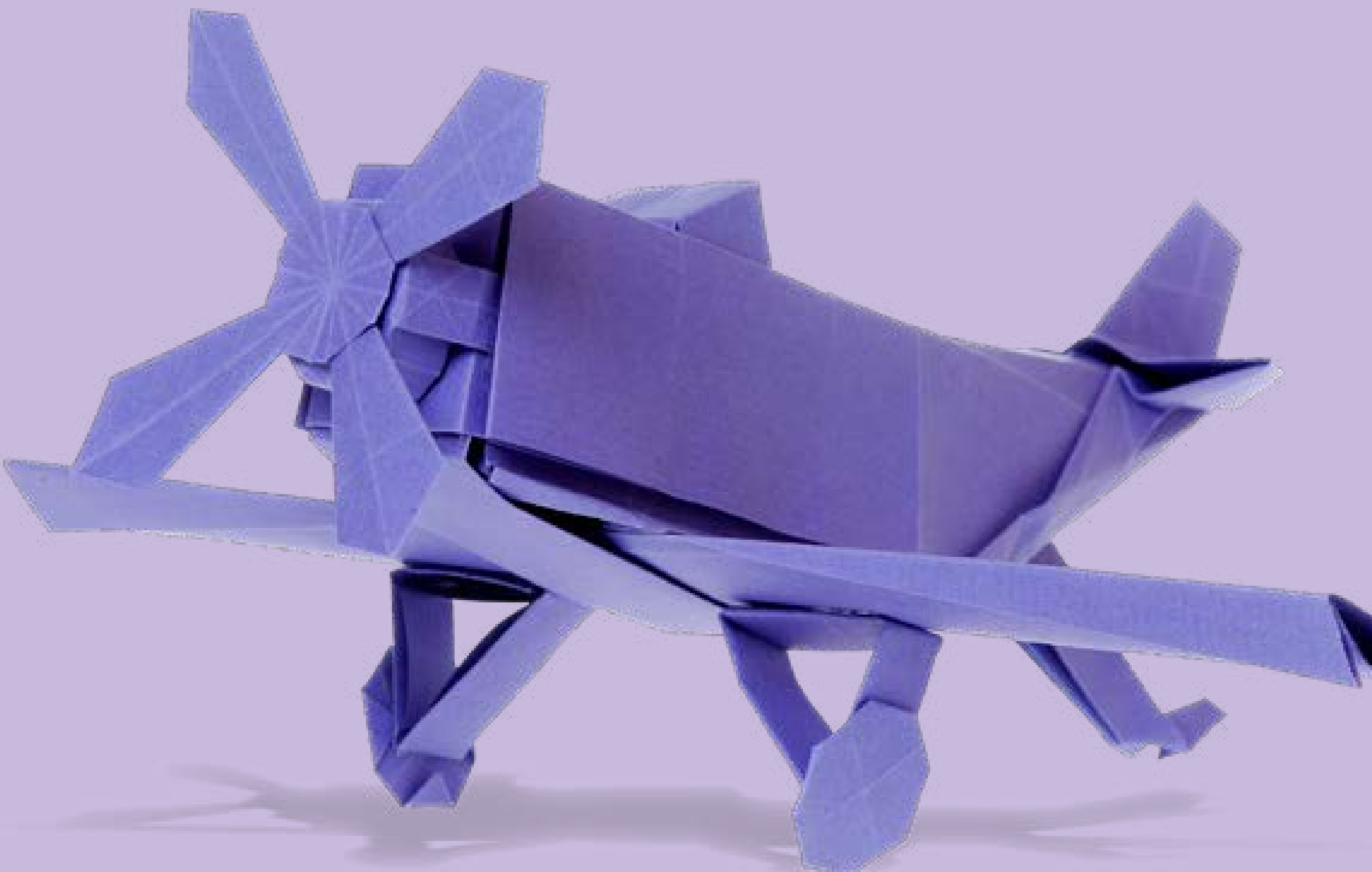
A Level
Physics



Specification

Pearson Edexcel Level 3 Advanced GCE in Physics (9PH0)

First teaching from September 2015

First certification from 2017

Issue 3

Pearson Edexcel Level 3 Advanced GCE in Physics (9PH0)

Specification

First certification 2017

Issue 3

Edexcel, BTEC and LCCI qualifications

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Original origami artwork: Mark Bolitho
Origami photography: Pearson Education Ltd/Naki Kouyioumtzis

ISBN 978 1 446 93602 3

From Pearson's Expert Panel for World Class Qualifications

May 2014

"The reform of the qualifications system in England is a profoundly important change to the education system. Teachers need to know that the new qualifications will assist them in helping their learners make progress in their lives.

When these changes were first proposed we were approached by Pearson to join an 'Expert Panel' that would advise them on the development of the new qualifications.

We were chosen, either because of our expertise in the UK education system, or because of our experience in reforming qualifications in other systems around the world as diverse as Singapore, Hong Kong, Australia and a number of countries across Europe.

We have guided Pearson through what we judge to be a rigorous qualification development process that has included:

- Extensive international comparability of subject content against the highest-performing jurisdictions in the world
- Benchmarking assessments against UK and overseas providers to ensure that they are at the right level of demand
- Establishing External Subject Advisory Groups, drawing on independent subject-specific expertise to challenge and validate our qualifications
- Subjecting the final qualifications to scrutiny against the DfE content and Ofqual accreditation criteria in advance of submission.

Importantly, we have worked to ensure that the content and learning is future oriented. The design has been guided by what is called an 'Efficacy Framework', meaning learner outcomes have been at the heart of this development throughout.

We understand that ultimately it is excellent teaching that is the key factor to a learner's success in education. As a result of our work as a panel we are confident that we have supported the development of qualifications that are outstanding for their coherence, thoroughness and attention to detail and can be regarded as representing world-class best practice."

Sir Michael Barber (Chair)
Chief Education Advisor, Pearson plc

Professor Lee Sing Kong
Director, National Institute of Education, Singapore

Bahram Bekhradnia
President, Higher Education Policy Institute

Professor Jonathan Osborne
Stanford University

Dame Sally Coates
Principal, Burlington Danes Academy

Professor Dr Ursula Renold
Federal Institute of Technology, Switzerland

Professor Robin Coningham
Pro-Vice Chancellor, University of Durham

Professor Bob Schwartz
Harvard Graduate School of Education

Dr Peter Hill
Former Chief Executive ACARA

All titles correct as at May 2014

Summary of Pearson Edexcel Level 3 Advanced GCE in Physics specification Issue 3 changes

Summary of changes made between previous issue and this current issue	**Page number**
Amendment to correct '*chemistry'* to '*physics'*	6
Amendment to correct the use of the negative sign for Activity	23
Amendment to correct the use of the negative sign for Activity	43
'*Subject to confirmation in spring 2015, following trialling*' has been deleted.	49
Amendment to correct 'fiduciary' to 'fiducial' marker.	81
Amendment to correct the use of the negative sign for Activity	101
Amendment to replace *Appendix 10* with revised version	105

Earlier issue(s) show(s) previous changes.

If you need further information on these changes or what they mean, contact us via our website at: qualifications.pearson.com/en/support/contact-us.html.

Introduction

The Pearson Edexcel Level 3 Advanced GCE in Physics is designed for use in schools and colleges. It is part of a suite of GCE qualifications offered by Pearson.

Purpose of the specification

This specification sets out:

- the objectives of the qualification
- any other qualifications that a student must have completed before taking the qualification
- any prior knowledge and skills that the student is required to have before taking the qualification
- any other requirements that a student must have satisfied before they will be assessed or before the qualification will be awarded
- the knowledge and understanding that will be assessed as part of the qualification
- the method of assessment and any associated requirements relating to it
- the criteria against which a student's level of attainment will be measured (such as assessment criteria).

Rationale

The Pearson Edexcel Level 3 Advanced GCE in Physics meets the following purposes, which fulfil those defined by the Office of Qualifications and Examinations Regulation (Ofqual) for GCE qualifications in their *GCE Qualification Level Conditions and Requirements* document, published in April 2014.

The purposes of this qualification are to:

- define and assess achievement of the knowledge, skills and understanding that will be needed by students planning to progress to undergraduate study at UK higher education institutions, particularly (although not only) in the same subject area
- set out a robust and internationally comparable post-16 academic course of study to develop that knowledge, skills and understanding
- enable HE institutions to identify accurately the level of attainment of students
- provide a basis for school and college accountability measures at age 18
- provide a benchmark of academic ability for employers.

Qualification aims and objectives

The aims and objectives of the Pearson Edexcel Level 3 Advanced GCE in Physics are to enable students to develop:

- essential knowledge and understanding of different areas of the subject and how they relate to each other
- a deep appreciation of the skills, knowledge and understanding of scientific methods
- competence and confidence in a variety of practical, mathematical and problem-solving skills
- their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- an understanding of how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society.

The context for the development of this qualification

All our qualifications are designed to meet our World Class Qualification Principles[1] and our ambition to put the student at the heart of everything we do.

We have developed and designed this qualification by:

- reviewing other curricula and qualifications to ensure that it is comparable with those taken in high-performing jurisdictions overseas
- consulting with key stakeholders on content and assessment, including subject associations, higher education academics, teachers and employers to ensure this qualification is suitable for a UK context
- reviewing the legacy qualification and building on its positive attributes.

This qualification has also been developed to meet criteria stipulated by Ofqual in their document *GCE Qualification Level Conditions and Requirements* and by the Department for Education (DfE) in their *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* document, published in April 2014.

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[1] Pearson's World Class Qualification Principles ensure that our qualifications are:

- **demanding**, through internationally benchmarked standards, encouraging deep learning and measuring higher-order skills
- **rigorous**, through setting and maintaining standards over time, developing reliable and valid assessment tasks and processes, and generating confidence in end users of the knowledge, skills and competencies of certified students
- **inclusive**, through conceptualising learning as continuous, recognising that students develop at different rates and have different learning needs, and focusing on progression
- **empowering**, through promoting the development of transferable skills, see *Appendix 1*.

Contents

Qualification at a glance

The Pearson Edexcel Level 3 Advanced GCE in Physics consists of three externally examined papers and the Science Practical Endorsement.

Students must complete all assessments in May/June in any single year.

The content for this qualification is presented in two different ways to provide two distinct, flexible, teaching and learning approaches to suit the needs of different types of student:

- a concept-led approach. This approach begins with a study of the laws, theories and models of physics and finishes with an exploration of their practical applications
- the Salters Horners context-led approach. This approach begins with the consideration of situations and applications that each draws on one or more areas of physics, and then moves on to the underlying physics laws, theories and models. This approach is based on the Salters Horners Advanced Physics (SHAP) Project.

These teaching approaches can be mixed to allow variety in course delivery. Teachers may select the approach that best meets the needs of their students. These different approaches lead to the same common assessment papers for this qualification.

Paper 1: Advanced Physics I	***Paper code: 9PH0/01**
• Externally assessed • Availability: May/June • First assessments: 2017	**30% of the total qualification**

Overview of content

This paper will examine the following topics.

Concept approach

- Working as a Physicist
- Mechanics
- Electric Circuits
- Further Mechanics
- Electric and Magnetic Fields
- Nuclear and Particle Physics

Salters Horners approach

- Working as a Physicist
- Higher, Faster, Stronger (HFS)
- Technology in Space (SPC) (except items 70 and 92–95)
- Digging up the Past (DIG) (except items 83–87)
- Transport on Track (TRA)
- The Medium is the Message (MDM)
- Probing the Heart of Matter (PRO)

Overview of assessment

- Assessment is 1 hour 45 minutes.
- The paper consists of 90 marks.
- The paper may include multiple-choice, short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 40% of the marks across the three papers will be awarded for mathematics at Level 2 or above.
- Students will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.

Paper 2: Advanced Physics II	*Paper code: 9PH0/02
• Externally assessed • Availability: May/June • First assessments: 2017	**30% of the total qualification**

Overview of content

This paper will examine the following topics.

Concept approach

- Working as a Physicist
- Materials
- Waves and Particle Nature of Light
- Thermodynamics
- Space
- Nuclear Radiation
- Gravitational Fields
- Oscillations

Salters Horners approach

- Working as a Physicist
- The Sound of Music (MUS)
- Good Enough to Eat (EAT)
- Technology in Space (SPC) (only items 70 and 92–95)
- Digging up the Past (DIG) (only items 83–87)
- Spare-Part Surgery (SUR)
- Build or Bust? (BLD)
- Reach for the Stars (STA)

Overview of assessment

- Assessment is 1 hour 45 minutes.
- The paper consists of 90 marks.
- The paper may include multiple-choice, short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 40% of the marks across the three papers will be awarded for mathematics at Level 2 or above.
- Students will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.

Paper 3: General and Practical Principles in Physics	*Paper code: 9PH0/03
• Externally assessed • Availability: May/June • First assessments: 2017	**40% of the total qualification**

Overview of content

- Questions in this paper may draw on any of the topics in this specification.
- The paper will include synoptic questions that may draw on two or more different topics.
- The paper will include questions that assess conceptual and theoretical understanding of experimental methods (indirect practical skills) that will draw on students' experiences of the core practicals.

Overview of assessment

- Assessment is 2 hours 30 minutes.
- The paper consists of 120 marks.
- The paper may include, short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 40% of the marks across the three papers will be awarded for mathematics at Level 2 or above.
- Some questions will assess conceptual and theoretical understanding of experimental methods (see *Appendix 5: Working scientifically*).
- Students will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.

Science Practical Endorsement**	***Paper code: 9PH0/04**

- Internally assessed and externally monitored by Pearson
- Availability: May/June
- First assessment: 2017

Overview of content

The assessment of practical skills is a compulsory requirement of the course of study for A level physics. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification.

Students must carry out a minimum of 12 practical activities which, together, meet the requirements of *Appendices 5b* (Practical skills identified for direct assessment and developed through teaching and learning) and *5c* (Use of apparatus and techniques) from the prescribed subject content.

The practical activities prescribed in this specification (the "core practicals") provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, students can also demonstrate these competencies in any additional practical activity undertaken throughout the course of study which covers the requirements of *Appendix 5c*.

Overview of assessment

Students' practical work will be assessed by teachers, using common practical assessment criteria (CPAC) that are consistent across exam boards. These criteria can be found on pages 48-49.

Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade.

Students may work in groups but teachers who award a pass to their students need to be confident of individual students' competence.

The correct application of CPAC to students' work will be monitored through a system of visits to centres. These visits will be coordinated across the exam boards by JCQ, to ensure that all centres are visited regularly, although not necessarily in each science subject.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

**Students will be assessed separately for the Science Practical Endorsement. The Endorsement will not contribute to the overall grade for this qualification, but the result will be recorded on the student's certificate.

Knowledge, skills and understanding

Overview

This qualification may be taught using either a concept approach or a context-led Salters Horners (SHAP) approach. The concept approach begins with a study of the laws, theories and models of physics and then explores their practical applications. The SHAP context-led approach begins with the consideration of applications that draw on one or more areas of physics, and moves on to the underlying laws, theories and models of physics.

These different approaches lead to the same common assessment papers for this qualification.

The content in this section has been arranged to match the concept approach. The same content, reordered for the context-led (SHAP) approach starts on page 26.

Content overview

Students are expected to demonstrate and apply the knowledge, understanding and skills described in the content. They are also expected to analyse, interpret and evaluate a range of scientific information, ideas and evidence using their knowledge, understanding and skills.

To demonstrate their knowledge, students should be able to undertake a range of activities, including the ability to recall, describe and define, as appropriate.

To demonstrate their understanding, students should be able to explain ideas and use their knowledge to apply, analyse, interpret and evaluate, as appropriate.

Students should consider ethical issues relating to the environment, evaluate risks and benefits of applications of physics, and evaluate ways in which society uses physics to inform decision making.

