AS/A Level GCE

GCE Physics B (Advancing Physics)

OCR Advanced Subsidiary GCE in Physics B (Advancing Physics) H159

OCR Advanced GCE in Physics B (Advancing Physics) H559

version 4 – September 2013

specification

QAN 500/2257/X
QAN 500/2205/2

Vertical black lines indicate a significant change to the previous version.

1 About these Qualifications

This booklet contains OCR's Advanced Subsidiary GCE and Advanced GCE specifications in Physics B (Advancing Physics) for teaching from September 2013.

Advancing Physics is an innovative AS GCE and Advanced GCE course, reflecting physics as it is practised and used today.

The AS course provides a satisfying experience for the candidate who chooses to take AS GCE Physics as part of a broad post-16 curriculum. At the end of the course candidates should know more of what physics is about and its place in the world. At the same time the AS course provides a sound foundation for the candidate who chooses to go on to the second year and to take the Advanced GCE award.

The A2 course leads to an Advanced GCE qualification which enables candidates to go on to degree level studies at university, particularly physics or engineering; at the same time it provides an interesting and stimulating experience for the candidate who does not pursue the subject further. The course appeals to, and provides for, all candidates, whether they anticipate achieving a grade E or a grade A.

For each year of the course there is a Students' Book and CD-ROM and for the teacher an enhanced CD-ROM, all published by Institute of Physics Publishing. The Advancing Physics website, http://advancingphysics.iop.org/, maintained by the Institute of Physics, provides up to date material to support candidates and teachers and a way for teachers to share their ideas. More information about all these resources can be found on the website.

The Advancing Physics course provides a distinctive structure within which candidates learn both about fundamental physical concepts and about physics in everyday and technological settings. It shows the usefulness of the subject and illustrates the impact that discoveries in physics have had on the way people live.

Key features of the course are:

- new material – a simple, direct and rigorous approach to modern ideas;
- new perspectives – different angles on familiar topics;
- encouragement for teachers and candidates to select topics of interest for further individual study;
- assessment methods which reflect and reward the teaching and learning styles encouraged by the course;
- extensive support materials for both teachers and candidates, including appropriate software, providing a variety of learning activities.

In Advancing Physics there are opportunities for candidates to:

- develop practical skills (for example, in choosing and using materials and equipment);
- practise data-handling skills (for example, estimating, presenting and analysing data);
- use their imagination (for example, suggesting an explanation);
- place physics in a social or historical context and argue about the issues that arise;
- be rewarded for initiative and interest in learning – for finding out for themselves;
- use information and communication technology as an integral part of learning physics.

Physics and mathematics go together naturally and inevitably. Three main kinds of mathematical activity crucial to physics are identified: 'getting out numbers'; analysis and presentation of data, and making models. The course treats mathematics as an integral part of doing physics; as an integral part of the pleasure of physics. The course is very positive about mathematics, stressing and demonstrating its value in physics: its power, its beauty and how it aids the imagination. To this end the teaching of some mathematics is incorporated within the context of the physics for which it is required. In this way, essential mathematical content is learnt and used in interesting contexts.

A range of assessment methods are used. Some aims of the course can best be assessed by written examinations and others through coursework. This variety is essential if the assessment is to reflect the wide variety of learning activities, which is a feature of the course.

In the AS course, candidates develop their ability to learn independently, and to develop their experimental and investigational skills and their research and communication skills. For the coursework assessment, candidates carry out two short tasks.

In the A2 half of the Advanced GCE course, the coursework consists of two more substantial pieces of work, recognising the more developed skills and maturity of students by this stage.

1.1 The Three-Unit AS

The Advanced Subsidiary GCE is both a ‘stand-alone’ qualification and also the first half of the corresponding Advanced GCE. The AS GCE is assessed at a standard appropriate for candidates who have completed the first year of study (both in terms of teaching time and content) of the corresponding two-year Advanced GCE course, ie between GCSE and Advanced GCE.

From September 2013 the AS GCE is made up of **three** mandatory units, of which **two** are externally assessed and **one** is internally assessed and will include the assessment of practical skills. These units form 50% of the corresponding six-unit Advanced GCE.

1.2 The Six-Unit Advanced GCE

From September 2013 the Advanced GCE is made up of **three** mandatory units at AS and **three** further mandatory units at A2.

Two of the AS and **two** of the A2 units are externally assessed.

The third AS unit and the third A2 unit are internally assessed and will include the assessment of practical skills.

1.3 Qualification Titles and Levels

These qualifications are shown on a certificate as:

- OCR Advanced Subsidiary GCE in Physics.
- OCR Advanced GCE in Physics.

Both qualifications are Level 3 in the National Qualification Framework (NQF).

1.4 Aims

The aims of these specifications are to encourage candidates to:

- develop and demonstrate a deeper appreciation of the skills, knowledge and understanding of *How Science Works*;
- develop their knowledge and understanding of physics and an appreciation of the link between theory and experiment;
- appreciate how physics has developed and is used in present day society, acknowledging the importance of physics as a human endeavour which has historical, social, philosophical, economic and technological connections;
- sustain and develop their enjoyment of, and interest in, physics;
- recognise the quantitative nature of physics and understand how mathematical expressions relate to physical principles. In the Advanced GCE course they should appreciate how scientific models are developed and the power they can have to help understanding;
- appreciate how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society;
- bring together knowledge to illustrate ways in which different areas of physics relate to each other.

The course should provide for candidates' futures by:

- developing their ability to learn independently;
- opening new horizons, giving them visions of a variety of possible careers and interests;
- providing a variety of activities to help them understand their own strengths and the possibilities for their future;
- providing opportunities for students to acquire and demonstrate competence in the Key Skills.

The course should develop candidates' interests by:

- stimulating their curiosity;
- providing depth and challenge;
- providing manageable choice;
- being up to date and connected to the life of the candidate.

The course should be made enjoyable by:

- using a wide range of teaching and learning styles;
- providing opportunities for students to explore their interests;
- giving candidates ownership of their learning.

The course must meet the expectations of:

- the candidate who is looking for interest, enjoyment and a worthwhile qualification;
- the teacher who is looking for a varied stimulating course with room for initiative and professional involvement;
- employers and higher education who expect qualified candidates to have certain skills and knowledge.

The course develops a culture of success through:

- being accessible to students from a range of backgrounds;
- providing opportunities for positive achievement;
- having an assessment model which is accessible and provides profitable experiences, while being discriminating, reliable and valid.

The course should tell of the values and virtues of physics, while never suggesting that it can cure all ills and answer all problems.

Not all of the above aims can, or should be, assessed although they do form an important part of both the AS and A2 courses. The knowledge, skills and understanding that candidates are required to demonstrate are set out in more detail in the assessment objectives in Section 4.7.

1.5 Prior Learning/Attainment

These specifications have been developed for students who wish to continue with a study of physics at Level 3 in the National Qualifications Framework (NQF). The AS specification has been written to provide progression from GCSE Science and GCSE Additional Science, or from GCSE Physics; achievement at a minimum of grade C in these qualifications should be seen as the normal requisite for entry to AS Physics. However, students who have successfully taken other Level 2 qualifications in Science or Applied Science with appropriate physics content may also have acquired sufficient knowledge and understanding to begin the AS physics course. Other students without formal qualifications may have acquired sufficient knowledge of physics to enable progression onto the course.

Recommended prior learning for the AS units is shown in the introduction to each AS unit. The A2 units build upon the knowledge and understanding acquired at AS.

Recommended prior learning for the A2 course is successful performance at AS Physics.

2 Summary of Content

2.1 AS Units

Unit G491: *Physics in Action*

- Communication
- Designer materials

Unit G492: *Understanding Processes and Experimentation and Data Handling*

- Waves and quantum behaviour
- Space, time and motion

Unit G493: *Physics in Practice*

- Quality of measurement
- Physics in use

2.2 A2 Units

Unit G494: *Rise and Fall of the Clockwork Universe*

- Models and rules
- Matter in extremes

Unit G495: *Field and Particle Pictures*

- Fields
- Fundamental particles

Unit G496: *Researching Physics*

- Practical investigation
- Research briefing

3 Unit Content

These specifications are set out in the form of teaching modules. Each teaching module is assessed within its associated unit of assessment.

Candidates should demonstrate:

(a) *Knowledge and understanding of phenomena, concepts and relationships by describing and explaining...*

There is within the course a core body of knowledge of phenomena, ideas and relationships. Candidates should be able to describe these phenomena, including how important types of observation and measurement may be made, and explain them in terms of appropriate ideas and relationships. They should be able to offer their own examples of phenomena illustrating the physical ideas and relationships. They should be able to show that certain relationships can be derived from others. They should be able to use the essential ideas in new contexts. They should be able to give, explain and justify examples of important ideas.

Within these specifications, learning outcomes which use the expression *Describe and explain...* indicate phenomena that candidates are expected to know and for which they should be able to give a simple theoretical account, including, where appropriate, showing how relationships can be derived from others. *Describe...* used alone indicates phenomena for which explanation is not required.

(b) *Scientific communication and comprehension of the language and representations of physics by making appropriate use of the terms and by sketching and interpreting graphs and diagrams*

Candidates need to be able to understand and use the language of physics, including graphs and diagrams as well as terminology.

Where the learning outcomes use the expression *Make appropriate use of the terms...* candidates should understand the terms listed when they read them and use them correctly in writing. They should be able to interpret graphs and diagrams and use sketch graphs and diagrams to help in their explanations of ideas. In presentations of data, candidates should be able to distinguish where a relationship has a plausible causal foundation from one in which the data merely reveals correlation.

Candidates will develop those communication skills which are specific to science, and in particular to physics: the ability to combine mathematics and coherent prose, with appropriate graphical and diagrammatic illustrations, to support or develop analysis and explanation of physical phenomena and their mathematical models, with due reference to issues of section (e) below where they apply. They should be able to obtain, select and evaluate scientific information and issues, and to select appropriate methods for presenting them effectively, with use of ICT where appropriate.

(c) *Quantitative and mathematical skills, knowledge and understanding by making calculations and estimates ... and by showing graphically*

Within these specifications learning outcomes which use the expression *Make calculations and estimates...* outline the ideas for which calculations or manipulation of equations may be required. Candidates may be asked to make sensible estimates of quantities and then show some calculation. Sometimes it is more appropriate to describe a relationship graphically. Candidates should be able to use diagrams to support their thinking when that is helpful.

Equations are available on the formula and data sheet: *Data, Formulae and Relationships* (See Appendix B).

(d) *Experimental and data handling skills*

In experimental work, candidates should choose and use appropriate materials and equipment, recognise the limitations of instruments, recognise and quantify the uncertainty of measurements, identify and make attempts to reduce important sources of uncertainty and identify and make attempts to remove possible systematic errors.

Candidates will need to practise the data-handling skills of estimating, presenting and analysing data, and to develop and practise these practical skills in a variety of new experimental contexts. In the AS course, this will culminate in the coursework component *Quality of Measurement* ,and in the A2 course these skills will further develop into the *Practical Investigation*, where students have to choose and deploy the skills for themselves. These skills will also be assessed in written examinations, with a particular emphasis in Section C of G492 (Understanding Processes).

(e) *Growth and use of scientific knowledge*

Candidates will need to identify the ways in which particular scientific discoveries, such as observations or theoretical models, become established or refuted in terms of the insights of individuals, the prior knowledge upon which those discoveries are founded and the role of the wider scientific community in confirming and accepting, or refuting and disqualifying, those new discoveries.

Candidates should be able to identify and assess the associated benefits and risks of practical applications of physics. Where ethical issues arise concerning the treatment of humans, other organisms and the environment candidates should be able to identify the issues involved and the different views that may be held on them, and suggest reasons for differences of opinion on those issues. These skills will also be assessed in written examinations.

Italicised phrases in statements within sections 3.1–3.6 are intended to clarify the scope of the topic for the teacher and candidate. Their function is normally to limit the scope.

The Assessment Objectives AO1, AO2 and AO3 in Section 4 refer extensively to How Science Works. The skills, knowledge and understanding of How Science Works detailed in the QCA AS and A Level criteria for science subjects are listed in Appendix F, which also shows how these are incorporated in the types of learning outcomes listed above.

AS Units

In the AS course, units G491 and G492 are each set out in two parts. Internally assessed coursework (Unit G493: Physics in Practice) builds on practical measurement concepts and skills developed during these two units, and also develops the skills of research and presentation of a topic chosen by the student.

Physics in Action (Unit G491) provides a graduated path from GCSE into the AS course, showing a wide variety of ways in which physics is currently put to use:

- **communication** is about electric circuits and sensors, waves as signals and about imaging, including some simple optics;

- **designer materials** introduces properties of materials, how these depend on the structure of the material and how they help determine the choice of material for a given purpose.

During this unit, uncertainties and systematic errors of measurement are introduced, and a first approach to methods of making better measurements is met.

Understanding Processes, Experimentation and Data Handling (Unit G492) is organised around different ways of understanding processes of change, the focus being on ‘curiosity-driven’ physics:

- **waves and quantum behaviour** is mainly about superposition phenomena of waves, especially electromagnetic waves, with a brief account of the quantum behaviour of photons and electrons;

- **space, time and motion** develops classical mechanics, including vectors.

During this unit, the earlier work on uncertainties and systematic errors of measurement, and methods of making better measurements, are further developed.

3.1 AS Unit G491: *Physics in Action*

This initial teaching unit is intended to:

- connect with candidates' interests and develop them further;
- provide a graduated path from GCSE work into A Level work;
- offer a satisfying and broad variety of kinds of experience and knowledge;
- show a wide variety of ways in which physics is currently put to use;
- develop skills and habits of independent working, and individual practical confidence and competence;
- offer up-to-date but accessible ideas and methods in physics.

The main focus in this unit is on varieties of physics in action, preparing the way for more theoretical 'curiosity driven' material in Unit G492. This is not to say that fundamental ideas are neglected: important ideas about information are approached through imaging and signalling; basic concepts of measurement are approached through sensors, in which work the fundamental concepts of electrical circuits are encountered; the crucial problems of relating macroscopic and microscopic views of the world are approached through the study of modern materials. Fundamental understandings of the world have a place too: for example, the existence of atoms, information from astronomical images, basic structures of matter, the fact that matter is made of charged particles.

The choice of examples of physics in action is intended to reflect current but long-lasting and important developments in the subject: the increasing importance of visualisation; the impact of microtechnology and communication technology; the drive to better instrumentation; the expanding field of studies of materials and condensed matter in all their many forms. The choice also reflects the great variety of ways in which physics is used today, including medical physics, communication, industrial measurement, optics and opto-electronics, and the study of new materials.

How Science Works

The assessment objectives in categories (a) *knowledge and understanding of phenomena, concepts and relationships,* (b) *scientific communication and comprehension of the language and representations of physics* and (c) *quantitative and mathematical skills* are listed as specific points for each section of this unit. However, the categories (d) *experimental and data handling* and (e) *growth and use of scientific knowledge* are generic skills that develop throughout the course. Accordingly, the latter two categories are specified below, with suggested examples for their introduction and development. The examples given are illustrative, not a list of instances candidates should study.

(d) Experimental and data handling skills

Candidates should be able to:

1. show a critical approach to measurement, including estimating uncertainties, checking the calibration of instruments and suggesting sources of systematic error and ways to correct for or reduce it, demonstrating these skills in their own experimentation and in analysing experimental methods and data supplied to them; they should be able to analyse data carefully and thoroughly, recognising the value of cross-checking results, including the possibility of making alternative or supplementary measurements;

2. take account of the following properties of measuring instruments and sensors: resolution, sensitivity, calibration, stability, response time and zero error, and consider limitations on the results the measuring instruments and sensors can give;

3. use dot-plots or histograms to estimate the mean and range of values and detect possible outliers. They should be able to express uncertainty or systematic error in absolute or percentage terms as appropriate and to represent uncertainties on graphs, using them to estimate uncertainty in gradient and intercept; they should be able to identify the largest source of percentage uncertainty in a measurement and consider how to reduce it to improve the measurement.

The range of a set of varying values will be sufficient to estimate the spread. Use of standard deviation is not required. The largest source of percentage uncertainty may be treated as a guide to the minimum uncertainty of the result of combining values, and as a good starting point for improving a measurement. For combining uncertainties, appropriate recalculation of a final result is sufficient.

Examples of appropriate measurements include:

resolution and scale of an image; focal length or power of a lens; frequency, time, distance and angle; temperature; light and sound intensity; electric current and potential difference; resistance or conductance; mechanical properties of materials; electrical properties of materials.

