Accredited

A LEVEL

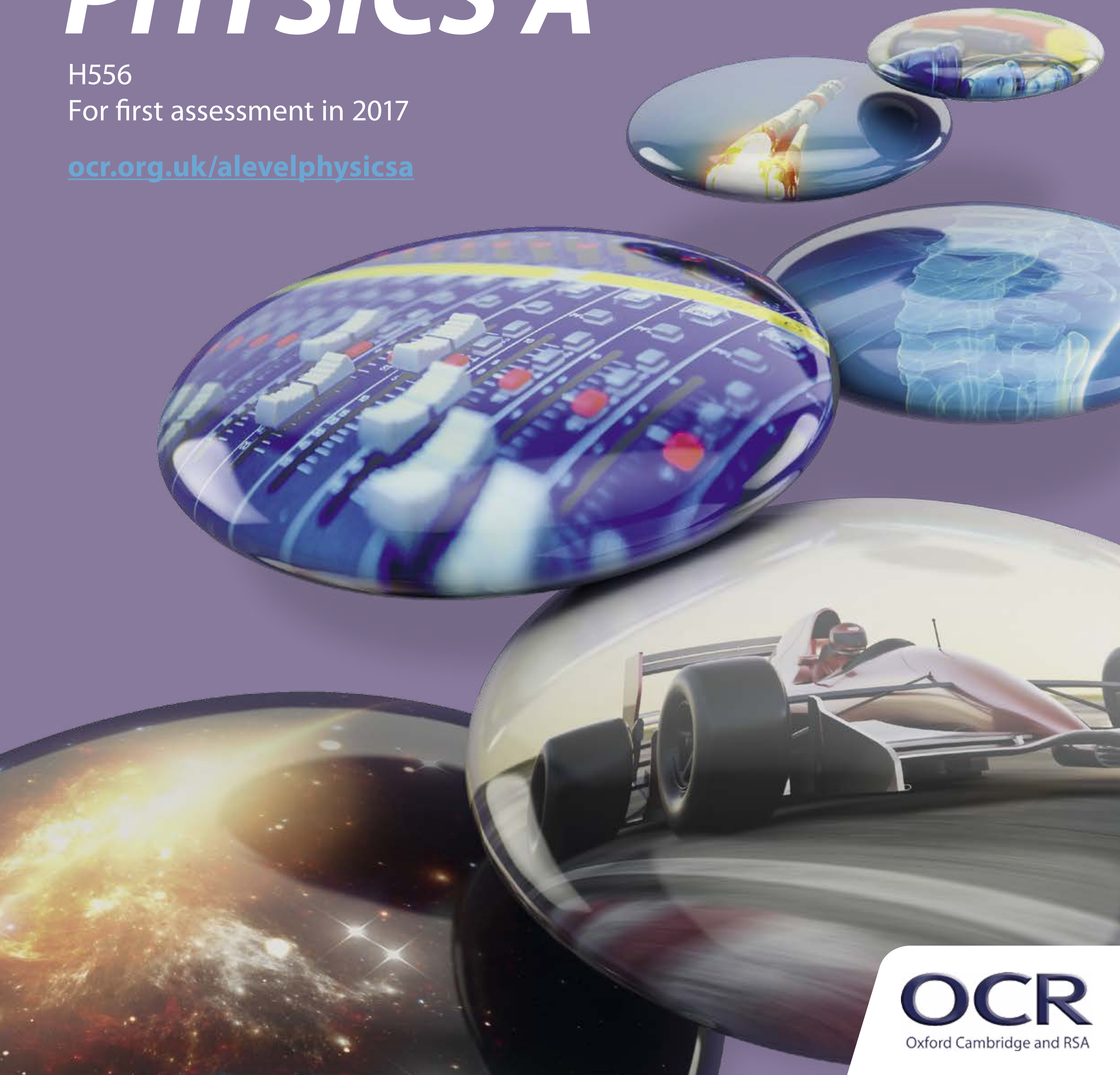
Specification

PHYSICS A

H556

For first assessment in 2017

ocr.org.uk/alevelphysicsa



OCR
Oxford Cambridge and RSA

We will inform centres about any changes to the specification. We will also publish changes on our website. The latest version of our specification will always be the one on our website (**ocr.org.uk**) and this may differ from printed versions.

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Contents

Introducing…
A Level Physics A (from September 2015)

Our vision for Science is to create specifications with content that will be up to date, scientifically accurate, developed by subject experts, and allow clear progression pathways (from GCSE to AS/A Level through to higher education, or other post-16 courses and employment). Courses will provide a rewarding experience across the ability range, genuinely challenging the most able learners. The assessment burden will be reduced as much as possible for centres through:

- Carefully designed assessments (straightforward to use for all centre types, large to small)
- Well-laid-out specifications and question papers
- Friendly and prompt support from our team of Subject Specialists
- Quality resource materials that help support a variety of good teaching approaches, drawing on expertise from across the subject community.

Our A Level Physics A specification takes a content-led approach to the course. This is a flexible approach where the specification is divided into topics, each covering different key concepts of physics. As learners progress through the course, they'll build on their knowledge of the laws of physics, applying their understanding to areas from sub-atomic particles to the entire universe.

We're striving for good science that's straightforward and engaging to teach, with fair, challenging and relevant assessment that works well in centres and promotes practical activity.

Meet the team

We have a dedicated team of subject specialists working on our A Level Physics qualifications.

Find out more about our Physics team at **ocr.org.uk/Scienceteam**

If you need specialist advice, guidance or support, get in touch:

- **01223 553998**
- **scienceGCE@ocr.org.uk**
- **@OCR_Science**

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

Teaching and learning resources

We recognise that the introduction of a new specification can bring challenges for implementation and teaching. Our aim is to help you at every stage and we're working hard to provide a practical package of support in close consultation with teachers and other experts, so we can help you to make the change.

Designed to support progression for all

Our resources are designed to provide you with a range of teaching activities and suggestions so you can select the best approach for your particular students. You are the experts on how your students learn and our aim is to support you in the best way we can.

We want to…

- Support you with a body of knowledge that grows throughout the lifetime of the specification
- Provide you with a range of suggestions so you can select the best activity, approach or context for your particular students
- Make it easier for you to explore and interact with our resource materials, in particular to develop your own schemes of work
- Create an ongoing conversation so we can develop materials that work for you.

Plenty of useful resources

You'll have four main types of subject-specific teaching and learning resources at your fingertips:

- Delivery Guides
- Transition Guides
- Topic Exploration Packs
- Lesson Elements.

Along with subject-specific resources, you'll also have access to a selection of generic resources that focus on skills development and professional guidance for teachers.

Skills Guides – we've produced a set of Skills Guides that are not specific to Physics, but each covers a topic that could be relevant to a range of qualifications – for example, communication, legislation and research. Download the guides at ocr.org.uk/skillsguides

Active Results – a free online results analysis service to help you review the performance of individual students or your whole school. It provides access to detailed results data, enabling more comprehensive analysis of results in order to give you a more accurate measurement of the achievements of your centre and individual students. For more details refer to ocr.org.uk/activeresults

Professional development

Take advantage of our improved Professional Development Programme, designed with you in mind. Whether you want to come to face-to-face events, look at our new digital training or search for training materials, you can find what you're looking for all in one place at the CPD Hub.

An introduction to the new specifications

We'll be running events to help you get to grips with our A Level Physics A qualification.

These events are designed to help prepare you for first teaching and to support your delivery at every stage.

Watch out for details at **cpdhub.ocr.org.uk**.

To receive the latest information about the training we'll be offering please register for A Level email updates at **ocr.org.uk/updates**.

1 Why choose an OCR A Level in Physics A?

1a. Why choose an OCR qualification?

Choose OCR and you've got the reassurance that you're working with one of the UK's leading exam boards. Our new A Level in Physics A course has been developed in consultation with teachers, employers and Higher Education to provide students with a qualification that's relevant to them and meets their needs.

We're part of the Cambridge Assessment Group, Europe's largest assessment agency and a department of the University of Cambridge. Cambridge Assessment plays a leading role in developing and delivering assessments throughout the world, operating in over 150 countries.

We work with a range of education providers, including schools, colleges, workplaces and other institutions in both the public and private sectors. Over 13,000 centres choose our A levels, GCSEs and vocational qualifications including Cambridge Nationals and Cambridge Technicals.

Our Specifications

We believe in developing specifications that help you bring the subject to life and inspire your students to achieve more.

We've created teacher-friendly specifications based on extensive research and engagement with the teaching community. They're designed to be straightforward and accessible so that you can tailor the delivery of the course to suit your needs. We aim to encourage learners to become responsible for their own learning, confident in discussing ideas, innovative and engaged.

We provide a range of support services designed to help you at every stage, from preparation through to the delivery of our specifications. This includes:

- A wide range of high-quality creative resources including:
  - delivery guides
  - transition guides
  - topic exploration packs
  - lesson elements
  - …and much more.
- Access to Subject Specialists to support you through the transition and throughout the lifetime of the specifications.
- CPD/Training for teachers to introduce the qualifications and prepare you for first teaching.
- Active Results – our free results analysis service to help you review the performance of individual students or whole schools.
- ExamCreator – our new online past papers service that enables you to build your own test papers from past OCR exam questions.

All A level qualifications offered by OCR are accredited by Ofqual, the Regulator for qualifications offered in England. The accreditation number for OCR's A Level in Physics A is QN: 601/4743/X.

1b. Why choose an OCR A Level in Physics A?

We appreciate that one size doesn't fit all so we offer two suites of qualifications in each science:

Physics A – a content-led approach. A flexible approach where the specification is divided into topics, each covering different key concepts of physics. As learners progress through the course they will build on their knowledge of the laws of Physics, applying their understanding to solve problems on topics ranging from sub-atomic particles to the entire universe. For A level only, the Practical Endorsement will also support the development of practical skills.

Physics B (Advancing Physics) – a context-led approach. Learners study physics in a range of different contexts, conveying the excitement of contemporary physics. The course provides a distinctive structure within which candidates learn about fundamental physical concepts and about physics in everyday and technological settings. Practical skills are embedded within the specification and learners are expected to carry out practical work in preparation for a written examination that will specifically test these skills.

All of our specifications have been developed with subject and teaching experts. We have worked in close consultation with teachers and representatives from Higher Education (HE) with the aim of including up-to-date relevant content within a framework that is interesting to teach and administer within all centres (large and small).

Our new A Level in Physics A qualification builds on our existing popular course. We've based the redevelopment of our A level sciences on an understanding of what works well in centres large and small and have updated areas of content and assessment where stakeholders have identified that improvements could be made. We've undertaken a significant amount of consultation through our science forums (which include representatives from learned societies, HE, teaching and industry) and through focus groups with teachers. Our papers and specifications have been trialled in centres during development to make sure they work well for all centres and learners.

The content changes are an evolution of our legacy offering and will be familiar to centres already following our courses, but are also clear and logically laid out for centres new to OCR, with assessment models that are straightforward to administer. We have worked closely with teachers and HE representatives to provide high quality support materials to guide you through the new qualifications.

Aims and learning outcomes

OCR's A Level in Physics A specification aims to encourage learners to:

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

1c. What are the key features of this specification?

