is established through a study of the photoelectric effect. Discrete energy levels in atoms can then be understood through line emission and absorption spectra. These ideas can then be extended to include band theory. Wave-particle duality and electron diffraction are also introduced.

An understanding of the production of X-rays involves the concept of photons. Examples of applications of X-rays are studied, including X-ray imaging and CT scanning.

Learning outcomes

Candidates should be able to:

25.1 Energy of a photon	a) appreciate the particulate nature of electromagnetic radiation b) recall and use $E = hf$
25.2 Photoelectric emission of electrons	a) understand that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature b) recall the significance of threshold frequency c) explain photoelectric phenomena in terms of photon energy and work function energy d) explain why the maximum photoelectric energy is independent of intensity, whereas the photoelectric current is proportional to intensity e) recall, use and explain the significance of $hf = \phi + \frac{1}{2}mv_{\max}^2$
25.3 Wave-particle duality	a) describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles b) recall and use the relation for the de Broglie wavelength $\lambda = \frac{h}{p}$
25.4 Energy levels in atoms and line spectra	a) 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 b) distinguish between emission and absorption line spectra c) recall and solve problems using the relation $hf = E_1 - E_2$

25.5 Band theory

- a) appreciate that, in a simple model of band theory, there are energy bands in solids
- b) understand the terms valence band, conduction band and forbidden band (band gap)
- c) use simple band theory to explain the temperature dependence of the resistance of metals and of intrinsic semiconductors
- d) use simple band theory to explain the dependence on light intensity of the resistance of an LDR

25.6 Production and use of X-rays

- a) explain the principles of the production of X-rays by electron bombardment of a metal target
 - b) describe the main features of a modern X-ray tube, including control of the intensity and hardness of the X-ray beam
 - c) understand 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
 - d) recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter
 - e) understand the purpose of computed tomography or CT scanning
 - f) understand the principles of CT scanning
 - g) understand how the image of an 8-voxel cube can be developed using CT scanning
-

26 Particle and nuclear physics

Alpha-particle scattering is studied as evidence for the structure of the atom.

Nuclear composition, in terms of nucleons, leads to an appreciation of mass defect and binding energy.

Nuclear processes including radioactive decay, fission and fusion are studied.

An introduction to fundamental particles is included.

Learning outcomes

Candidates should be able to:

26.1 Atoms, nuclei and radiation

- infer from the results of the α -particle scattering experiment the existence and small size of the nucleus
- describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons
- distinguish between nucleon number and proton number
- understand that an element can exist in various isotopic forms, each with a different number of neutrons
- use the usual notation for the representation of nuclides
- appreciate that nucleon number, proton number, and mass-energy are all conserved in nuclear processes
- show an understanding of the nature and properties of α -, β - and γ -radiations (both β^- and β^+ are included)
- state that (electron) antineutrinos and (electron) neutrinos are produced during β^- and β^+ decay

26.2 Fundamental particles

- appreciate that protons and neutrons are not fundamental particles since they consist of quarks
- describe a simple quark model of hadrons in terms of up, down and strange quarks and their respective antiquarks
- describe protons and neutrons in terms of a simple quark model
- appreciate that there is a weak interaction between quarks, giving rise to β decay
- describe β^- and β^+ decay in terms of a simple quark model
- appreciate that electrons and neutrinos are leptons

26.3 Mass defect and nuclear binding energy

- show an appreciation of the association between energy and mass as represented by $E = mc^2$ and recall and use this relationship**
- understand the significance of the terms mass defect and mass excess in nuclear reactions**
- represent simple nuclear reactions by nuclear equations of the form ${}^{14}_7\text{N} + {}^4_2\text{He} \rightarrow {}^{17}_8\text{O} + {}^1_1\text{H}$**
- define and understand the terms mass defect and binding energy**
- sketch the variation of binding energy per nucleon with nucleon number**
- explain what is meant by nuclear fusion and nuclear fission**
- explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission**

-
- 26.4 Radioactive decay**
- a) infer the random nature of radioactive decay from the fluctuations in count rate
 - b) show an appreciation of the spontaneous and random nature of nuclear decay
 - c) define the terms activity and decay constant and recall and solve problems using $A = \lambda N$
 - d) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_0 e^{-\lambda t}$, where x could represent activity, number of undecayed nuclei or received count rate
 - e) define half-life
 - f) solve problems using the relation $\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
-

4 Practical assessment

4.1 Introduction

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

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

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

Candidates' experimental skills will be assessed in Paper 3 and Paper 5. In each of these papers, the questions may be based on physics not included in the syllabus content, but candidates will be assessed on their practical skills rather than their knowledge of theory. Where appropriate, candidates will be told exactly what to do and how to do it.