The unit is designed to begin the development of skills of measurement and data handling, to be developed further later in the course.

Student activities are also carefully chosen, encouraged by appropriate coursework tasks, to begin early development of confidence, initiative, responsibility and good study habits, together with clearly focused experimental skills and knowledge.

Throughout the AS course, a main emphasis of practical work is on making measurements which are as good as is possible, and developing understanding of the systematic errors and experimental uncertainties that can affect the results obtained.

(e) Growth and use of scientific knowledge

Candidates should be able to:

1. describe examples of applications of technological or scientific knowledge;
2. suggest relevant arguments about issues concerning the value or significance of such applications.

Examples of relevant issues include:

practical or scientific implications of technical advances; social consequences of technological change; and historical, aesthetic, economic and environmental issues.

Examples of relevant technological and scientific advances include:

imaging; sensing; digital communications; development and choice of materials.

This unit consists of **two** modules:

- Module 1: **Communication** (PA 1)
- Module 2: **Designer Materials** (PA 2)

Either module may be covered first.

This module contains **two** sections:

- PA 1.1: **Imaging and signalling**
- PA 1.2: **Sensing**

These sections are about electric circuits and waves and about images, including some simple optics. The physics is approached through a study of sensors and how they work, and of how information can be processed, transmitted and presented.

Candidates have opportunities to develop IT skills through the use of image processing, data capture, signal processing and data analysis software.

Opportunities are given to put the physics in a broader perspective by considering, for example, the interpretation of images of the distant universe, or the limits of human visual perception.

Recommended prior knowledge

This work is a continuation of work on electricity and waves at GCSE.

Candidates are expected to:

- know about electric current, potential difference and resistance and power in circuits;
- know the relationship between current, resistance and voltage;
- know how current varies with voltage in a range of devices;
- to be familiar with the phenomena of reflection and refraction and be able to give a simple description of them;
- know the meaning of frequency, wavelength and amplitude of a wave;
- know about the electromagnetic spectrum and some uses of regions of the spectrum in medicine and communications.

Opportunities are provided for consolidating and developing this material, placing it on a more secure basis, so providing an appropriate path into Advanced GCE work.

PA 1.1: Imaging and signalling

In the context of the digital revolution in communication, this section introduces elementary ideas about image formation and digital imaging, and about the storage and transmission of digital information.

The material can be taught using up-to-date contexts such as mobile telephones, use of internet, email, and medical scanning and scientific imaging including remote sensing. There are opportunities to address human and social concerns, for example, the consequences of the growth of worldwide digital communications.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining:

   (i) the formation of a real image by a thin converging lens, understood as the lens changing the curvature of the incident wave-front;

   (ii) the storage of images in a computer as an array of numbers that may be manipulated to enhance the image (vary brightness and contrast, reduce noise, detect edges and use of false colour); *(candidates are not expected to carry out numerical manipulations in the examination; an understanding of the nature of the processes will be sufficient);*

   (iii) digitising a signal (which may contain noise); advantages and disadvantages of digital signals;

   (iv) the presence of a range of frequencies in a signal (its spectrum);

   (v) evidence of the polarisation of electromagnetic waves;

2. scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:

   (i) pixel, bit, byte, focal length and power, magnification, resolution, sampling, spectrum, signal, bandwidth, noise, polarisation, refractive index (understood as the ratio of speed of light in vacuum to the speed of light in material of lens);

   and by sketching and interpreting:

   (ii) diagrams of the passage of light through a converging lens;

   (iii) diagrams of wave-forms, and their spectra;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) the amount of information in an image = no. of pixels $\times$ bits per pixel;

   (ii) power of a converging lens $P = 1/f$, as change of curvature of wave-fronts produced by the lens;

   (iii) use of $\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$ (Cartesian convention); linear magnification $m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$ restricted to thin converging lenses and real images.

   (iv) $v = f\lambda$

   (v) amount of information, I, provides $N = 2^I$ alternatives; $I = \log_2 N$;

   (vi) minimum rate of sampling ≥ 2 × maximum frequency of signal;

   (vii) rate of transmission of digital information = samples per second × bits per sample;

   (viii) maximum bits per sample, b, limited by the ratio of total voltage variation to noise voltage variation: $b = \log_2(V\text{total}/V\text{noise})$;

and by showing graphically:

(xi) digitisation of an analogue signal for a given number of levels of resolution.

PA 1.2 Sensing

This section covers ideas involved in understanding electrical circuits, especially current, charge, potential difference, resistance, conductance and potential dividers in the context of modern sensors and instrumentation.

Candidates should develop skills of measurement, instrumentation and identification of uncertainty. It is expected that this will be taught in part through instrumentation tasks carried out in teams and reported to others.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases of:

   (i) current as the flow of charged particles;

   (ii) potential difference as energy per unit charge;

   (iii) resistance and conductance, including series and parallel combinations;

   (iv) effect of internal resistance and the meaning of emf;

   (v) dissipation of power in electric circuits;

   (vi) the relation between potential difference and current in ohmic resistors ('Ohm's Law');

   (vii) action of a potential divider;

2. scientific communication and comprehension of the language and representations of physics:

   (i) by making appropriate use of the terms, for electric circuits: *emf, potential difference, current, charge, resistance, conductance, series, parallel, internal resistance, load*;

   (ii) by recognising and using standard circuit symbols;

   (iii) by sketching and interpreting graphs of current against potential difference and graphs of resistance or conductance against temperature;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) $R = V/I$ $(G = I/V)$, $V = W/Q = P/I$, $P = IV = I^2R$, $W = VIt$, $V = E - Ir_{\text{internal}}$;

   (ii) $I = \dfrac{\Delta Q}{\Delta t}$, $R = R_1 + R_2 + \ldots$ (*series*), $G = G_1 + G_2 + \ldots$ (*parallel*);

   (iii) simple cases of a potential divider in a circuit.

This section is about materials and how their properties are related to their uses and their structures. Microscopic images are used to give evidence of structure at different scales.

The physics may be put into perspective through contexts such as the study of medical replacement materials, biological materials and engineering materials. Human and cultural issues arise, for example, in considering the impact of materials on technology and society and through the aesthetic appeal of materials.

*It is **not** intended that candidates acquire a detailed knowledge of a wide range of materials, and the terminology associated with each. It **is** intended that they have a reading comprehension of terms needed to understand accounts of the structure, uses and properties of materials. Examples should include: a metal, a semiconductor, a ceramic, a long-chain polymer and a composite material.*

Properties to be studied are restricted to simple mechanical and electrical properties.

Candidates should develop skills of measurement, instrumentation and identification of uncertainty. It is expected that this will be taught in part through measurement tasks carried out in teams and reported to others.

Recommended Prior Knowledge

- Some of this work is provided with a foundation in PA Module 1 *Communication*, in particular through ideas of resistance and conductance in circuits. If candidates are not confident with measuring resistance with an ohmmeter or with thinking of current as a flow of charged particles, that work may need to be brought forward here if PA Module 2 *Designer Materials* is taught before PA Module 1 *Communication*.

Assessable learning outcomes

1. Knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases of:

   (i) simple mechanical behaviour: types of deformation and fracture;

   (ii) simple electrical behaviour: the broad distinction between metals, semiconductors and insulators (only in terms of the number of mobile charge carriers, not their mobility);

   (iii) direct evidence of the size of particles and their spacing;

   (iv) behaviour and structure of classes of materials: metals, ceramics, polymers, composites;

   (v) one method of measuring:

   Young modulus and fracture stress;

   electrical conductivity or resistivity.

2. Scientific communication and comprehension of the language and representations of physics,

   by making appropriate use of the terms:

   (i) for mechanical properties and behaviour: stress, strain, Young modulus, fracture stress and yield stress, stiff, elastic, plastic, ductile, hard, brittle, tough;

   (ii) for electrical properties: resistivity, conductivity, charged carrier density;

   ability to sketch and interpret:

   (iii) stress–strain graphs up to fracture;

   (iv) tables and diagrams comparing materials by properties;

   (v) images showing structures of materials.

3. Quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) $R = \frac{\rho l}{A}$; $G = \frac{\sigma A}{l}$

   (ii) tensile/compressive stress, strain, Young modulus $E = \frac{stress}{strain}$.

3.2 AS Unit G492: *Understanding Processes, Experimentation and Data Handling*

Understanding Processes provides progression from the strong orientation towards application of *Physics in Action. Understanding Processes* is organised around different ways of understanding processes of change: motion in space and time, wave motion, quantum behaviour. Its focus, more than in *Physics in Action*, is on ‘curiosity-driven’ physics. While providing a sound foundation in the classical physics of mechanics and waves, the unit takes the story further forward, touching on the quantum probabilistic view.

There is progression in the use of mathematical ideas. In both modules, physical variables are extended from scalars to quantities that add like vectors, introducing this new mathematical structure. The work on motion is designed to pave the way for the introduction of differential equations in discrete time-step form in the A2 half of the Advanced GCE course.

Either module may be covered first. Some teachers may wish to introduce work on vector addition from UP 2 before work on combining phasors in UP 1.

The module is also designed to continue the development of skills of measurement and data handling introduced in *Physics in Action*.

The examination paper for *Understanding Processes* has been designed to test this measurement strand in Section C. Advance notice material, to be given to the students several weeks before the examination, will contain information in the form of descriptions of experiments, diagrams, data tables or graphs, but without the questions that are to be asked on that stimulus material. This will allow students, with their teacher, to analyse the given data in light of the knowledge, skills and understanding of the measurement strand developed through the course. This preparation is not to be taken into the examination; clean copies of all required material will be given in the examination paper. Questions may also test understanding of ideas and their relationships across the entire AS course.

How Science Works

The assessment objectives in categories (a) *knowledge and understanding of phenomena, concepts and relationships*, (b) *scientific communication and comprehension of the language and representations of physics* and (c) *quantitative and mathematical skills* are listed as specific points for each section of this unit. However, the categories (d) *experimental and data handling* and (e) *growth and use of scientific knowledge* are generic skills that develop throughout the course. Accordingly, the latter two categories are specified below, with suggested examples for their introduction and development. The examples given are illustrative, not a list of instances candidates should study.

(d) Experimental and data handling skills

Candidates should develop further their ability to:

1. plan experiments to measure physical quantities and investigate relationships, thinking critically about experimental methods and instrumentation and taking care to give values to an appropriate number of significant figures;

2. recognise systematic errors in measuring instruments or arising from experimental method and to propose ways of correcting or avoiding such errors;

3. identify and estimate the most important source of uncertainty in making a given measurement, by considering limitations of instruments or experimental method, and propose ways of reducing this uncertainty, including the appropriate use of repeat readings;

4. choose and use graphical displays of data to extract information from data and to communicate it effectively, including representing uncertainties graphically;

5. demonstrate these skills in their own experimentation and in analysing experimental methods and data supplied to them.

For estimation of uncertainty from repeated measurements, consideration of their range is sufficient. For combining uncertainties, appropriate recalculation of a final result is sufficient.

Examples of appropriate measurements include:

- *Speed of sound; wavelength of sound and light; the Planck constant, speed of electromagnetic disturbance (eg pulse along a cable); displacement, speed and acceleration of moving bodies; forces; changes in mechanical potential and kinetic energy.*

(e) Growth and use of scientific knowledge

Candidates should be able to:

1. identify and discuss ways in which interplay between experimental evidence and theoretical predictions have led to changes in scientific understanding of the physical world;

2. relate predictions from algebraic or computer models to real-life outcomes and evaluate the assumptions made in the model.

Examples of relevant changes in scientific understanding include:

- *ideas about the nature of light, including early particle theories, wave theories and quantum behaviour*.

Examples of relevant predictions include:

- *predictions from Newtonian mechanics of relative velocity, distance travelled (eg braking distance), changes of speed, changes of energy.*

This unit consists of **two** modules:

- Module 1: **Waves and Quantum Behaviour** (UP 1);
- Module 2: **Space, Time and Motion** (UP 2).

This section is mainly about superposition phenomena of waves, especially electromagnetic waves, with a brief account of the quantum behaviour of photons. Huygens' construction provides a link between the two ideas. Quantum behaviour is discussed through considering possible photon paths, avoiding the wave/particle dichotomy.

Use can be made of IT, with programs which model quantum behaviour.

Broader issues are raised in quantum theory about knowledge and its limits. Quantum theory provides a startling case where physicists have a mathematical framework that allows calculations of outstanding precision even though they do not have a fundamental agreement about the underlying picture of reality.

Candidates should develop skills of measurement, instrumentation and identification of uncertainty. It is expected that this will be taught in part through student measurement of quantities such as the wavelength of light with double slit and with a diffraction grating, and of the Planck constant with LEDs, with comparisons between individual and group results.

Recommended prior knowledge

Some of this work is a continuation of the work on light at GCSE. Candidates are expected to:

- know about reflection and refraction;
- know the meaning of frequency, wavelength and amplitude of a wave and know the relationship $v = f\lambda$.

Assessable learning outcomes

1. Knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases of:

    (i) production of standing waves by waves travelling in opposite directions;

    (ii) interference of waves from two slits;

    (iii) measurement of the speed of light, in terms of the difficulty of measurement requiring large distances and measurement of small time intervals and of the implications on understanding the nature of light (technical details are not expected);

    (iv) diffraction of waves passing through a narrow aperture;

    (v) diffraction by a grating;

    (vi) evidence that photons exchange energy in quanta $E = hf$

    (for example, one of light-emitting diodes, photoelectric effect or line spectra);

    (vii) quantum behaviour: quanta have a certain probability of arrival; the probability is obtained by combining amplitude and phase for all possible paths;

    (viii) evidence from electron diffraction that electrons show quantum behaviour.

    In this section where wave-forms, amplitudes and phases need to be combined, graphical methods are sufficient.

2. Scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:

   (i) *phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity.*

3. Quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) wavelength of standing waves (end corrections not required);

   (ii) path differences for double slits and diffraction grating, for constructive interference $n\lambda = d \sin\theta$ (both limited to case of distant screen);

   (iii) the energy carried by photons across the spectrum, $E = hf$.

Module UP 2: Space, Time and Motion

This section develops classical mechanics, including vectors. The kinematics of uniformly accelerated motion and the dynamics of motion in two dimensions under a constant force are covered.

The discussion of vectors in the context of journeys provides opportunities to reflect on how history, geography and technologies are related.

IT skills may be developed through the use of the computer as a modelling tool, although an extended account of modelling is reserved for A2.

Candidates should develop skills of measurement, instrumentation, identification of uncertainty and data analysis. It is expected that this will be taught in part through student measurement of displacement, velocity, time and force, and subsequent calculations using those data.

Recommended prior knowledge

This work is a continuation of the work on forces and motion at GCSE. The candidates are expected to:

- know and understand ideas about the way forces affect motion;
- be able to calculate speeds and accelerations.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases of:

   (i) the use of vectors to represent displacement, velocity and acceleration;

   (ii) the trajectory of a body moving under constant acceleration, in one or two dimensions;

   (iii) the independent effect of perpendicular components of a force;

   (iv) calculation of work done, including cases where the force is not parallel to the velocity;

   (v) power as rate of transfer of energy;

   (vi) measurement of displacement, velocity and acceleration;

2. scientific communication and comprehension of the language and representations of physics,

   by making appropriate use of the terms:

   (i) *displacement, speed, velocity, acceleration, force, mass, vector, scalar, power*;

   by sketching and interpreting:

   (i) graphs of accelerated motion, including slope and area below the graph

   (*displacement–time and velocity–time graphs; acceleration not necessarily constant*);

   (ii) graphical representation of addition of vectors and changes in vector magnitude and direction;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) the resolution of a vector into two components at right angles to each other;

   (ii) the addition of two vectors, graphically and algebraically (*algebraic calculations restricted to two perpendicular vectors*);

   (iii) the kinematic equations for constant acceleration derivable from $a = (v - u)/t$ and average velocity = $(v + u)/2$:

   $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$;

   (iv) the equation $F = ma$ where the mass is constant;

   (v) kinetic energy = $\frac{1}{2}mv^2$; work done $\Delta E = F\Delta S$;

   (vi) gravitational potential energy = mgh;

   (vii) force, energy and power: power = $\Delta E/t$, power = Fv;

   (viii) modelling changes of displacement and velocity in small discrete time steps, using a computational model or graphical representation of displacement and velocity vectors (*calculations restricted to zero or constant resultant force*).