Our Physics A specification is designed to inspire your learners. The course will develop their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with Physics. The specification:

- uses a content-led approach, enabling a flexible approach to the teaching order
- retains and refreshes the popular topics from the legacy OCR Physics A qualification (H558)
- is laid out clearly in a series of teaching modules with additional guidance added where required to clarify assessment requirements
- is co-teachable with the AS level
- embeds practical requirements within the teaching modules
- identifies Practical Endorsement requirements and how these can be integrated into teaching of content (see Section 5g)
- exemplifies the mathematical requirements of the course (see Section 5e)
- highlights opportunities for the introduction of key mathematical requirements (see Section 5e and the additional guidance column for each module) into your teaching
- identifies, within the additional guidance, how the skills, knowledge and understanding of How Science Works (HSW) can be incorporated within teaching.

1

Teacher support

The extensive support offered alongside this specification includes:

- **delivery guides –** providing information on assessed content, the associated conceptual development and contextual approaches to delivery
- **transition guides –** identifying the levels of demand and progression for different key stages for a particular topic and going on to provide links to high quality resources and 'checkpoint tasks' to assist teachers in identifying learners 'ready for progression'
- **lesson elements –** written by experts, providing all the materials necessary to deliver creative classroom activities
- **Active Results** (see Section 1a)
- **ExamCreator** (see Section 1a)
- **mock examinations service –** a free service offering a practice question paper and mark scheme (downloadable from a secure location).

Along with:

- Subject Specialists within the OCR science team to help with course queries
- teacher training
- *Science Spotlight* (our termly newsletter)
- OCR Science community
- a consultancy service (to advise on Practical Endorsement requirements)
- Practical Skills Handbook
- Maths Skills Handbook.

1

1d. How do I find out more information?

Whether new to our specifications, or continuing from our legacy offerings, you can find more information on our webpages at:

www.ocr.org.uk

Visit our Subject pages to find out more about the assessment package and resources available to support your teaching. The science team also release a termly newsletter *Science Spotlight* (despatched to centres and available from our subject pages).

Find out more?

Contact the Subject Specialists:
ScienceGCE@ocr.org.uk, 01223 553998.

Join our Science community: **http://social.ocr.org.uk/**

Check what CPD events are available:
www.cpdhub.ocr.org.uk

Follow us on Twitter: **@ocr_science**

2 The specification overview

2a. Overview of A Level in Physics A (H556)

Learners must complete all components (01, 02, 03 and 04) to be awarded the OCR A Level in Physics A.

<table>
<tr><th>Content Overview</th><th colspan="2">Assessment Overview</th></tr>
<tr><td rowspan="4">Content is split into six teaching modules:
• Module 1 – Development of practical skills in physics
• Module 2 – Foundations of physics
• Module 3 – Forces and motion
• Module 4 – Electrons, waves and photons
• Module 5 – Newtonian world and astrophysics
• Module 6 – Particles and medical physics
Component 01 assesses content from modules 1, 2, 3 and 5.
Component 02 assesses content from modules 1, 2, 4 and 6.
Component 03 assesses content from all modules (1 to 6).</td><td>Modelling physics (01)
100 marks
2 hours 15 minutes
written paper</td><td>37%
of total A level</td></tr>
<tr><td>Exploring physics (02)
100 marks
2 hours 15 minutes
written paper</td><td>37%
of total A level</td></tr>
<tr><td>Unified physics (03)
70 marks
1 hour 30 minutes
written paper</td><td>26%
of total A level</td></tr>
<tr><td>Practical Endorsement in physics
(04)
(non exam assessment)</td><td>Reported separately
(see Section 5g)</td></tr>
</table>

All components include synoptic assessment.

2

2b. Content of A Level in Physics A (H556)

The A Level in Physics A specification content is divided into six teaching modules. Each module is introduced with a summary of the physics it contains and each topic is also introduced with a short summary text. The assessable content is divided into two columns: **Learning outcomes** and **Additional guidance**.

The Learning outcomes may all be assessed in the examinations (with the exception of some of the skills in module **1.2** which will be assessed directly through the Practical Endorsement). The Additional guidance column is included to provide further advice on delivery and the expected skills required from learners.

References to HSW (Section 5d) are included in the guidance to highlight opportunities to encourage a wider understanding of science.

The mathematical requirements in Section 5e are also referenced by the prefix *M* to link the mathematical skills required for A Level Physics to examples of the physics content where those mathematical skills could be linked to learning.

The specification has been designed to be co-teachable with the standalone AS Level in Physics A qualification. The first four modules comprise the AS in Physics A course and learners studying the A level continue with the content of modules 5 and 6 in year 13.

The Data, Formulae and Relationships booklet in Section 5c will be available in examinations and learners are expected to become familiar with this booklet throughout the course.

A summary of the content for the A level course is as follows:

Module 1 – Development of practical skills in physics

1.1 Practical skills assessed in a written examination
1.2 Practical skills assessed in the practical endorsement

Module 2 – Foundations of physics

2.1 Physical quantities and units
2.2 Making measurements and analysing data
2.3 Nature of quantities

Module 3 – Forces and motion

3.1 Motion
3.2 Forces in action
3.3 Work, energy and power
3.4 Materials
3.5 Newton's laws of motion and momentum

Module 4 – Electrons, waves and photons

4.1 Charge and current
4.2 Energy, power and resistance
4.3 Electrical circuits
4.4 Waves
4.5 Quantum physics

Module 5 – Newtonian world and astrophysics

5.1 Thermal physics
5.2 Circular motion
5.3 Oscillations
5.4 Gravitational fields
5.5 Astrophysics and cosmology

Module 6 – Particles and medical physics

6.1 Capacitors
6.2 Electric fields
6.3 Electromagnetism
6.4 Nuclear and particle physics
6.5 Medical imaging

Assessment of practical skills and the Practical Endorsement

Module 1 of the specification content relates to the practical skills learners are expected to gain throughout the course, which are assessed throughout the written examinations and also through the Practical Endorsement (see Section 5g).

Practical activities are embedded within the learning outcomes of the course to encourage practical activities in the classroom which contribute to the achievement of the Practical Endorsement (Section 5g) as well as enhancing learners' understanding of physics theory and practical skills.

Opportunities for carrying out activities that could count towards the Practical Endorsement (Section 5g) are indicated throughout the specification. These are shown in the Additional guidance column as **PAG1** to **PAG10** (Practical Activity Group, see Section 5g). There are a wide variety of opportunities to assess **PAG 11** and **PAG12** throughout the qualification.

2

2c. Content of modules 1 to 6

Module 1: Development of practical skills in physics

Physics is a practical subject. The development and acquisition of practical skills is fundamental. The Physics A course provides learners with the opportunity to develop experimental methods and techniques for analysing empirical data. Skills in planning, implementing, analysing and evaluating, as outlined in **1.1**, will be assessed in the written papers.

1.1 Practical skills assessed in a written examination

Practical skills are embedded throughout all the content of this specification.

Learners will be required to develop a range of practical skills throughout their course in preparation for the written examinations.

1.1.1 Planning

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	experimental design, including to solve problems set in a practical context	Including selection of suitable apparatus, equipment and techniques for the proposed experiment. Learners should be able to apply scientific knowledge based on the content of the specification to the practical context. HSW3
(b)	identification of variables that must be controlled, where appropriate	
(c)	evaluation that an experimental method is appropriate to meet the expected outcomes.	HSW6

1.1.2 Implementing

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	how to use a wide range of practical apparatus and techniques correctly	As outlined in the content of the specification and the skills required for the practical endorsement. HSW4
(b)	appropriate units for measurements	*M0.1*
(c)	presenting observations and data in an appropriate format.	HSW8

2

1.1.3 Analysis

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	processing, analysing and interpreting qualitative and quantitative experimental results	Including reaching valid conclusions, where appropriate. HSW5
(b)	use of appropriate mathematical skills for analysis of quantitative data	Refer to Section 5d for a list of mathematical skills that learners should have acquired competence in as part of their course. HSW3
(c)	appropriate use of significant figures	*M1.1*
(d)	plotting and interpreting suitable graphs from experimental results, including	
	(i) selection and labelling of axes with appropriate scales, quantities and units	*M3.2*
	(ii) measurement of gradients and intercepts.	*M3.3, M3.4, M3.5*

1.1.4 Evaluation

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	how to evaluate results and draw conclusions	Learners should be able to evaluate how the scientific community use results to validate new knowledge and ensure integrity. HSW6, 11
(b)	the identification of anomalies in experimental measurements	
(c)	the limitations in experimental procedures	
(d)	precision and accuracy of measurements and data, including margins of error, percentage errors and uncertainties in apparatus	*M1.5*
(e)	the refining of experimental design by suggestion of improvements to the procedures and apparatus.	HSW3

2

1.2 Practical skills assessed in the practical endorsement

A range of practical experiences is a vital part of a learner's development as part of this course.

Learners should develop and practise a wide range of practical skills throughout the course as preparation for the Practical Endorsement, as well as for the written examinations.

The experiments and skills required for the Practical Endorsement will allow learners to develop and practise their practical skills, preparing learners for the written examinations.

Please refer to Section 5g (the Practical Endorsement) of this specification to see the list of practical experiences all learners should cover during the course. Further advice and guidance on the Practical Endorsement can be found in the Practical Skills Handbook support booklet.

1.2.1 Practical skills

	Learning outcomes	Additional guidance
	Practical work carried out throughout the course will enable learners to develop the following skills:	
Independent thinking		
(a)	apply investigative approaches and methods to practical work	Including how to solve problems in a practical context. HSW3
Use and application of scientific methods and practices		
(b)	safely and correctly use a range of practical equipment and materials	See Section 5g. Including identification of potential hazards. Learners should understand how to minimise the risks involved. HSW4
(c)	follow written instructions	HSW4
(d)	make and record observations/measurements	HSW8
(e)	keep appropriate records of experimental activities	See Section 5g.
(f)	present information and data in a scientific way	HSW8
(g)	use appropriate software and tools to process data, carry out research and report findings	*M3.1* HSW3
Research and referencing		
(h)	use online and offline research skills including websites, textbooks and other printed scientific sources of information	
(i)	correctly cite sources of information	The Practical Skills Handbook provides guidance on appropriate methods for citing information.

Instruments and equipment

(j)	use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification.	See Section 5g. HSW4

1.2.2 Use of apparatus and techniques

	Learning outcomes	Additional guidance
	Through use of the apparatus and techniques listed below, and a minimum of 12 assessed practicals (see Section 5g), learners should be able to demonstrate all of the practical skills listed within 1.2.1 and CPAC (Section 5g, ***Table 2****) as exemplified through:*	
(a)	use of appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles and volume) and to interpolate between scale markings	HSW4
(b)	use of appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance and mass)	HSW4
(c)	use of methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line	HSW4
(d)	use of a stopwatch or light gates for timing	HSW4
(e)	use of calipers and micrometers for small distances, using digital or vernier scales	HSW4
(f)	correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important	HSW4
(g)	designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components	HSW4
(h)	use of a signal generator and oscilloscope, including volts/division and time-base	HSW4
(i)	generating and measuring waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source	HSW4

(j)	use of a laser or light source to investigate characteristics of light, including interference and diffraction	HSW4
(k)	use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data	HSW3, HSW4
(l)	use of ionising radiation, including detectors.	HSW4

Module 2: Foundations of physics

The aim of this module is to introduce important conventions and ideas that permeate the fabric of physics. Understanding of physical quantities, S.I. units, scalars and vectors helps physicists to effectively communicate their ideas within the scientific community (HSW8, 11).