Students should develop their ability to apply mathematical skills to physics throughout the course. These skills include the ability to change the subject of an equation, substitute numerical values and solve algebraic equations using decimal and standard form, ratios, fractions and percentages. Further details of the skills that should be developed are given in *Appendix 6: Mathematical skills and exemplifications*. Students should also be familiar with Système Internationale d'Unités (SI) units and their prefixes, be able to estimate physical quantities and know the limits of physical measurements.

Core practicals will be assessed in the examination.

Students should be encouraged to use ICT throughout the course.

Practical assessment

Practical work is central to any study of physics. For this reason, the specification includes 16 core practical activities which form a thread linking theoretical knowledge and understanding to practical scenarios. In following this thread, students will build on practical skills learned at GCSE, becoming confident practical physicists, handling apparatus competently and safely. Using a variety of apparatus and techniques, they should be able to design and carry out both the core practical activities and their own investigations, collecting data which can be analysed and used to draw valid conclusions.

One important aspect of practical work is the ability to evaluate and manage potential risks. The variety of different practical techniques and scenarios in the core practical activities give students scope to consider risk management in different contexts.

Students should also consider the ethical issues presented by their work in the laboratory, which might include consideration for using minimum quantities of resources; the safe disposal of waste materials; and appropriate consideration for other people involved in their own work or who is working nearby.

Also central to the development of practical skills is the ability to communicate information and ideas through the use of appropriate terminology and ICT. Being able to communicate clearly the findings of practical work is arguably as important as the collection of accurate data.

In carrying out practical activities, students will be expected to use their knowledge and understanding to pose scientific questions which can be investigated through experimental activities. Such activities will enable students to collect data, analyse it for correlations and causal relationships, and to develop solutions to the questions posed.

Questions within written examination papers will aim to assess the knowledge and understanding that students gain while carrying out practical activities, within the context of the 16 core practical activities, as well as in novel practical scenarios. The written papers will test the skills of students in planning practical work – both in familiar and unfamiliar applications – including risk management and the selection of apparatus, with reasons. As part of data handling, students will be expected to use significant figures appropriately, to process data and to plot graphs. In analysing outcomes and drawing valid conclusions, students should critically consider methods and data, including assessing measurement uncertainties and errors.

Examination papers will also provide the opportunity for students to evaluate the wider role of the scientific community in validating new knowledge and the ways in which society as a whole uses science to inform decision making. Within this, they could be asked to consider the implications and applications of physics in terms of associated benefits and risks. Students may also be asked to evaluate methodology, evidence and data and resolve conflicting evidence.

Success in questions that indirectly assess practical skills within written papers will come more naturally to those candidates who have a solid foundation of laboratory practice and who, having carried them out, have a thorough understanding of practical techniques. Therefore, where possible, teachers should consider adding additional experiments to the core practical activities. The 16 core practicals will provide the basis from which some of the Paper 3 examination questions will be drawn.

Teachers should note that the completion of the 16 core practical activities can also provide evidence of competence for the Science Practical Endorsement (please see page 45) and that evidence must be provided for the 12 practical techniques listed in *Appendix 5c* through a minimum of 12 core practical activities.

Concept-led approach

The following section shows how the course may be taught using the concept-led approach. The subset of content required for the Advanced Subsidiary GCE qualification is listed on pages 8–16, while the remainder of the content required for this qualification is listed on pages 17–25.

Topic 1: Working as a Physicist

Throughout their study of physics at this level, students should develop their knowledge and understanding of what it means to work scientifically. They should also develop their competence in manipulating quantities and their units, including making estimates.

Students should gain experience of a wide variety of practical work that gives them opportunities to develop their practical and investigative skills by planning, carrying out and evaluating experiments. Through studying a range of examples, contexts and applications of physics, students should become increasingly knowledgeable of the ways in which the scientific community and society as a whole use scientific ideas and methods, and how the professional scientific community functions.

Students should develop their ability to communicate their knowledge and understanding of physics in ways that are appropriate to the content and to the audience.

It is not intended that this part of the specification be taught as a discrete topic. Rather, the knowledge and skills specified here should pervade the entire course and should be taught using examples and applications from the rest of the specification.

Students should:	
1.	know and understand the distinction between base and derived quantities and their SI units
2.	be able to demonstrate their knowledge of practical skills and techniques for both familiar and unfamiliar experiments
3.	be able to estimate values for physical quantities and use their estimate to solve problems
4.	understand the limitations of physical measurement and apply these limitations to practical situations
5.	be able to communicate information and ideas in appropriate ways using appropriate terminology
6.	understand applications and implications of science and evaluate their associated benefits and risks
7.	understand the role of the scientific community in validating new knowledge and ensuring integrity
8.	understand the ways in which society uses science to inform decision making

Topic 2: Mechanics

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include strobe photography or the use of a video camera to analyse projectile motion, determine the centre of gravity of an irregular rod, investigate the conservation of momentum using light gates and air track.

Mathematical skills that could be developed in this topic include plotting two variables from experimental data, calculating rate of change from a graph showing a linear relationship, drawing and using the slope of a tangent to a curve as a measure of rate of change, distinguishing between instantaneous rate of change and average rate of change and identifying uncertainties in measurements, using simple techniques to determine uncertainty when data are combined, using angles in regular 2D and 3D structures with force diagrams and using sin, cos and tan in physical problems.

This topic may be studied using applications that relate to mechanics, for example, sports.

Students should:	
9.	be able to use the equations for uniformly accelerated motion in one dimension: $s = \frac{(u+v)t}{2}$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
10.	be able to draw and interpret displacement-time, velocity-time and acceleration-time graphs
11.	know the physical quantities derived from the slopes and areas of displacement-time, velocity-time and acceleration-time graphs, including cases of non-uniform acceleration and understand how to use the quantities
12.	understand scalar and vector quantities and know examples of each type of quantity and recognise vector notation
13.	be able to resolve a vector into two components at right angles to each other by drawing and by calculation
14.	be able to find the resultant of two coplanar vectors at any angle to each other by drawing, and at right angles to each other by calculation
15.	understand how to make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity
16.	be able to draw and interpret free-body force diagrams to represent forces on a particle or on an extended but rigid body

Students should:	
17.	be able to use the equation $\sum F = ma$, and understand how to use this equation in situations where *m* is constant (Newton's second law of motion), including Newton's first law of motion where $a = 0$, objects at rest or travelling at constant velocity *Use of the term terminal velocity is expected*
18.	be able to use the equations for gravitational field strength $g = \frac{F}{m}$ and weight $W = mg$
19.	**CORE PRACTICAL 1: Determine the acceleration of a freely-falling object.**
20.	know and understand Newton's third law of motion and know the properties of pairs of forces in an interaction between two bodies
21.	understand that momentum is defined as $p = mv$
22.	know the principle of conservation of linear momentum, understand how to relate this to Newton's laws of motion and understand how to apply this to problems in one dimension
23.	be able to use the equation for the moment of a force, moment of force = Fx where x is the perpendicular distance between the line of action of the force and the axis of rotation
24.	be able to use the concept of centre of gravity of an extended body and apply the principle of moments to an extended body in equilibrium
25.	be able to use the equation for work $\Delta W = F\Delta s$, including calculations when the force is not along the line of motion
26.	be able to use the equation $E_k = \frac{1}{2}mv^2$ for the kinetic energy of a body
27.	be able to use the equation $\Delta E_{grav} = mg\Delta h$ for the difference in gravitational potential energy near the Earth's surface
28.	know, and understand how to apply, the principle of conservation of energy including use of work done, gravitational potential energy and kinetic energy
29.	be able to use the equations relating power, time and energy transferred or work done $P = \frac{E}{t}$ and $P = \frac{W}{t}$
30.	be able to use the equations $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$ and $\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$

Topic 3: Electric Circuits

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include estimating power output of an electric motor, using a digital voltmeter to investigate the output of a potential divider and investigating current/voltage graphs for a filament bulb, thermistor and diode.

Mathematical skills that could be developed in this topic include substituting numerical values into algebraic equations using appropriate units for physical quantities and applying the equation $y = mx + c$ to experimental data.

This topic may be studied using applications that relate to electricity, for example, space technology.

Students should:	
31.	understand that electric current is the rate of flow of charged particles and be able to use the equation $I = \frac{\Delta Q}{\Delta t}$
32.	understand how to use the equation $V = \frac{W}{Q}$
33.	understand that resistance is defined by $R = \frac{V}{I}$ and that Ohm's law is a special case when $I \propto V$ for constant temperature
34.	understand how the distribution of current in a circuit is a consequence of charge conservation
35.	understand how the distribution of potential differences in a circuit is a consequence of energy conservation
36.	be able to derive the equations for combining resistances in series and parallel using the principles of charge and energy conservation, and be able to use these equations
37.	be able to use the equations $P = VI$, $W = VIt$ and be able to derive and use related equations, e.g. $P = I^2R$ and $P = \frac{V^2}{R}$
38.	understand how to sketch, recognise and interpret current-potential difference graphs for components, including ohmic conductors, filament bulbs, thermistors and diodes
39.	be able to use the equation $R = \frac{\rho l}{A}$
40.	**CORE PRACTICAL 2: Determine the electrical resistivity of a material.**
41.	be able to use $I = nqvA$ to explain the large range of resistivities of different materials

Students should:	
42.	understand how the potential along a uniform current-carrying wire varies with the distance along it
43.	understand the principles of a potential divider circuit and understand how to calculate potential differences and resistances in such a circuit
44.	be able to analyse potential divider circuits where one resistance is variable including thermistors and light dependent resistors (LDRs)
45.	know the definition of *electromotive force (e.m.f.)* and understand what is meant by *internal resistance* and know how to distinguish between e.m.f. and *terminal potential difference*
46.	**CORE PRACTICAL 3: Determine the e.m.f. and internal resistance of an electrical cell.**
47.	understand how changes of resistance with temperature may be modelled in terms of lattice vibrations and number of conduction electrons and understand how to apply this model to metallic conductors and negative temperature coefficient thermistors
48.	understand how changes of resistance with illumination may be modelled in terms of the number of conduction electrons and understand how to apply this model to LDRs.

Topic 4: Materials

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic.

Mathematical skills that could be developed in this topic include determining the slope of a linear graph and calculating or estimating, by graphical methods as appropriate, the area between a curve and the *x*-axis and realising the physical significance of the area that has been determined.

This topic may be studied using applications that relate to materials, for example spare-part surgery.

Students should:		
49.	be able to use the equation density $\rho = \frac{m}{V}$	
50.	understand how to use the relationship upthrust = weight of fluid displaced	
51.	a.	be able to use the equation for viscous drag (Stokes' Law), $F = 6\pi\eta rv$.
	b.	understand that this equation applies only to small spherical objects moving at low speeds with *laminar flow* (or in the absence of *turbulent flow*) and that viscosity is temperature dependent
52.	**CORE PRACTICAL 4: Use a falling-ball method to determine the viscosity of a liquid.**	
53.	be able to use the Hooke's law equation, $\Delta F = k\Delta x$, where k is the stiffness of the object	
54.	understand how to use the relationships • *(tensile or compressive) stress = force/cross-sectional area* • *(tensile or compressive) strain= change in length/original length* • *Young modulus = stress/strain*	
55.	a.	be able to draw and interpret force-extension and force-compression graphs
	b.	understand the terms *limit of proportionality, elastic limit, yield point, elastic deformation* and *plastic deformation* and be able to apply them to these graphs
56.	be able to draw and interpret tensile or compressive stress-strain graphs, and understand the term *breaking stress*	
57.	**CORE PRACTICAL 5: Determine the Young modulus of a material**	
58.	be able to calculate the elastic strain energy E_{el} in a deformed material sample, using the equation $\Delta E_{el} = \frac{1}{2}F\Delta x$, and from the area under the force-extension graph *The estimation of area and hence energy change for both linear and non-linear force-extension graphs is expected*.	

Topic 5: Waves and Particle Nature of Light

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include determining the refractive index of solids and liquids, measuring the focal length of a lens, and using models of structures to investigate stress concentrations.

Mathematical skills that could be developed in this topic include using calculators to handle sin *x*, identifying uncertainties in measurements and using simple techniques to determine uncertainty when data are combined.

This topic may be studied using applications that relate to waves and light, for example medical physics.

Students should:	
59.	understand the terms *amplitude*, *frequency*, *period*, *speed* and *wavelength*
60.	be able to use the wave equation $v = f\lambda$
61.	be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules
62.	be able to describe transverse waves
63.	be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves
64.	**CORE PRACTICAL 6: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone.**
65.	know and understand what is meant by *wavefront*, *coherence*, *path difference*, *superposition*, *interference* and *phase*
66.	be able to use the relationship between *phase difference* and *path difference*
67.	know what is meant by a *standing/stationary* wave and understand how such a wave is formed, know how to identify nodes and antinodes
68.	be able to use the equation for the speed of a transverse wave on a string $v = \sqrt{\frac{T}{\mu}}$
69.	**CORE PRACTICAL 7: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire.**
70.	be able to use the equation intensity of radiation $I = \frac{P}{A}$
71.	know and understand that at the interface between medium 1 and medium 2 $n_1 \sin \theta_1 = n_2 \sin \theta_2$ where refractive index is $n = \frac{c}{v}$
72.	be able to calculate *critical angle* using $\sin C = \frac{1}{n}$
73.	be able to predict whether total internal reflection will occur at an interface
74.	understand how to measure the refractive index of a solid material

Students should:	
75.	understand the term *focal length* of converging and diverging lenses
76.	be able to use ray diagrams to trace the path of light through a lens and locate the position of an image
77.	be able to use the equation power of a lens $P = \frac{1}{f}$
78.	understand that for thin lenses in combination $P = P_1 + P_2 + P_3 + \ldots$
79.	know and understand the terms *real image* and *virtual image*
80.	be able to use the equation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ for a thin converging or diverging lens with the real is positive convention
81.	know and understand that magnification = image height/object height and $m = \frac{v}{u}$
82.	understand what is meant by *plane polarisation*
83.	understand what is meant by *diffraction* and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle
84.	be able to use $n\lambda = d\sin\theta$ for a diffraction grating
85.	**CORE PRACTICAL 8: Determine the wavelength of light from a laser or other light source using a diffraction grating.**
86.	understand how diffraction experiments provide evidence for the wave nature of electrons
87.	be able to use the de Broglie equation $\lambda = \frac{h}{p}$
88.	understand that waves can be transmitted and reflected at an interface between media
89.	understand how a pulse-echo technique can provide information about the position of an object and how the amount of information obtained may be limited by the wavelength of the radiation or by the duration of pulses
90.	understand how the behaviour of electromagnetic radiation can be described in terms of a wave model and a photon model, and how these models developed over time
91.	be able to use the equation $E = hf$, that relates the photon energy to the wave frequency
92.	understand that the absorption of a photon can result in the emission of a photoelectron
93.	understand the terms *threshold frequency* and *work function* and be able to use the equation $hf = \phi + \frac{1}{2}mv^2_{max}$
94.	be able to use the *electronvolt* (eV) to express small energies

Students should:	
95.	understand how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation
96.	understand atomic line spectra in terms of transitions between discrete energy levels and understand how to calculate the frequency of radiation that could be emitted or absorbed in a transition between energy levels.

Topic 6: Further Mechanics

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the effect of mass, velocity and radius of orbit on centripetal force.

Mathematical skills that could be developed in this topic include translating between degrees and radians and using trigonometric functions.

This topic may be studied using applications that relate to mechanics, for example, transportation.