3.3 AS Unit G493: *Physics in Practice*

Throughout the Advancing Physics course candidates develop their ability to learn independently, and develop their experimental and investigational skills and their research and communication skills. There are many opportunities for formative assessment as a candidate follows the course. Candidates can see their progress through the levels in the assessment criteria. The assessment recognises the wide range of skills candidates develop during the course.

All the coursework is assessed by the candidate's physics teacher using criteria set by OCR and externally moderated by OCR.

In the AS GCE course candidates carry out two short tasks: a measurement task, Quality of Measurement, and a presentation on a researched topic chosen by the candidate, Physics in Use. Together these form Unit G493: Physics in Practice.

In the A2 half of the Advanced GCE course the coursework consists of two more substantial pieces of work, recognising the more developed skills and maturity of candidates by this stage. The candidates tackle a Practical Investigation and produce a Research Briefing on topics chosen by the candidate. Together these form Unit G496: Researching Physics.

Unit G493: Physics in Practice (30 marks)

There are **two** short coursework tasks in Unit G493.

The two tasks are:

Quality of Measurement (20 marks)

- A report of a measurement or study of a physical relationship, with attention paid to improving the quality of measurement and making valid inferences from data.

Physics in Use (10 marks)

- A presentation on the use, properties and structure of a material.

The work is carried out during the AS course, and assessed at that time. The two pieces of work together form a coursework portfolio for which a single mark out of 30 is submitted for Unit G493.

Candidates undertake a task of one of the following kinds:

- a careful measurement of a physical quantity;
- a careful quantitative study of the relationship between two or more variables, where there are some indications from theory of what to expect;
- a careful calibration of a sensor or instrument;
- a careful study of one or more of the properties of a sensor or instrument;
- a careful comparison of methods of measuring the same thing.

The word ‘careful’ implies both practical skill (‘hands on’) and thoughtful analysis of problems and data (‘minds on’).

Candidates should demonstrate their ability to:

- recognise the qualities and limitations of measuring instruments, particularly resolution, sensitivity, calibration, response time, stability and zero error;
- identify and estimate the most important source of uncertainty in a measurement and seek ways to reduce it;
- consider the possibility of systematic errors and seek to estimate and remove them, including considering calibration;
- make effective plots to display relationships between measured quantities, with appropriate indication of uncertainty;
- use simple plots of the distribution of measured values to estimate the median (or mean) value and the spread (which may be estimated from the range of values), and to identify and account for potential outlying values.

A written report of the work done is produced. This task comes directly out of the measurement tasks that candidates have performed in their experimental work throughout the AS course.

Managing the Quality of Measurement Task

This task is expected to take no more than four hours of contact time, used in the laboratory for setting up and taking measurements, and an equivalent amount of time for writing the report. It is expected that the teacher will provide a clear problem or goal from the kind listed above.

The time allocation for the *Quality of Measurement* Task sets a modest bound on what candidates are expected to achieve. The experience should build on practical coursework and measurement skills developed at GCSE, and should be the practical climax to their AS course, having been prepared for by similar tasks carried out in teams throughout the year.

What are the aims?

Candidates should develop a sense of pride in measuring as well as possible given the tools they have, and to be clear about how well the job has been done. They should be able to experiment well, to recognise the limitations of instruments and to discuss the uncertainty of measurements, learning to look for important sources of uncertainty and attempt to reduce them. They should also consider possible systematic errors and try to remove them. Candidates should be able to analyse data carefully with intelligent use of graphs and tables, extracting as much information as possible and present a report that explains procedures used, communicates the results obtained and has a clear outcome that is qualified with statements of uncertainty.

Assessing the Measurement Task

This task provides an opportunity for students to demonstrate their practical, experimental, measuring and investigational skills. This task gives the opportunity within the AS course to assess practical aspects of the assessment objective AO3 *How Science Works* (section 4.1).

Details of the application of the assessment criteria are given in Appendix D.

Physics in Use

This task involves researching the nature and use of a material, and making a presentation about it. Each candidate may choose to give the presentation as an illustrated talk using a presentation program such as Microsoft PowerPoint, a web page, a video or a poster. It is envisaged that each candidate will choose the manner of presentation that appeals to them, and is suited to the audience and topic. Overlong presentations should be discouraged; ten minutes is probably about optimum.

New materials offer a wide variety of stimulating choice, but the choice of material is not restricted to novel materials. The presentation should show relationships between the properties and uses of the material. Some aspect of the wider context, for example, a social, historical, economic or personal context must be considered.

Material from the presentation must be available in a folder which can be sent to moderators.

This task comes directly out of the work done in relation to *Designer materials* in module PA 2 of Unit G491. The assessment rewards independent learning and presentation of physics in a non-written format.

Managing the *Physics in Use* task

This task is expected to take no more than three hours of contact time; this includes that required for students' oral presentations to the whole class. Candidates should perhaps use around two further hours for research and writing.

What are the aims?

By the time of the presentation, candidates' understanding and vocabulary should have developed significantly from the GCSE background with which they started the course. They should feel confident to access and make use of information from a variety of sources, and be extending their study in a direction which interests them.

It is hoped they will enjoy careful research, and consider their fellow-candidates, the audience, as they prepare this research for presentation.

Assessing the *Physics in Use* task

This task provides an opportunity to assess the candidates' independent learning and presentation of physics in a non-written format. The assessment addresses, in particular, aspects of AO1 *Knowledge with understanding* and AO2 *Application of knowledge with understanding, synthesis and evaluation.*

Details of application of the assessment criteria are given in Appendix D.

A2 Units

In A2, Unit G494 and Unit G495 deliver the new physics in the second half of the Advanced GCE course. The two internally assessed coursework tasks of Unit G496 are less closely tied to the content of the course, allowing candidates to choose their own context for further study.

Rise and Fall of the Clockwork Universe (Unit G494) develops the grand conception of the world as a 'mathematical machine', which transformed Western culture. Some of its limits are also shown. The content of this unit is set out in two modules:

- **Models and rules** (RF 1) covers the core physics of random decay and the decay of the charge on a capacitor, energy and momentum, the harmonic oscillator and circular orbits. The field model is developed through consideration of gravitational fields;
- **Matter in extremes** (RF 2) shows how theories of matter and atoms explain behaviour: covering the kinetic theory of gases, thermal behaviour of matter and the effect of temperature.

Field and Particle Pictures (Unit G495) introduces the modern picture of fields and particle interactions as fundamental mechanisms of nature. The content of this unit is set out in two modules:

- **Fields** (FP 1) covers ideas about electromagnetism, electric fields and potential;
- **Fundamental particles** (FP 2) is about atomic, nuclear and sub-nuclear structure, with attention to ionising radiation and risk.

This unit also consolidates, puts together and uses physics ideas from the whole course. A number of case studies show how different aspects of the physics in the course are used to tackle problems.

3.4 A2 Unit G494: *Rise and Fall of the Clockwork Universe*

Rise and Fall of the Clockwork Universe (G494) develops the grand conception of the world as a 'mathematical machine'. Some of its limits are also shown. The content of this unit is set out in two modules:

- **Models and rules** (RF 1) covers the core physics of random decay and the decay of the charge on a capacitor, energy and momentum, the harmonic oscillator and circular orbits. The field model is developed through consideration of gravitational fields;

- **Matter in extremes** (RF 2) shows how theories of matter and atoms explain behaviour: covering the kinetic theory of gases, thermal behaviour of matter and the effect of temperature.

The grand conception, coming from Descartes, Newton and Leibniz, of the world as a 'mathematical machine', is developed. Some of its limitations are also shown. In this framework, the formalism of differential equations, an essential tool of the physicist, is developed, and also the concept of a field. This is the context for core work on force and motion, and orbits and gravity. But it leads towards the structure and behaviour of atoms, where quantum and statistical ideas start to take over.

Overall, the unit raises issues of simplification and idealisation in models, and the extent to which these are desirable or necessary. Models can be seen as artificial worlds over which the human maker has complete control. This is the source of their definiteness and determinism. Models allow analogies to be seen between otherwise very different physical processes. A difference can be seen between models in which well-determined behaviour is due to exact rules operating on variables (as in the harmonic oscillator) or to smooth averages over many particles (as in radioactive decay). Both strategies inform the structure behind this half of the Advanced GCE A2 course.

How Science Works

The assessment objectives in categories (a) *knowledge and understanding of phenomena, concepts and relationships*, (b) *scientific communication and comprehension of the language and representations of physics* and (c) *quantitative and mathematical skills* are listed as specific points for each section of this unit. However, the categories (d) *experimental and data handling* and (e) *growth and use of scientific knowledge* are generic skills that develop throughout the course. Accordingly, the latter two categories are specified below, with suggested examples for their introduction and development. The examples given are illustrative, not a list of instances candidates should study.

(d) Experimental and data handling skills

Candidates should be able to:

1. plan and perform experiments to confirm or to determine mathematical relationships, eg *systems which may or may not produce proportional, exponential, simple harmonic, inverse or inverse square relationships;* these should incorporate the skills and techniques developed throughout the AS course to ensure that the quality of data obtained is taken into account;

2. identify, given appropriate data, the consequences of systematic error and uncertainty in measurements and the need to reduce these, eg *in measurement of astronomical distances related to calculations of the size or age of the universe, and the effect of increased resolution and greater range of observations on those calculations;*

3. use computers to create and manipulate simple models of physical systems and to evaluate the strengths and weaknesses of the use of computer models in analysis of physical systems, eg *the approximations and simplifications necessary in computer models, the ability of powerful computers to model very complex systems;*

4. plan, conduct, evaluate and further develop the practical study of a problem in an extended, open-ended investigation of a physical situation chosen by the student (this investigation may be done within the teaching of this unit or within that of G495, at a time convenient for the centre).

(e) Growth and use of scientific knowledge

Candidates should be able to identify and describe:

1. the nature and use of mathematical models, eg *models of random variation producing mathematical relationships, iterative and iconic models to predict behaviour in systems too complex for simple analysis; systematic analysis, using physical principles, to produce mathematical relationships;*

2. changes in established scientific views with time, eg *the explanatory power of Newton's contributions to mechanics and gravitation, the implications of special relativity, the cosmological view of the universe (which is being continually refined), the statistical nature of the kinetic theory of gases and of the Boltzmann factor;*

3. an issue arising from scientific research and development, stating more than one viewpoint that people might have about it, eg *the understanding gained from space exploration and its incidental benefits, such as prestige, international co-operation and development in related disciplines, and drawbacks, such as cost and diversion of funds from other research.*

Synoptic assessment

All A2 assessment units have elements of synoptic assessment. For Unit G494, this will involve those aspects of the AS course which are appropriate for the content specified here. The AS content needed is listed below under *Recommended prior knowledge*.

This unit consists of **two** modules:

- Module 1: **Models and rules** (RF1);

- Module 2: **Matter in extremes** (RF2).

Either module may be covered first.

This module covers the core physics of radioactive decay and decay of charge on a capacitor, energy and momentum, the harmonic oscillator and circular orbits. The field model is developed through consideration of gravitational fields. The idea of differential equations and their solution by numerical or graphical methods is built up gradually using finite difference methods.

Opportunities arise to discuss the place of mathematics in physics: is mathematics part of the nature of the world or an artefact of our way of doing things? There are opportunities too for candidates to pursue their own interests when considering applications of these ideas.

Recommended prior knowledge

The work is a continuation of the AS course as well as picking up on some ideas from GCSE. Candidates are expected to:

- show knowledge and understanding of digital images as arrays of binary digits encoding pixel values, and of their manipulation and storage (AS 1.1.1 Imaging and signalling);
- show knowledge and understanding of digital communication as a series of binary digits encoding sampled signal values, and of the frequency spectrum of a signal (AS 1.1.1 Imaging and signalling);
- show knowledge and understanding of current as a flow of charged particles and potential difference as energy per unit charge, and be able to perform circuit calculations involving current, potential difference, resistance and energy (AS 1.1.2 Sensing);
- know that radioactivity arises from the breakdown of an unstable nucleus and that there are three main types of radioactive emission with different penetrating powers (Sc7c);
- know the relationship between force and work (AS 2.2 Space time and motion);
- know the quantitative links between kinetic energy, potential energy and work (AS 2.2 Space time and motion);
- know about the bodies in the solar system and that gravitational forces determine the movement of planets, moons, comets and satellites (Sc8c).

This module contains **three** sections:

- RF 1.1 **Creating models**;
- RF 1.2 **Out into space**;
- RF 1.3 **Our place in the universe**.

RF 1.1 Creating models

This section first considers models where the rate of change of a quantity is proportional to that quantity. It then goes on to consider the model of simple harmonic motion.

Candidates and teachers are encouraged to use computer modelling for this work, allowing candidates to develop their IT skills. The central importance of the exponential function develops candidates' skills in Application of Number.

Radioactive decay and capacitor discharge provide a context, but the point of view is broader, looking at these as examples of any kind of change where the change is proportional to the amount. Candidates have the opportunity to study examples of their own choice, for example, the action of heart defibrillators or camera flash units.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases involving:

   (i) capacitance as the ratio $C = Q/V$;

   (ii) the energy on a capacitor $E = \frac{1}{2}QV$;

   (iii) the exponential form of the decay of charge on a capacitor as due to the rate of removal of charge being proportional to the charge remaining;

   $$\frac{\mathrm{d}Q}{\mathrm{d}t} = -\frac{Q}{RC};$$

   (iv) the exponential form of radioactive decay as a random process with a fixed probability, the number of nuclei decaying being proportional to the number remaining;

   $$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N;$$

   (v) simple harmonic motion of a mass with a restoring force proportional to displacement such that

   $$\frac{\mathrm{d}^2x}{\mathrm{d}t^2} = -\frac{k}{m}x;$$

   (vi) kinetic and potential energy changes in simple harmonic motion;

   (vii) free and forced vibrations, damping and resonance

   (qualitative treatment only);

2. scientific communication and comprehension of the language and representations of physics by making appropriate use of the terms:

   (i) for a capacitor: time constant τ;

   (ii) for radioactive decay: *activity, decay constant* λ, *half-life* $T_{½}$, *probability, randomness*;

   (iii) for oscillating systems: *simple harmonic motion, period, frequency, free* and *forced oscillations, resonance*;

   by expressing in words and vice-versa:

   (iv) relationships of the form $\frac{dx}{dt} = -kx$, where rate of change is proportional to amount present;

   by sketching, plotting from data and interpreting:

   (v) decay curves, plotted directly or logarithmically;

   (vi) energy of capacitor as area below a Q–V graph;

   (vii) energy of stretched spring as area below a force–extension graph;

   (viii) v–t and a–t graphs of simple harmonic motion including their relative phases;

   (ix) amplitude of a resonator against driving frequency;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) calculating activity and half life of a radioactive source from data, $T_{½} = \frac{\ln 2}{\lambda}$;

   (ii) solving equations of the form $\frac{dN}{dt} = -\lambda N$ by iterative numerical or graphical methods

   ($N = N_0 \exp(-\lambda t)$ as the analytic solution);

   (iii) calculating time constant τ of a capacitor circuit from data; $\tau = RC$; $Q = Q_0 \exp(-t/RC)$;

   (iv) solving equations of the form $\frac{dQ}{dt} = -\frac{Q}{RC}$ by iterative numerical or graphical methods;

   (v) $C = Q/V$, $I = \Delta Q/\Delta t$, $E = ½QV$, $E = ½\ CV^2$;

   (vi) $T = 2\pi\sqrt{\frac{m}{k}}$, with $f = \frac{1}{T}$; and analogous equations such as that for the simple pendulum;

   (vii) $F = kx$; $E = ½kx^2$;

   (viii) solving equations of the form $\frac{d^2x}{dt^2} = -\frac{k}{m}x$ by iterative numerical or graphical methods;

(ix) $x = A \sin 2\pi ft$ or $x = A \cos 2\pi ft$;

(x) $E_{total} = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$.

RF 1.2 Out into space

This section develops ideas about gravitational field and potential. Free fall as ‘zero gravity’, space flight and planetary orbits are considered. Momentum, kinetic and potential energies and conservation laws are covered.

There are extended opportunities to use modelling software.