4.2 Paper 3

In some examination series, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. In other series, only Advanced Practical Skills 1 will be available. 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 Centres 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 Centres may wish to enter all of their candidates for the same paper. Each of these papers will be timetabled on a different day.

Paper 3 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 conclusions.

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

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

4.2.1 Mark scheme for Paper 3

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	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Manipulation, measurement and observation	7 marks	Successful collection of data	5 marks
		Range and distribution of values	1 mark
		Quality of data	1 mark
Presentation of data and observations	6 marks	Table of results	1 mark
		Recording of data, observations and calculations	2 marks
		Graph	3 marks
Analysis, conclusions and evaluation	4 marks	Interpretation of graph	2 marks
		Drawing conclusions	2 marks

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

Question 2			
Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Manipulation, measurement and observation	5 marks	Successful collection of data	4 marks
		Quality of data	1 mark
Presentation of data and observations	2 marks	Recording of data, observations and calculations	2 marks
Analysis, conclusions and evaluation	10 marks	Drawing conclusions	1 mark
		Estimating uncertainties	1 mark
		Identifying limitations	4 marks
		Suggesting improvements	4 marks

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

4.2.2 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, top-pan balances, newton-meters, analogue or digital electrical meters, measuring cylinders, calipers*, micrometer screw gauges and thermometers
- use a stopwatch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations
- use both analogue scales and digital displays.

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

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

Candidates should be able to:

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

As an example of accepted 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)' or 'current / mA' would be allowed. Headings such as ' I mA' or just 'mA' are not acceptable. The quantity or the unit or both may be written in words rather than symbols. Conventional symbols or abbreviations (such as p.d.) may be used without explanation.

Recording of data, observations and calculations

Candidates should be able to:

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

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

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.

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.

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.

Analysis, conclusions and evaluation

Interpretation of graph

Candidates should be able to:

- relate straight-line graphs to equations of the form $y = mx + c$, and derive expressions that equate to the gradient and/or the y-intercept of their graphs
- read the 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
- determine the uncertainty in a final result
- express the uncertainty in a measurement as an absolute, fractional or percentage uncertainty, and translate between these forms
- express the uncertainty in a repeated measurement as half the range of the repeated readings.

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 in a school laboratory. 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. Improvements that could have been made with the apparatus provided while following the instructions in the question will not normally gain credit.

4.2.3 Administration of Paper 3

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

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

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

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 describe information required by the Examiners. This will include a set of numerical results for the experiments, which the Supervisor should obtain out of sight of the candidates. A Supervisor's Report is included in the Confidential Instructions. Centres must complete this and enclose a copy in each envelope of scripts. If any assistance is given to candidates, the Supervisor's Report must include full details of this assistance. The marking process may be delayed and candidates may be disadvantaged if the Supervisor's Report or sample results are missing or do not contain the information required.

If there is any doubt about the interpretation of the Confidential Instructions or the suitability of the apparatus available, enquiries should be sent to Cambridge, using either email (info@cie.org.uk) or fax (+44 1223 553558) or telephone (+44 1223 553554).

4.2.4 Apparatus that is used regularly

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

Cells: 1.5V

Connecting leads and crocodile clips

Digital ammeter, minimum ranges 0–1 A reading to 0.01 A or better, 0–200 mA reading to 0.1 mA or better, 0–20 mA reading to 0.01 mA or better (digital multimeters are suitable)

Digital voltmeter, minimum ranges 0–2 V reading to 0.001 V or better, 0–20 V reading to 0.01 V or better (digital multimeters are suitable)

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

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

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

Switch

Wire: constantan 26, 28, 30, 32, 34, 36, 38 swg or similar metric sizes

Long stem thermometer: -10°C to $110^{\circ}\text{C} \times 1^{\circ}\text{C}$

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

Plastic or polystyrene cup 200 cm^3

Stirrer

Adhesive putty (e.g. Blu-Tack)

Adhesive tape (e.g. Sellotape)

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

Bar magnet

Bare copper wire: 18, 20, 26 swg or similar metric sizes

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

Card

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

G-clamp

Magnadur ceramic magnets

Mass hanger

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

Modelling clay (e.g. Plasticine)

Newton-meter (1 N, 10 N)

Pendulum bob

Protractor

Pulley

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

Scissors

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

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 or digital calipers (this item may often be shared between sets of apparatus)
Wire cutters

4.2.5 Safety in the laboratory

Responsibility for safety matters rests with Centres. Attention is drawn to the following UK associations, publications and regulations.

Associations

CLEAPSS is an advisory service providing support in practical science and technology.
www.cleapss.org.uk

The Association for Science Education promotes excellence in science teaching and learning.
www.ase.org.uk

Publications

Safeguards in the School Laboratory, ASE, 11th edition, 2006
Topics in Safety, ASE, 3rd edition, 2001
CLEAPSS Laboratory Handbook, updated annually (available to CLEAPSS members only)

UK Regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002
www.legislation.gov.uk/ukxi/2002/2677/contents/made

A brief guide may be found at:
www.hse.gov.uk/pubns/indg136.pdf

4.3 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 will not require laboratory facilities.