Students should:	
97.	understand how to use the equation impulse $= F\Delta t = \Delta p$ (Newton's second law of motion)
98.	**CORE PRACTICAL 9: Investigate the relationship between the force exerted on an object and its change of momentum.**
99.	understand how to apply conservation of linear momentum to problems in two dimensions
100.	**CORE PRACTICAL 10: Use ICT to analyse collisions between small spheres, e.g. ball bearings on a table top.**
101.	understand how to determine whether a collision is elastic or inelastic
102.	be able to derive and use the equation $E_k = \frac{p^2}{2m}$ for the kinetic energy of a non-relativistic particle
103.	be able to express angular displacement in radians and in degrees, and convert between these units
104.	understand what is meant by *angular velocity* and be able to use the equations $v = \omega r$ and $T = \frac{2\pi}{\omega}$
105.	be able to use vector diagrams to derive the equations for centripetal acceleration $a = \frac{v^2}{r} = r\omega^2$ and understand how to use these equations
106.	understand that a resultant force (centripetal force) is required to produce and maintain circular motion
107.	be able to use the equations for centripetal force $F = ma = \frac{mv^2}{r} = mr\omega^2$

Topic 7: Electric and Magnetic Fields

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include using a coulomb meter to measure charge stored and using an electronic balance to measure the force between two charges.

Mathematical skills that could be developed in this topic include sketching relationships which are modelled by $y = k/x$, and $y = k/x^2$, using logarithmic plots to test exponential and power law variations, interpreting logarithmic plots and sketching relationships that are modelled by $y = e^{-x}$.

This topic may be studied using applications that relate to fields, for example, communications and display techniques.

Students should:
108. understand that an electric field (force field) is defined as a region where a charged particle experiences a force
109. understand that electric field strength is defined as $E = \frac{F}{Q}$ and be able to use this equation
110. be able to use the equation $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$, for the force between two charges
111. be able to use the equation $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the electric field due to a point charge
112. know and understand the relation between electric field and electric potential
113. be able to use the equation $E = \frac{V}{d}$ for an electric field between parallel plates
114. be able to use $V = \frac{Q}{4\pi\varepsilon_0 r}$ for a radial field
115. be able to draw and interpret diagrams using field lines and equipotentials to describe radial and uniform electric fields
116. understand that capacitance is defined as $C = \frac{Q}{V}$ and be able to use this equation
117. be able to use the equation $W = \frac{1}{2}QV$ for the energy stored by a capacitor, be able to derive the equation from the area under a graph of potential difference against charge stored and be able to derive and use the equations $W = \frac{1}{2}CV^2$ and $W = \frac{\frac{1}{2}Q^2}{C}$
118. be able to draw and interpret charge and discharge curves for resistor capacitor circuits and understand the significance of the time constant *RC*

Students should:
119. **CORE PRACTICAL 11: Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through a resistor.**
120. be able to use the equation $Q = Q_0 e^{-t/RC}$ and derive and use related equations for exponential discharge in a resistor-capacitor circuit, $I = I_0 e^{-t/RC}$, and $V = V_0 e^{-t/RC}$ and the corresponding log equations $\ln Q = \ln Q_0 - \frac{t}{RC}$, $\ln I = \ln I_0 - \frac{t}{RC}$ and $\ln V = \ln V_0 - \frac{t}{RC}$
121. understand and use the terms *magnetic flux density B*, *flux* ϕ and *flux linkage N*ϕ
122. be able to use the equation $F = Bqv \sin\theta$ and apply Fleming's left-hand rule to charged particles moving in a magnetic field
123. be able to use the equation $F = BIl \sin\theta$ and apply Fleming's left-hand rule to current carrying conductors in a magnetic field
124. understand the factors affecting the e.m.f. induced in a coil when there is relative motion between the coil and a permanent magnet
125. understand the factors affecting the e.m.f. induced in a coil when there is a change of current in another coil linked with this coil
126. understand how to use Lenz's law to predict the direction of an induced e.m.f., and how the prediction relates to energy conservation
127. understand how to use Faraday's law to determine the magnitude of an induced e.m.f. and be able to use the equation that combines Faraday's and Lenz's laws $\mathcal{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$
128. understand what is meant by the terms *frequency*, *period, peak value* and *root-mean-square value* when applied to alternating currents and potential differences
129. be able to use the equations $V_{rms} = \frac{V_0}{\sqrt{2}}$ and $I_{rms} = \frac{I_0}{\sqrt{2}}$

Topic 8: Nuclear and Particle Physics

Mathematical skills that could be developed in this topic include using appropriate units in calculations.

Students should:
130. understand what is meant by *nucleon number (mass number)* and *proton number (atomic number)*
131. understand how large-angle alpha particle scattering gives evidence for a nuclear model of the atom and how our understanding of atomic structure has changed over time
132. understand that electrons are released in the process of thermionic emission and how they can be accelerated by electric and magnetic fields
133. understand the role of electric and magnetic fields in particle accelerators (linac and cyclotron) and detectors (general principles of ionisation and deflection only)
134. be able to derive and use the equation $r = \frac{p}{BQ}$ for a charged particle in a magnetic field
135. be able to apply conservation of charge, energy and momentum to interactions between particles and interpret particle tracks
136. understand why high energies are required to investigate the structure of nucleons
137. be able to use the equation $\Delta E = c^2 \Delta m$ in situations involving the creation and annihilation of matter and antimatter particles
138. be able to use MeV and GeV (energy) and MeV/c^2, GeV/c^2 (mass) and convert between these and SI units
139. understand situations in which the relativistic increase in particle lifetime is significant (use of relativistic equations not required)
140. know that in the standard quark-lepton model particles can be classified as: • baryons (e.g. neutrons and protons) which are made from three quarks • mesons (e.g. pions) which are made from a quark and an antiquark • leptons (e.g. electrons and neutrinos) which are fundamental particles • photons and that the symmetry of the model predicted the top quark
141. know that every particle has a corresponding antiparticle and be able to use the properties of a particle to deduce the properties of its antiparticle and vice versa
142. understand how to use laws of conservation of charge, baryon number and lepton number to determine whether a particle interaction is possible
143. be able to write and interpret particle equations given the relevant particle symbols.

Topic 9: Thermodynamics

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the relationship between the volume and temperature of a fixed mass of gas.

Mathematical skills that could be developed in this topic include substituting numerical values into algebraic equations using appropriate units for physical quantities.

This topic may be studied using applications that relate to thermodynamics, for example space technology.

Students should:
144. be able to use the equations $\Delta E = mc\Delta\theta$ and $\Delta E = L\Delta m$
145. **CORE PRACTICAL 12: Calibrate a thermistor in a potential divider circuit as a thermostat.**
146. **CORE PRACTICAL 13: Determine the specific latent heat of a phase change.**
147. understand the concept of *internal energy* as the random distribution of potential and kinetic energy amongst molecules
148. understand the concept of *absolute zero* and how the average kinetic energy of molecules is related to the absolute temperature
149. be able to derive and use the equation $pV = \frac{1}{3}Nm\langle c^2\rangle$ using the kinetic theory model
150. be able to use the equation $pV = NkT$ for an ideal gas
151. **CORE PRACTICAL 14: Investigate the relationship between pressure and volume of a gas at fixed temperature.**
152. be able to derive and use the equation $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
153. understand what is meant by a *black body radiator* and be able to interpret radiation curves for such a radiator
154. be able to use the Stefan-Boltzmann law equation $L = \sigma AT^4$ for black body radiators
155. be able to use Wien's law equation $\lambda_{max}T = 2.898 \times 10^{-3}$ m K for black body radiators.

Topic 10: Space

Mathematical skills that could be developed in this topic include using approximations and sketching relationships which are modelled by $y = k/x^2$.

This topic may be studied using contexts such as the formation and evolution of stars and the history and future of the universe.

Students should:
156. be able to use the equation, intensity $I = \frac{L}{4\pi d^2}$ where L is luminosity and d is distance from the source
157. understand how astronomical distances can be determined using trigonometric parallax
158. understand how astronomical distances can be determined using measurements of intensity received from standard candles (objects of known luminosity)
159. be able to sketch and interpret a simple Hertzsprung-Russell diagram that relates stellar luminosity to surface temperature
160. understand how to relate the Hertzsprung-Russell diagram to the life cycle of stars
161. understand how the movement of a source of waves relative to an observer/detector gives rise to a shift in frequency (Doppler effect)
162. be able to use the equations for redshift $z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer and $v = H_0 d$ for objects at cosmological distances
163. understand the controversy over the age and ultimate fate of the universe associated with the value of the Hubble constant and the possible existence of dark matter.

Topic 11: Nuclear Radiation

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include measuring the half-life of a radioactive material.

Mathematical skills that could be developed in this topic include applying the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example. $\Delta x / \Delta t = -\lambda x$ using a graphical method or spreadsheet modelling and understanding probability in the context of radioactive decay.

This topic may be studied using applications that relate to nuclear radiation, for example nuclear power stations and medical physics.

Students should:
164. understand the concept of *nuclear binding* energy and be able to use the equation $\Delta E = c^2 \Delta m$ in calculations of nuclear mass (including mass deficit) and energy
165. use the *atomic mass unit (u)* to express small masses and convert between this and SI units
166. understand the processes of nuclear fusion and fission with reference to the binding energy per nucleon curve
167. understand the mechanism of nuclear fusion and the need for very high densities of matter and very high temperatures to bring about and maintain nuclear fusion
168. understand that there is background radiation and how to take appropriate account of it in calculations
169. understand the relationships between the nature, penetration, ionising ability and range in different materials of nuclear radiations (alpha, beta and gamma)
170. be able to write and interpret nuclear equations given the relevant particle symbols
171. **CORE PRACTICAL 15: Investigate the absorption of gamma radiation by lead.**
172. understand the spontaneous and random nature of nuclear decay
173. be able to determine the half-lives of radioactive isotopes graphically and be able to use the equations for radioactive decay: activity $A = \lambda N$, $\frac{dN}{dt} = -\lambda N$, $\lambda = \frac{\ln 2}{t_{1/2}}$, $N = N_0 e^{-\lambda t}$ and $A = A_0 e^{-\lambda t}$ and derive and use the corresponding log equations.

Topic 12: Gravitational Fields

Mathematical skills that could be developed in this topic include sketching relationships that are modelled by $y = k/x$, $y = k/x^2$.

Students should:
174. understand that a gravitational field (force field) is defined as a region where a mass experiences a force
175. understand that gravitational field strength is defined as $g = \frac{F}{m}$ and be able to use this equation
176. be able to use the equation $F = \frac{Gm_1m_2}{r^2}$ (Newton's law of universal gravitation)
177. be able to derive and use the equation $g = \frac{Gm}{r^2}$ for the gravitational field due to a point mass
178. be able to use the equation $V_{grav} = \frac{-Gm}{r}$ for a radial gravitational field
179. be able to compare electric fields with gravitational fields
180. be able to apply Newton's laws of motion and universal gravitation to orbital motion.

Topic 13: Oscillations

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include measuring gravitational field strength using a simple pendulum and measuring a spring constant from simple harmonic motion.

Mathematical skills that could be developed in this topic include sketching relationships that are modelled by *y* = sin *x*, *y* = cos *x*.

Students should:
181. understand that the condition for simple harmonic motion is $F = -kx$, and hence understand how to identify situations in which simple harmonic motion will occur
182. be able to use the equations $a = -\omega^2 x$, $x = A\cos \omega t$, $v = -A\omega \sin \omega t$, $a = -A\omega^2 \cos \omega t$, and $T = \frac{1}{f} = \frac{2\pi}{\omega}$ and $\omega = 2\pi f$ as applied to a simple harmonic oscillator
183. be able to use equations for a simple harmonic oscillator $T = 2\pi\sqrt{\frac{m}{k}}$, and a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$
184. be able to draw and interpret a displacement–time graph for an object oscillating and know that the gradient at a point gives the velocity at that point
185. be able to draw and interpret a velocity–time graph for an oscillating object and know that the gradient at a point gives the acceleration at that point
186. understand what is meant by *resonance*
187. **CORE PRACTICAL 16: Determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses.**
188. understand how to apply conservation of energy to damped and undamped oscillating systems
189. understand the distinction between *free* and *forced oscillations*
190. understand how the amplitude of a forced oscillation changes at and around the natural frequency of a system and know, qualitatively, how damping affects resonance
191. understand how damping and the plastic deformation of ductile materials reduce the amplitude of oscillation.

Salters Horners approach

The following section shows how the course may be taught using the Salters Horners (SHAP) context-led approach. The subset of content required for the Advanced Subsidiary GCE qualification is listed on pages 27–35, while the remainder of the content required for this qualification is listed on pages 36–44.

Working as a Physicist

Throughout their study of physics at this level, students should develop their knowledge and understanding of what it means to work scientifically. They should also develop their competence in manipulating quantities and their units, including making estimates. They should experience a wide variety of practical work, giving them opportunities to develop their practical and investigative skills by planning, carrying out and evaluating experiments. Through studying a range of examples, contexts and applications of physics, students should become increasingly knowledgeable of the ways in which the scientific community, and society as a whole, use scientific ideas and methods, and how the professional scientific community functions. They should develop their abilities to communicate their knowledge and understanding of physics in ways that are appropriate to the content and to the audience.

It is not intended that this part of the specification is taught as a discrete topic. Rather, the knowledge and skills specified here should pervade the entire course and should be taught using examples and applications from throughout the rest of the specification.

Students should:	
1.	know and understand the distinction between base and derived quantities and their SI units
2.	be able to demonstrate their knowledge of practical skills and techniques for both familiar and unfamiliar experiments
3.	be able to estimate values for physical quantities and use their estimate to solve problems
4.	understand the limitations of physical measurement and apply these limitations to practical situations
5.	be able to communicate information and ideas in appropriate ways using appropriate terminology
6.	understand applications and implications of science and evaluate their associated benefits and risks
7.	understand the role of the scientific community in validating new knowledge and ensuring integrity
8.	understand the ways in which society uses science to inform decision making

Higher, Faster, Stronger (HFS)

An exploration of the physics behind a variety of sports, using use video clips, ICT and laboratory practical activities:

- graphs and equations of motion in sprinting and jogging
- work and power in weightlifting
- forces and equilibrium in rock climbing
- moments and equilibrium in gymnastics
- forces and projectiles in tennis and ski-jumping
- force and energy in bungee jumping.

There are opportunities for students to collect and analyse data using a variety of methods, and to communicate their knowledge and understanding using appropriate terminology.

Students should:	
9.	be able to use the equations for uniformly accelerated motion in one dimension: $s = \frac{(u+v)t}{2}$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
10.	be able to draw and interpret displacement-time, velocity-time and acceleration-time graphs
11.	know the physical quantities derived from the slopes and areas of displacement-time, velocity-time and acceleration-time graphs, including cases of non-uniform acceleration, and understand how to use the quantities
12.	understand scalar and vector quantities, and know examples of each type of quantity and recognise vector notation
13.	be able to resolve a vector into two components at right angles to each other by drawing and by calculation
14.	be able to find the resultant of two coplanar vectors at any angle to each other by drawing, and at right angles to each other by calculation
15.	understand how to make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity
16.	be able to draw and interpret free-body force diagrams to represent forces on a particle or on an extended but rigid body
17.	be able to use the equation $\sum F = ma$, and understand how to use this equation in situations where m is constant (Newton's second law of motion), including Newton's first law of motion where a = 0, objects at rest or travelling at constant velocity Use of the term *terminal velocity* is expected
18.	be able to use the equations for gravitational field strength $g = \frac{F}{m}$ and weight $W = mg$

Students should:	
19.	**CORE PRACTICAL 1: Determine the acceleration of a freely-falling object.**
20.	know and understand Newton's third law of motion, and know the properties of pairs of forces in an interaction between two bodies
21.	understand that momentum is defined as $p = mv$
22.	know the principle of conservation of linear momentum, understand how to relate this to Newton's laws of motion and understand how to apply this to problems in one dimension
23.	be able to use the equation for the moment of a force, moment of force $= Fx$ where *x* is the perpendicular distance between the line of action of the force and the axis of rotation
24.	be able to use the concept of centre of gravity of an extended body and apply the principle of moments to an extended body in equilibrium
25.	be able to use the equation for work $\Delta W = F\Delta s$, including calculations when the force is not along the line of motion
26.	be able to use the equation $E_k = \frac{1}{2}mv^2$ for the kinetic energy of a body
27.	be able to use the equation $\Delta E_{\mathrm{grav}} = mg\Delta h$ for the difference in gravitational potential energy near the Earth's surface
28.	know, and understand how to apply, the principle of conservation of energy, including use of work done, gravitational potential energy and kinetic energy
29.	be able to use the equations relating power, time and energy transferred or work done $P = \frac{E}{t}$ and $P = \frac{W}{t}$
30.	be able to use the equations $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$ and $\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$

The Sound of Music (MUS)

A study of music and recorded sound, focusing on the production of sound by musical instruments and the operation of a CD/DVD player:

- synthesised and 'natural' sounds
- travelling waves and standing/stationary waves in string and wind instruments
- reading a CD/DVD by laser.