Space flight and astronomical data provide a context and there are opportunities to discuss how ideas developed by Galileo, Kepler and Newton make it possible to do such things as weigh the Earth, explain tides and broadcast TV globally by satellites.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing, and explaining cases involving:

    (i) force as rate of change of momentum;

    (ii) work done, including cases where the force is not along the line of motion;

    (iii) conservation of momentum; Newton’s 3rd Law as a consequence;

    (iv) changes of gravitational and kinetic energy;

    (v) motion in a uniform gravitational field;

    (vi) the gravitational field and potential of a point mass;

    (vii) motion in a horizontal circle and in a circular gravitational orbit;

2. scientific communication and comprehension of the language and representations of physics,

    by making appropriate use of the terms:

    (i) *force, kinetic and potential energy, momentum, gravitational field, gravitational potential, equipotential surface;*

    by sketching and interpreting:

    (ii) graphs showing gravitational potential as area under a gravitational field versus distance graph;

(iii) graphs showing force as related to the tangent of a graph of gravitational potential energy versus distance;

(iv) diagrams of gravitational fields and the corresponding equipotential surfaces;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) gravitational potential energy change *mgh*;

   (ii) energy exchange, work done, $\Delta E = F\,\Delta s$; no work done when the force is perpendicular to the velocity;

   (iii) momentum, $p = mv$, $F = \Delta mv/\Delta t$;

   (iv) $a = \frac{v^2}{r}$, $F = \frac{mv^2}{r}$;

   (v) for the radial components: $F_{grav} = -\frac{GmM}{r^2}$, $g = \frac{F_{grav}}{m} = -\frac{GM}{r^2}$;

   (vi) gravitational potential energy $E_{\text{grav}} = -\frac{GmM}{r}$;

   (vii) $V_{grav} = \frac{E_{grav}}{m} = -\frac{GM}{r}$.

RF 1.3 Our place in the universe

This section covers a descriptive and mainly qualitative outline of the main features of the observable universe consistent with the hot big bang model of its origin. The ideas of the universality of the speed of light and the relativistic consequence of time dilation are introduced.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing:

   (i) the use of radar-type measurements to determine distances within the solar system; how distance is measured and defined in units of time, assuming the relativistic principle of the invariance of the speed of light;

   (ii) effect of relativistic time dilation using the relativistic factor $\gamma = \frac{1}{\sqrt{1-v^2/c^2}}$;

   (iii) the measurement of relative velocities by radar observation;

   (*simple arguments using two successive pulses are sufficient);*

   (iv) evidence of a 'hot big bang' origin of the universe from:

   - cosmological red-shifts (Hubble's law);
   - cosmological microwave background;

2. scientific communication and comprehension of the language and representations of physics, by sketching and interpreting:

   (i) logarithmic scales of magnitudes of quantities: distance, size, mass, energy, power, brightness;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) distances and ages of astronomical objects;

   (ii) distances and relative velocities from radar-type measurements.

Matter in extremes considers how kinetic theory explains the behaviour of matter in probabilistic and mechanical terms. These ideas are extended to high and low temperatures. The beginnings of the basis of thermodynamic thinking appear in the form of the Boltzmann factor. These are all fundamental ideas of importance in understanding matter.

Recommended prior knowledge

The work is a continuation of work from earlier in the A2 course as well as picking up on some ideas from GCSE. Candidates are expected to:

- show knowledge and understanding of conservation of energy and momentum (A2 RF1.2);
- know about energy transfers as a result of temperature differences (Sc7a).

This module contains **two** sections:

- RF 2.1: **matter: very simple;**
- RF 2.2: **matter: hot or cold.**

RF 2.1 Matter: very simple

The behaviour of an ideal gas is explained in terms of kinetic theory. Its behaviour is understood as the result of averaging over a very large number of individual particle interactions.

There are opportunities to consider the work in its historical context, especially the resistance to ideas about the existence of atoms and the nature of a vacuum.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases involving:

   (i) energy transfer producing a change in temperature;

   (ii) the behaviour of ideal gases;

   (iii) the kinetic theory of ideal gases;

   (iv) temperature as proportional to average energy per particle; average energy $\cong kT$ as a useful approximation;

   (v) random walk of molecules in a gas: distance gone in N steps related to $\sqrt{N}$;

2. scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:

   (i) *ideal gas, root mean square speed, absolute temperature, internal energy, Avogadro constant, Boltzmann constant, gas constant, mole*;

   by sketching and interpreting:

   (ii) relationships between p, V, N and T for an ideal gas;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) temperature and energy change using $\Delta E = mc\Delta\theta$;

   (ii) $pV = NkT$ where $N = nN_A$ and $Nk = nR$;

   (iii) $pV = \frac{1}{3}Nm\overline{c^2}$;

   (iv) number of moles n and Avogadro constant N_A.

RF 2.2 Matter: hot or cold

In this section, temperature is related to the probability that particles occupy quantum states of different energies and the Boltzmann factor is introduced as the link between energy and temperature. The important idea that differences drive change is developed here.

Opportunities are provided for considering a range of contemporary topics such as the state and behaviour of matter in the early universe, superconductivity at low temperatures, the behaviour of 'soft matter' (such as polymers) and rates of reaction.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing, explaining and giving examples of:

   (i) ratios of numbers of particles in quantum states of different energy, at different temperatures (*classical approximation only)*;

   (ii) qualitative effects of temperature in processes with an activation energy

   (*for example, changes of state, thermionic emission, ionisation, conduction in semiconductors, viscous flow)*;

2. scientific communication and comprehension of the language and representations of physics by sketching and interpreting:

   (i) graphs showing the variation of the Boltzmann factor with energy and temperature;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:

   (i) ratios of characteristic energies to the energy kT ;

   (ii) Boltzmann factor, $e^{-E/kT}$.

3.5 A2 Unit G495: *Field and Particle Pictures*

Field and Particle Pictures (G495) introduces the modern picture of fields and particle interactions as fundamental mechanisms of nature. The content of this unit is set out in two modules:

- **Fields** covers ideas about electromagnetism, electric field and potential;

- **Fundamental particles** is about atomic, nuclear and sub-nuclear structure, with attention to ionising radiation and risk.

This unit also consolidates, puts together and uses physics ideas from the whole course. A number of case studies show how different aspects of the physics in the course are used to tackle problems.

The idea of a field is fundamental in physics, particularly the electromagnetic field, which is both of importance in engineering and as the origin of forces binding charges together in atoms. Elementary particles have come to be seen not just as acted on by fields, but as carriers of the field. This makes it appropriate that ideas of field and particle are developed together.

The aim is to achieve a balance between developing basic ideas, such as electric field and potential, and the constituent particles of atoms, nuclei and nucleons, and of recognising important areas of application, such as electromagnetic machines and the uses and dangers of radioactive materials and ionising radiation. Fields and particles play crucial roles in both.

Candidates should further develop their ability to recognise the limitations of measuring instruments and to identify and estimate the most important source of uncertainty in a measurement.

How Science Works

The assessment objectives in categories (a) *knowledge and understanding of phenomena*, *concepts and relationships*, (b) *scientific communication and comprehension of the language and representations of physics* and (c) *quantitative and mathematical skills* are listed as specific points for each section of this assessment unit. However, the categories (d) *experimental and data handling* and (e) *growth and use of scientific knowledge* are generic skills that develop throughout the course. Accordingly, the latter two categories are specified below, with suggested examples for their introduction and development. The examples given are illustrative, not a list of instances candidates should study.

(d) Experimental and data handling skills

Candidates should be able to:

1. perform experiments to obtain data safely and with all the skills and techniques developed throughout the AS course to ensure that the quality of data obtained is taken into account, eg *safe use of radioactive sources to determine range of alpha and beta particles;*

2. plan, conduct, evaluate and further develop the practical study of a problem, in an extended, open-ended investigation of a physical situation chosen by the student (this investigation may be done within the teaching of this unit or within that of G494, at a time convenient for the centre).

(e) Growth and use of scientific knowledge

Candidates should be able to identify and describe:

1. changes in established scientific views with time,. eg *the developing understanding of the structure of the atom;*

2. the nature of risk and of scientific responsibility, eg *decisions that need to be made on an acceptable radiation dose in different circumstances, or on the disposal of nuclear waste;*

3. an issue arising from scientific and technological developments, stating more than one viewpoint that people might have about it.

Examples of relevant scientific and technological developments include:

applications of electromagnetism; research into particle physics; different uses of radioactive materials; nuclear power.

Examples of relevant issues include:

associated benefits (such as prestige, international co-operation and development in related disciplines) and risks or costs (including diversion of funds from other research); scientific understanding gained; aesthetic, economic and environmental issues.

Synoptic assessment

All A2 assessment units have elements of synoptic assessment. For Unit G495, this will take two forms.

- For questions in Sections A and B of the examination paper based on the specification content below, synoptic assessment will involve those aspects of the AS course, and also the earlier A2 Unit G494, which are appropriate for the content specified in this unit. The AS and prior A2 content needed is listed below under *Recommended prior knowledge*.
- Section C is based on the Advance Notice article, to be given to the candidates several weeks before the examination. This article will consist of a printed text about physics (approximately 1500 words) which includes data and diagrams. They have the opportunity to study the passage in advance of the examination. In the examination they receive a new copy of the passage together with the (unseen) questions about the content. This form of comprehension / data analysis paper allows candidates to have plenty of time to read the passage, look up unfamiliar ideas and discuss them with their teacher before sitting down to answer the questions. While the context of the passage may be unfamiliar to the candidates, the physics that they are asked to use will be drawn from across the whole Advanced GCE course. The paper tests the synoptic ability of the candidate, and will also test the candidate's ability in the *How Science Works* areas of *Experimental and data handling skills*, and *Growth and use of scientific knowledge*.

The content of this unit is set out in **two** modules:

- Module 1: **Fields** (FP 1);
- Module 2: **Fundamental particles** (FP 2).

Either module may be covered first.

Electromagnetic machines – transformer, dynamo, motor – introduce magnetic fields in a strongly applied context. An introduction of this kind can help to give the field, otherwise a difficult abstraction, a greater sense of practical reality through studying real devices.

The electric field, as the interaction between charges at rest, links back by analogy to the gravitational field (RF 1.2), with the idea of electric potential also drawing together previous ideas about potential difference. The ideas find immediate use in consideration of scattering and of forces between sub-atomic particles (FP 2.1).

These two sections can be taken in either order.

Opportunities exist to discuss the social impact of the widespread distribution and use of electrical power, and its influence on industrial societies.

There are opportunities to use computers to build models, for example, of electric fields or equipotential surfaces.

Recommended prior knowledge

The work is a continuation of the AS course as well as picking up on some ideas from GCSE. Candidates are expected to:

- show knowledge and understanding of current as a flow of charged particles and potential difference as energy per unit charge, and to able to perform circuit calculations involving current, potential difference, resistance and energy (PA 1.2 Sensing);
- know about radial gravitational fields, gravitational potential and motion in a circle (RF 1.2 Out into space).

This module contains **two** sections:

- FP 1.1: **electromagnetic machines;**
- FP 1.2: **charge and field.**

FP 1.1 Electromagnetic machines

This section covers the design and working of transformers, dynamos and motors, and through them develops fundamental equations and relationships of electromagnetism.

There is scope for discussing a wide variety of electromagnetic devices, with uses in, for example: transport, medicine and power generation, seen from a largely technological point of view. There is an opportunity to consider the influences on technological development and the social changes such developments can bring.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases involving:
   (i) the action of a transformer: magnetic flux from a coil; induced emf = rate of change of flux linked;

   (ii) the action of a dynamo: change of flux linked produced by relative motion of flux and conductor;

   (iii) the action of a motor, including a simple induction motor;

   (iv) electromagnetic forces; qualitatively as arising from tendency of flux lines to contract or interaction of induced poles; quantitative calculation limited to force on a straight current-carrying wire in a uniform field;

   (v) Simple linked electric and magnetic circuits: flux produced by current turns, need for large conductance and permeance (understood as a magnetic equivalent to electrical conductance and with analogous dependence on the dimensions and nature of the magnetic medium) and effect of increasing the dimensions of an electromagnetic machine; qualitative effect of iron and air gap;

2. scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:
   (i) *B-field, flux, flux linkage, induced emf, eddy currents*;

   by sketching and interpreting:

   (ii) graphs of variations of currents, flux and induced emf;

   (iii) diagrams of lines of flux in magnetic circuits; continuity of lines of flux;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:
   (i) $\Phi = BA, \varepsilon = -\dfrac{\mathrm{d}(\Phi N)}{\mathrm{d}t}$;

   (ii) $F = ILB$

   (calculations restricted to current or velocity perpendicular to uniform magnetic field);

   (iii) $\dfrac{V_1}{V_2} = \dfrac{N_1}{N_2}$ for an ideal transformer;

   (iv) $\dfrac{I_2}{I_1} = \dfrac{N_1}{N_2}$ for an ideal transformer.

FP 1.2 Charge and field

This section covers interactions between charged particles, and ideas about electric field and potential. The main work here is the core study of static electric fields and the inverse square law, seen as analogous to the gravitational case. But candidates will be aware that 'at rest' is a relative notion, and reference can be made here and elsewhere to connections between electric and magnetic effects.

It would be possible to integrate this with work in section 5.2.1 on scattering by charged particles.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases involving:
   (i) uniform electric field $E = V/d$;

   (ii) the electric field of a charged object, and the force on a charge in an electric field; inverse square law for point charge (spherical symmetry);

   (iii) electrical potential energy and electric potential due to a point charge; $1/r$ relationship;

   (iv) evidence for the discreteness of the charge on an electron (eg *Millikan oil drop experiment*);

   (v) the force on a moving charged particle due to a uniform magnetic field;

2. scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:
   (i) *charge, electric field* and *potential; equipotential surface, electronvolt*;

   by sketching and interpreting:

   (ii) graphs of electric field versus distance; electric potential as area under curve;

   (iii) graphs of electric potential or potential energy against distance; relation of electric field to tangent to graph;

   (iv) diagrams of electric fields and the corresponding equipotential surfaces;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:
   (i) for radial components: $F_{electric} = \frac{kqQ}{r^2}$, $E_{electric} = \frac{F_{electric}}{q} = \frac{kQ}{r^2}$ $\left[k = \frac{1}{4\pi\varepsilon_0}\right]$;

   (ii) $E_{electric} = -\frac{dV_{electric}}{dx}$, $E_{electric} = \frac{V}{d}$ (*for a uniform field*);

   (iii) $V_{electric} = \frac{kQ}{r}$;

   (iv) $F = qvB$.

The work here concerns the structure and binding of atoms and nuclei and the nature of fundamental particles, successively going into deeper and deeper levels of structure. Besides taking this fundamental viewpoint, the practical implications of radioactivity and ionising radiation are considered, with an introduction to the idea of risk.

Opportunities exist to consider social issues, particularly financial and environmental costs and benefits. The module also raises questions about the ultimate nature of the physical world.

Recommended prior knowledge

The work is a continuation of the AS course as well as picking up on some ideas from GCSE. candidates are expected to:

- know about the force acting on a charge moving in a uniform magnetic field (FP 1.1 Electromagnetic machines);
- know about motion in a circle (RF 1.2 Out into space);
- know that radioactivity arises from the breakdown of an unstable nucleus and that there are three main types of radioactive emission (alpha, beta and gamma) with different penetrating powers (Sc7c);
- know that activity is the rate of decay of a radioactive sample and that activity is given by $\frac{\mathrm{d}N}{\mathrm{d}t}$ (RF 1.1 Creating models);
- know and be able to use the exponential form of radioactive decay (RF 1.1 Creating models).

This module contains **two** sections:

- FP 2.1: **Probing deep into matter;**
- FP 2.2: **Ionising radiation and risk.**

FP 2.1 Probing deep into matter

A central notion here is that of scattering, as a source of evidence about the structure of atoms and nucleons. The use of accelerators helps reinforce understanding of the motion of charged particles in electric and magnetic fields. Evidence is given of discrete energy levels in atoms, and quantum ideas (AS) are put to use in explaining their origin, using a crude model of a particle in a box. Simple relativistic thinking (RF 1.3) explains the increased measured lifetimes of fast-moving decaying particles.

Opportunities are provided to discuss international co-operation in large-scale experiments. Social debate about the costs and benefits of pure fundamental research can be discussed.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining:
   (i) use of particle accelerators to generate high-energy beams of particles for scattering

   (*details of the construction of accelerators are not required*);

   (ii) evidence from scattering for a small massive nucleus within the atom;

   (iii) evidence of discrete energy levels in atoms

   (*for example, from collisions with electrons or from line spectra*);

   (iv) a simple model of the atom as the quantum behaviour of electrons in a confined space;

   (v) simple picture of the internal structure of protons and neutrons;

   (vi) relativistic calculations for particles travelling at very high speed, eg *in particle accelerators* or *cosmic rays*;

2. scientific communication and comprehension of the language and representations of physics, by making appropriate use of the terms:

   (i) *energy level, scattering, nucleus, proton, neutron, nucleon, electron, positron, quark, gluon, neutrino, hadron, lepton, antiparticle*;

   by sketching and interpreting:

   (ii) paths of scattered particles;

   (iii) electron standing waves in simple models of an atom;

3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:
   (i) motion of a charged particle in magnetic field using $F = qvB$;

   (ii) kinetic and potential energy of a scattered charged particle;

   (iii) $E_{\text{rest}} = mc^2$ and relativistic factor $\gamma = \frac{E_{\text{total}}}{E_{\text{rest}}}$.