It should be stressed that learners cannot be adequately prepared for this paper without extensive laboratory work during their course of study. Teachers must plan a practical course where the skills required for this paper are developed and practised over a period of time with a ‘hands on’ approach.

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

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

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

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

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 will be structured but candidates will be expected to decide for themselves what they need to do in order to reach an answer. They will also be required to estimate the uncertainty in their answer.

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

4.3.1 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	Mark allocation	Breakdown of skills	Mark allocation
Planning	15 marks	Defining the problem	2 marks
		Methods of data collection	4 marks
		Method of analysis	3 marks
		Additional detail including safety considerations*	6 marks

*The 6 marks for additional detail will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Question 2			
Skill	Mark allocation	Breakdown of skills	Minimum mark allocation*
Analysis, conclusions and evaluation	15 marks	Data analysis	1 mark
		Table of results	1 mark
		Graph	2 marks
		Conclusion	3 marks
		Treatment of uncertainties	3 marks

*The remaining 5 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

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

Method of analysis

Candidates should be able to:

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

Additional detail including safety considerations

Up to six marks will be available for additional relevant detail including safety precautions.

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

For safety considerations, candidates should be able to:

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

Marks may also be awarded for detailed use of apparatus.

Candidates should be able to:

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

Analysis, conclusions and evaluation

Data analysis

Candidates should be able to:

- rearrange expressions into the forms $y = mx + c$, $y = ax^n$ and $y = ae^{kx}$
- 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
- calculate other quantities from their raw data
- use the correct number of significant figures for these calculated quantities following the conventions required for Paper 3.

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

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

Table of results

Candidates should be able to:

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

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 when the trend on the graph is linear
- draw a curved trend line and a tangent to the curve where appropriate.

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 or tangent to a curve
- 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.

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.

5 General syllabus requirements and information

5.1 Mathematical requirements

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

Arithmetic

Candidates should be able to:

- recognise and use expressions in decimal and standard form (scientific) notation
- **recognise and use binary notation**
- use an electronic calculator 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 required.
- substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations
- set up simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models
- **recognise and use the logarithms of expressions like ab , $\frac{a}{b}$, 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
- understand and use the symbols $<$, $>$, \leq , \geq , \ll , \gg , \approx , $/$, \propto , $\langle x \rangle$ ($= \bar{x}$), Σ , Δx , δx , $\sqrt{\quad}$

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 cuboids, cylinders and spheres
- use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle
- use sines, cosines and tangents of angles (especially for 0° , 30° , 45° , 60° , 90°)
- **use the trigonometric relationships for triangles:**

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

$$a^2 = b^2 + c^2 - 2bc \cos A$$

- **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, convert 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
- determine the gradient, intercept and intersection of linear graphs
- choose, by inspection, a straight line which will serve as the line of best fit through a set of data points presented graphically
- draw a curved trend line through a set of data points presented graphically, when the arrangement of these data points is clearly indicative of a non-linear relationship
- 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 $\frac{1}{x}$, x^2 , $\frac{1}{x^2}$, $\sin x$, $\cos x$, e^{-x}
- **use logarithmic plots to test exponential and power law variations**
- draw a tangent to a curve, and understand and use the gradient of the tangent as a means to obtain the gradient of the curve at a point
- understand and use the area below a curve where the area has physical significance.

5.2 Summary of key quantities, symbols and units

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

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

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

Other quantities		
acceleration	a	m s^{-2}
acceleration of free fall	g	m s^{-2}
activity of radioactive source	A	Bq
amplitude	x_0	m
angle	θ	$^\circ$, rad
angular displacement	θ	$^\circ$, rad
angular frequency	ω	rad s^{-1}
angular speed	ω	rad s^{-1}
angular velocity	ω	rad s^{-1}
area	A	m^2
atomic mass	m_a	kg, u
attenuation/absorption coefficient	μ	m^{-1}
Avogadro constant	N_A	mol^{-1}
Boltzmann constant	k	J K^{-1}
capacitance	C	F
Celsius temperature	θ	$^\circ\text{C}$
decay constant	λ	s^{-1}
density	ρ	kg m^{-3}
displacement	s, x	m
distance	d	m
efficiency	η	
electric charge	q, Q	C