Waves and photons are used to model the behaviour of light.

There are opportunities for students to develop ICT skills and other skills relating to investigation and to communication.

Students should:	
59.	understand the terms *amplitude*, *frequency*, *period*, *speed* and *wavelength*
60.	be able to use the wave equation $v = f\lambda$
61.	be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules
62.	be able to describe transverse waves
63.	be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves
64.	**CORE PRACTICAL 6: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone.**
65.	know and understand what is meant by *wavefront*, *coherence*, *path difference*, *superposition*, *interference* and *phase*
66.	be able to use the relationship between *phase difference* and *path difference*
67.	know what is meant by a *standing/stationary wave* and understand how such a wave is formed, know how to identify nodes and antinodes
68.	be able to use the equation for the speed of a transverse wave on a string $v = \sqrt{\frac{T}{\mu}}$
69.	**CORE PRACTICAL 7: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire.**
90.	understand how the behaviour of electromagnetic radiation can be described in terms of a wave model and a photon model, and how these models developed over time
91.	be able to use the equation $E = hf$, that relates the photon energy to the wave frequency
96.	understand atomic line spectra in terms of transitions between discrete energy levels and understand how to calculate the frequency of radiation that could be emitted or absorbed in a transition between energy levels.

Good Enough to Eat (EAT)

A case study of the production of sweets and biscuits:

- measuring and controlling the flow of a viscous liquid
- mechanical testing of products
- using refractometry and polarimetry to monitor sugar concentration.

There are opportunities for students to develop practical techniques and thus to carry out experimental and investigative activities.

Students should:
49. be able to use the equation density $\rho = \frac{m}{V}$
50. understand how to use the relationship upthrust = weight of fluid displaced
51. a. be able to use the equation for viscous drag (Stokes' Law), $F = 6\pi\eta rv$. b. understand that this equation applies only to small spherical objects moving at low speeds with *laminar flow* (or in the absence of *turbulent flow*) and that viscosity is temperature dependent
52. **CORE PRACTICAL 4: Use a falling-ball method to determine the viscosity of a liquid.**
53. be able to use the Hooke's law equation, $\Delta F = k\Delta x$, where k is the stiffness of the object
55. a. be able to draw and interpret force-extension and force-compression graphs b. understand the terms limit of proportionality, *elastic limit, yield point, elastic deformation and plastic deformation* and be able to apply them to these graphs
71. know and understand that at the interface between medium 1 and medium 2 $n_1 \sin\theta_1 = n_2 \sin\theta_2$ where refractive index is $n = \frac{c}{v}$
72. be able to calculate *critical angle* using $\sin C = \frac{1}{n}$
73. be able to predict whether total internal reflection will occur at an interface
74. understand how to measure the refractive index of a solid material
82. understand what is meant by *plane polarisation*.

Technology in Space (SPC)

The focus is on a satellite whose instruments are run from a solar power supply:

- illuminating solar cells
- operation of photocells
- design and operation of dc circuits
- combining sources of e.m.f.

Mathematical models are developed to describe ohmic behaviours and the variation of resistance with temperature. Simple conceptual models are used for the flow of charge in a circuit, for the operation of a photocell, and for the variation of resistance with temperature.

Waves and photons are used to model the behaviour of light and there is some discussion of the historical development of the photoelectric effect.

There are opportunities to develop ICT skills using the internet, spreadsheets and software for data analysis and display.

Students should:	
31.	understand that electric current is the rate of flow of charged particles and be able to use the equation $I = \frac{\Delta Q}{\Delta t}$
32.	understand how to use the equation $V = \frac{W}{Q}$
33.	understand that resistance is defined by $R = \frac{V}{I}$ and that Ohm's law is a special case when $I \propto V$ for constant temperature
34.	understand how the distribution of current in a circuit is a consequence of charge conservation
35.	understand how the distribution of potential differences in a circuit is a consequence of energy conservation
36.	be able to derive the equations for combining resistances in series and parallel using the principles of charge and energy conservation, and be able to use these equations
37.	be able to use the equations $P = VI$, $W = VIt$ and be able to derive and use related equations, e.g. $P = I^2R$ and $P = \frac{V^2}{R}$
38.	understand how to sketch, recognise and interpret current-potential difference graphs for components, including ohmic conductors, filament bulbs, thermistors and diodes
45.	know the definition of *electromotive force (e.m.f.)* and understand what is meant by *internal resistance* and know how to distinguish between e.m.f. and *terminal potential difference*
46.	**CORE PRACTICAL 3: Determine the e.m.f. and internal resistance of an electrical cell.**

Students should:	
47.	understand how changes of resistance with temperature may be modelled in terms of lattice vibrations and number of conduction electrons and understand how to apply this model to metallic conductors and negative temperature coefficient thermistors
48.	understand how changes of resistance with illumination may be modelled in terms of the number of conduction electrons and understand how to apply this model to LDRs
70.	be able to use the equation intensity of radiation $I = \frac{P}{A}$
92.	understand that the absorption of a photon can result in the emission of a photoelectron
93.	understand the terms *threshold frequency* and *work function* and be able to use the equation $hf = \phi + \frac{1}{2}mv_{\max}^2$
94.	be able to use the *electronvolt* (eV) to express small energies
95.	understand how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Digging up the Past (DIG)

The excavation of an archaeological site, from geophysical surveying to artefact analysis:

- resistivity surveying
- artefact analysis by X-ray imaging and diffraction
- artefact analysis by electron microscopy.

Waves are used to model the behaviour of electromagnetic radiation and electrons.

Through a variety of practical and ICT activities, there are opportunities to revisit, review and build on work from previous topics.

Students should:	
39.	be able to use the equation $R = \frac{\rho l}{A}$
40.	**CORE PRACTICAL 2: Determine the electrical resistivity of a material.**
41.	be able to use $I = nqvA$ to explain the large range of resistivities of different materials
42.	understand how the potential along a uniform current-carrying wire varies with the distance along it
43.	understand the principles of a potential divider circuit and understand how to calculate potential differences and resistances in such a circuit
44.	be able to analyse potential divider circuits where one resistance is variable including thermistors and light dependent resistors (LDRs)
83.	understand what is meant by *diffraction* and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle
84.	be able to use $n\lambda = dsin\theta$ for a diffraction grating
85.	**CORE PRACTICAL 8: Determine the wavelength of light from a laser or other light source using a diffraction grating.**
86.	understand how diffraction experiments provide evidence for the wave nature of electrons
87.	be able to use the de Broglie equation $\lambda = \frac{h}{p}$

Spare-Part Surgery (SUR)

A study of the physics associated with spare-part surgery for joint replacements and lens implants:

- mechanical properties of bone and replacement materials
- lens implants and the optical system of the eye
- 'designer' materials for medical use
- ultrasound imaging.

Through a variety of practical and ICT activities, there are opportunities to revisit, review and build on work from previous topics.

Students should:	
54.	understand how to use the relationships: • *(tensile or compressive) stress = force/cross-sectional area* • *(tensile or compressive) strain = change in length/original length* • *Young modulus = stress/strain*
56.	be able to draw and interpret tensile or compressive stress-strain graphs, and understand the term *breaking stress*
57.	**CORE PRACTICAL 5: Determine the Young modulus of a material.**
58.	be able to calculate the elastic strain energy E_{el} in a deformed material sample, using the equation $\Delta E_{el} = \frac{1}{2} F \Delta x$, and from the area under the force-extension graph *The estimation of area and hence energy change for both linear and non-linear force-extension graphs is expected*
75.	understand the term *focal length* of converging and diverging lenses
76.	be able to use ray diagrams to trace the path of light through a lens and locate the position of an image
77.	be able to use the equation power of a lens $P = \frac{1}{f}$
78.	understand that for thin lenses in combination $P = P_1 + P_2 + P_3 + \ldots$
79.	know and understand the terms *real image* and *virtual image*
80.	be able to use the equation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ for a thin converging or diverging lens with the real-is-positive convention
81.	know and understand that magnification = image height/object height and $m = \frac{v}{u}$
88.	understand that waves can be transmitted and reflected at an interface between media
89.	understand how a pulse-echo technique can provide information about the position of an object and how the amount of information obtained may be limited by the wavelength of the radiation or by the duration of pulses.

Transport on Track (TRA)

A study of a modern rail transport system with an emphasis on safety and control:

- track circuits and signalling
- sensing speed
- mechanical braking
- regenerative and eddy current braking
- crash-proofing.

Students use mathematical models to describe the behaviour of moving vehicles and to model electromagnetic induction, capacitor discharge and AC circuits.

There are opportunities to develop ICT skills.

Students should:
97. understand how to use the equation impulse = $F\Delta t = \Delta p$ (Newton's second law of motion)
98. **CORE PRACTICAL 9: Investigate the relationship between the force exerted on an object and its change of momentum.**
101. understand how to determine whether a collision is elastic or inelastic
116. understand that capacitance is defined as $C = \frac{Q}{V}$ and be able to use this equation
118. be able to draw and interpret charge and discharge curves for resistor–capacitor circuits and understand the significance of the time constant *RC*
119. **CORE PRACTICAL 11: Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through a resistor.**
120. be able to use the equation $Q = Q_0 e^{-t/RC}$ and derive and use related equations for exponential discharge in a resistor-capacitor circuit, $I = I_0\, e^{-t/RC}$, and $V = V_0\, e^{-t/RC}$ and the corresponding log equations $\ln Q = \ln Q_0 - \frac{t}{RC}$, $\ln I = \ln I_0 - \frac{t}{RC}$ and $\ln V = \ln V_0 - \frac{t}{RC}$
121. understand and use the terms *magnetic flux density B*, *flux* ϕ and *flux linkage N*ϕ
123. be able to use the equation $F = BIl \sin\theta$ and apply Fleming's left-hand rule to current carrying conductors in a magnetic field
124. understand the factors affecting the e.m.f. induced in a coil when there is relative motion between the coil and a permanent magnet
125. understand the factors affecting the e.m.f. induced in a coil when there is a change of current in another coil linked with this coil
126. understand how to use Lenz's law to predict the direction of an induced e.m.f. and how the prediction relates to energy conservation

Students should:
127. understand how to use Faraday's law to determine the magnitude of an induced e.m.f. and be able to use the equation that combines Faraday's and Lenz's laws $\mathcal{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$
128. understand what is meant by the terms *frequency*, *period*, *peak value* and *root-mean-square value* when applied to alternating currents and potential differences
129. be able to use the equations $V_{rms} = \frac{V_0}{\sqrt{2}}$ and $I_{rms} = \frac{I_0}{\sqrt{2}}$

The Medium is the Message (MDM)

An exploration of the physics involved in a variety of modern communication and display techniques:

- fibre optics and exponential attenuation
- CDD imaging
- cathode ray tube
- liquid crystal and LED displays.

There are opportunities to develop ICT skills and use computer simulations.

Students should:
108. understand that an electric field (force field) is defined as a region where a charged particle experiences a force
109. understand that electric field strength is defined as $E = \frac{F}{Q}$ and be able to use this equation
112. know and understand the relation between electric field and electric potential
113. be able to use the equation $E = \frac{V}{d}$ for an electric field between parallel plates
115. be able to draw and interpret diagrams using field lines and equipotentials to describe radial and uniform electric fields
117. be able to use the equation $W = \frac{1}{2}QV$ for the energy stored by a capacitor, be able to derive the equation from the area under a graph of potential difference against charge stored and be able to derive and use the equations $W = \frac{1}{2}CV^2$ and $W = \frac{\frac{1}{2}Q^2}{C}$
132. understand that electrons are released in the process of thermionic emission and how they can be accelerated by electric and magnetic fields.

Probing the Heart of Matter (PRO)

An area of fundamental physics that is the subject of current research, involving the acceleration and detection of high-energy particles and the interpretation of experiments:

- alpha scattering and the nuclear model of the atom
- accelerating particles to high energies
- detecting and interpreting the interactions between particles
- the quark-lepton model.

Students study the development of the nuclear model and the quark-lepton model to describe matter on a subatomic scale.

There are opportunities to develop ICT skills.

Students should:
99. understand how to apply conservation of linear momentum to problems in two dimensions
100. **CORE PRACTICAL 10: Use ICT to analyse collisions between small spheres, e.g. ball bearings on a table top.**
102. be able to derive and use the equation $E_k = \frac{p^2}{2m}$ for the kinetic energy of a non-relativistic particle
103. be able to express angular displacement in radians and in degrees, and convert between these units
104. understand what is meant by *angular velocity* and be able to use the equations $v = \omega r$ and $T = \frac{2\pi}{\omega}$
105. be able to use vector diagrams to derive the equations for centripetal acceleration $a = \frac{v^2}{r} = r\omega^2$ and understand how to use these equations
106. understand that a resultant force (centripetal force) is required to produce and maintain circular motion
107. be able to use the equations for centripetal force $F = ma = \frac{mv^2}{r} = mr\omega^2$
110. be able to use the equation $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$, for the force between two charges
111. be able to use the equation $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the electric field due to a point charge
114. be able to use $V = \frac{Q}{4\pi\varepsilon_0 r}$ for a radial field

Students should:
122. be able to use the equation $F = Bqv \sin\theta$ and apply Fleming's left-hand rule to charged particles moving in a magnetic field
130. understand what is meant by *nucleon number* (*mass number*) and *proton number* (*atomic number*)
131. understand how large-angle alpha particle scattering gives evidence for a nuclear model of the atom and how our understanding of atomic structure has changed over time
133. understand the role of electric and magnetic fields in particle accelerators (linac and cyclotron) and detectors (general principles of ionisation and deflection only)
134. be able to derive and use the equation $r = \frac{p}{BQ}$ for a charged particle in a magnetic field
135. be able to apply conservation of charge, energy and momentum to interactions between particles and interpret particle tracks
136. understand why high energies are required to investigate the structure of nucleons
137. be able to use the equation $\Delta E = c^2 \Delta m$ in situations involving the creation and annihilation of matter and antimatter particles
138. be able to use MeV and GeV (energy) and MeV/c^2, GeV/c^2 (mass) and convert between these and SI units
139. understand situations in which the relativistic increase in particle lifetime is significant (use of relativistic equations not required)
140. know that in the standard quark-lepton model particles can be classified as: • baryons (e.g. neutrons and protons) which are made from three quarks • mesons (e.g. pions) which are made from a quark and an antiquark • leptons (e.g. electrons and neutrinos) which are fundamental particles • photons and that the symmetry of the model predicted the top quark
141. know that every particle has a corresponding antiparticle and be able to use the properties of a particle to deduce the properties of its antiparticle and vice versa
142. understand how to use laws of conservation of charge, baryon number and lepton number to determine whether a particle interaction is possible
143. be able to write and interpret particle equations given the relevant particle symbols.

Build or Bust? (BLD)

A study of some aspects of building design, including withstanding earthquake damage, vibration isolation and temperature control:

- earthquake detection
- vibration and resonance in structures
- damping vibration using ductile materials
- sensing temperature
- energy, temperature change and phase change.

The behaviour of oscillators is modelled using the mathematics of simple harmonic motion, and physical models are used to explore the behaviour of structures.