2

2.1 Physical quantities and units

This section provides knowledge and understanding of physical quantities and units.

2.1.1 Physical quantities

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	physical quantities have a numerical value and a unit	*M0.1*
(b)	making estimates of physical quantities listed in this specification.	*M0.4*

2.1.2 S.I. units

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Système Internationale (S.I.) base quantities and their units – mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)	HSW8
(b)	derived units of S.I. base units	Examples: momentum $\longrightarrow$ kg m s^{-1} and density $\longrightarrow$ kg m^{-3}
(c)	units listed in this specification	
(d)	checking the homogeneity of physical equations using S.I. base units	
(e)	prefixes and their symbols to indicate decimal submultiples or multiples of units – pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)	As set out in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000).
(f)	the conventions used for labelling graph axes and table columns.	As set out in above, e.g. speed / m s^{-1}. HSW8

2

2.2 Making measurements and analysing data

This section provides knowledge and understanding of physical measurements and treatment of errors and uncertainties.

2.2.1 Measurements and uncertainties

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	systematic errors (including zero errors) and random errors in measurements	
(b)	precision and accuracy	As discussed in *The Language of Measurement* (ASE 2010).
(c)	absolute and percentage uncertainties when data are combined by addition, subtraction, multiplication, division and raising to powers	As set out in the ASE publication *Signs*, *Symbols and Systematics* (*The ASE Companion to 16–19 Science,* 2000). A rigorous statistical treatment is not expected. *M1.5*
(d)	graphical treatment of errors and uncertainties; line of best fit; worst line; absolute and percentage uncertainties; percentage difference.	An elementary knowledge of error bars is expected at A level. HSW5 *M1.5*

2.3 Nature of quantities

This section provides knowledge and understanding of scalars and vectors quantities. Vector quantities add and subtract very differently to scalar quantities; hence it is important to know whether a quantity is a vector or a scalar.

2.3.1 Scalars and vectors

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	scalar and vector quantities	Learners will also be expected to give examples of each.
(b)	vector addition and subtraction	
(c)	vector triangle to determine the resultant of any two coplanar vectors	To be done by calculation or by scale drawing *M0.6, M4.2, M4.4*
(d)	resolving a vector into two perpendicular components; $F_x = F\cos\theta$; $F_y = F\sin\theta$.	*M0.6, M4.5*

Module 3: Forces and motion

The term *force* is generally used to indicate a push or a pull. It is difficult to give a proper definition for a force, but in physics we can easily describe what a force can do.

A resultant force acting on an object can accelerate the object in a specific direction. The subsequent motion of the object can be analysed using equations of motion. Several forces acting on an object can prevent the object from either moving or rotating. Forces can also change the shape of an object. There are many other things that forces can do.

In this module, learners will learn how to model the motion of objects using mathematics, understand the effect forces have on objects, learn about the important connection between force and energy, appreciate how forces cause deformation and understand the importance of Newton's laws of motion.

3.1 Motion

This section provides knowledge and understanding of key ideas used to describe and analyse the motion of objects in both one-dimension and in two-dimensions. It also provides learners with opportunities to develop their analytical and experimental skills.

The motion of a variety of objects can be analysed using ICT or data-logging techniques (HSW3). Learners also have the opportunity to analyse and interpret experimental data by recognising relationships between physical quantities (HSW5). The analysis of motion gives many opportunities to link to How Science Works. Examples relate to detecting the speed of moving vehicles, stopping distances and freefall (HSW2, 9, 10, 11, 12).

3.1.1 Kinematics

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	displacement, instantaneous speed, average speed, velocity and acceleration	*M0.1, M1.4, M3.7, M3.9* HSW10, 12
(b)	graphical representations of displacement, speed, velocity and acceleration	*M3.6* HSW3 Using data-loggers to analyse motion.
(c)	Displacement–time graphs; velocity is gradient	*M3.4, M3.7*
(d)	Velocity–time graphs; acceleration is gradient; displacement is area under graph.	Learners will also be expected to estimate the area under non-linear graphs. *M3.5, M4.3*

3.1.2 Linear motion

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)**	the equations of motion for constant acceleration in a straight line, including motion of bodies falling in a uniform gravitational field without air resistance $v = u + at$ $\quad s = \frac{1}{2}(u + v)t$ $s = ut + \frac{1}{2}at^2$ $\quad v^2 = u^2 + 2as$	*M2.2, M2.4, M3.3* HSW9
	(ii)	techniques and procedures used to investigate the motion and collisions of objects	**PAG1** Apparatus may include trolleys, air-track gliders, ticker timers, light gates, data-loggers and video techniques. HSW4, 9, 10
(b)	**(i)**	acceleration *g* of free fall	
	(ii)	techniques and procedures used to determine the acceleration of free fall using trapdoor and electromagnet arrangement or light gates and timer	**PAG1** HSW4, 5, 7 Determining *g* in the laboratory.
(c)		reaction time and thinking distance; braking distance and stopping distance for a vehicle.	HSW5, 9, 10, 11, 12

3.1.3 Projectile motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	independence of the vertical and horizontal motion of a projectile	
(b)	two-dimensional motion of a projectile with constant velocity in one direction and constant acceleration in a perpendicular direction.	*M0.6, M4.5*

3.2 Forces in action

This section provides knowledge and understanding of the motion of an object when it experiences several forces and also the equilibrium of an object. Learners will also learn how pressure differences give rise to an *upthrust* on an object in a fluid.

There are opportunities to consider contemporary applications of terminal velocity, moments, couples, pressure, and Archimedes principle (HSW6, 7, 9, 11, 12).

Experimental work must play a pivotal role in the acquisition of key concepts and skills (HSW4).

2

3.2.1 Dynamics

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	net force = mass × acceleration; $F = ma$	Learners will also be expected to recall this equation. *M1.1*
(b)	the newton as the unit of force	
(c)	weight of an object; $W = mg$	Learners will also be expected to recall this equation.
(d)	the terms tension, normal contact force, upthrust and friction	
(e)	free-body diagrams	
(f)	one- and two-dimensional motion under constant force.	

3.2.2 Motion with non-uniform acceleration

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	drag as the frictional force experienced by an object travelling through a fluid	
(b)	factors affecting drag for an object travelling through air	HSW6
(c)	motion of objects falling in a uniform gravitational field in the presence of drag	HSW9
(d)	**(i)** terminal velocity	HSW1, 5
	(ii) techniques and procedures used to determine terminal velocity in fluids.	**PAG1** e.g. ball-bearing in a viscous liquid or cones in air. HSW4 Investigating factors affecting terminal velocity.

3.2.3 Equilibrium

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	moment of force	
(b)	couple; torque of a couple	
(c)	the principle of moments	
(d)	centre of mass; centre of gravity; experimental determination of centre of gravity	
(e)	equilibrium of an object under the action of forces and torques	
(f)	condition for equilibrium of three coplanar forces; triangle of forces.	*M4.1, M4.2, M4.4*

3.2.4 Density and pressure

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	density; $\rho = \frac{m}{V}$	*M0.1, M4.3*
(b)	pressure; $p = \frac{F}{A}$ for solids, liquids and gases	
(c)	$p = h\rho g$; upthrust on an object in a fluid; Archimedes' principle.	*M2.1* HSW4, 7, 11

3.3 Work, energy and power

Words like *energy*, *power* and *work* have very precise meaning in physics. In this section the important link between work done and energy is explored. Learners have the opportunity to apply the important principle of conservation of energy to a range of situations. The analysis of energy transfers provides the opportunity for calculations of efficiency and the subsequent evaluation of issues relating to the individual and society (HSW2, 5, 8, 9, 10, 11, 12).

3.3.1 Work and conservation of energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	work done by a force; the unit joule	
(b)	$W = Fx\cos\theta$ for work done by a force	
(c)	the principle of conservation of energy	HSW2
(d)	energy in different forms; transfer and conservation	
(e)	transfer of energy is equal to work done.	

3.3.2 Kinetic and potential energies

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	kinetic energy of an object; $E_k = \frac{1}{2}mv^2$	Learners will also be expected to recall this equation and derive it from first principles. *M0.5*
(b)	gravitational potential energy of an object in a uniform gravitational field; $E_p = mgh$	Learners will also be expected to recall this equation and derive it from first principles.
(c)	the exchange between gravitational potential energy and kinetic energy.	HSW5, 6

3.3.3 Power

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	power; the unit watt; $P = \frac{W}{t}$	
(b)	$P = Fv$	Learners will also be expected to derive this equation from first principles.
(c)	efficiency of a mechanical system; $\text{efficiency} = \frac{\textit{useful output energy}}{\textit{total input energy}} \times 100\%$	*M0.3* HSW9, 10, 12

2

3.4 Materials

This section examines the physical properties of springs and materials.

Learners can carry out a range of experimental work to enhance their knowledge and skills, including the management of risks and analysis of data to provide evidence for relationships between physical quantities. There are opportunities to consider the selection of appropriate materials for practical applications (HSW5, 6, 8, 9, 12).

3.4.1 Springs

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	tensile and compressive deformation; extension and compression	
(b)	Hooke's law	
(c)	force constant k of a spring or wire; $F = kx$	
(d)	**(i)** force–extension (or compression) graphs for springs and wires	*M3.2*
	(ii) techniques and procedures used to investigate force–extension characteristics for arrangements which may include springs, rubber bands, polythene strips.	**PAG2** HSW5, 6

3.4.2 Mechanical properties of matter

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	force–extension (or compression) graph; work done is area under graph	*M3.1*
(b)	elastic potential energy; $E = \frac{1}{2}Fx$; $E = \frac{1}{2}kx^2$	*M0.5, M3.12*
(c)	stress, strain and ultimate tensile strength	
(d)	**(i)** Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$, $E = \frac{\sigma}{\varepsilon}$	*M3.1*
	(ii) techniques and procedures used to determine the Young modulus for a metal	**PAG2**
(e)	stress–strain graphs for typical ductile, brittle and polymeric materials	*M3.2* HSW8
(f)	elastic and plastic deformations of materials.	HSW4, 5, 9, 12 Investigating the properties of materials **PAG2**

3.5 Newton's laws of motion and momentum

This section provides knowledge and understanding of Newton's laws – fundamental laws that can be used to predict the motion of all colliding or interacting objects in applications such as sport (HSW1, 2). Newton's law can also be used to understand some of the safety features in cars, such as air bags, and to evaluate the benefits and risks of such features (HSW9). Learners should be aware that the introduction of mandatory safety features in cars is a consequence of the scientific community analysing the forces involved in collisions and investigating potential solutions to reduce the likelihood of personal injury (HSW10, 11, 12).

There are many opportunities for learners to carry out experimental work and analyse data using ICT techniques (HSW3).