FP 2.2 Ionising radiation and risk

This section deals with radioactive decay as a random process, bringing back quantum ideas about the statistical nature of quantum predictions. Changes in nuclear binding energy per nucleon are seen as driving the different types of decay, arising both from the strong forces between nucleons and from the charge on protons.

Opportunities exist to consider the uses and dangers of ionising radiations in, for example, medicine, food hygiene and power production.

Assessable learning outcomes

Candidates should demonstrate evidence of:

1. knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases involving:
   - (i) the nature and effects of ionising radiations: differences in ionising and penetrating power, effects on living tissue;
   - (ii) the stability and decay of nuclei in terms of binding energy; transformation of nucleus on emission of radiation; qualitative variation of binding energy with proton and neutron number ("Nuclear Valley");
   - (iii) nuclear fission and fusion; nuclear power generation;
2. scientific communication and comprehension of the language and representations of physics:
   by making appropriate use of the terms:
   - (i) *nucleon number, proton number, isotope, binding energy, absorbed* and *effective dose, risk*;

   by sketching and interpreting:
   - (ii) plots of binding energy of nuclei against proton and neutron number;
3. quantitative and mathematical skills, knowledge and understanding by making calculations and estimates involving:
   - (i) activity of a sample of radioactive material (eg *related to half-life or decay constant*);
   - (ii) absorbed dose in Gray = energy deposited per unit mass;
   - (iii) effective dose in Sievert = absorbed dose in Gray × quality factor;
   - (iv) energy changes from nuclear transformations: $E_{rest} = mc^2$.

3.6 A2 Unit G496: *Researching Physics*

There are two coursework tasks in the A2 half of the Advanced GCE course. Each provides an opportunity for candidates to work independently, choosing their own topic for study. The tasks require more time from the candidate and it is expected there will be a significant difference in the outcome in comparison with those tasks tackled in the AS course.

Practical Investigation (20 marks)

- A report of an extended investigation of a practical problem related to physics or its applications. The practical investigation should be carried out on any aspect of physics of interest to the candidate.

Research Briefing (10 marks)

- A short written (max 2000 words) and verbal report based on the individual work of a candidate summarising a topic of physics of his or her own choosing that requires the use and synthesis of ideas from different areas of the subject. Assessment criteria include the ability to defend and explain the ideas under questioning.

The Practical Investigation is expected to take two weeks of contact time and the associated independent study time, and the Research Briefing half of that. The two pieces of work together form a coursework portfolio for which a single mark out of 30 is submitted for Unit G496.

Practical Investigation

Each candidate carries out an investigation of a practical problem related to physics or its applications. It is anticipated that candidates will use a wide variety of experiments and techniques in this extended investigation. The most suitable topic is a clearly defined problem, which offers scope for genuine investigation, rather than routine, mechanical and unimaginative work. The topic should afford the candidate the opportunity to use physics at an Advanced GCE standard.

What are the aims?

One of the central features of the course is the emphasis placed on learning physics through the interplay of theory and experiment – so that candidates understand where ideas come from, how they make sense and how they may be used. This is made possible through the range and variety of illustrative experiments, practical demonstrations and investigations that candidates meet during the course. But the importance of the experimental work extends beyond the fulfilment of this objective. Many students will study more science when they leave school or college, and there are some whose careers will involve science. An ability to investigate an unfamiliar situation in a sensible and scientific way is an asset not only to these students, but to all in tackling practical problems in everyday life. To this end, it is hoped that the development of experimental and investigative skills is a significant feature throughout the course.

Building on the AS Quality of Measurement task, it is expected that candidates should use skills developed there, namely:

- recognise the qualities and limitations of measuring instruments, particularly resolution, sensitivity, calibration, response time, stability and zero error;
- identify and estimate the most important source of uncertainty in a measurement;
- make effective plots to display relationships between measured quantities, with appropriate indication of uncertainty;
- use simple plots of the distribution of measured values to estimate the median (or mean) value and the spread (which may be estimated from the range of values), and to identify and account for potential outlying values to quantify and enhance their investigation.

The outcome of the task is a written report that describes the process of the investigation and discusses the conclusions that may be drawn from the practical work done.

Managing the Practical Investigation

The time allocated to this task is ten hours of teaching time and an equivalent amount of time in research and writing up the report.

To begin, the candidate chooses an interesting topic for investigation and carries out some preliminary research – analysing the topic, getting 'a feel' for the relevant factors, considering the selection of appropriate apparatus and measuring techniques, carrying out a literature search, if appropriate – with a view to deciding upon an experimental design that will allow the first set(s) of readings to be taken.

The next stages are to carry out the Investigation in the laboratory, to keep a record of the experimental work and results, in the form of a daily diary, and then to submit the finished report to the teacher for assessment. The assessment should be based on observation of the work done, and on discussion with the candidate, as well as information revealed in the written report.

This task provides an opportunity for candidates to demonstrate their experimental and investigative skills. The assessment addresses all practical aspects of Assessment Objective AO3 How Science Works.

Details of application of the assessment criteria are given in Appendix D.

What are the aims?

This task is designed to assess the ability of a candidate to find information from a variety of sources; to compare, analyse and evaluate the information obtained, and to synthesise and summarise the essential points. The Research Briefing gives candidates an opportunity to be rewarded for:

- working independently;
- drawing together ideas from different aspects of physics;
- selecting and extracting information from a variety of sources;
- applying knowledge and understanding of basic ideas to a new topic;
- translating and interpreting information;
- placing physics ideas in a wider human or social context;
- communicating scientific ideas in continuous prose using good English;
- using published material as part of research.

The nature of the task

This task involves researching a topic of the student's choice to produce a Research Briefing. The student will need to be able to explain the content of the Briefing and to respond to questions that test understanding and mastery of the material. The task is modelled on the professional activity in which members of a research group brief one another on recent work in the field, but adapted to the assessment of A-Level students.

The student should collect, analyse, evaluate and summarise information about a topic that involves a significant range of physics ideas. The information is to be obtained from the candidate's own research using a representative range and variety of sources. These sources might include books, journals, pamphlets, surveys, interviews, libraries, databases and web sites on the internet. The topic may be experimental, theoretical or applied. The topic must be approved in advance by the class teacher. The teacher should ensure that the student chooses a topic that will enable them to fulfil the assessment criteria.

Managing the *Research Briefing* task

This task is expected to take no more than three hours of contact time; this includes that required for students' discussions with the teacher and/or the whole class. Candidates should use around five further hours for research and writing.

The outcome of the task is a written Research Briefing (2–3 pages A4, about 1000 words), in the candidate's own words, that summarises the key results and ideas in the topic studied. This must be based on the candidate's own independent study of sources.

Candidates must keep a list of sources used, which the teacher can sample as necessary to check on authenticity.

The Research Briefing will be sent to Moderators, together with the teacher's report on the student's response to questioning and understanding of the material, and the overall assessment.

Assessing the *Research Briefing*

This task provides an opportunity to assess some aspects of AO1 *Knowledge and understanding* and AO2 *Application of knowledge and understanding of science and AO3 How Science Works*, and has a strong synoptic component. The task and its assessment are designed to make mindless copying of source material unrewarding.

In assessing the work, the teacher must use three sources of evidence:

1. the written Research Briefing;
2. the list of sources used;
3. the candidate's ability to explain the Briefing verbally or by some other appropriate method, and to respond to questions that test understanding of the topic, including questions about sources;

and should use

4. observation of and interaction with the candidate during the preparatory work.

The Research Briefing must:

- be in the candidate's own words;
- explain the main results and ideas in the topic studied, and what they are based on, where relevant how they have developed or changed, or are novel or disputed;
- give arguments for the importance and/or interest of the topic, which may include its relevance to specific issues (eg scientific, technological, ethical, social, economic or environmental).

Details of application of the assessment criteria are given in Appendix D.

4 Schemes of Assessment

4.1 AS GCE Scheme of Assessment

AS GCE Physics B (Advancing Physics) (H159)	
AS Unit G491: *Physics in Action*	
30% of the total AS GCE marks 1 h written paper 60 marks	Candidates answer **all** questions.
	Section A: short questions (approximately **20** marks for this section)
	Section B: structured questions (approximately **40** marks for this section)
AS Unit G492: *Understanding Processes, Experimentation and Data Handling*	
50% of the total AS GCE marks 2 h written paper 100 marks	Candidates answer **all** questions
	Section A: short questions (approximately **20** marks for this section)
	Section B: structured questions (approximately **40** marks for this section)
	Section C: This section contains questions based on an Advance Notice issued to centres some weeks prior to the examination (approximately **40** marks for this section).
AS Unit G493: *Physics in Practice*	
20% of the total AS GCE marks Coursework 30 marks	Candidates carry out two short tasks: a measurement task and a presentation on a researched topic chosen by the candidate.
	Assessment Criteria: please refer to Appendix D at the end of this specification.

4.2 Advanced GCE Scheme of Assessment

Advanced GCE Physics B (Advancing Physics) (H559)	
AS Units as above, Unit G491 being 15% of the total Advanced GCE marks, Unit G492 being 25% of the Advanced GCE marks and Unit G493 being 10% of the Advanced GCE marks.	
A2 Unit G494: *Rise and Fall of the Clockwork Universe*	
15% of the total Advanced GCE marks 1.25 h written paper 60 marks	Candidates answer **all** questions.
	Section A: short questions (approximately **20** marks for this section)
	Section B: structured questions (approximately **40** marks for this section)
	This unit is synoptic.
A2 Unit G495: *Field and Particle Pictures*	
25% of the total Advanced GCE marks 2 h written paper 100 marks	Candidates answer **all** questions.
	Section A: short questions (approximately **20** marks for this section)
	Section B: structured questions (approximately **40** marks for this section)
	Section C: This section contains questions based on an Advance Notice issued to centres some weeks prior to the examination (approximately **40** marks for this section).
	This unit is synoptic.
A2 Unit G496: *Researching Physics*	
10% of the total Advanced GCE marks Coursework 30 marks	Candidates carry out a practical investigation and produce a research briefing on topics chosen by the candidate.
	Assessment Criteria: please refer to Appendix D at the end of this specification.

4.3 Unit Order

The normal order in which the unit assessments could be taken is AS Units G491, G492 and G493 in the first year of study, leading to an AS GCE award, then A2 Units G494, G495 and G496 leading to the Advanced GCE award.

Alternatively, candidates may take a valid combination of unit assessments at the end of their AS GCE or Advanced GCE course in a ‘linear’ fashion.

4.4 Unit Options (at AS/A2)

There are no optional units in the AS GCE specification; for AS GCE Physics B (Advancing Physics) candidates must take AS Units G491, G492 and G493.

There are no optional units in the Advanced GCE specification; for Advanced GCE Physics B (Advancing Physics) candidates take AS Units G491, G492 and G493, *and* A2 Units G494, G495 and G496.

4.5 Synoptic Assessment (A Level GCE)

Synoptic assessment tests the candidates’ understanding of the connections between different elements of the subject.

Synoptic assessment involves the explicit drawing together of knowledge, understanding and skills learned in different parts of the Advanced GCE course. The emphasis of synoptic assessment is to encourage the development of the understanding of the subject as a discipline. All A2 units, whether internally or externally assessed contain synoptic assessment.

Synoptic assessment requires candidates to make and use connections within and between different areas of physics at AS and A2, for example, by:

- applying knowledge and understanding of more than one area to a particular situation or context;
- using knowledge and understanding of principles and concepts in planning experimental and investigative work and in the analysis and evaluation of data;
- bringing together scientific knowledge and understanding from different areas of the subject and applying them.

All A2 units, G494–G496, contain some synoptic assessment. There is particular emphasis on synoptic skills in the internally assessed Investigation and Research Briefing (Unit G496) and in Section C of Unit G495, but Section B questions of Unit G494 will also test the ability to relate issues learned within that unit to the material covered earlier.

4.6 Assessment Availability

There is one examination series each year in June.

From 2014, both AS units and A2 units will be assessed in June only.

4.7 Assessment Objectives

Candidates are expected to demonstrate the following in the context of the content described:

AO1 Knowledge and Understanding

- recognise, recall and show understanding of scientific knowledge;
- select, organise and communicate relevant information in a variety of forms.

AO2 Application of Knowledge and Understanding

- analyse and evaluate scientific knowledge and processes;
- apply scientific knowledge and processes to unfamiliar situations including those related to issues;
- assess the validity, reliability and credibility of scientific information.

AO3 How Science Works

- demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods;
- make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy;
- analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.

AO weightings in AS GCE

Unit	% of AS GCE			Total
	AO1	AO2	AO3	
AS Unit G491: *Physics in Action*	14	10	6	30%
AS Unit G492: *Understanding Processes, Experimentation and Data Handling*	20	16	14	50%
AS Unit G493: *Physics in Practice*	2	6.6	11.4	20%
	36%	32.6%	31.4%	100%

AO weightings in Advanced GCE

Unit	% of Advanced GCE			Total
	AO1	AO2	AO3	
AS Unit G491: *Physics in Action*	7	5	3	15%
AS Unit G492: *Understanding Processes, Experimentation and Data Handling*	10	8	7	25%
AS Unit G493: *Physics in Practice*	1	3.3	5.7	10%
A2 Unit G494: *Rise and Fall of the Clockwork Universe*	5	7	3	15%
A2 Unit G495: *Field and Particle Physics*	8	10	7	25%
A2 Unit G496: *Researching Physics*	1	3.3	5.7	10%
	32%	36.7%	31.3%	100%

4.8 Quality of Written Communication

Quality of Written Communication is assessed in all units and credit may be restricted if communication is unclear.

Candidates will:

- ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear;
- select and use a form and style of writing appropriate to purpose and to complex subject matter;
- organise information clearly and coherently, using specialist vocabulary when appropriate.

5 Technical Information

5.1 Making Unit Entries

Please note that centres must be registered with OCR in order to make any entries, including estimated entries. It is recommended that centres apply to OCR to become a registered centre well in advance of making their first entries. Centres must have made an entry for a unit in order for OCR to supply the appropriate forms or moderator details for coursework.

It is essential that unit entry codes are quoted in all correspondence with OCR. See Sections 4.1 and 4.2 for these unit entry codes.

5.2 Making Qualification Entries

Candidates must enter for qualification certification separately from unit assessment(s). If a certification entry is **not** made, no overall grade can be awarded.

Candidates may enter for:

- AS GCE certification (entry code H159).
- Advanced GCE certification (entry code H559).

A candidate who has completed all the units required for the qualification, and who did not request certification at the time of entry, may enter for certification either in the same examination series (within a specified period after publication of results) or in a later series.

AS GCE certification is available from June 2014.
Advanced GCE certification is available from June 2014.

5.3 Grading

All GCE units are awarded a–e. The Advanced Subsidiary GCE is awarded on the scale A–E with access to an A*. To be awarded an A*, candidates will need to achieve a grade A on their full A level qualification and an A* on the aggregate of their A2 units. Grades are reported on certificates. Results for candidates who fail to achieve the minimum grade (E or e) will be recorded as unclassified (U or u) and this is **not** certificated.

A Uniform Mark Scale (UMS) enables comparison of candidates' performance across units and across series and enables candidates' scores to be put on a common scale for aggregation purposes. The three-unit AS GCE has a total of 300 *uniform* marks and the six-unit Advanced GCE has a total of 600 *uniform* marks.

OCR converts the candidate's raw mark for each unit to a *uniform* mark. The maximum *uniform* mark for any unit depends on that unit's weighting in the specification. In these Physics B (Advancing Physics) specifications the six units of the Advanced GCE specification have *uniform* mark weightings of 15%/25%/10%/15%/25%/10% (and the three units of the AS GCE specification have *uniform* mark weightings of 30%/50%/20%). The *uniform* mark totals are 90/150/60/90/150/60 respectively. Each unit's *raw* mark grade boundary equates to the *uniform* mark boundary at the same grade. Intermediate marks are converted on a pro-rata basis.