Students should:
144. be able to use the equations $\Delta E = mc\Delta\theta$ and $\Delta E = L\Delta m$
145. **CORE PRACTICAL 12: Calibrate a thermistor in a potential divider circuit as a thermostat.**
146. **CORE PRACTICAL 13: Determine the specific latent heat of a phase change.**
181. understand that the condition for simple harmonic motion is $F = -kx$, and hence understand how to identify situations in which simple harmonic motion will occur
182. able to use the equations $a = -\omega^2 x$, $x = A\cos\omega t$, $v = -A\omega\sin\omega t$, $a = -A\omega^2\cos\omega t$, and $T = \frac{1}{f} = \frac{2\pi}{\omega}$ and $\omega = 2\pi f$ as applied to a simple harmonic oscillator
183. be able to use equations for a simple harmonic oscillator $T = 2\pi\sqrt{\frac{m}{k}}$, and a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$
184. be able to draw and interpret a displacement–time graph for an object oscillating and know that the gradient at a point gives the velocity at that point
185. be able to draw and interpret a velocity–time graph for an oscillating object and know that the gradient at a point gives the acceleration at that point
186. understand what is meant by *resonance*
187. **CORE PRACTICAL 16: Determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses.**
188. understand how to apply conservation of energy to damped and undamped oscillating systems
189. understand the distinction between *free* and *forced oscillations*
190. understand how the amplitude of a forced oscillation changes at and around the natural frequency of a system and know, qualitatively, how damping affects resonance
191. understand how damping and the plastic deformation of ductile materials reduce the amplitude of oscillation.

Reach for the Stars (STA)

The focus is on physical interpretation of astronomical observations, the formation and evolution of stars, and the history and future of the universe:

- distances of stars
- masses of stars
- energy sources in stars
- star formation
- star death and the creation of chemical elements
- the history and future of the universe.

Students use the molecular kinetic theory of matter, and the Big Bang model of the universe, and carry out mathematical modelling of gravitational force and radioactive decay.

Students should:
147. understand the concept of *internal energy* as the random distribution of potential and kinetic energy amongst molecules
148. understand the concept of *absolute zero* and how the average kinetic energy of molecules is related to the absolute temperature
149. be able to derive and use the equation, $pV = \frac{1}{3}Nm<c^2>$ using the kinetic theory model
150. be able to use the equation $pV = NkT$ for an ideal gas
151. **CORE PRACTICAL 14: Investigate the relationship between pressure and volume of a gas at fixed temperature.**
152. be able to derive and use the equation $\frac{1}{2}m<c^2> = \frac{3}{2}kT$
153. understand what is meant by a *black body radiator* and be able to interpret radiation curves for such a radiator
154. be able to use the Stefan-Boltzmann law equation $L = \sigma AT^4$ for black body radiators
155. be able to use Wien's law equation $\lambda_{max}T$ = 2.898 x 10^{-3} m K for black body radiators
156. be able to use the equation $I = \frac{L}{4\pi d^2}$ where L is luminosity and d is distance from the source
157. understand how astronomical distances can be determined using trigonometric parallax
158. understand how astronomical distances can be determined using measurements of intensity received from standard candles (objects of known luminosity)
159. be able to sketch and interpret a simple Hertzsprung-Russell diagram which relates stellar luminosity to surface temperature
160. understand how to relate the Hertzsprung-Russell diagram to the life cycle of stars

Students should:	
161.	understand how the movement of a source of waves relative to an observer/detector gives rise to a shift in frequency (Doppler effect)
162.	be able to use the equations for redshift $z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer and $v = H_0 d$ for objects at cosmological distances
163.	understand the controversy over the age and ultimate fate of the universe associated with the value of the Hubble constant and the possible existence of dark matter
164.	understand the concept of *nuclear binding energy*, and be able to use the equation $\Delta E = c^2 \Delta m$ in calculations of nuclear mass (including *mass deficit*) and energy
165.	use the *atomic mass unit (u)* to express small masses, and convert between this and SI units
166.	understand the processes of nuclear fusion and fission with reference to the binding energy per nucleon curve
167.	understand the mechanism of nuclear fusion and the need for very high densities of matter and very high temperatures to bring about and maintain nuclear fusion
168.	understand that there is background radiation and how to take appropriate account of it in calculations
169.	understand the relationships between the nature, penetration, ionising ability and range in different materials of nuclear radiations (alpha, beta and gamma)
170.	be able to write and interpret nuclear equations given the relevant particle symbols
171.	**CORE PRACTICAL 15: Investigate the absorption of gamma radiation by lead.**
172.	understand the spontaneous and random nature of nuclear decay
173.	be able to determine the half-lives of radioactive isotopes graphically and be able to use the equations for radioactive decay: activity $A = \lambda N$, $\frac{dN}{dt} = -\lambda N$, $\lambda = \frac{\ln 2}{t_{½}}$, $N = N_0 e^{-\lambda t}$ and $A = A_0 e^{-\lambda t}$ and derive and use the corresponding log equations.
174.	understand that a gravitational field (force field) is defined as a region where a mass experiences a force
175.	understand that gravitational field strength is defined as $g = \frac{F}{m}$ and be able to use this equation
176.	be able to use the equation $F = \frac{Gm_1m_2}{r^2}$ (Newton's law of universal gravitation)

Students should:
177. be able to derive and use the equation $g = \frac{Gm}{r^2}$ for the gravitational field due to a point mass
178. be able to use the equation $V_{grav} = \frac{-Gm}{r}$ for a radial gravitational field
179. be able to compare electric fields with gravitational fields
180. be able to apply Newton's laws of motion and universal gravitation to orbital motion.

Science Practical Endorsement

Overview

The assessment of practical skills is a compulsory requirement of the course of study for A level qualifications in biology, chemistry and physics. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills will be common to all awarding organisations. These arrangements include:

- A minimum of 12 practical activities to be carried out by each student which, together, meet the requirements of Appendices 5b (Practical skills identified for direct assessment and developed through teaching and learning) and 5c (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education. The required practical activities will be defined by each awarding organisation.
- Teachers will assess students against Common Practical Assessment Criteria (CPAC) issued by the awarding organisations. The CPAC are based on the requirements of *Appendices 5b* and *5c* of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.
- Each student will keep an appropriate record of their practical work, including their assessed practical activities
- Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade
- There will be no separate assessment of practical skills for AS qualifications.
- Students will answer questions in the AS and A level examination papers that assess the requirements of *Appendix 5a* (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education. These questions may draw on, or range beyond, the practical activities included in the specification.

Setting practical work

Teaching and learning

Teachers should ensure that the core practicals listed in the subject content are incorporated into teaching and learning and that students carry them out. This is to support development of competency for the practical endorsement but also because students will be indirectly assessed on their practical skills in the examinations. Teachers should consider setting additional practical work to support teaching and learning.

Teachers must devise and retain a teaching plan that shows when practicals will be covered in teaching and learning.

Conditions for assessing practical work

Authenticity

Students and teachers must sign the Practical competency authentication sheet (see *Appendix 4*).

Collaboration

Students may work in pairs on some practicals, where this is appropriate, provided they are able to produce individual evidence to meet the competency statements.

Feedback

Teachers may help students to understand instructions and may provide feedback to support development of the competencies. Teachers should be confident that students have developed their skills and thus students should be able to demonstrate the competencies independently by the end of the course.

Resources

Students must have access to the equipment needed to carry out the core practicals. Students must also have access to IT and internet facilities.

Supervision

Teachers must ensure that students are supervised appropriately.

Evidence of practical work

Evidence should be collected of practical work that is sufficient to show that the competencies have been achieved. Evidence may take a variety of forms.

Students should attempt all 16 practicals given in the qualification content.

Observations and notes by teachers

Teachers should observe sufficient student practicals to ensure that competencies have been achieved.

Student records

Students should keep notes of their practical work sufficient to show evidence of the practical competencies on making and recording observations and researching, referencing and reporting.

Assessing practical work

Teachers should make a judgement of student practical competence using the Common Practical Assessment Criteria on the following pages. Teachers should include any comments on the Practical competency authentication sheet (see *Appendix 4*) to justify the decision made.

The practical activities prescribed in the specification provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, students can also demonstrate these competencies in any additional practical activity undertaken throughout the course of study which covers the requirements of *Appendix 5c*.

Common Practical Assessment Criteria (CPAC)

Teachers must assess student practicals against the following competencies.

Criteria for the assessment of GCE Science practical competency for Biology, Chemistry and Physics	
Competency	**The criteria for a pass** In order to be awarded a Pass a learner must, by the end of the practical science assessment, consistently and routinely meet the criteria in respect of each competency listed below. A learner may demonstrate the competencies in any practical activity undertaken as part of that assessment throughout the course of study. Learners may undertake practical activities in groups. However, the evidence generated by each learner must demonstrate that he or she independently meets the criteria outlined below in respect of each competency. Such evidence: (a) will comprise of both the learner's performance during each practical activity and his or her contemporaneous record of the work that he or she has undertaken during that activity, and (b) must include evidence of independent application of investigative approaches and methods to practical work.
1. Follows written procedures	a) Correctly follows written instructions to carry out the experimental techniques or procedures.
2. Applies investigative approaches and methods when using instruments and equipment	a) Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting. b) Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments when necessary. c) Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled. d) Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.

Criteria for the assessment of GCE Science practical competency for Biology, Chemistry and Physics	
3. Safely uses a range of practical equipment and materials	a) Identifies hazards and assesses risks associated with these hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field. b) Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.
4. Makes and records observations	a) Makes accurate observations relevant to the experimental or investigative procedure. b) Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.
5. Researches, references and reports	a) Uses appropriate software and/or tools to process data, carry out research and report findings. b) Cites sources of information demonstrating that research has taken place, supporting planning and conclusions.

Marking and standardisation

The practical work is assessed by teachers. Pearson will support teachers in making judgements against the criteria for assessment.

In coordination with other exam boards, Pearson will monitor how schools provide students with opportunities to develop and demonstrate the required practical skills and how they mark the assessments.

Every school will be monitored at least once in a two-year period in respect of at least one of the A level science subjects. These monitoring visits will be coordinated by JCQ, who will undertake communications with centres to facilitate the allocation of exam board monitoring visits.

In common with other exam boards, Pearson will require centres to provide a statement confirming they have taken reasonable steps to secure that students:

- undertook the minimum number of practical activities, and
- made a contemporaneous record of their work.

If a school fails to provide a statement, or provides a false statement, this will be treated as malpractice and/or maladministration.

Students will only get a certificate for the practical assessment if they achieve at least a grade E in the examined part of the qualification.

Students who do not pass the practical assessment will have a 'Not Classified' outcome included on their certificate unless they were exempt from the assessment because of a disability.

Malpractice

Candidate malpractice

Candidate malpractice refers to any act by a candidate that compromises or seeks to compromise the process of assessment or which undermines the integrity of the qualifications or the validity of results/certificates.

Candidate malpractice in controlled assessments discovered before the candidate has signed the declaration of authentication form does not need to be reported to Pearson.

Candidate malpractice found in controlled assessments after the declaration of authenticity has been signed, and in examinations **must** be reported to Pearson on a *JCQ Form M1* (available at www.jcq.org.uk/exams-office/malpractice). The completed form can be emailed to pqsmalpractice@pearson.com or posted to Investigations Team, Pearson, 190 High Holborn, London, WC1V 7BH. Please provide as much information and supporting documentation as possible. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report candidate malpractice constitutes staff or centre malpractice.

Staff/centre malpractice

Staff and centre malpractice includes both deliberate malpractice and maladministration of our qualifications. As with candidate malpractice, staff and centre malpractice is any act that compromises or seeks to compromise the process of assessment or undermines the integrity of the qualifications or the validity of results/certificates.

All cases of suspected staff malpractice and maladministration **must** be reported immediately, before any investigation is undertaken by the centre, to *Pearson on a JCQ Form M2(a)* (available at www.jcq.org.uk/exams-office/malpractice). The form, supporting documentation and as much information as possible can be emailed to pqsmalpractice@pearson.com or posted to Investigations Team, Pearson, 190 High Holborn, London, WC1V 7BH. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report malpractice itself constitutes malpractice.

More detailed guidance on malpractice can be found in the latest version of the document *General and Vocational Qualifications Suspected Malpractice in Examinations and Assessments Policies and Procedures,* available at www.jcq.org.uk/exams-office/malpractice.

Assessment

Assessment summary

Summary of table of assessment

Students must complete all assessment in May/June in any single year.

Paper 1: Advanced Physics I	***Paper code: 9PH0/01**
• Questions draw on content from the topics listed in the section *Qualification at a glance.* • Questions are broken down into a number of parts. • Availability: May/June • First assessment: 2017 • The assessment is 1 hour 45 minutes. • The assessment consists of 90 marks.	**30% of the total qualification**

Paper 2: Advanced Physics II	***Paper code: 9PH0/02**
• Questions draw on content from the topics listed in the section *Qualification at a glance.* • Questions are broken down into a number of parts. • Availability: May/June • First assessment: 2017 • The assessment is 1 hour 45 minutes. • The assessment consists of 90 marks.	**30% of the total qualification**

Paper 3: General and Practical Principles in Physics	***Paper code: 9PH0/03**
• Questions draw on content from any of the topics in the specification. • Questions are broken down into a number of parts. • Questions may involve two or more topics. • Availability: May/June • First assessment: 2017 • The assessment is 2 hours 30 minutes. • The assessment consists of 120 marks.	**40% of the total qualification**

Science Practical Endorsement**   ***Paper code: 9PH0/04**
• Internally assessed and externally moderated by Pearson.   • Availability: May/June   • First assessment: 2017   • The practical endorsement is teacher assessed against the Common Practical Assessment Criteria (CPAC).

The sample assessment materials can be found in the *Pearson Edexcel Level 3 Advanced GCE in Physics Sample Assessment Materials* document.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

**Students will be assessed separately for the Science Practical Endorsement.

The Endorsement will not contribute to the overall grade for this qualification, but the result will be recorded on the student's certificate.

Assessment Objectives and weightings

Students must:		% in GCE
AO1	Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures	31–33
AO2	Apply knowledge and understanding of scientific ideas, processes, techniques and procedures: • in a theoretical context • in a practical context • when handling qualitative data • when handling quantitative data	41-43
AO3	Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to: • make judgements and reach conclusions • develop and refine practical design and procedures	25-27
	Total	**100%**

Breakdown of Assessment Objectives

Paper	AO1	AO2	AO3	Total for all Assessment Objectives
Paper 1: Advanced Physics I	11–13%	12–14%	5–7%	30%
Paper 2: Advanced Physics II	11–13%	12–14%	5–7%	30%
Paper 3: General and Practical Principles in Physics	8–10%	16–18%	13–15%	40%
Total for this qualification	**31–33%**	**41–43%**	**25–27%**	**100%**

Entry and assessment information

Student entry

Details of how to enter students for the examinations for this qualification can be found in our *UK Information Manual*. A copy is made available to all examinations officers and is available on our website at: www.edexcel.com/iwantto/Pages/uk-information-manual.aspx

Discount code and performance tables

Centres should be aware that students who enter for more than one GCE qualification with the same discount code will have only one of the grades they achieve counted for the purpose of the school and college performance tables. This will be the grade for the larger qualification (i.e. the A Level grade rather than the AS grade). If the qualifications are the same size, then the better grade will be counted (please see *Appendix 3: Codes*).

Students should be advised that if they take two GCE qualifications with the same discount code, colleges, universities and employers they wish to progress to are likely to take the view that this achievement is equivalent to only one GCE. The same view may be taken if students take two GCE qualifications that have different discount codes but have significant overlap of content. Students or their advisers who have any doubts about their subject combinations should check with the institution they wish to progress to before embarking on their programmes.

Access arrangements, reasonable adjustments and special consideration

Access arrangements are agreed before an assessment. They allow students with special educational needs, disabilities or temporary injuries to:

- access the assessment
- show what they know and can do without changing the demands of the assessment.