2

3.5.1 Newton's laws of motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's three laws of motion	HSW7
(b)	linear momentum; $p = mv$; vector nature of momentum	
(c)	net force = rate of change of momentum; $F = \frac{\Delta p}{\Delta t}$	Learners are expected to know that $F = ma$ is a special case of this equation. HSW9, 10 *M2.1, M3.9*
(d)	impulse of a force; impulse = $F\Delta t$	
(e)	impulse is equal to the area under a force–time graph.	Learners will also be expected to estimate the area under non-linear graphs. HSW3 Using a spreadsheet to determine impulse from F–t graph. *M3.8, M4.3*

3.5.2 Collisions

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the principle of conservation of momentum	HSW7
(b)	collisions and interaction of bodies in one dimension and in two dimensions	Two-dimensional problems will only be assessed at A level. HSW11, 12
(c)	perfectly elastic collision and inelastic collision.	HSW1, 2, 6

2

Module 4: Electrons, waves and photons

The aim of this module is to ultimately introduce key ideas of quantum physics. Electromagnetic waves (e.g. light) have a dual nature. They exhibit both wave and particle-like behaviour. The wave–particle dual nature is also found to be characteristic of all particles (e.g. electrons).

Before any sophisticated work can be done on quantum physics, learners need to appreciate what electrons are and how they behave in electrical circuits. A basic understanding of wave properties is also required.

In this module, learners will learn about electrons, electric current, electrical circuits, wave properties, electromagnetic waves and, of course, quantum physics.

Learners have the opportunity to appreciate how scientific ideas of quantum physics developed over time (HSW7) and their validity rested on the foundations of experimental work (HSW1 and HSW2).

4.1 Charge and current

This short section introduces the ideas of charge and current. Understanding electric current is essential when dealing with electrical circuits. This section does not lend itself to practical work but to introducing important ideas. The continuity equation ($I = Anev$) is developed using these key ideas. This section concludes with categorising all materials in terms of their ability to conduct.

4.1.1 Charge

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electric current as rate of flow of charge; $I = \frac{\Delta Q}{\Delta t}$	
(b)	the coulomb as the unit of charge	
(c)	the elementary charge *e* equals 1.6 × 10^{-19} C	Learners will be expected to know that an electron has charge –*e* and a proton a charge +*e*. HSW7
(d)	net charge on a particle or an object is quantised and a multiple of *e*	
(e)	current as the movement of electrons in metals and movement of ions in electrolytes	HSW7
(f)	conventional current and electron flow	HSW7
(g)	Kirchhoff's first law; conservation of charge.	

4.1.2 Mean drift velocity

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	mean drift velocity of charge carriers	
(b)	$I = Anev$, where n is the number density of charge carriers	*M0.2*
(c)	distinction between conductors, semiconductors and insulators in terms of n.	HSW1, 2

4.2 Energy, power and resistance

This section provides knowledge and understanding of electrical symbols, electromotive force, potential difference, resistivity and power. The scientific vocabulary developed here is a prerequisite for understanding electrical circuits in **4.3**.

There is a desire to use energy saving devices, such as LED lamps, in homes. Learners have the opportunity to understand the link between environmental damage from power stations and the impetus to use energy saving devices in the home (HSW10) and how customers can make informed decisions when buying domestic appliances (HSW12).

There are many opportunities for learners to use spreadsheets in the analysis and presentation of data (HSW3), to carry out practical activities to understand concepts (HSW4) and to analyse data to find relationships between physical quantities (HSW5).

4.2.1 Circuit symbols

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	circuit symbols	As set out in ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000).* HSW8
(b)	circuit diagrams using these symbols.	

4.2.2 E.m.f. and p.d

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	potential difference (p.d.); the unit volt	
(b)	electromotive force (e.m.f.) of a source such as a cell or a power supply	Epsilon is used as the symbol for e.m.f. to avoid confusion with E which is used for energy and electric field. The ASE guide 'Signs symbols and systematics' details E as the correct symbol for e.m.f. and this will be credited in all examinations.
(c)	distinction between e.m.f. and p.d. in terms of energy transfer	
(d)	energy transfer; $W = VQ$; $W = \mathcal{E}Q$.	

(e)	energy transfer $eV = \frac{1}{2}mv^2$ for electrons and other charged particles.	

4.2.3 Resistance

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	resistance; $R = \frac{V}{I}$; the unit ohm	Learners will also be expected to recall this equation.
(b)	Ohm's law	
(c)	**(i)** I–V characteristics of resistor, filament lamp, thermistor, diode and light-emitting diode (LED)	*M3.12* HSW5, 8, 9
	(ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components.	**PAG3** HSW3, 4, 5 Investigating components and analysing data using spreadsheet.
(d)	light-dependent resistor (LDR); variation of resistance with light intensity.	

4.2.4 Resistivity

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** resistivity of a material; the equation $R = \frac{\rho L}{A}$	
	(ii) techniques and procedures used to determine the resistivity of a metal.	**PAG3**
(b)	the variation of resistivity of metals and semiconductors with temperature	HSW2
(c)	negative temperature coefficient (NTC) thermistor; variation of resistance with temperature.	HSW5

4.2.5 Power

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the equations $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$	*M2.2*
(b)	energy transfer; $W = VIt$	

(c)	the kilowatt-hour (kW h) as a unit of energy; calculating the cost of energy.	Learners will be expected to link this with 3.3.3(c) HSW10,12

4.3 Electrical circuits

This section provides knowledge and understanding of electrical circuits, internal resistance and potential dividers. LDRs and thermistors are used to show how changes in light intensity and temperature respectively can be monitored using potential dividers.

Setting up electrical circuits, including potential divider circuits, provides an ideal way of enhancing experimental skills, understanding electrical concepts and managing risks when using power supplies (HSW4). Learners are encouraged to communicate scientific ideas using appropriate terminology (HSW8). This section provides ample opportunities for learners to design circuits and carry out appropriate testing for faults and there are opportunities to study the many applications of electrical circuits (HSW1, 2, 3, 5, 6, 9, 12).

2

4.3.1 Series and parallel circuits

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Kirchhoff's second law; the conservation of energy	
(b)	Kirchhoff's first and second laws applied to electrical circuits	
(c)	total resistance of two or more resistors in series; $R = R_1 + R_2 + .$	
(d)	total resistance of two or more resistors in parallel; $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$	
(e)	analysis of circuits with components, including both series and parallel	
(f)	analysis of circuits with more than one source of e.m.f.	

4.3.2 Internal resistance

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		source of e.m.f.; internal resistance	HSW9, 12
(b)		terminal p.d.; 'lost volts'	
(c)	**(i)**	the equations $\mathcal{E} = I(R + r)$ and $\mathcal{E} = V + Ir$	HSW5, 6
	(ii)	techniques and procedures used to determine the internal resistance of a chemical cell or other source of e.m.f.	**PAG4** HSW4, HSW8 Investigating the internal resistance of a power supply.

2

4.3.3 Potential dividers

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	potential divider circuit with components	Learners will also be expected to know about a potentiometer as a potential divider.
(b)	potential divider circuits with variable components e.g. LDR and thermistor	
(c)	**(i)** potential divider equations e.g. $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$ and $\frac{V_1}{V_2} = \frac{R_1}{R_2}$	*M2.3*
	(ii) techniques and procedures used to investigate potential divider circuits which may include a sensor such as a thermistor or an LDR.	**PAG4** HSW4 Designing temperature and light sensing circuits.

4.4 Waves

This section provides knowledge and understanding of wave properties, electromagnetic waves, superposition and stationary waves. The wavelength of visible light is too small to be measured directly using a ruler. However, superposition experiments can be done in the laboratory to determine wavelength of visible light using a laser and a double slit.

There are opportunities to discuss how the double-slit experiment demonstrated the wave-like behaviour of light (HSW7).

The breadth of the topic covering sound waves and the electromagnetic spectrum provides scope for learners to appreciate the wide ranging applications of waves and their properties. (HSW1, 2, 5, 8, 9, 12)

4.4.1 Wave motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	progressive waves; longitudinal and transverse waves	HSW8
(b)	**(i)** displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave	HSW8
	(ii) techniques and procedures used to use an oscilloscope to determine frequency	**PAG5**
(c)	the equation $f = \frac{1}{T}$	
(d)	the wave equation $v = f\lambda$	

(e)	graphical representations of transverse and longitudinal waves		HSW5
(f)	**(i)**	reflection, refraction, polarisation and diffraction of all waves	Learners will be expected to know that diffraction effects become significant when the wavelength is comparable to the gap width.
	(ii)	techniques and procedures used to demonstrate wave effects using a ripple tank	HSW1, 4
	(iii)	techniques and procedures used to observe polarising effects using microwaves and light	**PAG5**
(g)	intensity of a progressive wave; $I = \frac{P}{A}$; intensity $\propto$ (amplitude)^2.		

2

4.4.2 Electromagnetic waves

	Learning outcomes		Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:		
(a)	electromagnetic spectrum; properties of electromagnetic waves		
(b)	orders of magnitude of wavelengths of the principal radiations from radio waves to gamma rays		
(c)	plane polarised waves; polarisation of electromagnetic waves		Learners will be expected to know about polarising filters for light and metal grilles for microwaves in demonstrating polarisation. HSW9
(d)	**(i)**	refraction of light; refractive index; $n = \frac{c}{v}$; $n \sin\theta =$ constant at a boundary where θ is the angle to the normal	
	(ii)	techniques and procedures used to investigate refraction and total internal reflection of light using ray boxes, including transparent rectangular and semi-circular blocks	**PAG6**
(e)	critical angle; $\sin C = \frac{1}{n}$; total internal reflection for light.		

4.4.3 Superposition

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	(i) the principle of superposition of waves	
	(ii) techniques and procedures used for superposition experiments using sound, light and microwaves	**PAG5**
(b)	graphical methods to illustrate the principle of superposition	
(c)	interference, coherence, path difference and phase difference	
(d)	constructive interference and destructive interference in terms of path difference and phase difference	
(e)	two-source interference with sound and microwaves	
(f)	Young double-slit experiment using visible light	Learners should understand that this experiment gave a classical confirmation of the wave-nature of light. HSW7 Internet research on the ideas of Newton and Huygens about the nature of light.
(g)	(i) $\lambda = \frac{ax}{D}$ for all waves where $a << D$	*M4.6*
	(ii) techniques and procedures used to determine the wavelength of light using (1) a double-slit, and (2) a diffraction grating.	**PAG5** $d \sin\theta = n\lambda$ and diffraction gratings will only be assessed at A level

4.4.4 Stationary waves

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	stationary (standing) waves using microwaves, stretched strings and air columns	
(b)	graphical representations of a stationary wave	
(c)	similarities and the differences between stationary and progressive waves	
(d)	nodes and antinodes	
(e)	(i) stationary wave patterns for a stretched string and air columns in closed and open tubes	

	Learning outcomes	Additional guidance
	(ii) techniques and procedures used to determine the speed of sound in air by formation of stationary waves in a resonance tube	**PAG5**
(f)	the idea that the separation between adjacent nodes (or antinodes) is equal to $\lambda/2$, where λ is the wavelength of the progressive wave	
(g)	fundamental mode of vibration (1st harmonic); harmonics.	

4.5 Quantum physics

This section provides knowledge and understanding of photons, the photoelectric effect, de Broglie waves and wave–particle duality.