Uniform marks correspond to *unit* grades as follows:

(Advanced GCE) Unit Weighting	Maximum Unit Uniform Mark	Unit Grade					
		a	b	c	d	e	u
25%	150	150–120	119–105	104–90	89–75	74–60	59–0
15%	90	90–72	71–63	62–54	53–45	44–36	35–0
10%	60	60–48	47–42	41–36	35–30	29–24	23–0

OCR adds together the unit *uniform* marks and compares these to pre-set boundaries (see the table below) to arrive at *qualification* grades.

Qualification	Qualification Grade					
	A	B	C	D	E	U
AS GCE	300–240	239–210	209–180	179–150	149–120	119–0
Advanced GCE	600–480	479–420	419–360	359–300	299–240	239–0

Candidates achieving at least 480 *uniform* marks in their Advanced GCE, ie grade A, and who also gain at least 270 *uniform* marks in their three A2 units will receive an A* grade.

5.4 Result Enquiries and Appeals

Under certain circumstances, a centre may wish to query the grade available to one or more candidates or to submit an appeal against an outcome of such an enquiry. Enquiries about unit results must be made immediately following the series in which the relevant unit was taken.

For procedures relating to enquires on results and appeals, centres should consult the OCR *Administration Guide for General Qualifications* and the document *Enquiries about Results and Appeals – Information and Guidance for Centres* produced by the Joint Council. Copies of the most recent editions of these papers can be obtained from OCR.

5.5 Shelf-life of Units

Individual unit results, prior to certification of the qualification, have a shelf-life limited only by that of the qualification.

5.6 Unit and Qualification Re-sits

There is no restriction on the number of times a candidate may re-sit each unit before entering for certification for an AS GCE or Advanced GCE.

Candidates may enter for the full qualifications an unlimited number of times.

5.7 Guided Learning Hours

AS GCE Physics B (Advancing Physics) requires **180** guided learning hours in total.
Advanced GCE Physics B (Advancing Physics) requires **360** guided learning hours in total.

5.8 Code of Practice/Subject Criteria/Common Criteria Requirements

These specifications comply in all respects with current *GCSE, GCE, GNVQ and AEA Code of Practice* as available on the QCA website, the subject criteria for GCE Physics and *The Statutory Regulation of External Qualifications 2004*.

5.9 Arrangements for Candidates with Particular Requirements

For candidates who are unable to complete the full assessment or whose performance may be adversely affected through no fault of their own, teachers should consult the *Access Arrangements and Special Consideration: Regulations and Guidance Relating to Candidates who are Eligible for Adjustments in Examinations* produced by the Joint Council. In such cases advice should be sought from OCR as early as possible during the course.

5.10 Prohibited Qualifications and Classification Code

Candidates who enter for the OCR GCE specifications may not also enter for any other GCE specification with the certification title *Physics* in the same examination series.

Every specification is assigned to a national classification code indicating the subject area to which it belongs.

Centres should be aware that candidates who enter for more than one GCE qualification with the same classification code will have only one grade (the highest) counted for the purpose of the School and College Achievement and Attainment Tables.

The classification code for these specifications is 1210.

5.11 Coursework Administration/Regulations

Supervision and Authentication

As with all coursework, teachers must be able to verify that the work submitted for assessment is the candidate's own work. Sufficient work must be carried out under direct supervision to allow the teacher to authenticate the coursework marks with confidence.

Submitting marks to OCR

Centres must have made an entry for a unit in order for OCR to supply the appropriate forms or moderator details for coursework. Coursework administration documents are sent to centres on the basis of estimated entries. Marks may be submitted to OCR either via Interchange, on the computer-printed Coursework Mark Sheets (MS1) provided by OCR (sending the top copy to OCR and the second copy to their allocated moderator) or by EDI (centres using EDI are asked to print a copy of their file and sign it before sending to their allocated moderator).

Deadline for the receipt of coursework marks is:
15 May for the June series.

The awarding body must require centres to obtain from each candidate a signed declaration that authenticates the coursework they produce as their own. For regulations governing coursework, centres should consult the OCR *Administration Guide for General Qualifications.* Further copies of the coursework administration documents are available on the OCR website (www.ocr.org.uk).

Standardisation and Moderation

All internally-assessed coursework is marked by the teacher and internally standardised by the centre. Marks must be submitted to OCR by the agreed date, after which postal moderation takes place in accordance with OCR procedures.

The purpose of moderation is to ensure that the standard for the award of marks in internally-assessed coursework is the same for each centre, and that each teacher has applied the standards appropriately across the range of candidates within the centre.

The sample of work which is submitted to the moderator for moderation must show how the marks have been awarded in relation to the marking criteria.

Minimum Coursework Required

If a candidate submits no work for a unit, then the candidate should be indicated as being absent from that unit on the coursework mark sheets submitted to OCR. If a candidate completes any work at all for that unit then the work should be assessed according to the criteria and marking instructions and the appropriate mark awarded, which may be zero.

6 Other Specification Issues

6.1 Overlap with other Qualifications

There is a small degree of overlap between the content of these specifications and those for other sciences. Examples of overlap include:

Chemistry

- Unit G495 Nuclear Physics: The nuclear atom
- Unit G491 Quantum Physics: Spectra

Science

- Unit G494 Communication by satellite
- Unit G495 Nuclear Physics: The nuclear atom

6.2 Progression from these Qualifications

Throughout the course, candidates are introduced to the ideas of physics and their application to a variety of contexts, both every day and more specialised. Their understanding of How Science Works in physics is deepened.

The specification thus provides a valuable education for candidates who take physics or related subjects no further. It is also an excellent foundation for further study of physics, engineering (and related subjects such as metallurgy and materials science) or other sciences.

6.3 Key Skills Mapping

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

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

Unit	C				AoN			IT			WwO			IOLP			PS		
	.1a	.1b	.2	.3	.1	.2	.3	.1	.2	.3	.1	.2	.3	.1	.2	.3	.1	.2	.3
G491	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G492	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G493				✓	✓	✓	✓	✓	✓	✓									
G494	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G495	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G496		✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓

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

The course develops candidates' understanding of how scientific ideas are accepted and rejected on the basis of empirical evidence, and how scientific controversies can arise from different ways of interpreting such evidence. The course provides many opportunities to discuss the way physics is applied and used, and to evaluate the benefits and drawbacks of scientific and technological developments for individuals, communities and environments. It reflects some of the contributions of physics to culture and some of the influence of culture on physics.

There are opportunities within Advancing Physics to develop ideas about how physics interacts with industrial development and how development of physics is affected by economic decisions including:

- the development of communications technology (Communication in Unit G491);
- the development of new materials (Designer materials in Unit G491);
- the use of imaging to collect and use information (Communication in Unit G491);
- the consequence of developments in transport and travel (Space and time in Unit G492);
- the development of large multinational physics experiments (Fields in Unit G495);
- the generation and distribution of electricity (Fields in Unit G495);
- the design of electromagnetic machines (Fields in Unit G495);
- assessing risk (Fundamental particles in Unit G495).

These opportunities can also be considered as examples of How Science Works (Section 5).

6.5 Sustainable Development, Health and Safety Considerations and European Developments

There are opportunities within Advancing Physics to consider environmental issues in the context of the physics ideas. For example:

- tracking changes in the environment using remote sensing (Communication in Module G491);
- consideration of the impact of the manufacturing, use and disposal of materials (Designer materials in Module G491);
- the effect on the environment of radioactivity, both natural and man-made (Fundamental particles in Module G495).

These opportunities can also be considered as examples of How Science Works (Section 5).

There are opportunities within Advancing Physics to consider issues related to Health Education including:

- use of a variety of imaging techniques in medicine (Communication in Module G491);
- developing materials for use in medicine, such as artificial limbs (Designer materials in Module G491);
- use of radioactivity in diagnosis and treatment and the risks it poses (Fundamental particles in Module G495);
- analysis of risk (Fundamental particles in Module G495).

These opportunities can also be considered as examples of How Science Works (Section 5).

Physics is of its nature international in outlook. European (and other) contributions to physics are explicitly recognised in the course. The value of European co-operation is reflected both in discussion of its role in particle physics (in Module G495) and through historical examples of European cross-fertilisation of ideas, for example in wave theory (in Module G492) and electromagnetism (in Module G495). The Research Briefing could, circumstances permitting, exploit visits abroad (for example, CERN, DESY or Grenoble). In both the presentation Physics in Use (Module G493) and the Research Briefing (in Module G496) students are asked to place the physics in a wider context, which may include the European context.

These opportunities can also be considered as examples of How Science Works (Section 5).

6.6 Avoidance of Bias

OCR has taken great care in the preparation of these specifications and assessment materials to avoid bias of any kind.

6.7 Language

These specifications and associated assessment materials are in English only.

6.8 Disability Discrimination Act Information Relating to these Specifications

AS/A levels often require assessment of a broad range of competences. This is because they are general qualifications and, as such, prepare candidates for a wide range of occupations and higher level courses.

The revised AS/A level qualification and subject criteria were reviewed to identify whether any of the competences required by the subject presented a potential barrier to any disabled candidates. If this was the case, the situation was reviewed again to ensure that such competences were included only where essential to the subject. The findings of this process were discussed with disability groups and with disabled people.

Reasonable adjustments are made for disabled candidates in order to enable them to access the assessments. For this reason, very few candidates will have a complete barrier to any part of the assessment. Information on reasonable adjustments is found in *Access Arrangements and Special Consideration Regulations and Guidance Relating to Candidates who are Eligible for Adjustments in Examinations* produced by the Joint Council (refer to Section 5.9 of this specification).

Candidates who are still unable to access a significant part of the assessment, even after exploring all possibilities through reasonable adjustments, may still be able to receive an award. They would be given a grade on the parts of the assessment they have taken and there would be an indication on their certificate that not all of the competences have been addressed. This will be kept under review and may be amended in the future.

Practical assistants may be used for manipulating equipment and making observations. Technology may help visually impaired students to take readings and make observations.

Appendix A: Performance Descriptions

Performance descriptions have been created for all GCE subjects. They describe the learning outcomes and levels of attainment likely to be demonstrated by a representative candidate performing at the A/B and E/U boundaries for AS and A2.

In practice most candidates will show uneven profiles across the attainments listed, with strengths in some areas compensating in the award process for weaknesses or omissions elsewhere. Performance descriptions illustrate expectations at the A/B and E/U boundaries of the AS and A2 as a whole; they have not been written at unit level.

Grade A/B and E/U boundaries should be set using professional judgement. The judgement should reflect the quality of candidates' work, informed by the available technical and statistical evidence. Performance descriptions are designed to assist examiners in exercising their professional judgement. They should be interpreted and applied in the context of individual specifications and their associated units. However, performance descriptions are not designed to define the content of specifications and units.

The requirement for all AS and A Level specifications to assess candidates' quality of written communication will be met through one or more of the assessment objectives.

The performance descriptions have been produced by the regulatory authorities in collaboration with the awarding bodies.

AS performance descriptions for physics

	Assessment Objective 1	Assessment Objective 2	Assessment Objective 3
Assessment Objectives	**Knowledge and understanding of science and of How science works** Candidates should be able to: • recognise, recall and show understanding of scientific knowledge; • select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of How science works** Candidates should be able to: • analyse and evaluate scientific knowledge and processes; • apply scientific knowledge and processes to unfamiliar situations including those related to issues; • assess the validity, reliability and credibility of scientific information.	**How science works** Candidates should be able to: • demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods; • make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy; • analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.

A/B boundary Performance Descriptions	Candidates characteristically: a) demonstrate knowledge of most principles, concepts and facts from the AS specification; b) show understanding of most principles, concepts and facts from the AS specification; c) select relevant information from the AS specification; d) organise and present information clearly in appropriate forms using scientific terminology.	Candidates characteristically: a) apply principles and concepts in familiar and new contexts involving only a few steps in the argument; b) describe significant trends and patterns shown by data presented in tabular or graphical form and interpret phenomena with few errors and present arguments and evaluations clearly; c) explain and interpret phenomena with few errors and present arguments and evaluations clearly; d) carry out structured calculations with few errors and demonstrate good understanding of the underlying relationships between physical quantities.	Candidates characteristically: a) devise and plan experimental and investigative activities, selecting appropriate techniques; b) demonstrate safe and skilful practical techniques; c) make observations and measurements with appropriate precision and record these methodically; d) interpret, explain, evaluate and communicate the results of their own and others experimental and investigative activities, in appropriate contexts.
E/U boundary Performance Descriptions	Candidates characteristically: a) demonstrate knowledge of some principles and facts from the AS specification; b) show understanding of some principles and facts from the AS specification; c) select some relevant information from the AS specification; d) present information using basic terminology from the AS specification.	Candidates characteristically: a) apply a given principle to material presented in familiar or closely related contexts involving only a few steps in the argument; b) describe some trends or patterns shown by data presented in tabular or graphical form; c) provide basic explanations and interpretations of some phenomena, presenting very limited evaluations; d) carry out some steps within calculations.	Candidates characteristically: a) devise and plan some aspects of experimental and investigative activities; b) demonstrate safe practical techniques; c) make observations and measurements, and record them; d) interpret, explain and communicate some aspects of the results of their own and others experimental and investigative activities, in appropriate contexts.

A2 performance descriptions for physics

	Assessment Objective 1	Assessment Objective 2	Assessment Objective 3
Assessment Objectives	**Knowledge and understanding of science and of How science works** Candidates should be able to: • recognise, recall and show understanding of scientific knowledge; • select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of How science works** Candidates should be able to: • analyse and evaluate scientific knowledge and processes; • apply scientific knowledge and processes to unfamiliar situations including those related to issues; • assess the validity, reliability and credibility of scientific information.	**How science works** Candidates should be able to: • demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods; • make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy; • analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.

<table>
<tr><td>A/B boundary Performance Descriptions</td><td>Candidates characteristically:
a) demonstrate detailed knowledge of most principles, concepts and facts from the A2 specification;
b) show understanding of most principles, concepts and facts from the A2 specification;
c) select relevant information from the A2 specification;
d) organise and present information clearly in appropriate forms using scientific terminology.</td><td>Candidates characteristically:
a) apply principles and concepts in familiar and new contexts involving several steps in the argument;
b) describe significant trends and patterns shown by complex data presented in tabular or graphical form, interpret phenomena with few errors, and present arguments and evaluations clearly and logically;
c) explain and interpret phenomena effectively, presenting arguments and evaluations;
d) carry out extended calculations, with little or no guidance, and demonstrate good understanding of the underlying relationships between physical quantities;
e) select a wide range of facts, principles and concepts from both AS and A2 specifications;
f) link together appropriate facts principles and concepts from different areas of the specification.</td><td>Candidates characteristically:
a) devise and plan experimental and investigative activities, selecting appropriate techniques;
b) demonstrate safe and skilful practical techniques;
c) make observations and measurements with appropriate precision and record these methodically;
d) interpret, explain, evaluate and communicate the results of their own and others' experimental and investigative activities, in appropriate contexts.</td></tr>
<tr><td>E/U boundary Performance Descriptions</td><td>Candidates characteristically:
a) demonstrate knowledge of some principles and facts from the A2 specification;
b) show understanding of some principles and facts from the A2 specification;
c) select some relevant information from the A2 specification;
d) present information using basic terminology from the A2 specification.</td><td>Candidates characteristically:
a) apply given principles or concepts in familiar and new contexts involving a few steps in the argument;
b) describe, and provide a limited explanation of, trends or patterns shown by complex data presented in tabular or graphical form;
c) provide basic explanations and interpretations of some phenomena, presenting very limited arguments and evaluations;
d) carry out routine calculations, where guidance is given;
e) select some facts, principles and concepts from both AS and A2 specifications;
f) put together some facts, principles and concepts from different areas of the specification.</td><td>Candidates characteristically:
a) devise and plan some aspects of experimental and investigative activities;
b) demonstrate safe practical techniques;
c) make observations and measurements and record them;
d) interpret, explain and communicate some aspects of the results of their own and others experimental and investigative activities, in appropriate contexts.</td></tr>
</table>

Appendix B: Data, Formulae and Relationships

The data, formulae and relationships relevant to each unit will be printed as an insert to the examination paper.

Data

Values are given to three significant figures, except where more – or fewer – are useful.