The intention behind an access arrangement is to meet the particular needs of an individual student with a disability without affecting the integrity of the assessment. Access arrangements are the principal way in which awarding bodies comply with the duty under the Equality Act 2010 to make 'reasonable adjustments'.

Access arrangements should always be processed at the start of the course. Students will then know what is available and have the access arrangement(s) in place for assessment.

Reasonable adjustments

The Equality Act 2010 requires an awarding organisation to make reasonable adjustments where a person with a disability would be at a substantial disadvantage in undertaking an assessment. The awarding organisation is required to take reasonable steps to overcome that disadvantage.

A reasonable adjustment for a particular person may be unique to that individual and therefore might not be in the list of available access arrangements.

Whether an adjustment will be considered reasonable will depend on a number of factors, which will include:

- the needs of the student with the disability
- the effectiveness of the adjustment
- the cost of the adjustment; and
- the likely impact of the adjustment on the student with the disability and other students.

An adjustment will not be approved if it involves unreasonable costs to the awarding organisation, timeframes or affects the security or integrity of the assessment. This is because the adjustment is not 'reasonable'.

Special consideration

Special consideration is a post-examination adjustment to a student's mark or grade to reflect temporary injury, illness or other indisposition at the time of the examination/assessment, which has had, or is reasonably likely to have had, a material effect on a candidate's ability to take an assessment or demonstrate their level of attainment in an assessment.

Further information

Please see our website for further information about how to apply for access arrangements and special consideration.

For further information about access arrangements, reasonable adjustments and special consideration, please refer to the JCQ website: www.jcq.org.uk.

Equality Act 2010 and Pearson's equality policy

Equality and fairness are central to our work. Our equality policy requires all students to have equal opportunity to access our qualifications and assessments, and our qualifications to be awarded in a way that is fair to every student.

We are committed to making sure that:

- students with a protected characteristic (as defined by the Equality Act 2010) are not, when they are undertaking one of our qualifications, disadvantaged in comparison to students who do not share that characteristic
- all students achieve the recognition they deserve for undertaking a qualification and that this achievement can be compared fairly to the achievement of their peers.

You can find details on how to make adjustments for students with protected characteristics in the policy document *Access Arrangements, Reasonable Adjustments and Special Considerations*, which is on our website, www.edexcel.com/Policies.

Synoptic assessment

Synoptic assessment requires students to work across different parts of a qualification and to show their accumulated knowledge and understanding of a topic or subject area.

Synoptic assessment enables students to show their ability to combine their skills, knowledge and understanding with breadth and depth of the subject.

In this qualification, synoptic assessment can be found in *Paper 3: General and Practical Principles in Physics*.

Awarding and reporting

This qualification will be graded, awarded and certificated to comply with the requirements of the current *Code of Practice* published by the Office of Qualifications and Examinations Regulation (Ofqual).

This qualification will be graded and certificated on a six-grade scale from A* to E using the total subject mark. Individual papers are not graded.

The first certification opportunity for the Pearson Edexcel Level 3 Advanced GCE in Physics will be 2017.

Students whose level of achievement is below the minimum judged by Pearson to be of sufficient standard to be recorded on a certificate will receive an unclassified U result.

Language of assessment

Assessment of this qualification will be available in English. All student work must be in English.

Other information

Student recruitment

Pearson follows the JCQ policy concerning recruitment to our qualifications in that:

- they must be available to anyone who is capable of reaching the required standard
- they must be free from barriers that restrict access and progression
- equal opportunities exist for all students.

Prior learning and other requirements

There are no prior learning or other requirements for this qualification.

Students who would benefit most from studying this qualification are likely to have a Level 2 qualification such as a GCSE in Additional Science or Physics.

Progression

Students can progress from this qualification to:

- a range of different, relevant academic or vocational higher education qualifications
- employment in a relevant sector
- further training.

Relationship between Advanced Subsidiary GCE and Advanced GCE

The content for Advanced GCE in Physics includes all the content studied at Advanced Subsidiary GCE. Advanced GCE in Physics builds on the knowledge, skills, and understanding achieved when studying the Advanced Subsidiary GCE in Physics.

Progression from Advanced Subsidiary GCE to Advanced GCE

Students who have achieved the Advanced Subsidiary GCE in Physics can progress to the Advanced GCE in Physics. Students will have covered content common to both qualifications but the Advanced GCE has additional content that will need to be covered; all the assessment for the Advanced GCE qualification must be taken at the end of the course.

Relationship between GCSE and Advanced GCE

Students cover Key Stage 4 fundamental core concepts in sciences at GCSE and continue to cover these concepts and additional subject material in the Advanced GCE at Key Stage 5.

Progression from GCSE to Advanced GCE

Students will draw on knowledge and understanding achieved in GCSE Additional Science or GCSE Physics to progress to an Advanced GCE in Physics qualification.

Appendices

Appendix 1: Transferable skills

The need for transferable skills

In recent years, higher education institutions and employers have consistently flagged the need for students to develop a range of transferable skills to enable them to respond with confidence to the demands of undergraduate study and the world of work.

The Organisation for Economic Co-operation and Development (OECD) defines skills, or competencies, as 'the bundle of knowledge, attributes and capacities that can be learned and that enable individuals to successfully and consistently perform an activity or task and can be built upon and extended through learning.' [1]

To support the design of our qualifications, the Pearson Research Team selected and evaluated seven global 21st-century skills frameworks. Following on from this process, we identified the National Research Council's (NRC) framework as the most evidence-based and robust skills framework. We adapted the framework slightly to include the Program for International Student Assessment (PISA) ICT Literacy and Collaborative Problem Solving (CPS) Skills.

The adapted National Research Council's framework of skills involves: [2]

Cognitive skills

- **Non-routine problem solving** – expert thinking, metacognition, creativity.
- **Systems thinking** – decision making and reasoning.
- **Critical thinking** – definitions of critical thinking are broad and usually involve general cognitive skills such as analysing, synthesising and reasoning skills.
- **ICT literacy** – access, manage, integrate, evaluate, construct and communicate. [3]

Interpersonal skills

- **Communication** – active listening, oral communication, written communication, assertive communication and non-verbal communication.
- **Relationship-building skills** – teamwork, trust, intercultural sensitivity, service orientation, self-presentation, social influence, conflict resolution and negotiation.
- **Collaborative problem solving** – establishing and maintaining shared understanding, taking appropriate action, establishing and maintaining team organisation.

[1] OECD – *Better Skills, Better Jobs, Better Lives* (OECD Publishing, 2012)

[2] Koenig J A, National Research Council – *Assessing 21st Century Skills: Summary of a Workshop* (National Academies Press, 2011)

[3] PISA – *The PISA Framework for Assessment of ICT Literacy* (2011)

Intrapersonal skills

- **Adaptability** – ability and willingness to cope with the uncertain, handling work stress, adapting to different personalities, communication styles and cultures, and physical adaptability to various indoor and outdoor work environments.
- **Self-management and self-development** – ability to work remotely in virtual teams, work autonomously, be self-motivating and self-monitoring, willing and able to acquire new information and skills related to work.

Transferable skills are the skills that enable young people to face the demands of further and higher education, as well as the demands of the workplace, and are important in the teaching and learning of this qualification. We will provide teaching and learning materials, developed with stakeholders, to support our qualifications.

Appendix 2: Level 3 Extended Project qualification

What is the Extended Project qualification?

The Extended Project is a standalone qualification that can be taken alongside GCEs. It supports the development of independent learning skills and helps to prepare students for their next step – whether that be university study or employment. The qualification:

- is recognised by higher education for the skills it develops
- is worth half of an Advanced GCE qualification at grades to A*–E
- carries UCAS points for university entry.

The Extended Project encourages students to develop skills in the following areas: research, critical thinking, extended writing and project management. Students identify and agree a topic area of their choice (which may or may not be related to a GCE subject they are already studying), guided by their teacher.

Students can choose from one of four approaches to produce:

- a dissertation (for example an investigation based on predominately secondary research)
- an investigation/field study (for example a practical experiment)
- a performance (for example in music, drama or sport)
- an artefact (for example creating a sculpture in response to a client brief or solving an engineering problem).

The qualification is non-examination assessment based and students are assessed on the skills of managing, planning and evaluating their project. Students will research their topic, develop skills to review and evaluate the information, and then present the final outcome of their project.

Students: what they need to do

The Extended Project qualification requires students to:

- select a topic of interest for an in-depth study and negotiate the scope of the project with their teacher
- identify and draft an objective for their project (for example in the form of a question, hypothesis, challenge, outline of proposed performance, issue to be investigated or commission for a client) and provide a rationale for their choice
- produce a plan for how they will deliver their intended objective
- conduct research as required by the project brief, using appropriate techniques
- carry out the project using tools and techniques safely
- share the outcome of the project using appropriate communication methods, including a presentation.

Teachers: key information

- The Extended Project has 120 guided learning hours (GLH) consisting of:
  - a taught 40-GLH element that includes teaching the technical skills (for example research skills)
  - a guided 80-GLH element that includes mentoring students through the project work.
- Group work is acceptable, however it is important that each student provides evidence of their own contribution and produces their own report.
- 100% externally moderated.
- Four Assessment Objectives: manage, use resources, develop and realise, review.
- Can be run over 1, 1½ or 2 years.
- Can be submitted in January or June.

What is the Extended Project for physics?

The Extended Project creates the opportunity to develop transferable skills for progression to higher education and to the workplace through the exploration of either an area of personal interest, or a topic of interest, from within the physics qualification content.

For example, physics students could choose to carry out an investigation that would give them an opportunity to develop their skills in data collection, the development and testing of hypotheses and the application of mathematical models in data analysis. Alternatively, they could work on the design of an artefact or dissertation as a way of exploring the use of physics in engineering contexts.

Skills developed

Through the Extended Project students will develop skills in the following areas:

- independent research skills, including skills in primary research and the selection of appropriate methods for data collection
- extended reading and academic writing, including reading scientific literature and writing about trends or patterns in data sets
- planning/project management, including the refining of hypotheses to be tested in investigations
- data handling and evaluation, including the comparison of data from primary research with published data and exploration of the significance of results
- evaluation of arguments and processes, including arguments in favour of alternative interpretations of data and evaluation of experimental methodology
- critical thinking.

In the context of the Extended Project, critical thinking refers to the ability to identify and develop arguments for a point of view or hypothesis and to consider and respond to alternative arguments.

The Extended Project is an ideal vehicle to support the development of skills identified in *Appendix 1*.

Using the Extended Project to support breadth and depth

There is no specified material that students are expected to study and, in the Extended Project, students are assessed on the quality of the work they produce and the skills they develop and demonstrate through completing this work. Students can use the Extended Project to demonstrate *extension* in one or more dimensions:

- ***deepening understanding***: where a student explores a topic in greater depth than in the specification content
- ***broadening skills***: the student learns a new skill. In a physics-based project, this might involve learning to assemble and manipulate an unfamiliar piece of apparatus or learning advanced data-handling techniques
- ***widening perspectives***: the student's project spans different subjects. This might involve discussing historical, philosophical or ethical aspects of a physics-based topic or making links with other subject areas such as chemistry or economics.

Choosing topics and narrowing down to a question

A dissertation, typically around 6000 words in length, involves addressing a research question through a literature review and argumentative discussion while an investigation/field study involves data collection and analysis, leading to a written report of around 5000 words.

For example, consider a student with an interest in acoustics who decided to carry out an investigation to explore the effect of different variables such as the volume, density and stiffness of foam on sound absorption. The investigation involved secondary research to establish the theoretical background to the project and to find out how absorption is measured, what techniques can be used to gather data and to explore the context in which such physics is used (for example in industry). The student collected data using appropriately designed experiments. The student's own data were compared with published data, and the trends and patterns in data analysed, with consideration of the significance of the results obtained, and an attempt to interpret them in the light of the mathematical models that the student had learned about through research. Finally, the student's project ended with a review of the effectiveness of the investigation and an oral presentation of the main findings and arguments considered.

Physics-based dissertation projects can cover a wide variety of topics, as these examples illustrate:

- Why did the Titanic sink?
- Are wind turbines a good solution to the energy crisis?
- Can we justify human space exploration?
- Is it possible to believe in God and the Big Bang?
- How did the Copernican paradigm shift affect subsequent developments in cosmology?
- Is wi-fi safe?

Examples of possible investigation Extended Project titles include:

- How does solar activity affect weather?
- Do 'sharkskin' swimsuits give the wearer an unfair advantage?
- Over its working lifetime, does the energy output from a photovoltaic solar panel exceed the energy required to make, install and operate it?

There is also scope for physics-based artefact Extended Projects. For example, a student might set out to design, make and test an item of apparatus such as a sundial or a spectrometer. Extended Projects involving a performance or event can also be physics based. For example, an incident or issue could be explored through drama (as Bertholt Brecht did with the `Trial of Galileo').

Appendix 3: Codes

Type of code	Use of code	Code number
Discount codes	Every qualification eligible for performance tables is assigned a discount code indicating the subject area to which it belongs. Discount codes are published by DfE.	Please see the GOV.UK website*
Regulated Qualifications Framework (RQF) codes	Each qualification title is allocated an Ofqual Regulated Qualifications Framework (RQF) code. The RQF code is known as a Qualification Number (QN). This is the code that features in the DfE Section 96 and on the LARA as being eligible for 16–18 and 19+ funding, and is to be used for all qualification funding purposes. The QN will appear on students' final certification documentation.	The QN for the qualification in this publication is: 601/4848/2
Subject codes	The subject code is used by centres to enter students for a qualification. Centres will need to use the entry codes only when claiming students' qualifications.	Advanced GCE – 9PH0
Paper code	These codes are provided for reference purposes. Students do not need to be entered for individual papers.	Paper 1: 9PH0/01 Paper 2: 9PH0/02 Paper 3: 9PH0/03 Science Practical Endorsement: 9PH0/04

*www.gov.uk/government/publications/key-stage-4-qualifications-discount-codes-and-point-scores

Appendix 4: Practical competency authentication sheet

For students to gain the Science Practical Endorsement, centres will need to:

- ensure that there is evidence that students have completed the necessary practical activities, meeting the requirements of *Appendix 5c*
- ensure that there is evidence that students have met the requirements of each of the CPAC statements, in accordance with the guidelines provided for achieving the 'pass' standard
- complete an authentication sheet for their students.

Centres will also need to have had a satisfactory monitoring visit, according to the guidelines for monitoring visits, as set down by the JCQ.

Evidence for meeting practical attendance and CPAC competency may be provided in a variety of formats using student lab books or practical portfolios; and registers or tracking spreadsheets.

A final version of the authentication statement will be made available to schools in time for the first submission of entries in 2017.

Appendix 5: Working scientifically

Appendices 5, 5a, 5b and 5c are taken from the document *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* published by the DfE April 2014. Working scientifically is achieved through practical activities.

Specifications in biology, chemistry and physics must encourage the development of the skills, knowledge and understanding in science through teaching and learning opportunities for regular hands-on practical work.

In order to develop the necessary skills, knowledge and understanding, students studying biology, chemistry and physics will be required to have carried out a minimum of 12 practical activities, which will contribute towards the Practical Endorsement. These skills, knowledge and understanding will also be assessed in written examinations in the context of these, and other, practical activities.

The skills can be split into those which can be assessed through written examinations (*Appendix 5a*); and those that will be assessed by teachers through appropriate practical activities (*Appendix 5b*).

The practical activities highlighted as the minimum requirement within specifications must cover the use of apparatus and practical techniques identified for each science (*Appendix 5c*).