In the photoelectric effect experiment, electromagnetic waves are used to eject surface electrons from metals. The electrons are ejected instantaneously and their energy is independent of the intensity of the radiation. The wave model is unable to explain the interaction of these waves with matter. This single experiment led to the development of the photon model and was the cornerstone of quantum physics. Learners have the opportunity to carry out internet research into how the ideas of quantum physics developed (HSW1, 2, 7) and how scientific community validates the integrity of new knowledge before its acceptance (HSW11).

4.5.1 Photons

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the particulate nature (photon model) of electromagnetic radiation	
(b)	photon as a quantum of energy of electromagnetic radiation	
(c)	energy of a photon; $E = hf$ and $E = \frac{hc}{\lambda}$	
(d)	the electronvolt (eV) as a unit of energy	
(e)	**(i)** using LEDs and the equation $eV = \frac{hc}{\lambda}$ to estimate the value of Planck constant h	No knowledge of semiconductor theory is required. HSW11
	(ii) Determine the Planck constant using different coloured LEDs.	**PAG6**

2

4.5.2 The photoelectric effect

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** photoelectric effect, including a simple experiment to demonstrate this effect	Learners should understand that the photoelectric effect provides evidence for particulate nature of electromagnetic radiation. HSW1, 2, 3, 7, 11 Internet research on the development of quantum physics.
	(ii) demonstration of the photoelectric effect using, e.g. gold-leaf electroscope and zinc plate	
(b)	a one-to-one interaction between a photon and a surface electron	
(c)	Einstein's photoelectric equation $hf = \phi + KE_{max}$	*M2.3*
(d)	work function; threshold frequency	
(e)	the idea that the maximum kinetic energy of the photoelectrons is independent of the intensity of the incident radiation	
(f)	the idea that rate of emission of photoelectrons above the threshold frequency is directly proportional to the intensity of the incident radiation.	

4.5.3 Wave–particle duality

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electron diffraction, including experimental evidence of this effect	Learners should understand that electron diffraction provides evidence for wave-like behaviour of particles.
(b)	diffraction of electrons travelling through a thin slice of polycrystalline graphite by the atoms of graphite and the spacing between the atoms	
(c)	the de Broglie equation $\lambda = \frac{h}{p}$.	

Module 5: Newtonian world and astrophysics

The aim of this module is to show the impact Newtonian mechanics has on physics. The microscopic motion of atoms can be modelled using Newton's laws and hence provide us with an understanding of macroscopic quantities such as pressure and temperature. Newton's law of gravitation can be used to predict the motion of planets and distant galaxies. In the final section we explore the intricacies of stars and the expansion of the Universe by analysing the electromagnetic radiation from space. As such, it lends itself to the consideration of how the development of the scientific model is improved based on the advances in the means of observation (HSW1, 2, 5, 6, 7, 8, 9, 11).

In this module, learners will learn about thermal physics, circular motion, oscillations, gravitational field, astrophysics and cosmology.

5.1 Thermal physics

This section provides knowledge and understanding of temperature, matter, specific heat capacity and specific latent heat with contexts involving heat transfer and change of phase (HSW1, 2, 5, 7).

Experimental work can be carried out to safely investigate specific heat capacity of materials (HSW4).

It also provides an opportunity to discuss how Newton's laws can be used to model the behaviour of gases (HSW1) and significant opportunities for the analysis and interpretation of data (HSW5).

5.1.1 Temperature

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	thermal equilibrium	
(b)	absolute scale of temperature (i.e. the thermodynamic scale) that does not depend on property of any particular substance	HSW7
(c)	temperature measurements both in degrees Celsius (°C) and in kelvin (K)	HSW7
(d)	$T(K) \approx \theta(^\circ C) + 273$.	

5.1.2 Solid, liquid and gas

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules	HSW1
(b)	simple kinetic model for solids, liquids and gases	HSW1
(c)	Brownian motion in terms of the kinetic model of matter and a simple demonstration using smoke particles suspended in air	HSW2

(d) internal energy as the sum of the random distribution of kinetic and potential energies associated with the molecules of a system

(e) absolute zero (0 K) as the lowest limit for temperature; the temperature at which a substance has minimum internal energy

(f) increase in the internal energy of a body as its temperature rises

(g) changes in the internal energy of a substance during change of phase; constant temperature during change of phase.

5.1.3 Thermal properties of materials

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	specific heat capacity of a substance; the equation $E = mc\Delta\theta$	HSW4 Estimating specific heat capacity, using method of mixture.
(b)	**(i)** an electrical experiment to determine the specific heat capacity of a metal or a liquid	HSW5
	(ii) techniques and procedures used for an electrical method to determine the specific heat capacity of a metal block and a liquid	
(c)	specific latent heat of fusion and specific latent heat of vaporisation; $E = mL$	
(d)	**(i)** an electrical experiment to determine the specific latent heat of fusion and vaporisation	
	(ii) techniques and procedures used for an electrical method to determine the specific latent heat of a solid and a liquid.	

5.1.4 Ideal gases

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	amount of substance in moles; Avogadro constant N_A equals 6.02 × 10^{23} mol^{-1}	
(b)	model of kinetic theory of gases	assumptions for the model: large number of molecules in random, rapid motion particles (atoms or molecules) occupy negligible volume compared to the volume of gas all collisions are perfectly elastic and the time of the collisions is negligible compared to the time between collisions negligible forces between particles except during collision HSW1
(c)	pressure in terms of this model	HSW1, 2 Explanation of pressure in terms of Newtonian theory.
(d)	**(i)** the equation of state of an ideal gas $pV = nRT$, where n is the number of moles	
	(ii) techniques and procedures used to investigate PV = constant (Boyle's law) and $\frac{P}{T} = \text{constant}$	**PAG8**
	(iii) an estimation of absolute zero using variation of gas temperature with pressure	**PAG8**
(e)	the equation $pV = \frac{1}{3}Nm\overline{c^2}$, where N is the number of particles (atoms or molecules) and $\overline{c^2}$ is the mean square speed	Derivation of this equation is not required. HSW2
(f)	root mean square (r.m.s.) speed; mean square speed	Learners should know about the general characteristics of the Maxwell-Boltzmann distribution.
(g)	the Boltzmann constant; $k = \frac{R}{N_A}$	
(h)	$pV = NkT$; $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$	Learners will also be expected to know the derivation of the equation $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ from $pV = \frac{1}{3}Nm\overline{c^2}$ and $pV = NkT$. HSW2
(i)	internal energy of an ideal gas.	

5.2 Circular motion

There are many examples of objects travelling at constant speed in circles, e.g. planets, artificial satellites, charged particles in a magnetic field, etc. The physics in all these cases can be described and analysed using the ideas developed by Newton. The concepts in this section have applications in many contexts present in other sections of this specification, such as planetary motion in section 5.4.3 (HSW1, 2, 5, 9).

This section provides knowledge and understanding of circular motion and important concepts such as centripetal force and acceleration.

2

5.2.1 Kinematics of circular motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the radian as a measure of angle	*M4.7*
(b)	period and frequency of an object in circular motion	
(c)	angular velocity ω, $\omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$	

5.2.2 Centripetal force

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	a constant net force perpendicular to the velocity of an object causes it to travel in a circular path	HSW1, 2, 5, 9
(b)	constant speed in a circle; $v = \omega r$	
(c)	centripetal acceleration; $a = \frac{v^2}{r}$; $a = \omega^2 r$	*M2.4*
(d)	**(i)** centripetal force; $F = \frac{mv^2}{r}$; $F = m\omega^2 r$	
	(ii) techniques and procedures used to investigate circular motion using a whirling bung.	

5.3 Oscillations

Oscillatory motion is all around us, with examples including atoms vibrating in a solid, a bridge swaying in the wind, the motion of pistons of a car and the motion of tides. (HSW1, 2, 3, 5, 6, 8, 9, 10, 12)

This section provides knowledge and understanding of simple harmonic motion, forced oscillations and resonance.

5.3.1 Simple harmonic oscillations

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	displacement, amplitude, period, frequency, angular frequency and phase difference	*M4.7* HSW8
(b)	angular frequency ω; $\omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$	
(c)	**(i)** simple harmonic motion; defining equation $a = -\omega^2 x$	HSW5
	(ii) techniques and procedures used to determine the period/frequency of simple harmonic oscillations	**PAG10** e.g. mass on a spring, pendulum
(d)	solutions to the equation $a = -\omega^2 x$ e.g. $x = A\cos\omega t$ or $x = A\sin\omega t$	*M3.9, M3.12*
(e)	velocity $v = \pm\omega\sqrt{A^2 - x^2}$ hence $v_{max} = \omega A$	*M2.2*
(f)	the period of a simple harmonic oscillator is independent of its amplitude (isochronous oscillator)	
(g)	graphical methods to relate the changes in displacement, velocity and acceleration during simple harmonic motion.	HSW1

5.3.2 Energy of a simple harmonic oscillator

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	interchange between kinetic and potential energy during simple harmonic motion	HSW2
(b)	energy-displacement graphs for a simple harmonic oscillator	HSW6

5.3.3 Damping

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	free and forced oscillations	
(b)	**(i)** the effects of damping on an oscillatory system	HSW9, 12
	(ii) observe forced and damped oscillations for a range of systems	
(c)	resonance; natural frequency	HSW9, 12
(d)	amplitude-driving frequency graphs for forced oscillators	
(e)	practical examples of forced oscillations and resonance.	HSW9, 12

5.4 Gravitational fields

This section provides knowledge and understanding of Newton's law of gravitation, planetary motion and gravitational potential and energy.

Newton's law of gravitation can be used to predict the motion of orbiting satellites, planets and even why some objects in our Solar system have very little atmosphere with the opportunity to analyse evidence and look at causal relationships (HSW1, 2, 5, 7).

Geostationary satellites have done much to improve telecommunications around the world. They are expensive; governments and industry have to make difficult decisions when building new ones. Learners have the opportunity to discuss the societal benefits of satellites and the risks they pose when accidents do occur (HSW9, 10).

5.4.1 Point and spherical masses

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	gravitational fields are due to objects having mass	
(b)	modelling the mass of a spherical object as a point mass at its centre	
(c)	gravitational field lines to map gravitational fields	HSW1
(d)	gravitational field strength; $g = \frac{F}{m}$.	
(e)	the concept of gravitational fields as being one of a number of forms of field giving rise to a force.	Learners will be expected to link this with section 6.2

5.4.2 Newton's law of gravitation

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's law of gravitation; $F = -\frac{GMm}{r^2}$ for the force between two point masses	*M2.3*
(b)	gravitational field strength $g = -\frac{GM}{r^2}$ for a point mass	
(c)	gravitational field strength is uniform close to the surface of the Earth and numerically equal to the acceleration of free fall.	

5.4.3 Planetary motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Kepler's three laws of planetary motion	HSW7
(b)	the centripetal force on a planet is provided by the gravitational force between it and the Sun	
(c)	the equation $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$	Learners will also be expected to derive this equation from first principles. HSW1
(d)	the relationship for Kepler's third law $T^2 \propto r^3$ applied to systems other than our solar system	
(e)	geostationary orbit; uses of geostationary satellites.	HSW1, 2, 9, 10 Predicting geostationary orbit using Newtonian laws.