Physical constants

speed of light	c	3.00×10^{8} m s^{-1}
permittivity of free space	ε_0	8.85×10^{-12} C^2 N^{-1} m^{-2} (or F m^{-1})
electric force constant	$k = \frac{1}{4\pi\varepsilon_0}$	8.98×10^{9} N m^2 C^{-2} ($\approx 9 \times 10^{9}$ N m^2 C^{-2})
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N A^{-2} (or H m^{-1})
charge on electron	e	-1.60×10^{-19} C
mass of electron	m_e	9.11×10^{-31} kg = 0.000 55 u
mass of proton	m_p	1.673×10^{-27} kg = 1.007 3 u
mass of neutron	m_n	1.675×10^{-27} kg = 1.008 7 u
mass of alpha particle	m_α	6.646×10^{-27} kg = 4.001 5 u
Avogadro constant	L, N_A	6.02×10^{23} mol^{-1}
Planck constant	h	6.63×10^{-34} J s
Boltzmann constant	k	1.38×10^{-23} J K^{-1}
molar gas constant	R	8.31 J mol^{-1} K^{-1}
gravitational force constant	G	6.67×10^{-11} N m^2 kg^{-2}

Other data

standard temperature and pressure (stp)		273 K (0 °C), 1.01×10^5 Pa (1 atmosphere)
molar volume of a gas at stp	V_m	2.24×10^{-2} m^3
gravitational field strength at the Earth's surface in the UK	g	9.81 N kg^{-1}

Conversion factors

unified atomic mass unit	1u	$= 1.661 \times 10^{-27}$ kg
	1 day	$= 8.64 \times 10^4$ s
	1 year	$\approx 3.16 \times 10^7$ s
	1 light year	$\approx 10^{16}$ m

Mathematical constants and equations

e = 2.72 $\pi = 3.14$ 1 radian = 57.3°

arc = $r\theta$

$\sin\theta \approx \tan\theta \approx \theta$
and $\cos\theta \approx 1$ for small θ

$\ln(x^n) = n \ln x$

$\ln(e^{kx}) = kx$

circumference of circle = $2\pi r$

area of circle = πr^2

surface area of cylinder = $2\pi rh$

volume of cylinder = $\pi r^2 h$

surface area of sphere = $4\pi r^2$

volume of sphere = $\frac{4}{3}\pi r^3$

Prefixes

10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{3}	10^{6}	10^{9}
p	n	μ	m	k	M	G

Formulae and relationships

Imaging and signalling

focal length	$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$	Cartesian convention (object distance u, image distance v, focal length f)
refractive index	$n = \frac{\text{speed of light in vacuo}}{\text{speed of light in medium}}$	(refractive index n)
Noise limitation on maximum bits per sample	$b = \log_2(V_{total}/V_{noise})$	(maximum bits per sample b, total voltage variation V_{total}, noise votage V_{noise})

Electricity

power	$P = IV = I^2R$	(power P, potential difference V, current I)
	$V_{load} = \varepsilon - Ir$	(emf ε, internal resistance r)
conductance	$G = \frac{I}{V}$	(conductance G)
	$G = G_1 + G_2 + ...$	(conductors in parallel)
resistance	$R = R_1 + R_2 + ...$	(resistors in series)
conductivity and resistivity	$G = \frac{\sigma A}{l}$, $R = \frac{\rho l}{A}$	(conductivity σ, resistivity ρ, cross-section A, length l)
capacitance	energy stored $= \frac{1}{2}QV = \frac{1}{2}CV^2$	(charge Q, capacitance C)
discharge of capacitor	$Q = Q_0 e^{-t/RC}$	(initial charge Q_0, time constant RC)
	$\tau = RC$	(time constant τ)

Materials

for a material in tension

Hooke's law	$F = kx$	(tension F, spring constant k, extension x)

$$\text{stress} = \frac{\text{tension}}{\text{cross-sectional area}}$$

$$\text{strain} = \frac{\text{extension}}{\text{original length}}$$

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}$$

$$\text{elastic strain energy} = \tfrac{1}{2}kx^2$$

Gases

kinetic theory of gases

$$pV = \frac{1}{3}Nm\overline{c^2}$$

(pressure p, volume V, number of molecules N, mass of molecule m, mean square speed $\overline{c^2}$)

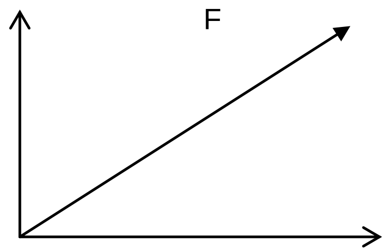
Motion and forces

force = rate of change of momentum

impulse = $F\Delta t$ (force F)

power = Fv (velocity v)

components of a vector in two perpendicular directions



equations for uniformly accelerated motion

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

(initial speed u, final speed v, time taken t, acceleration a, distance travelled s)

for circular motion

$$a = \frac{v^2}{r} \quad F = \frac{mv^2}{r}$$

(radius of circle r)

Energy and thermal effects

efficiency

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}}$$

energy

$$\Delta E = mc\Delta\theta$$

(change in energy ΔE, mass m, specific thermal capacity c, temperature change $\Delta\theta$)

Boltzmann factor

$$e^{(-E/kT)}$$

Waves

	$n\lambda = d\sin\theta$	(on a distant screen from a diffraction grating or double slit; order *n,* wavelength λ, angles of maxima θ)
	$v = f\lambda$	(wave speed *v*, frequency *f*, wavelength λ)

Oscillations

	$\frac{d^2x}{dt^2} = a = -\left(\frac{k}{m}\right)x = -(2\pi f)^2 x$	(acceleration *a*, force per unit displacement *k*, mass *m*, displacement *x* frequency *f*)
	$x = A \cos 2\pi ft$	(amplitude *A*, time *t*)
	$x = A \sin 2\pi ft$	
	$T = 2\pi\sqrt{\frac{m}{k}}$	(periodic time *T*)
	$f = \frac{1}{T}$	
total energy	$E = \frac{1}{2}kA^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$	

Atomic and nuclear physics

radioactive decay	$\frac{\Delta N}{\Delta t} = -\lambda N$	(number *N,* decay constant λ)
	$N = N_0 e^{-\lambda t}$	(initial number N_0)
	$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$	(half-life $T_{\frac{1}{2}}$)

absorbed dose = energy deposited per unit mass

dose equivalent = absorbed dose × quality factor

risk = probability × consequence

expected random variation in N random counts is of the order $\sqrt{N}$

mass–energy relationship	$E_{\text{rest}} = mc^2$	(energy E, mass m, speed of light c)
	$\gamma = \dfrac{1}{\sqrt{1 - v^2/c^2}} = \dfrac{E_{total}}{E_{rest}}$	
energy–frequency relationship for photons	$E = hf$	(photon energy E, Planck constant h, frequency f)
	$\lambda = \dfrac{h}{p}$	(wavelength λ, Planck constant h, momentum p (= mv for slow moving particles))

Field and potential

for all fields	$\text{field strength} = -\frac{dV}{dr} \approx -\frac{\Delta V}{\Delta r}$	(potential gradient dV/dr)
gravitational fields	$g = \frac{F}{m}$	(gravitational field strength g, gravitational force F, mass m)
	$V_{grav} = -\frac{GM}{r}$ $F = \frac{GMm}{r^2}$	(gravitational potential V_{grav}, force F, gravitational constant G, mass M, distance r)
Electric fields	$E = \frac{F}{q}$	(electric field strength E, electric force F, charge q)
	$V_{elec} = \frac{kQ}{r}$ $F = \frac{kQq}{r^2}$	(electric potential V_{elec}, force F, electric force constant k, charge Q, distance r)

Electromagnetism

force on a current carrying conductor	$F = ILB$	(flux density B, current I, length L)
force on a moving charge	$F = qvB$	(charge q, velocity perpendicular to field v)
	$\varepsilon = -\frac{d(N\Phi)}{dt}$	(induced emf ε, flux Φ, number of turns linked N)

Appendix C: Symbols and Units used in Question Papers

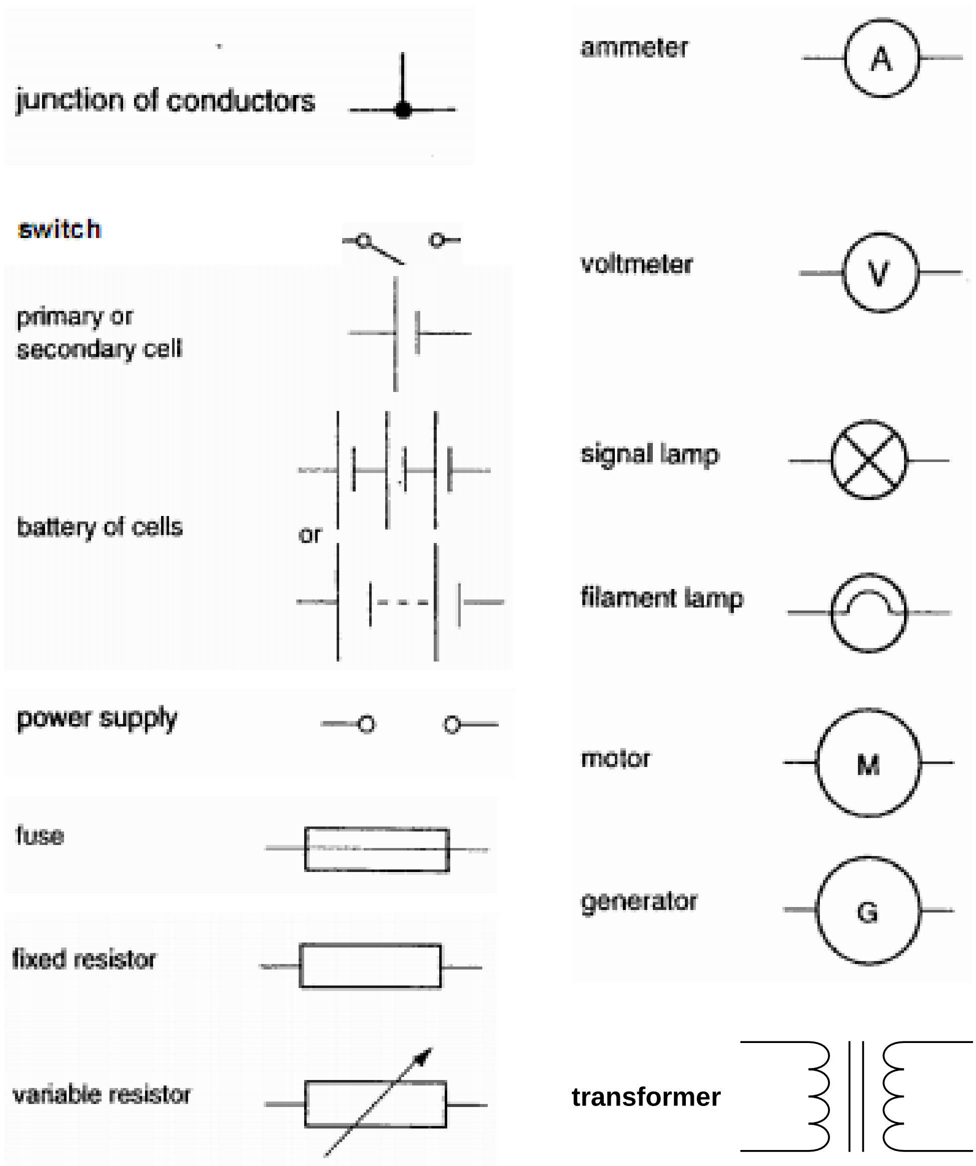
The following list illustrates the symbols and units which are used in the AS and A2 question papers.

Quantity	Usual symbol	Usual unit
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
distance	d	m
displacement	x or s	m
area	A	m^2
volume	V	m^3
density	ρ	kg m^{-3}
speed	u, v, c	m s^{-1}
velocity	u, v, c	m s^{-1}
acceleration	a	m s^{-2}
acceleration of free fall	g	m s^{-2}
force	F	N
momentum	p	N s
work	W	J
energy	E, W	J
potential energy	E_P	J
kinetic energy	E_K	J

Quantity	Usual symbol	Usual unit
energy transferred thermally (heating)	Q	J
power	P	W
pressure	p	Pa
gravitational constant	G	N kg^{-2} m^{2}
gravitational field strength	g	N kg^{-1}
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	rad s^{-1}
period	T	s
frequency	f	Hz
angular frequency	ω	rad s^{-1}
wavelength	λ	m
speed of electromagnetic waves	c	m s^{-1}
electric charge	Q, q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force (emf)	ε	V
resistance	R	Ω
conductance	G	S
resistivity	ρ	Ω m
conductivity	σ	S m^{-1}
electric field strength	E	N C^{-1}, V m^{-1}
permittivity of free space	ε_0	F m^{-1}
capacitance	C	F
time constant	τ	s
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_0	H m^{-1}

Quantity	Usual symbol	Usual Unit
stress		Pa
strain		fraction or per cent
spring constant	k	N m^{-1}
Young modulus	E	Pa
Celsius temperature	θ	°C
specific heat capacity	c	J kg^{-1} K^{-1}
specific latent heat	L	J kg^{-1}
molar gas constant	R	J K^{-1} mol^{-1}
Boltzmann constant	k	J K^{-1}
Avogadro constant	L, N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s
work function energy	W	J, eV
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}
half-life	$T_{1/2}$	s
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
proton number	Z	
nucleon number	A	
neutron number	N	

Standard Electrical Symbols



Appendix D: Coursework

It is intended that the assessment of coursework should be transparent to candidates and straightforward for teachers.

The criteria framework

The criteria consist of a general statement of the intent of the criterion, followed by statements describing levels of performance on a scale 1 to 5, with statements for ratings 1, 3 and 5. Levels 2 and 4 are to be obtained by interpolating.

Assessment of coursework

For each coursework task an Assessment Grid, consisting of a matrix of mark descriptors, is provided in the *Advancing Physics Coursework Handbook*, available from OCR, also available on the OCR website (www.ocr.org.uk). This is used by the assessor to determine the mark to be awarded for each aspect of the assessment.

The criteria provide the framework within which fair-minded and informed decisions can be made that result in ratings that fairly reflect the level of performance, are internally consistent and comparable with those produced in other centres. The person responsible for teaching the students must carry out the assessment. Where several teachers in a centre are involved, it is expected that arrangements will be made to ensure that they are all interpreting the criteria in the same way and that their marking is internally standardised.

It is important to realise that the coursework can be fairly and effectively assessed at this general level, without becoming immersed in detail. The criteria are based on the system successfully used in *Advancing Physics* from its pilot in 1999. The assessment is recorded by annotation of the assessment sheets provided in Appendix D and annotation of the work. The teacher is asked to mark on the assessment sheet the ‘best fit’ descriptor for each of the criteria shown. These judgements are then used to determine the mark out of five awarded for that criterion. If necessary teachers are invited to write a few words about the evidence they are taking into account, both from personal observation and from the written outcome. The record of personal observation should be brief and factual, and will certainly be recollection rather than verbatim reporting.

It is an important feature of the coursework that it is assumed that teacher and candidate will work closely together throughout. This must be done in such a way that it is possible for the teacher to work closely with a candidate *and* allow room for the candidate to perform at all levels.

One significant difference from the scheme used in the preceding specification, in line with the simplification of the coursework demands on candidates and teachers alike, and with the reduced weighting given to coursework, is that the number of strands to be assessed on the five-point scale is reduced to four for the practical tasks, *Quality of Measurement* and the *Practical Investigation*, and to two for the research tasks *Physics in Use* and the *Research Briefing*.

The criteria framework

For the two practical tasks, AS *Quality of Measurement* and A2 *Practical Investigation*, there are four strands of assessment, giving a raw score total of 20 marks for each.

For the two non-practical tasks, AS *Physics in Use* and A2 *Research Briefing*, there are two strands of assessment, giving a raw score total of 10 marks for each.

Each strand consists of a general statement of the intent of the criterion, followed by a matrix of statements describing levels of performance on a scale of 1 to 5, with descriptors of the achievement required for ratings 1, 3 and 5. Levels 2 and 4 are to be obtained by interpolation. Having obtained marks for each such set of statements, the average of the set gives the mark for that strand.

Strands of assessment in the *Quality of Measurement* task

1. Quality of practical work in the laboratory

   Was the practical work done systematically and carefully, showing skill in handling and using apparatus? Were sufficient observations and measurements made to deal with the problem? Were results tabulated carefully in a well-thought-out structure, recorded as they were taken? Were measurements made so as to minimise systematic error, and to reduce uncertainty to the limits allowed by the apparatus?