Appendix 5a: Practical skills identified for indirect assessment and developed through teaching and learning

Question papers will assess the following student's abilities:

a) Independent thinking

- solve problems set in practical contexts
- apply scientific knowledge to practical contexts

b) Use and application of scientific methods and practices

- comment on experimental design and evaluate scientific methods
- present data in appropriate ways
- evaluate results and draw conclusions with reference to measurement uncertainties and errors
- identify variables including those that must be controlled

c) Numeracy and the application of mathematical concepts in a practical context

- plot and interpret graphs
- process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
- consider margins of error, accuracy and precision of data

d) Instruments and equipment

- know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Appendix 5b: Practical skills identified for direct assessment and developed through teaching and learning

Practical work carried out throughout the course will enable students to develop the following skills.

a) Independent thinking

- apply investigative approaches and methods to practical work

b) Use and apply scientific methods and practices

- safely and correctly use a range of practical equipment and materials
- follow written instructions
- make and record observations
- keep appropriate records of experimental activities
- present information and data in a scientific way
- use appropriate software and tools to process data, carry out research and report findings

c) Research and referencing

- use online and offline research skills including websites, textbooks and other printed scientific sources of information
- correctly cite sources of information

d) Instruments and equipment

- use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Appendix 5c: Use of apparatus and techniques

Use of apparatus and techniques – physics

Specifications for physics must give students opportunities to use relevant apparatus to develop and demonstrate these techniques.

All of the techniques listed below will be assessed through a minimum of 12 identified practical activities within each specification. These 'core' practicals must allow students to demonstrate all of the practical skills given in *Appendix 5b*.

Practical techniques to be gained by candidates

1. Use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings.
2. Use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass).
3. Use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line.
4. Use stopwatch or light gates for timing.
5. Use calipers and micrometers for small distances, using digital or vernier scales.
6. Correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important.
7. Design, construct and check circuits using DC power supplies, cells, and a range of circuit components.
8. Use signal generator and oscilloscope, including volts/div and time-base
9. Generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source.
10. Use laser or light source to investigate characteristics of light, including interference and diffraction.
11. Use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data.
12. Use ionising radiation, including detectors.

Appendix 5d: Mapping between Appendix 5c and core practicals

This qualification gives students opportunities to use relevant apparatus to develop practical skills and demonstrate competency in a range of practical techniques.

All of the techniques listed in *Appendix 5c* will be assessed through a series of core practical activities within this specification.

To achieve the Science Practical Endorsement, students need to show competence in the 12 practical techniques listed in *Appendix 5c: Use of apparatus and techniques*.

The following table shows how each core practical activity, listed in the content, maps to the required practical techniques in *Appendix 5c: Use of apparatus and techniques*.

Physics Core Practical	**Practical technique in *Appendix 5c***											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1: Determine the acceleration of a freely-falling object	✓	✓		✓						✓		
2: Determine the electrical resistivity of a material	✓	✓			✓	✓	✓					
3: Determine the e.m.f. and internal resistance of an electrical cell		✓				✓	✓					
4: Use a falling-ball method to determine the viscosity of a liquid	✓	✓	✓	✓	✓							
5: Determine the Young modulus of a material	✓				✓							
6: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone	✓		✓					✓	✓			
7: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire	✓	✓	✓					✓	✓		✓	
8: Determine the wavelength of light from a laser or other light source using a diffraction grating	✓		✓							✓		
9: Investigate the relationship between the force exerted on an object and its change of momentum	✓	✓	✓	✓							✓	
10: Use ICT to analyse collisions between small spheres, e.g. ball bearings on a table top	✓	✓	✓		✓						✓	
11: Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through a resistor		✓				✓	✓	✓			✓	

Physics Core Practical	Practical technique in *Appendix 5c*											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
12: Calibrate a thermistor in a potential divider circuit as a thermostat	✓	✓	✓			✓	✓				✓	
13: Determine the specific latent heat of a phase change	✓	✓	✓									
14: Investigate the relationship between pressure and volume of a gas at fixed temperature	✓											
15: Investigate the absorption of gamma radiation by lead		✓	✓		✓							✓
16: Determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses	✓	✓	✓	✓							✓	

Appendix 6: Mathematical skills and exemplifications

The information in this appendix has been taken directly from the document *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* published by the Department for Education (April 2014).

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

The assessment of quantitative skills will include at least 10% level 2 or above mathematical skills for biology and psychology, 20% for chemistry and 40% for physics. These skills will be applied in the context of the relevant science A Level.

All mathematical content must be assessed within the lifetime of the specification.

The following tables illustrate where these mathematical skills may be developed and could be assessed in each of the sciences. Those shown in bold type would only be tested in the full A Level course.

This list of examples is not exhaustive. These skills could be developed in other areas of specification content.

	Mathematical skills	Exemplification of mathematical skill in the context of A Level Physics (assessment is not limited to the examples given below)
(i) C.0 – arithmetic and numerical computation		
C.0.1	Recognise and make use of appropriate units in calculations	Students may be tested on their ability to: • identify the correct units for physical properties such as m s^{-1}, the unit for velocity • convert between units with different prefixes, e.g. cm^3 to m^3
C.0.2	Recognise and use expressions in decimal and standard form	Students may be tested on their ability to: • use physical constants expressed in standard form such as $c = 3.00 \times 10^8$ m s^{-1}
C.0.3	Use ratios, fractions and percentages	Students may be tested on their ability to: • calculate efficiency of devices • calculate percentage uncertainties in measurements
C.0.4	Estimate results	Students may be tested on their ability to: • estimate the effect of changing experimental parameters on measurable values
C.0.5	Use calculators to find and use power, **exponential and logarithmic functions**	Students may be tested on their ability to: • **solve for unknowns in decay problems such as** $N = N_0 e^{-\lambda t}$
C.0.6	Use calculators to handle sin *x*, cos *x*, tan *x* when *x* is expressed in degrees or radians	Students may be tested on their ability to: • calculate the direction of resultant vectors

	Mathematical skills	Exemplification of mathematical skill in the context of A Level Physics (assessment is not limited to the examples given below)
(ii) C.1 – handling data		
C.1.1	Use an appropriate number of significant figures	Students may be tested on their ability to: • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement
C.1.2	Find arithmetic means	Students may be tested on their ability to: • calculate a mean value for repeated experimental readings
C.1.3	Understand simple probability	Students may be tested on their ability to: • understand probability in the context of radioactive decay
C.1.4	Make order of magnitude calculations	Students may be tested on their ability to: • evaluate equations with variables expressed in different orders of magnitude
C.1.5	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers	Students may be tested on their ability to: • determine the uncertainty where two readings for length need to be added together

	Mathematical skills	Exemplification of mathematical skill in the context of A Level Physics (assessment is not limited to the examples given below)
(iii)	**C.2 – algebra**	
C.2.1	Understand and use the symbols: =, <, <<, >>, >, ∝, ≈, Δ	Students may be tested on their ability to: • recognise the significance of the symbols in the expression $F \propto \Delta p/\Delta t$
C.2.2	Change the subject of an equation, including non-linear equations	Students may be tested on their ability to: • rearrange $E = mc^2$ to make m the subject
C.2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Students may be tested on their ability to: • calculate the momentum p of an object by substituting the values for mass m and velocity v into the equation $p = mv$
C.2.4	Solve algebraic equations, including quadratic equations	Students may be tested on their ability to: • solve kinematic equations for constant acceleration such as $v = u + at$ and $s = ut + ½ at^2$
C.2.5	**Use logarithms in relation to quantities that range over several orders of magnitude**	Students may be tested on their ability to: • **recognise and interpret real-world examples of logarithmic scales**
(iv)	**C.3 – graphs**	
C.3.1	Translate information between graphical, numerical and algebraic forms	Students may be tested on their ability to: • calculate Young modulus for materials using stress-strain graphs
C.3.2	Plot two variables from experimental or other data	Students may be tested on their ability to: • plot graphs of extension of a wire against force applied
C.3.3	Understand that $y = mx + c$ represents a linear relationship	Students may be tested on their ability to: • rearrange and compare $v = u + at$ with $y = mx + c$ for velocity-time graph in constant acceleration problems
C.3.4	Determine the slope and intercept of a linear graph	Students may be tested on their ability to: • read off and interpret intercept point from a graph, e.g. the initial velocity in a velocity-time graph

	Mathematical skills	Exemplification of mathematical skill in the context of A Level Physics (assessment is not limited to the examples given below)
(iv) C.3 – graphs		
C.3.5	Calculate rate of change from a graph showing a linear relationship	Students may be tested on their ability to: • calculate acceleration from a linear velocity-time graph
C.3.6	Draw and use the slope of a tangent to a curve as a measure of rate of change	Students may be tested on their ability to: • draw a tangent to the curve of a displacement–time graph and use the gradient to approximate the velocity at a specific time
C.3.7	Distinguish between instantaneous rate of change and average rate of change	Students may be tested on their ability to: • understand that the gradient of the tangent of a displacement–time graph gives the velocity at a point in time which is a different measure to the average velocity
C.3.8	Understand the possible physical significance of the area between a curve and the *x* axis and be able to calculate it or estimate it by graphical methods as appropriate	Students may be tested on their ability to: • recognise that for a capacitor the area under a voltage-charge graph is equivalent to the energy stored
C.3.9	Apply the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, e.g. $\Delta x / \Delta t = -\lambda x$ using a graphical method or spreadsheet modelling	Students may be tested on their ability to: • determine *g* from distance-time plot, projectile motion
C.3.10	**Interpret logarithmic plots**	Students may be tested on their ability to: • **obtain time constant for capacitor discharge by interpreting plot of log *V* against time**

	Mathematical skills	Exemplification of mathematical skill in the context of A Level Physics (assessment is not limited to the examples given below)
(iv) C.3 – graphs		
C.3.11	**Use logarithmic plots to test exponential and power law variations**	Students may be tested on their ability to: • **use logarithmic plots with decay law of radioactivity/charging and discharging of a capacitor**
C.3.12	Sketch relationships which are modelled by $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = kx$, $y = \sin x$, $y = \cos x$, $\boldsymbol{y = e^{\pm x}}$**, and** $\boldsymbol{y = \sin^2 x}$**,** $\boldsymbol{y = \cos^2 x}$ ***a*** **as applied to physical relationships**	Students may be tested on their ability to: • **sketch relationships between pressure and volume for an ideal gas**
(v) C.4 – geometry and trigonometry		
C.4.1	Use angles in regular 2D and 3D structures	Students may be tested on their ability to: • interpret force diagrams to solve problems
C.4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Students may be tested on their ability to: • draw force diagrams to solve mechanics problems
C.4.3	Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres	Students may be tested on their ability to: • calculate the area of the cross section to work out the resistance of a conductor given its length and resistivity
C.4.4	Use Pythagoras' theorem, and the angle sum of a triangle	Students may be tested on their ability to: • calculate the magnitude of a resultant vector, resolving forces into components to solve problems
C.4.5	Use sin, cos and tan in physical problems	Students may be tested on their ability to: • resolve forces into components
C.4.6	Use of small angle approximations including $\sin \theta \approx \theta$, $\tan \theta \approx \theta$, $\cos \theta \approx 1$ for small θ where appropriate	Students may be tested on their ability to: • calculate fringe separations in interference patterns
C.4.7	Understand the relationship between degrees and radians and translate from one to the other	Students may be tested on their ability to: • convert angle in degrees to angle in radians

Appendix 7: Command words used in examination papers

The following table lists the command words used in the external assessments.

Command word	Definition
Add/Label	Requires the addition or labelling to a stimulus material given in the question, for example labelling a diagram or adding units to a table.
Assess	Give careful consideration to all the factors or events that apply and identify which are the most important or relevant. Make a judgement on the importance of something, and come to a conclusion where needed.
Calculate	Obtain a numerical answer, showing relevant working. If the answer has a unit, this must be included.
Comment on	Requires the synthesis of a number of variables from data/information to form a judgement.
Compare and contrast	Looking for the similarities **and** differences of two (or more) things. Should not require the drawing of a conclusion. Answer must relate to both (or all) things mentioned in the question. The answer must include at least one similarity and one difference.
Complete	Requires the completion of a table/diagram.
Criticise	Inspect a set of data, an experimental plan or a scientific statement and consider the elements. Look at the merits and/or faults of the information presented and back judgements made.
Deduce	Draw/reach conclusion(s) from the information provided.
Derive	Combine two or more equations or principles to develop a new equation.
Describe	To give an account of something. Statements in the response need to be developed as they are often linked but do not need to include a justification or reason.
Determine	The answer must have an element which is quantitative from the stimulus provided, or must show how the answer can be reached quantitatively.

Command word	Definition
Devise	Plan or invent a procedure from existing principles/ideas
Discuss	• Identify the issue/situation/problem/argument that is being assessed within the question. • Explore all aspects of an issue/situation/problem/argument. • Investigate the issue/situation etc by reasoning or argument.
Draw	Produce a diagram either using a ruler or using freehand.
Evaluate	Review information then bring it together to form a conclusion, drawing on evidence including strengths, weaknesses, alternative actions, relevant data or information. Come to a supported judgement of a subject's qualities and relation to its context.
Explain	An explanation requires a justification/exemplification of a point. The answer must contain some element of reasoning/justification, this can include mathematical explanations.
Give/state/name	All of these command words are really synonyms. They generally all require recall of one or more pieces of information.
Give a reason/ reasons	When a statement has been made and the requirement is only to give the reasons why.
Identify	Usually requires some key information to be selected from a given stimulus/resource.
Justify	Give evidence to support (either the statement given in the question or an earlier answer).
Plot	Produce a graph by marking points accurately on a grid from data that is provided and then drawing a line of best fit through these points. A suitable scale and appropriately labelled axes must be included if these are not provided in the question.
Predict	Give an expected result.
Show that	Prove that a numerical figure is as stated in the question. The answer must be to at least 1 more significant figure than the numerical figure in the question.
Sketch	Produce a freehand drawing. For a graph, this would require a line and labelled axis with important features indicated, the axes are not scaled.
State what is meant by	When the meaning of a term is expected but there are different ways of how these can be described.
Write	When the questions ask for an equation.

Appendix 8: Formulae sheet

Students need not memorise formulae for this qualification.

The formulae below will be supplied in each examination. Any other formulae that are required will be provided in the question. Symbols used comply with the Association for Science Education (ASE) guidelines (which are based on International Union of Pure and Applied Physics (IUPAP) recommendations).