5.4.4 Gravitational potential and energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	gravitational potential at a point as the work done in bringing unit mass from infinity to the point; gravitational potential is zero at infinity	
(b)	gravitational potential $V_g = -\frac{GM}{r}$ at a distance r from a point mass M; changes in gravitational potential	
(c)	force–distance graph for a point or spherical mass; work done is area under graph	HSW5
(d)	gravitational potential energy $E = mV_g = -\frac{GMm}{r}$ at a distance r from a point mass M	
(e)	escape velocity.	HSW1, HSW2 Predicting the escape velocity of atoms from the atmosphere of planets.

5.5 Astrophysics and cosmology

This section provides knowledge and understanding of stars, Wien's displacement law, Stefan's law, Hubble's law and the Big Bang.

Learners have the opportunity to appreciate how scientific ideas of the Big Bang developed over time and how its validity is supported by research and experimental work carried out by the scientific community (HSW2, 7, 8, 11).

2

5.5.1 Stars

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the terms planets, planetary satellites, comets, solar systems, galaxies and the universe	HSW7
(b)	formation of a star from interstellar dust and gas in terms of gravitational collapse, fusion of hydrogen into helium, radiation and gas pressure	Learners are not expected to know the details of fusion in terms of Einstein's mass-energy equation.
(c)	evolution of a low-mass star like our Sun into a red giant and white dwarf; planetary nebula	HSW8
(d)	characteristics of a white dwarf; electron degeneracy pressure; Chandrasekhar limit	HSW8
(e)	evolution of a massive star into a red super giant and then either a neutron star or black hole; supernova	HSW8
(f)	characteristics of a neutron star and a black hole	HSW8
(g)	Hertzsprung–Russell (HR) diagram as luminosity-temperature plot; main sequence; red giants; super red giants; white dwarfs.	HSW8

5.5.2 Electromagnetic radiation from stars

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	energy levels of electrons in isolated gas atoms	
(b)	the idea that energy levels have negative values	
(c)	emission spectral lines from hot gases in terms of emission of photons and transition of electrons between discrete energy levels	HSW2, 8
(d)	the equations $hf = \Delta E$ and $\frac{hc}{\lambda} = \Delta E$	Learners will also require knowledge of section 4.5
(e)	different atoms have different spectral lines which can be used to identify elements within stars	

(f)	continuous spectrum, emission line spectrum and absorption line spectrum	
(g)	transmission diffraction grating used to determine the wavelength of light	The structure and use of an optical spectrometer are not required; **PAG5**
(h)	the condition for maxima $d\sin\theta = n\lambda$, where d is the grating spacing	Proof of this equation is not required.
(i)	use of Wien's displacement law $\lambda_{max} \propto \frac{1}{T}$ to estimate the peak surface temperature (of a star)	*M0.4* HSW5
(j)	luminosity L of a star; Stefan's law $L = 4\pi r^2 \sigma T^4$ where σ is the Stefan constant	Learners will also require knowledge of 4.4.1
(k)	use of Wien's displacement law and Stefan's law to estimate the radius of a star.	*M0.4* HSW5

5.5.3 Cosmology

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	distances measured in astronomical unit (AU), light-year (ly) and parsec (pc)	*M4.6*
(b)	stellar parallax; distances the parsec (pc)	
(c)	the equation $p = \frac{1}{d}$, where p is the parallax in seconds of arc and d is the distance in parsec	
(d)	the Cosmological principle; universe is homogeneous, isotropic and the laws of physics are universal	
(e)	Doppler effect; Doppler shift of electromagnetic radiation	
(f)	Doppler equation $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer	
(g)	Hubble's law; $v \approx H_0 d$ for receding galaxies, where H_0 is the Hubble constant	HSW7
(h)	model of an expanding universe supported by galactic red shift	HSW2, 7, 8, 11
(i)	Hubble constant H_0 in both $\text{km s}^{-1}\text{Mpc}^{-1}$ and s^{-1} units	
(j)	the Big Bang theory	HSW7, 9, 10, 12

(k)	experimental evidence for the Big Bang theory from microwave background radiation at a temperature of 2.7 K	HSW7, HSW11 The development and acceptance of Big Bang theory by the scientific community.
(l)	the idea that the Big Bang gave rise to the expansion of space-time	
(m)	estimation for the age of the universe; $t \approx H_0^{-1}$	*M1.4* HSW7
(n)	evolution of the universe after the Big Bang to the present	HSW1, 2, 5, 6, 7, 8, 9, 10, 11
(o)	current ideas; universe is made up of dark energy, dark matter, and a small percentage of ordinary matter.	

Module 6: Particles and medical physics

In this module, learners will learn about capacitors, electric field, electromagnetism, nuclear physics, particle physics and medical imaging.

2

6.1 Capacitors

This section introduces the basic properties of capacitors and how they are used in electrical circuits. The use of capacitors as a source of electrical energy is then developed. This section introduces the mathematics of exponential decay, which is also required for the decay of radioactive nuclei in **6.4**.

This section provides knowledge and understanding of capacitors and exponential decay.

Experimental work provides an excellent way to understand the behaviour of capacitors in electrical circuits and the management of safety and risks when using power supplies (HSW4). There are many opportunities for learners to use spreadsheets in the analysis and presentation of data (HSW3). The varied uses of capacitors give the opportunity for the consideration of their use in many practical applications (HSW2, 5, 6, 9)

6.1.1 Capacitors

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	capacitance; $C = \frac{Q}{V}$; the unit farad	
(b)	charging and discharging of a capacitor or capacitor plates with reference to the flow of electrons	HSW2
(c)	total capacitance of two or more capacitors in series; $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + ...$	
(d)	total capacitance of two or more capacitors in parallel; $C = C_1 + C_2 + ...$	
(e)	**(i)** analysis of circuits containing capacitors, including resistors	HSW5
	(ii) techniques and procedures used to investigate capacitors in both series and parallel combinations using ammeters and voltmeters.	**PAG9**

6.1.2 Energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	p.d. – charge graph for a capacitor; energy stored is area under graph	*M3.8* HSW5
(b)	energy stored by capacitor; $W = \frac{1}{2}QV$, $W = \frac{1}{2}\frac{Q^2}{C}$ and $W = \frac{1}{2}V^2C$	HSW6
(c)	uses of capacitors as storage of energy.	HSW9

6.1.3 Charging and discharging capacitors

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** charging and discharging capacitor through a resistor	
	(ii) techniques and procedures to investigate the charge and the discharge of a capacitor using both meters and data-loggers	**PAG9** HSW4 Investigating the charge and discharge of capacitors in the laboratory.
(b)	time constant of a capacitor–resistor circuit; $\tau = CR$	HSW9
(c)	equations of the form $x = x_0 e^{-\frac{t}{CR}}$ and $x = x_0(1 - e^{-\frac{t}{CR}})$ for capacitor–resistor circuits	Learners will be expected to know how ln*x*–*t* graphs can be used to determine *CR*. *M0.5, M2.5, M3.10, M3.12*
(d)	graphical methods and spreadsheet modelling of the equation $\frac{\Delta Q}{\Delta t} = -\frac{Q}{CR}$ for a discharging capacitor	HSW3 Using spreadsheets to model the discharge of a capacitor. *M3.9*
(e)	exponential decay graph; constant-ratio property of such a graph.	*M3.11*

6.2 Electric fields

This section provides knowledge and understanding of Coulomb's law, uniform electric fields, electric potential and energy.

6.2.1 Point and spherical charges

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electric fields are due to charges	
(b)	modelling a uniformly charged sphere as a point charge at its centre	HSW1
(c)	electric field lines to map electric fields	
(d)	electric field strength; $E = \frac{F}{Q}$.	

6.2.2 Coulomb's law

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Coulomb's law; $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ for the force between two point charges	Learners will also require knowledge of section 3.2
(b)	electric field strength $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for a point charge	
(c)	similarities and differences between the gravitational field of a point mass and the electric field of a point charge	Learners will also require knowledge of 5.4
(d)	the concept of electric fields as being one of a number of forms of field giving rise to a force.	Learners will be expected to link this with 5.4

6.2.3 Uniform electric field

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	uniform electric field strength; $E = \frac{V}{d}$	
(b)	parallel plate capacitor; permittivity; $C = \frac{\varepsilon_0 A}{d}$; $C = \frac{\varepsilon A}{d}$; $\varepsilon = \varepsilon_r \varepsilon_0$	Learners are not expected to know why the relative permittivity $\varepsilon_r \geqslant 1$.

(c)	motion of charged particles in a uniform electric field.	Learners will also require knowledge of 3.1, 3.2 and 3.3 HSW2

6.2.4 Electric potential and energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electric potential at a point as the work done in bringing unit positive charge from infinity to the point; electric potential is zero at infinity	
(b)	electric potential $V = \frac{Q}{4\pi\varepsilon_0 r}$ at a distance r from a point charge; changes in electric potential	
(c)	capacitance $C = 4\pi\varepsilon_0 R$ for an isolated sphere	Derivation expected from equation for electric potential and $Q = VC$.
(d)	force–distance graph for a point or spherical charge; work done is area under graph	HSW5
(e)	electric potential energy $= Qq/4\pi\varepsilon r = \frac{Qq}{4\pi\varepsilon_0 r}$ of a distance r from a point charge Q.	

6.3 Electromagnetism

This section provides knowledge and understanding of magnetic fields, motion of charged particles in magnetic fields, Lenz's law and Faraday's law. The application of Faraday's law may be used to demonstrate how science has benefited society with important devices such as generators and transformers. Transformers are used in the transmission of electrical energy using the national grid and are an integral part of many electrical devices in our homes. The application of Lenz's law allows discussion of the use of scientific knowledge to present a scientific argument (HSW1, 2, 3, 5, 6, 7, 8, 9, 11, 12).

6.3.1 Magnetic fields

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	magnetic fields are due to moving charges or permanent magnets	
(b)	magnetic field lines to map magnetic fields	
(c)	magnetic field patterns for a long straight current-carrying conductor, a flat coil and a long solenoid	
(d)	Fleming's left-hand rule	HSW7
(e)	**(i)** force on a current-carrying conductor; $F = BIL\sin\theta$	

	(ii)	techniques and procedures used to determine the uniform magnetic flux density between the poles of a magnet using a current-carrying wire and digital balance	
(f)		magnetic flux density; the unit tesla.	

6.3.2 Motion of charged particles

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	force on a charged particle travelling at right angles to a uniform magnetic field; $F = BQv$	
(b)	charged particles moving in a uniform magnetic field; circular orbits of charged particles in a uniform magnetic field	Learners will also require knowledge of 3.2, 3.3 and 5.2 HSW1
(c)	charged particles moving in a region occupied by both electric and magnetic fields; velocity selector.	HSW1, 2, 6

6.3.3 Electromagnetism

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		magnetic flux ϕ; the unit weber; $\phi = BA\cos\theta$	
(b)		magnetic flux linkage	
(c)		Faraday's law of electromagnetic induction and Lenz's law	HSW2, 7
(d)	**(i)**	e.m.f. = − rate of change of magnetic flux linkage; $\mathcal{E} = -\frac{\Delta(N\phi)}{\Delta t}$	*M3.9* HSW2, 8
	(ii)	techniques and procedures used to investigate magnetic flux using search coils	
(e)		simple a.c. generator	HSW8
(f)	**(i)**	simple laminated iron-cored transformer; $\frac{n_s}{n_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$ for an ideal transformer	*M0.3* HSW9
	(ii)	techniques and procedures used to investigate transformers.	HSW3, 9

6.4 Nuclear and particle physics

This section provides knowledge and understanding of the atom, nucleus, fundamental particles, radioactivity, fission and fusion.