Quantity	Usual symbols	Usual unit
electric field strength	E	$\text{NC}^{-1}, \text{Vm}^{-1}$
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
electron mass	m_e	kg, u
elementary charge	e	C
energy	E, U, W	J
force	F	N
frequency	f	Hz
gravitational constant	G	$\text{Nm}^2 \text{kg}^{-2}$
gravitational field strength	g	N kg^{-1}
gravitational potential	ϕ	J kg^{-1}
half-life	$t_{\frac{1}{2}}$	s
Hall voltage	V_H	V
heating	q, Q	J
intensity	I	Wm^{-2}
internal energy change	ΔU	J
kinetic energy	E_k	J
magnetic flux	Φ	Wb
magnetic flux density	B	T
mean-square speed	$\langle c^2 \rangle$	$\text{m}^2 \text{s}^{-2}$
molar gas constant	R	$\text{J mol}^{-1} \text{K}^{-1}$
molar mass	M	kg mol^{-1}
moment of force	T	Nm
momentum	p	Ns
neutron mass	m_n	kg, u
neutron number	N	
nucleon number	A	
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
period	T	s
permeability of free space	μ_0	H m^{-1}
permittivity of free space	ϵ_0	F m^{-1}
phase difference	ϕ	$^\circ, \text{rad}$
Planck constant	h	J s
potential energy	E_p	J

Quantity	Usual symbols	Usual unit
power	P	W
pressure	p	Pa
proton mass	m_p	kg, u
proton number	Z	
ratio of powers		dB
relative atomic mass	A_r	
relative molecular mass	M_r	
resistance	R	Ω
resistivity	ρ	$\Omega \text{ m}$
specific acoustic impedance	Z	$\text{kg m}^{-2} \text{ s}^{-1}$
specific heat capacity	c	$\text{J kg}^{-1} \text{ K}^{-1}$
specific latent heat	L	J kg^{-1}
speed	u, v, w, c	m s^{-1}
speed of electromagnetic waves	c	m s^{-1}
spring constant	k	N m^{-1}
strain	ε	
stress	σ	Pa
torque	T	N m
velocity	u, v, w, c	m s^{-1}
volume	V, v	m^3
wavelength	λ	m
weight	W	N
work	w, W	J
work function energy	Φ	J
Young modulus	E	Pa

5.3 Glossary of command words

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 imply either 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.

5.4 Data and formulae

The following data and formulae will appear as pages 2 and 3 in Papers 1, 2 and 4.

Data

speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$

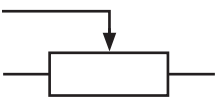

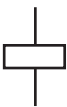


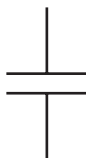

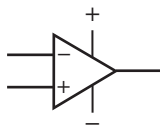
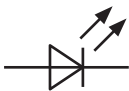
Formulae

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	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho gh$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
energy of charged capacitor	$W = \frac{1}{2} QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

5.5 Circuit symbols

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

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

potentiometer		oscilloscope	
relay coil		antenna	
transformer		capacitor	
diode		operational amplifier	
light-emitting diode			

6 Other information

Equality and inclusion

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

The standard assessment arrangements may present unnecessary barriers for candidates with disabilities or learning difficulties. Arrangements can be put in place for these candidates to enable them to access the assessments and receive recognition of their attainment. Access arrangements will not be agreed if they give candidates an unfair advantage over others or if they compromise the standards being assessed. Candidates who are unable to access the assessment of any component may be eligible to receive an award based on the parts of the assessment they have taken.

Information on access arrangements is found in the *Cambridge Handbook*, which can be downloaded from the website www.cie.org.uk/examsOfficers

Language

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

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, A* being the highest and E the lowest. 'Ungraded' indicates that the candidate's performance fell short of the standard required for grade E. 'Ungraded' will be reported on the statement of results but not on the certificate. The letters Q (result pending), X (no result) and Y (to be issued) may also appear on the statement of results but not on the certificate.

Cambridge International AS Level results are shown by one of the grades a, b, c, d or e, indicating the standard achieved, 'a' being the highest and 'e' the lowest. 'Ungraded' indicates that the candidate's performance fell short of the standard required for grade 'e'. 'Ungraded' will be reported on the statement of results but not on the certificate. The letters Q (result pending), X (no result) and Y (to be issued) may also appear 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.

Entry option codes

To maintain the security of our examinations, we produce question papers for different areas of the world, known as ‘administrative zones’. Where the entry option code has two digits, the first digit is the component number given in the syllabus. The second digit is the location code, specific to an administrative zone.

Entry option codes and instructions for making entries can be found in the *Cambridge Guide to Making Entries*. Other exams administration documents, including timetables and administrative instructions, can be found at www.cie.org.uk/examsofficers

Cambridge International Examinations
1 Hills Road, Cambridge, CB1 2EU, United Kingdom
Tel: +44 (0)1223 553554 Fax: +44 (0)1223 553558
Email: info@cie.org.uk www.cie.org.uk

® IGCSE is the registered trademark of Cambridge International Examinations.

© Cambridge International Examinations September 2016