Level 1	Methods and approach have limitations, with shortcomings in the measurements and observations and limited attention to practical detail.
Level 3	Methods and approach are adequate, with relevant measurements and observations and competent attention to practical detail.
Level 5	Methods and approach are well chosen, with sufficient measurements and observations made to deal with the problem and considerable skill used to obtain them, avoiding unnecessary systematic error.

2. Quality of thought about uncertainty and systematic error, and attempts to improve the measurements

   Were the relevant properties of sensors and measuring instruments studied and assessed systematically and carefully? Was the calibration of instruments considered, and attempted where possible? Was the largest source of uncertainty identified and estimated? Were possible systematic errors considered, and their sign identified? Did the student suggest and try out possible improvements to the experimental method and apparatus used?

Level 1	Measuring instruments are used directly without consideration of their properties; little understanding of the nature of error or uncertainty is shown, and data is limited to a simple set of measurements.
Level 3	Some efforts are made to use measuring instruments to their best advantage; error and uncertainty are considered, possibly with some flaws in approach, and some improvements to experimental method are considered.
Level 5	The relevant properties of measuring instruments are assessed systematically; errors and uncertainty are identified and, where possible, reduced and improvements to the experiment to reduce error and uncertainty are tried out.

3. Quality of communication of physics in the report

Is the report clear, well-ordered and concise, with enough detail to allow someone else to repeat the experiment and obtain similar measurements? Does the report explain clearly the physics of the experiment? Was available ICT used well? Are graphs and tables well-chosen, and presented so as to communicate the findings as well as possible? Is the use of English effective for the purpose?

Level 1	Recording and presentation of data lacks clarity; graphical plots may be inappropriate or incorrect and the report is poorly structured and presented.
Level 3	Data are presented clearly, with some possible inconsistencies in headings, units or significant figures; graphical plots are clear and the report covers most details needed to repeat the experiment.
Level 5	Data are presented clearly and effectively with correct headings, units, tolerances and significant figures; graphical plots are well chosen to display the data to good effect and the report is clear, concise, well-structured and gives all details needed for someone else to repeat the work.

4. Quality of handling and analysis of data

Was data analysed with care and attention, looking for anomalies or unexpected features, and extracting as much information as possible? Does the analysis demonstrate a clear and correct understanding of the physics involved? Were results cross-checked through alternative ways of looking at the data or going back to the apparatus? Was there a clear claim about the outcome, qualified with statements of uncertainty and possible systematic error?

Level 1	Analysis is limited to direct calculations or plots of measured data with possible major flaws in physics, or no attempt to explain the outcomes in terms of physical ideas, and limited attempt to discuss shortcomings in procedures.
Level 3	Some correct calculations of relevant quantities are made with an attempt to discuss the outcomes in terms of physical explanations (including discussion of errors and uncertainties) with minor errors of physics in the analysis. Obvious anomalies are noted.
Level 5	Data are analysed carefully, extracting as much information as possible, leading to a clear claim about the outcome, well-founded in the data and analysis, demonstrating understanding of the physics and relating uncertainties in the conclusions to limitations of the procedures and the measurements made.

Strands of assessment in the *Physics in Use* task

1. Quality of the research and presentation

Does the presentation have a clear context? Has the student worked independently, taking advice where appropriate? Is there a good range of sources, correctly attributed and listed? Is it presented clearly, with good use of illustrations, images and data where appropriate?

Level 1	Some data and facts about the chosen topic are included as a consequence of substantial guidance having been given, with at least one identified source used, and the content of the presentation is related to the title but lacks coherence.
Level 3	The report has a definite focus, with work produced independently with some advice, with some sources identified, and the presentation shows care in ordering and choice of data and illustrations.
Level 5	The presentation has a clear focus, with substantial independent work, taking advice where appropriate, a good range of sources clearly attributed and a clear structure to the presentation that aids clarity.

2. Use and understanding of physics

   Does the presentation include a substantial amount of physics at AS standard? Has the student used a range of material properties at microscopic and macroscopic scales to explain the use of the material in its context? Has the student shown understanding of physics in interpreting and explaining the behaviour of the material in its context?

Level 1	The work is purely descriptive, with aspects of the topic not linked to the topic and in which the physics is mainly descriptive.
Level 3	Relevant physics at AS Level is included in development of the topic, with at least one aspect of the topic linked in terms of physical explanation to the context chosen and explained with some understanding of physics.
Level 5	A substantial amount of physics at AS Level is included, with a range of aspects of the topic linked in terms of physical explanation to the context chosen and explained with a sound understanding of physics.

Strands of assessment in the *Practical Investigation*

1. Approach and experimental skill

   Was the practical work done systematically and carefully, showing skill in handling and using apparatus? Was the work well-planned and done in a careful, methodical way? Was flair or inventiveness shown in doing the job as well as possible? Were sufficient observations and measurements made to deal with the problem?

Level 1	The problem is defined in simple terms, with help needed to get started. The approach has shortcomings or limitations, with little attempt to deal with interfering effects.
Level 3	The definition of the problem is sound but lacking in detail. Methods and approach are adequate and practical work is competent.
Level 5	The problem is clearly analysed in terms of the underlying physics. The methods and approach are well chosen and considerable skill and care is used to obtain results.

2. Progress, independence and use of physical thinking

Is a sound knowledge of physics used to make decisions about the progress of the investigation? Does the student show initiative and make use of advice where appropriate? Are there a good range of experiments, showing progression and development?

Level 1	The work is largely empirical, with the student needing considerable guidance. Experimental work is limited or lacking in demand.
Level 3	Some knowledge of the relevant physics is demonstrated, but not utilised fully in making decisions about the progress of the investigation. Some guidance is needed, or progress is limited by not seeking it when necessary. A relevant set of experiments, or several variables in one experiment, are investigated.
Level 5	Sound knowledge of physics is used to make decisions about the progress of the investigation. Initiative is shown and advice is actively sought and used. A good range of experiments show progression and development. Work is limited only by the time available.

3. Quality and presentation of observations

Does the report explain clearly the physics of the experiment? Were graphs and plots well-chosen and carefully and accurately plotted, with appropriate scales, units, best-fit lines and uncertainty bars, so as to communicate the findings as well as possible? Is the use of English effective for the purpose?

Level 1	Data is limited in quantity or range, and may have shortcomings in presentation; graphical plots may be inappropriate of unclear. The physics of the experiment is poorly explained.
Level 3	A satisfactory range of data is collected and displayed clearly, with possible inconsistencies in headings, units or significant figures; graphical plots are clear and without distracting elements. The report is legible but may have shortcomings in structure, length or quality of English.
Level 5	A good range of data is collected and displayed clearly and correctly; graphical plots are well-chosen to display the data to best effect. The report is concise and well-written and adds value to the investigation with good structuring and clear illustrations and referencing.

4. Conclusions and evaluation

Was physical understanding used to decide on how to analyse data? Was data analysed with care and attention, looking for anomalies or unexpected features, and extracting as much information as possible? Was there a clear claim about the outcome, qualified with statements of uncertainty and possible systematic error? Does the analysis demonstrate a clear and correct understanding of the physics involved?

Level 1	Analysis is limited to direct comparisons or plots of measured data. There is little attempt to explain the outcomes in terms of physical ideas. Discussion of the limitations of the procedures is missing or incorrect.
Level 3	Some valid calculations of derived quantities are attempted, and there is an attempt to explain the outcomes in physical terms with few major errors. The main limitations of the procedures are discussed.
Level 5	The data are analysed in depth to allow the student to propose relationships between variables and discuss the outcomes in terms of relevant physics. Uncertainties in conclusions are discussed in terms of the limitations of the procedures used.

Strands of assessment in the *Research Briefing*

1. Quality of the Research Briefing

   Would this briefing usefully and effectively inform another A-Level student about the essentials of a suitably demanding new topic? Is the understanding that it contains correct, clearly explained and kept to essentials? Is it presented so as to make it straightforward to follow and comprehend?

Level 1	Considerable guidance was needed with the chosen topic. At least one source was identified, and may be used extensively. The briefing is too long, or too short, lacking in relevance in parts and with poor structure and attribution of quotations
Level 3	Some of the potential of the topic was developed and several sources of information were used, perhaps without cross-checking. The briefing is neatly produced and of the required length, but may have flaws of logical structure or in written English.
Level 5	There is a clear focus on a challenging topic, chosen independently, with an appropriate range and variety of sources with cross-checking of information. The briefing is clear, succinct and well-written.

2. Use and understanding of physics

   Is this the student's own work, developing a personal understanding of a new topic that involves substantial use of physics, through seeking out sources, assessing them critically, working on understanding them and expressing the ideas so as to make them understandable to others?

Level 1	The ideas used require little physics at A Level. The briefing is unselective and not reworked into a summary. Questioning reveals that many of the physics ideas are not well understood.
Level 3	The chosen topic requires some knowledge of physics at A Level. There has been some selection of essential ideas, but the focus of essentials is unclear or incomplete. Questions asked are mainly dealt with competently, showing that the physics ideas are mostly understood, although there may be some misunderstandings.
Level 5	The chosen topic requires substantial knowledge of A-Level physics, involving ideas or applications new to the student. Essential ideas have been thoughtfully selected and reworked into a coherent summary. Questioning reveals a good understanding of the physics ideas included.

Appendix E: Mathematical Requirements

In order to be able to develop their skills, knowledge and understanding in physics, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics relevant to the subject as indicated below.

1 Arithmetic and numerical computation:

- (a) recognise and use expressions in decimal and standard form;
- (b) use ratios, fractions and percentages;
- (c) use calculators to find and use power, exponential and logarithmic functions;
- (e) use calculators to handle sin *x*, cos *x*, tan *x* when *x* is expressed in degrees or radians.

2 Handling data:

- (a) use an appropriate number of significant figures;
- (b) find arithmetic means;
- (c) make order of magnitude calculations.

3 Algebra:

- (a) understand and use the symbols: =, <, <<, >>, >, α, ~;
- (b) change the subject of an equation;
- (c) substitute numerical values into algebraic equations using appropriate units for physical quantities;
- (d) solve simple algebraic equations.

4 Graphs:

- (a) translate information between graphical, numerical and algebraic forms;
- (b) plot two variables from experimental or other data;
- (c) understand that $y = mx + c$ represents a linear relationship;
- (d) determine the slope and intercept of a linear graph;

(e) draw and use the slope of a tangent to a curve as a measure of rate of change;

(f) understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or measure it by counting squares as appropriate;

(g) use logarithmic plots to test exponential and power law variations;

(h) sketch simple functions including $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = \sin x$, $y = \cos x$,

$y = e^{-x}$.

5 Geometry and trigonometry:

(a) calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres;

(b) use Pythagoras' theorem, and the angle sum of a triangle;

(c) use sin, cos and tan in physical problems;

(d) understand the relationship between degrees and radians and translate from one to the other.

Appendix F: How Science Works

The Assessment Objectives AO1, AO2 and AO3 in Section 4 refer extensively to *How Science Works*. The skills, knowledge and understanding of *How Science Works* detailed in the QCA AS and A Level criteria for science subjects consist of the following requirements:

1. Use theories, models and ideas to develop and modify scientific explanations.
2. Use knowledge and understanding to pose scientific questions, define scientific problems and present scientific arguments and scientific ideas.
3. Use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems.
4. Communicate information and ideas in appropriate ways using appropriate terminology.
5. Obtaining, analysing and evaluating data:
    a. Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.
    b. Analyse and interpret data to provide evidence, recognising correlations and causal relationships.
    c. Evaluate methodology, evidence and data, and resolve conflicting evidence.
6. Applications, implications and ethical considerations:
    a. Consider applications and implications of science and appreciate their associated benefits and risks.
    b. Consider ethical issues in the treatment of humans, other organisms and the environment.
7. Scientific knowledge in its social context:
    a. Appreciate the tentative nature of scientific knowledge.
    b. Appreciate the role of the scientific community in validating new knowledge and ensuring integrity.
    c. Appreciate the ways in which society uses science to inform decision-making.

These are incorporated into the specification content under five headings

(a) Knowledge and understanding of phenomena, concepts and relationships by describing and explaining.....

This section addresses mainly qualitative aspects of requirements 1, 2 and 3 above.

(b) Scientific communication and comprehension of the language and representations of physics by making appropriate use of the terms ... and by sketching and interpreting graphs and diagrams

This section addresses requirement 4 above within the framework set by requirements 1 to 3, including scientific communication skills, and the analysis of data of requirement 5b.

(c) Quantitative and mathematical skills, knowledge and understanding by making calculations and estimates ... and by showing graphically

This section addresses specific quantitative aspects of requirements 1, 2 and 3 above.

(d) Experimental and data handling skills

This section addresses requirement 5 above, and also those aspects of requirements 1, 2 and 3 associated with practical activities.

(e) Growth and use of scientific knowledge

This section addresses requirements 6 and 7 above, as they apply to the relevant content.

Appendix G: Health and Safety

In UK law, health and safety is the responsibility of the employer. For most establishments entering candidates for AS and Advanced GCE, this is likely to be the local education authority or the governing body. Employees, i.e. teachers and lecturers, have a duty to cooperate with their employer on health and safety matters. Various regulations, but especially the COSHH Regulations 2002 and the Management of Health and Safety at Work Regulations 1999, require that before any activity involving a hazardous procedure or harmful micro-organisms is carried out, or hazardous chemicals are used or made, the employer must provide a risk assessment. A useful summary of the requirements for risk assessment in school or college science can be found at www.ase.org.uk/htm/teacher_zone/safety_in_science_education.php.

For members, the CLEAPSS® guide, *Managing Risk Assessment in Science** offers detailed advice. Most education employers have adopted a range of nationally available publications as the basis for their Model Risk Assessments. Those commonly used include:

- *Safety in Science Education*, DfEE, 1996, HMSO, ISBN 0 11 270915 X.

  Now out of print but sections are available at:
  www.ase.org.uk/htm/teacher_zone/safety_in_science_education.php;

- *Topics in Safety*, 3rd edition, 2001, ASE ISBN 0 86357 316 9;

- *Safeguards in the School Laboratory*, 11th edition, 2006, ASE ISBN 978 0 86357 408 5;

- CLEAPSS® *Hazcards*, 2007 edition and later updates*;

- CLEAPSS® *Laboratory Handbook**;

- *Hazardous Chemicals*, A Manual for Science Education, 1997, SSERC Limited

  ISBN 0 9531776 0 2 (see www.sserc.org.uk/public/hazcd/whats_new.htm).

Where an employer has adopted these or other publications as the basis of their model risk assessments, an individual school or college then has to review them, to see if there is a need to modify or adapt them in some way to suit the particular conditions of the establishment.

Such adaptations might include a reduced scale of working, deciding that the fume cupboard provision was inadequate or the skills of the candidates were insufficient to attempt particular activities safely. The significant findings of such risk assessment should then be recorded, for example on schemes of work, published teachers guides, work sheets, etc. There is no specific legal requirement that detailed risk assessment forms should be completed, although a few employers require this.

Where project work or individual investigations, sometimes linked to work-related activities, are included in specifications this may well lead to the use of novel procedures, chemicals or micro-organisms, which are not covered by the employer's model risk assessments. The employer should have given guidance on how to proceed in such cases. Often, for members, it will involve contacting CLEAPSS® (or, in Scotland, SSERC).

*****These, and other CLEAPSS® publications, are on the CLEAPSS® Science Publications CD-ROM issued annually to members. Note that CLEAPSS® publications are only available to members. For more information about CLEAPSS® go to www.cleapss.org.uk. In Scotland, SSERC (www.sserc.org.uk) has a similar role to CLEAPSS® and there are some reciprocal arrangements.

Appendix H: Support and Resources for Advancing Physics

The course is supported by a full range of resources, both in print and in electronic form, published by Institute of Physics Publishing. There are full colour student texts and students' CD-ROMs for each year of course. The CD-ROM includes a Study Guide to support the candidate throughout the course. Revision is supported by *Summary checkup* lists, Quick check sections in each chapter of the student texts, by the *Checklists* and *A-Z of Key Terms* on the CD-ROMs, and by a specially written *Revision Guide*, available on CD-ROM, consisting of revision notes, summary diagrams and examination past-paper questions with worked solutions, in both PDF and Microsoft Word formats.

The teacher's CD-ROM contains all materials on the student CD-ROMs, including worked solutions to questions, and also provides more detailed support for teaching the course. OCR and the *Advancing Physics* project will provide support for teachers through INSET, a user group network, a newsletter and the dedicated website http://advancingphysics.iop.org/.