Nuclear power stations provide a significant fraction of the energy needs of many countries. They are expensive; governments have to make difficult decisions when building new ones. The building of nuclear power stations can be used to evaluate the benefits and risks to society (HSW9). Ethical, environmental and decision making issues may also be discussed (HSW10 and HSW12). The development of the atomic model also addresses issues of scientific development and validation (HSW7, 11).

2

6.4.1 The nuclear atom

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	alpha-particle scattering experiment; evidence of a small charged nucleus	HSW7
(b)	simple nuclear model of the atom; protons, neutrons and electrons	
(c)	relative sizes of atom and nucleus	*M0.4, M1.4*
(d)	proton number; nucleon number; isotopes; notation ${}^{A}_{Z}X$ for the representation of nuclei	
(e)	strong nuclear force; short-range nature of the force; attractive to about 3 fm and repulsive below about 0.5 fm	1 fm = 10^{-15} m
(f)	radius of nuclei; $R = r_0A^{1/3}$ where r_0 is a constant and A is the nucleon number	
(g)	mean densities of atoms and nuclei.	HSW7

6.4.2 Fundamental particles

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	particles and antiparticles; electron–positron, proton-antiproton, neutron-antineutron and neutrino-antineutrino	HSW7, 9
(b)	particle and its corresponding antiparticle have same mass; electron and positron have opposite charge; proton and antiproton have opposite charge	
(c)	classification of hadrons; proton and neutron as examples of hadrons; all hadrons are subject to the strong nuclear force	
(d)	classification of leptons; electron and neutrino as examples of leptons; all leptons are subject to the weak nuclear force	HSW7, 9

(e)	simple quark model of hadrons in terms of up (u), down (d) and strange (s) quarks and their respective anti-quarks	
(f)	quark model of the proton (uud) and the neutron (udd)	
(g)	charges of the up (u), down (d), strange (s), anti-up ($\overline{u}$), anti-down ($\overline{d}$) and the anti-strange ($\overline{s}$) quarks as fractions of the elementary charge *e*	
(h)	beta-minus (β^-) decay; beta-plus (β^+) decay	
(i)	β^- decay in terms of a quark model; $d \rightarrow u + {}^{0}_{-1}e + \overline{\nu}$	
(j)	β^+ decay in terms of a quark model; $u \rightarrow d + {}^{0}_{+1}e + \nu$	
(k)	balancing of quark transformation equations in terms of charge	
(l)	decay of particles in terms of the quark model.	

6.4.3 Radioactivity

			Learning outcomes	Additional guidance
			Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)			radioactive decay; spontaneous and random nature of decay	*M1.3*
(b)	**(i)**		α-particles, β-particles and γ-rays; nature, penetration and range of these radiations	
	(ii)		techniques and procedures used to investigate the absorption of α-particles, β-particles and γ-rays by appropriate materials	
(c)			nuclear decay equations for alpha, beta-minus and beta-plus decays; balancing nuclear transformation equations	
(d)			activity of a source; decay constant λ of an isotope; $A = \lambda N$	Learners will also require knowledge of 5.1.4(a)
(e)	**(i)**		half-life of an isotope; $\lambda t_{1/2} = \ln(2)$	
	(ii)		techniques and procedures used to determine the half-life of an isotope such as protactinium	**PAG7**
(f)	**(i)**		the equations $A = A_0 e^{-\lambda t}$ and $N = N_0 e^{-\lambda t}$, where *A* is the activity and *N* is the number of undecayed nuclei	*M3.12*
	(ii)		simulation of radioactive decay using dice	*M1.3*

(g)	graphical methods and spreadsheet modelling of the equation $\frac{\Delta N}{\Delta t} = -\lambda N$ for radioactive decay	HSW3 Using spreadsheets to model the radioactive decay of nuclei. *M0.5, M2.5, M3.9*
(h)	radioactive dating, e.g. carbon-dating.	

6.4.4 Nuclear fission and fusion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Einstein's mass–energy equation; $\Delta E = \Delta mc^2$	
(b)	energy released (or absorbed) in simple nuclear reactions	
(c)	creation and annihilation of particle–antiparticle pairs	
(d)	mass defect; binding energy; binding energy per nucleon	
(e)	binding energy per nucleon against nucleon number curve; energy changes in reactions	
(f)	binding energy of nuclei using $\Delta E = \Delta mc^2$ and masses of nuclei	
(g)	induced nuclear fission; chain reaction	
(h)	basic structure of a fission reactor; components – fuel rods, control rods and moderator	
(i)	environmental impact of nuclear waste	HSW9, HSW10, HSW12 Decision making process when building new nuclear power stations.
(j)	nuclear fusion; fusion reactions and temperature	Learners will also require knowledge of 5.1.4
(k)	balancing nuclear transformation equations.	

6.5 Medical imaging

This section provides knowledge and understanding of X-rays, CAT scans, PET scans and ultrasound scans. This section shows how the developments in medical imaging have led to a number of valuable non-invasive techniques used in hospitals.

Not all hospitals in this country are equipped with complex scanners. Learners have the chance to discuss the ethical issues in the treatment of humans and the ways in which society uses science to inform decision making (HSW10 and 12).

6.5.1 Using X-rays

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	basic structure of an X-ray tube; components – heater (cathode), anode, target metal and high voltage supply	
(b)	production of X-ray photons from an X-ray tube	

(c)	X-ray attenuation mechanisms; simple scatter, photoelectric effect, Compton effect and pair production	
(d)	attenuation of X-rays; $I = I_0 e^{-\mu x}$, where μ is the attenuation (absorption) coefficient	*M0.5, M3.11*
(e)	X-ray imaging with contrast media; barium and iodine	HSW9, 10, 12
(f)	computerised axial tomography (CAT) scanning; components – rotating X-tube producing a thin fan-shaped X-ray beam, ring of detectors, computer software and display	
(g)	advantages of a CAT scan over an X-ray image.	HSW9, 10, 12

2

6.5.2 Diagnostic methods in medicine

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	medical tracers; technetium–99m and fluorine–18	HSW9, 10
(b)	gamma camera; components – collimator, scintillator, photomultiplier tubes, computer and display; formation of image	
(c)	diagnosis using gamma camera	
(d)	positron emission tomography (PET) scanner; annihilation of positron–electron pairs; formation of image	HSW9, 10, 12
(e)	diagnosis using PET scanning.	HSW10, HSW12 Issues raised when equipping a hospital with an expensive scanner.

6.5.3 Using ultrasound

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	ultrasound; longitudinal wave with frequency greater than 20 kHz	
(b)	piezoelectric effect; ultrasound transducer as a device that emits and receives ultrasound	
(c)	ultrasound A-scan and B-scan	HSW9, 10, 12
(d)	acoustic impedance of a medium; $Z = \rho c$	
(e)	reflection of ultrasound at a boundary; $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$	*M0.3*

(f) impedance (acoustic) matching; special gel used in ultrasound scanning

(g) Doppler effect in ultrasound; speed of blood in the patient; $\frac{\Delta f}{f} = \frac{2v\cos\theta}{c}$ for determining the speed v of blood.

2d. Prior knowledge, learning and progression

This specification has been developed for learners who wish to continue with a study of physics at Level 3. The A level specification has been written to provide progression from GCSE Science, GCSE Additional Science, GCSE Further Additional Science, GCSE Physics or from AS Level Physics. Learners who have successfully taken other Level 2 qualifications in Science or Applied Science with appropriate physics content may also have acquired sufficient knowledge and understanding to begin the A Level Physics course.

There is no formal requirement for prior knowledge of physics for entry onto this qualification. Other learners without formal qualifications may have acquired sufficient knowledge of physics to enable progression onto the course.

Some learners may wish to follow a physics course for only one year as an AS, in order to broaden their curriculum, and to develop their interest and understanding of different areas of the subject. Others may follow a co-teachable route, completing the one–year AS course and/or then moving to the two–year A level developing a deeper knowledge and understanding of physics and its applications.

The A Level Physics course will prepare learners for progression to undergraduate study, enabling them to enter a range of academic and vocational careers in mathematics-related courses, physical sciences, engineering, medicine, computing and related sectors. For learners wishing to follow an apprenticeship route or those seeking direct entry into physical science careers, this A level provides a strong background and progression pathway.

There are a number of Science specifications at OCR. Find out more at **www.ocr.org.uk**.

3 Assessment of OCR A Level in Physics A

3a. Forms of assessment

All three externally assessed components (01–03) contain some synoptic assessment, some extended response questions and some stretch and challenge questions.

Stretch and challenge questions are designed to allow the most able learners the opportunity to demonstrate the full extent of their knowledge and skills.

Stretch and challenge questions will support the awarding of A* grade at A level, addressing the need for greater differentiation between the most able learners.

3

Modelling physics (Component 01)

This component is worth 100 marks and is split into two sections and assesses content from teaching modules 1, 2, 3 and 5. Learners answer all questions.

Section A contains multiple choice questions. This section of the paper is worth 15 marks.

Section B includes short answer question styles (structured questions, problem solving, calculations, practical) and extended response questions. This section of the paper is worth 85 marks.

Exploring physics (Component 02)

This component is worth 100 marks and is split into two sections and assesses content from teaching modules 1, 2, 4 and 6. Learners answer all questions.

Section A contains multiple choice questions. This section of the paper is worth 15 marks.

Section B includes short answer question styles (structured questions, problem solving, calculations, practical) and extended response questions. This section of the paper is worth 85 marks.

Unified physics (Component 03)

This component assesses content from across all teaching modules 1 to 6. Learners answer all questions. This component is worth 70 marks.

Question styles include short answer (structured questions, problem solving, calculations, practical) and extended response questions.

Practical Endorsement in physics (Component 04)

Performance in this component is reported separately to the performance in the A level as measured through externally assessed components 01 to 03. This non-exam assessment component rewards the development of practical competency in physics and is teacher assessed. Learners demonstrate competence in the range of skills and techniques specified in Section 1.2 of the specification by carrying out a minimum of 12 assessed practical activities. The Practical Endorsement is teacher assessed against the Common Practical Assessment Criteria as specified in Section 5g.

Learners may work in groups but must demonstrate and record independent evidence of their competency. Teachers who award a pass to their learners must be confident that each learner consistently and routinely exhibits the competencies listed in Section 5g and has demonstrated competence in all the skills detailed in section 1.2.1 and in all the apparatus and techniques detailed in Section 1.2.2 before completion of the A level course. The practical activities provided by OCR are all mapped against the specification and assessment criteria.

3b. Assessment objectives (AO)

There are three assessment objectives in OCR's A Level in Physics A. These are detailed in the table below.

Learners are expected to demonstrate their ability to:

	Assessment Objective
AO1	Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures.
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.
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.

AO weightings in A Level in Physics A

The relationship between the assessment objectives and the components are shown in the following table:

Component	% of A level Physics A (H556)		
	AO1	AO2	AO3
Modelling physics (H556/01)	13–14	15–16	8–9
Exploring physics (H556/02)	13–14	15–16	8–9
Unified physics (H556/03)	5–6	10–11	9–10
Practical endorsement in physics (H556/04)*	N/A	N/A	N/A
Total	**31–34**	**40–43**	**25–28**

* The Practical endorsement is assessed and reported separately from the overall A level grade (see Section 5g).