Mechanics

Kinematic equations of motion	$s = \frac{(u+v)t}{2}$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
Forces	$\Sigma F = ma$ $g = \frac{F}{m}$ $W = mg$ Moment of force $= Fx$
Momentum	$p = mv$
Work, energy and power	$\Delta W = F\Delta s$ $E_k = \frac{1}{2}mv^2$ $\Delta E_{\text{grav}} = mg\Delta h$ $P = \frac{E}{t}$ $P = \frac{W}{t}$ $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$ $\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$

Electricity

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power, energy and efficiency

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$F = k\Delta x$$

Pressure

$$p = \frac{F}{A}$$

Young modulus

Stress $\sigma = \frac{F}{A}$

Strain $\varepsilon = \frac{\Delta x}{x}$

$E = \frac{\sigma}{\varepsilon}$

Elastic strain energy $\Delta E_{el} = \frac{1}{2} F \Delta x$

Waves and particle nature of light

Wave speed $v = f\lambda$

Speed of a transverse wave on a string $v = \sqrt{\frac{T}{\mu}}$

Intensity of radiation $I = \frac{P}{A}$

Power of a lens $P = \frac{1}{f}$

$P = P_1 + P_2 + P_3 + \ldots$

Thin lens equation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Magnification for a lens magnification = Image height/Object height

$m = \frac{v}{u}$

Diffraction grating $n\lambda = d\sin\theta$

Refractive index	$n_1 \sin \theta_1 = n_2 \sin \theta_2$ $n = \frac{c}{v}$
Critical angle	$\sin C = \frac{1}{n}$
Photon model	$E = hf$
Einstein's photoelectric equation	$hf = \phi + \frac{1}{2} m v_{\max}^2$
de Broglie wavelength	$\lambda = \frac{h}{p}$

Further mechanics

Impulse	$F\Delta t = \Delta p$
Kinetic energy of a non-relativistic particle	$E_k = \frac{p^2}{2m}$
Motion in a circle	$v = \omega r$ $T = \frac{2\pi}{\omega}$ $F = ma = \frac{mv^2}{r}$ $a = \frac{v^2}{r}$ $a = r\omega^2$
Centripetal force	$F = \frac{mv^2}{r}$ $F = mr\omega^2$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \frac{\tfrac{1}{2}Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 \, \mathrm{e}^{-t/RC}$$

Resistor-capacitor discharge

$$I = I_o \, e^{-t/RC}$$

$$V = V_o \, e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$F = BIl \sin \theta$

$F = Bqv \sin \theta$

Faraday's and Lenz's Laws

$\mathscr{E} = \frac{-\,\mathrm{d}(N\phi)}{\mathrm{d}t}$

Root-mean-square values

$V_{rms} = \frac{V_0}{\sqrt{2}}$

$I_{rms} = \frac{I_0}{\sqrt{2}}$

Nuclear and particle physics

In a magnetic field

$r = \frac{p}{BQ}$

Thermodynamics

Heating

$\Delta E = mc\Delta\theta$

$\Delta E = L\Delta m$

Molecular kinetic theory

$\frac{1}{2}m<c^2> = \frac{3}{2}kT$

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

Ideal gas equation

$pV = NkT$

Stefan-Boltzmann law

$L = \sigma T^4 A$

$L = 4\pi r^2 \sigma T^4$

Wien's law

$\lambda_{\max} T = 2.898 \text{ x } 10^{-3} \text{ m K}$

Space

Radiant energy flux

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2 \Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{½}}$$

$$N = N_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1 m_2}{r^2}$$

Gravitational field

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$F = -kx$

$a = -\omega^2 x$

$x = A\cos \omega t$

$v = -A\omega \sin \omega t$

$a = -A\omega^2 \cos \omega t$

$T = \frac{1}{f} = \frac{2\pi}{\omega}$

$\omega = 2\pi f$

Simple harmonic oscillator

$T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{l}{g}}$

Appendix 9: Data sheet

The value of the following constants will be provided in each examination paper.

Acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$	
Coulomb law constant	$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19} \text{ C}$	
Electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$	
Electronvolt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	
Gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$	
Gravitational field strength	$g = 9.81 \text{ N kg}^{-1}$	(close to Earth's surface)
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$	
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$	
Proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8} \text{ m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27} \text{ kg}$	

Appendix 10: Uncertainties and practical work

The aim of physics in studying natural phenomena is to develop explanations based on empirical evidence. Hence there is a central concern about the quality of evidence and of the explanations that are based on it. This involves an appreciation of the causes of uncertainties that can arise in practical work and how they should be dealt with, both in planning an experiment to minimise these uncertainties and in forming a valid conclusion.

There is no practical examination in this qualification and a set of practical skills has been identified as appropriate for indirect assessment. Practical skills should be developed by carrying out practical work throughout the course, for example by carrying out the Core Practicals listed in the Specification. The assessment of these skills will be through examination questions, in particular for Unit 3: Practical Skills in Physics I and Unit 6: Practical Skills in Physics II.

It is clearly important that the words used within the practical context have a precise and scientific meaning as distinct from their everyday usage. The terms used for this assessment will be those described in the publication by the Association for Science Education (ASE) entitled The Language of Measurement (ISBN 9780863574245). In adopting this terminology, it should be noted that **certain terms will have a meaning different to that in the previous specification**. In accordance with common practice, this qualification will adopt the Uncertainty Approach to measurement. Using this approach assumes that the measurement activity produces an interval of reasonable values together with a statement of the confidence that the true value lies within this interval.

The following Glossary is a selection of terms from the list in The Language of Measurement published by ASE (ISBN 9780863574245).

Glossary

Term	Meaning and notes
Validity	A measurement is valid if it measures what it is supposed to be measuring – this depends both on the method and the instruments.
True value	The value that would have been obtained in an ideal measurement – with the exception of a fundamental constant the true value is considered unknowable.
Accuracy	A measurement result is considered accurate if it is judged to be close to the true value. It is a quality denoting the closeness of agreement between measurement and true value – it cannot be quantified and is influenced by random and systematic errors.
Precision	A quality denoting the closeness of agreement (consistency) between values obtained by repeated measurement – this is influenced only by random effects and can be expressed numerically by measures such as standard deviation. A measurement is precise if the values 'cluster' closely together.
Repeatability	The precision obtained when measurement results are obtained by a single operator using a single method over a short timescale. A measurement is repeatable when similar results are obtained by students from the same group using the same method. Students can use the precision of their measurement results to judge this.
Reproducibility	The precision obtained when measurement results are obtained by different operators using different pieces of apparatus. A measurement is reproducible when similar results are obtained by students from different groups using different methods or apparatus. This is a harder test of the quality of data.
Uncertainty	The interval within which the true value can be considered to lie with a given level of confidence or probability – any measurement will have some uncertainty about the result, this will come from variation in the data obtained and be subject to systematic or random effects. This can be estimated by considering the instruments and the method and will usually be expressed as a range such as 20 °C ± 2 °C. The confidence will be qualitative and based on the goodness of fit of the line of best fit and the size of the percentage uncertainty.
Error	The difference between the measurement result and the true value if a true value is thought to exist. This is not a mistake in the measurement. The error can be due to both systematic and random effects and an error of unknown size is a source of uncertainty.
Resolution	The smallest measuring interval and the source of uncertainty in a single reading.
Significant figures (SF)	The number of SF used in recording the measurements depends on the resolution of the measuring instruments and should usually be the same as given in the instrument with the fewest SF in its reading.

Uncertainties in practice

What are uncertainties and why are they important?

When you repeat a measurement you often get different results. There is an **uncertainty** in the measurement that you have taken. It is important to be able to determine the uncertainty in measurements so that its effect can be taken into consideration when drawing conclusions about experimental results. The uncertainty might be the **resolution of the instrument** or, if the readings were repeated, the uncertainty might be **half the range** of the repeats. If the uncertainty is predictable, i.e. it is **systematic**, then the uncertainty should be subtracted from each reading, for example if there is a zero error on an instrument.

Recording data

Results should be recorded to the resolution of the measuring instrument which means there will be a consistent number of decimal places for the readings for any one variable.

If raw data goes over a power of ten we would not penalise a mixture of significant figures. When data is processed, these values should be recorded to a consistent number of significant figures which is usually 3 as this is what we can usually confidently plot on a graph.

Calculating uncertainties

There are several techniques that will produce an **estimate** of the uncertainty in the value of the mean. Since we are expecting students to produce an estimate of the uncertainty any suitable value that indicates half the range is acceptable.

Example: A student measures the diameter of a metal canister using a ruler graduated in mm and records these results:

Diameter/mm			
Reading 1	Reading 2	Reading 3	Mean
66	65	61	64

The uncertainty in the mean value (64 mm) can be calculated as follows:

a) Using the half range

The range of readings is 61 mm – 66 mm so half the range is used to determine the uncertainty.

Uncertainty in the mean diameter= (66 mm – 61 mm)/2 = 2.5 mm
Therefore, the diameter of the metal canister is 64 mm ± 2.5 mm.

Since a ruler graduated in mm could easily be read to ± 0.5 mm, it is acceptable to quote the uncertainty as ± 2.5 mm for this experiment.

b) Using the reading furthest from the mean

In this case, the measurement of 61 mm is further from the average value than 66 mm therefore we can use this value to calculate the uncertainty in the mean.

Uncertainty in the mean diameter= 64 mm – 61 mm = 3 mm.
Therefore, the diameter of the metal canister is 64 mm ± 3 mm.

c) Using the resolution of the instrument

This is used if a single reading is taken or if repeated readings have the same value. This is because there is an uncertainty in the measurement because the instrument used to take the measurement has its own limitations. If the three readings obtained above were all 64 mm then the value of the diameter being measured lies somewhere between 63.5 mm and 64.5 mm since a metre rule could easily be read to half a millimetre. In this case, the uncertainty in the diameter is 0.5 mm.

Therefore, the diameter of the metal canister is 64 mm ± 0.5 mm.

This also applies to digital instruments. An ammeter records currents to 0.1 A. A current of 0.36 A would be displayed as 0.4 A, and a current of 0.44 A would also be displayed as 0.4 A. The resolution of the instrument is 0.1 A but the uncertainty in a reading is 0.05 A.

Calculating percentage uncertainties

The percentage uncertainty in a measurement can be calculated using:

Percentage uncertainty = (Uncertainty of measurement/Measurement) × 100%

In the above example the percentage uncertainty in the diameter of the metal canister is:

Percentage uncertainty = (3/64) × 100% = 4.7%

Often the radius would be used in a calculation, for example in a calculation of volume. In this case, the percentage uncertainty for the radius of the canister is the same as its diameter, i.e. 4.7%, and not half of the percentage uncertainty. This is one reason why the percentage uncertainty in a measurement is useful.

Additionally, the value is less than 5%, which shows that the measurement is probably repeatable. Note that a percentage uncertainty would normally be quoted to 1 or 2 sf.

Compounding uncertainties

Calculations often use more than one measurement. Each measurement will have its own uncertainty, so it is necessary to combine the uncertainties for each measurement to calculate the overall uncertainty in the calculation provided all the measured quantities are independent of one another.

There are three methods of compounding uncertainties depending on whether the measurements in a calculation are raised to a power, multiplied/divided, or added/subtracted.

a) Raising a measurement to a power

If a measurement is raised to a power, for example squared or cubed, then the percentage uncertainty is multiplied by that power to give the total percentage uncertainty.

Example: A builder wants to calculate the area of a square tile. He uses a rule to measure the two adjacent sides of a square tile and obtains the following results:

Length of one side = 84 mm ± 0.5 mm

Length of perpendicular side = 84 mm ± 0.5 mm

The percentage uncertainty in the length of each side of this square tile is given by:

Percentage uncertainty = (0.5/84) × 100% = 0.59 % = 0.6 %

The area of the tile A is given by A = 84 × 84 = 7100 mm^2

Note that this is to 2 sf since the measurements are to 2 sf.

The percentage uncertainty in the area of the square tile is calculated by multiplying the percentage uncertainty in the length by 2.

Percentage uncertainty in A = 2 × 0.6% = 1.2%

Therefore the uncertainty in A = 7100 × 1.2% = 85 mm^2

So A = 7100 mm^2 ± 1.2% or A = 7100 mm^2 ± 85 mm^2

b) Multiplying or dividing measurements

The total percentage uncertainty is calculated by adding together the percentage uncertainties for each measurement.

Example: A metallurgist is determining the purity of a sample of an alloy that is in the shape of a cube by determining the density of the material.

The following readings are taken:

Length of each side of the cube= 24.0 mm ± 0.5 mm

Mass of cube = 48.23 g ± 0.05 g

She calculates (i) the density of the material and (ii) the percentage uncertainty in the density of the material.

(i) Density of alloy = mass / volume = mass / $length^3$

= $(48.23 \times 10^{-3}$ kg) / $(24.0 \times 10^{-3}$ m$)^3$ = 3490 kg m^{-3}

(ii) Percentage uncertainty in the length = 0.5 / 24.0 × 100% = 2.1%

Percentage uncertainty in the mass = 0.05/48.23 × 100% = 0.1%

Percentage uncertainty in density = 3 × 2.1% +0.1% = 6.4% (or 6%)

Therefore, the density of the material = 3490 kg m^{-3} ± 6% or 3490 kg m^{-3} ± 210 kg m^{-3}

Example: A student calculates the volume of a drinks can and the percentage uncertainty for the final value.

The student determines that the radius of the metal can is 33 mm with an uncertainty of 1% so the cross-sectional area A of the canister is:

$A = \pi r^2 = \pi (33)^2 = 3.4 \times 10^3$ mm^2 ± 2%

Notice that the result has been expressed using scientific notation so that we can write down just two significant figures. The calculator answer (3421.1...) gives the impression of far more sf than is justified when the radius is only known to the nearest mm.

The cross-sectional area was calculated by squaring the radius. Since two quantities have in effect been multiplied together, the percentage uncertainty in the value of the cross-sectional area is found by adding the percentage uncertainty of the radius to the percentage uncertainty of the radius – doubling it.

The student measures the length L of the can = 115 mm ± 2 mm

The volume V of the can is

$V = 3.4 \times 10^3\ \text{mm}^2 \times 115\ \text{mm} = 3.9 \times 10^5\ \text{mm}^3 = 3.9 \times 10^{-4}\ \text{m}^3$

The percentage uncertainty in this value is obtained by adding together an appropriate combination of the uncertainties

Percentage uncertainty in L = (2/115) × 100% = 1.7

Therefore, percentage uncertainty in V= 2% + 1.7% = 3.7%

Volume $V = 3.91 \times 10^{-4}\ \text{m}^3 \pm 3.7\% = 3.91 \times 10^{-4}\ \text{m}^3 \pm 1.4 \times 10^{-5}\ \text{m}^3$

Again, an overall percentage uncertainty of less than 5% suggests that this determination of the volume of a can is repeatable.

c) Adding or subtracting measurements

When measurements are added or subtracted in a calculation then the uncertainty for each measurement is added to calculate the total uncertainty.

Example: A student wants to determine the thickness of the walls of a plastic pipe. He measures the internal and external diameters of the pipe using vernier calipers and obtains the following readings:

Internal diameter = 101.4 mm ± 0.1 mm

External diameter = 102.8 mm ± 0.3 mm

The difference between these two measurements is 1.4 mm ± 0.4 mm

Since the difference in the radius is required then both the diameter **and** the uncertainty must be divided by 2 (since the percentage uncertainty remains the same), therefore the thickness of the walls is 0.7 mm ± 0.2 mm.

Using uncertainties in drawing conclusions

Often an experiment will require a comparison to a known value. This is when the uncertainty can be used to assess whether the measured value is accurate or not. This can be achieved in the following ways:

a) Calculating maximum and minimum values

The final uncertainty can be used to determine the range in which the measured value may lie. If the known value lies within this range then we can say that the measured value is accurate.

Example: A student used a simple pendulum to obtain a value of $g = 10.1\ \text{m s}^{-2}$. The experimental percentage uncertainty was calculated as 4%.

Minimum value of $g = 10.1 - (10.1 \times 4\%) = 9.7\ \text{m s}^{-2}$

Since the accepted value of $g = 9.81\ \text{m s}^{-2}$ lies above the minimum value, then we can conclude that the measured value of g is accurate.

This method should always be used when the percentage uncertainty in the value is known.

b) Calculating a percentage difference

If the measured value has been determined from a graph and there is no information about the percentage uncertainty of the measured value, then percentage difference can be used to comment on accuracy. If the percentage difference is less than 5%, then this is an indication that the result is accurate.

In the above example, the percentage difference is calculated as:

Percentage difference = (10.1−9.81)/9.81 × 100% = 3%

As this is less than 5% we can conclude that the measured value of *g* is accurate.

c) Observations from graphs

There is no expectation that error bars should be added to graphs.

If a straight-line graph through the origin is expected but the line of best fit of the plotted points does not pass through the origin, then this is an indication of a systematic error. If there is a large scatter of points around the line of best fit this is an indication of a large uncertainty possibly due to random errors.

Appendix 11: Support from the University of York

The Salters Horners Advanced Physics (SHAP) project team in the University of York Science Education Group runs in-service courses for teachers and technicians from centres that are following, or preparing to follow, this qualification.

The project team also runs an advice service to help with questions concerning the teaching of the course, and produces newsletters that are distributed to centres using this specification.

Centres following this qualification may be eligible for additional financial support (for example book grants) from the Salters and Horners companies.

There are email support groups for SHAP teachers and technicians.

For further information about the SHAP approach to teaching for this qualification, and about the support available to centres, please visit the SHAP website: www.york.ac.uk/org/seg/salters/physics or contact the project administrator at:

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VAT Reg No GB 278 537121

ISBN 978-1-4469-3602-3