3c. Assessment availability

There will be one examination series available each year in May/June for **all** learners.

All examined components must be taken in the same examination series at the end of the course.

This specification will be certificated from the June 2017 examination series onwards.

3d. Retaking the qualification

Candidates can retake the qualification as many times as they wish. They retake all examined components of the qualification. Candidates can choose either to retake the Practical Endorsement or to carry forward their result for the Practical Endorsement by using the carry forward entry option (see Section 4a). The result for the Practical Endorsement may be carried forward for the lifetime of the specification.

A candidate who is retaking A Level Physics A may re-use a previous result for the Practical Endorsement, even if it was awarded by another awarding organisation or if it was awarded for an alternative suite [e.g. a Practical Endorsement pass result from A Level Physics A could be re-used for retaking A Level Physics B (Advancing Physics)].

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3e. Assessment of extended responses

The assessment materials for this qualification provide learners with the opportunity to demonstrate their ability to construct and develop a sustained and coherent line of reasoning and marks for extended responses are integrated into the marking criteria.

3f. Synoptic assessment

Synoptic assessment tests the learners' understanding of the connections between different elements of the subject.

Synoptic assessment involves the explicit drawing together of knowledge, understanding and skills learned in different parts of the A level course. The emphasis of synoptic assessment is to encourage the development of the understanding of the subject as a discipline. All components within Physics A contain an element of synoptic assessment.

Synoptic assessment requires learners to make and use connections within and between different areas of physics, for example, by:

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

3g. Calculating qualification results

A learner's overall qualification grade for A Level in Physics A will be calculated by adding together their marks from the three examined components taken to give their total weighted mark.

This mark will then be compared to the qualification level grade boundaries for the relevant exam series to determine the learner's overall qualification grade.

A learner's result for their Practical Endorsement in physics component will not contribute to their overall qualification grade.

4 Admin: what you need to know

The information in this section is designed to give an overview of the processes involved in administering this qualification so that you can speak to your exams officer. All of the following processes require you to submit something to OCR by a specific deadline. More information about these processes, together with the deadlines, can be found in the OCR *Admin Guide and Entry Codes: 14–19 Qualifications*, which can be downloaded from the OCR website: www.ocr.org.uk

4a. Pre-assessment

Estimated entries

Estimated entries are your best projection of the number of learners who will be entered for a qualification in a particular series. Estimated entries should be submitted to OCR by the specified deadline. These do not incur a cost and do not commit your centre in any way.

4

Registration for the Practical Endorsement

From autumn 2015 (and each autumn thereafter) JCQ will ask each centre to indicate which awarding organisation it intends to use for its entries in A level Physics and to provide the name of the lead teacher. JCQ will allocate centres to awarding organisations for the purpose of the monitoring visits. Centres will receive communications concerning the visits from awarding organisations, not from JCQ.

Lead teachers are required to undertake the free on-line training provided (available at: https://practicalendorsement.ocr.org.uk) on the implementation of the Practical Endorsement and must then disseminate this information to all other teachers of that science within the centre so that each teacher can apply the standards appropriately. Your registration is not communicated to any organisation other than the awarding organisation responsible for your monitoring visit, and then only at the time you are selected for monitoring.

Final entries

Final entries provide OCR with detailed data for each learner, showing each assessment to be taken. It is essential that you use the correct entry code, considering the relevant entry rules.

Final entries must be submitted to OCR by the published deadlines or late entry fees will apply.

All learners taking A Level in Physics A must be entered for one of the entry options shown on the following table:

Entry option		Component		
Entry code	**Title**	**Code**	**Title**	**Assessment type**
H556	Physics A	01	Modelling physics	External assessment
		02	Exploring physics	External assessment
		03	Unified physics	External assessment
		04	Practical Endorsement in physics	Non-exam assessment (Visiting monitoring)

Entry option		Component		
Entry code	**Title**	**Code**	**Title**	**Assessment type**
H556C	Physics A	01	Modelling physics	External assessment
		02	Exploring physics	External assessment
		03	Unified physics	External assessment
		80	Practical Endorsement in physics – Carried Forward*	Non-exam assessment (Carried Forward)

*The carry forward option will be available for the first time from June 2018.

Private candidates

Private candidates can be entered for examinations at an OCR-approved centre even if they are not enrolled as a learner there.

Private candidates may be home-schooled, receiving private tuition or self-taught. They must be based in the UK.

The A Level Physics A qualification requires candidates to complete a Practical Endorsement incorporating a minimum of 12 practical activities, allowing them to demonstrate a range of practical skills, use of apparatus and techniques to fulfil the Common Practical Assessment Criteria. The Practical Endorsement is an essential part of the course and will allow candidates to develop skills for further study or employment as well as imparting important knowledge that is part of the specification.

Private candidates need to make contact with a centre where they will be allowed to carry out the Practical Endorsement. The centre may charge for this facility and OCR recommends that the arrangement is made early in the course.

Head of Centre Annual Declaration

The Head of Centre is required to provide a declaration to the JCQ as part of the annual NCN update, conducted in the autumn term, to confirm that all candidates at the centre have had the opportunity to undertake the prescribed practical activities.

Please see the JCQ publication *Instructions for conducting non-examination assessments* for further information.

Any failure by a centre to provide the Head of Centre Annual Declaration will result in your centre status being suspended and could lead to the withdrawal of our approval for you to operate as a centre.

4b. Accessibility and special consideration

Reasonable adjustments and access arrangements allow learners with special educational needs, disabilities or temporary injuries to access the assessment and show what they know and can do, without changing the demands of the assessment.

Applications for these should be made before the examination series. Detailed information about eligibility for access arrangements can be found in the JCQ *Access Arrangements and Reasonable Adjustments.*

Special consideration is a post-assessment adjustment to marks or grades to reflect temporary injury, illness or other indisposition at the time the assessment was taken. Detailed information about eligibility for special consideration can be found in the JCQ *A guide to the special consideration process.*

4c. External assessment arrangements

Regulations governing examination arrangements are contained in the JCQ publication *Instructions for conducting examinations*.

Learners are permitted to use a scientific or graphical calculator for components 01, 02 and 03. Calculators are subject to the rules in the document *Instructions for Conducting Examinations* published annually by JCQ (www.jcq.org.uk).

4d. Admin of non-exam assessment

Regulations governing examination arrangements are contained in the JCQ document *Instructions for conducting non-examination assessments.* Appendix 1 of this document gives specific details for the Practical Skills Endorsement for A level sciences designed for use in England.

OCR's *Admin Guide and Entry Codes: 14–19 Qualifications* also provides guidance for centres.

Centres must have made an entry to the A level qualification in order for OCR to supply the appropriate forms for monitoring and data entry.

The deadline for the receipt of the first Practical Endorsement results is 15 May 2017 and subsequently on an annual basis.

Further copies of the coursework administration documents are available on the OCR website **www.ocr.org.uk**

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4e. Results and certificates

Grade scale

A level qualifications are graded on the scale: A*, A, B, C, D, E, where A* is the highest. Learners who fail to reach the minimum standard for E will be Unclassified (U). Only subjects in which grades A* to E are attained will be recorded on certificates.

Results for the A Level Sciences Practical Endorsements will be shown independently of the qualification grade on the certificate. Candidates who fulfil the requirements and reach the minimum standard will be awarded a Pass grade. Candidates who fail to reach the minimum standard will be recorded as 'Not Classified' and this will also be reported on the certificate.

Results

Results are released to centres and learners for information and to allow any queries to be resolved **before** certificates are issued.

Centres will have access to the following results information for each learner:

- the grade for the qualification
- the raw mark for each component
- the total weighted mark for the qualification.

The following supporting information will be available:

- raw mark grade boundaries for each component
- weighted mark grade boundaries for each entry option.

Until certificates are issued, results are deemed to be provisional and may be subject to amendment. A learner's final results will be recorded on an OCR certificate.

The qualification title will be shown on the certificate as 'OCR Level 3 Advanced GCE in Physics A'.

4f. Post-results services

A number of post-results services are available:

- **Enquiries about results** – If you are not happy with the outcome of a learner's results, centres may submit an enquiry about results.
- **Missing and incomplete results** – This service should be used if an individual subject result for a learner is missing, or the learner has been omitted entirely from the results supplied.
- **Access to scripts** – Centres can request access to marked scripts.
- **Practical Endorsement** – Since monitoring and any potential request for further visits take place throughout the period of the qualification, there is no post-results service provided.

4g. Malpractice

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Any breach of the regulations for the conduct of examinations and coursework may constitute malpractice (which includes maladministration) and must be reported to OCR as soon as it is detected.

Detailed information on malpractice can be found in the *Suspected Malpractice in Examinations and Assessments: Policies and Procedures* published by JCQ.

5 Appendices

5a. Overlap with other qualifications

There is a small degree of overlap between the content of this specification and those for other AS level/A level Sciences.

Examples of overlap include:

Geology

- Half-life.

Chemistry

- Atomic structure.

Science

- Atomic structure.
- Electromagnetic spectrum.

5b. Avoidance of bias

The A level qualification and subject criteria have been reviewed in order to identify any feature which could disadvantage learners who share a protected characteristic as defined by the Equality Act 2010. All reasonable steps have been taken to minimise any such disadvantage.

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5c. Physics A data sheet

Data, Formulae and Relationships

The data, formulae and relationships in this data sheet will be printed for distribution with the examination papers.

Data

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

Physical constants

acceleration of free fall	g	$9.81\ \text{m s}^{-2}$
elementary charge	e	$1.60 \times 10^{-19}\ \text{C}$
speed of light in a vacuum	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Planck constant	h	$6.63 \times 10^{-34}\ \text{J s}$
Avogadro constant	N_A	$6.02 \times 10^{23}\ \text{mol}^{-1}$
molar gas constant	R	$8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
Boltzmann constant	k	$1.38 \times 10^{-23}\ \text{J K}^{-1}$
gravitational constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
permittivity of free space	ε_0	$8.85 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}\ (\text{F m}^{-1})$
electron rest mass	m_e	$9.11 \times 10^{-31}\ \text{kg}$
proton rest mass	m_p	$1.673 \times 10^{-27}\ \text{kg}$
neutron rest mass	m_n	$1.675 \times 10^{-27}\ \text{kg}$
alpha particle rest mass	m_α	$6.646 \times 10^{-27}\ \text{kg}$
Stefan constant	σ	$5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$

Quarks

up quark	charge = $+\frac{2}{3}e$
down quark	charge = $-\frac{1}{3}e$
strange quark	charge = $-\frac{1}{3}e$

Conversion factors

unified atomic mass unit	1 u = 1.661×10^{-27} kg
electronvolt	1 eV = 1.60×10^{-19} J
day	1 day = 8.64×10^{4} s
year	1 year $\approx 3.16 \times 10^{7}$ s
light year	1 light year $\approx 9.5 \times 10^{15}$ m
parsec	1 parsec $\approx 3.1 \times 10^{16}$ m

Mathematical equations

arc length = $r\theta$

circumference of circle = $2\pi r$

area of circle = πr^2

curved surface area of cylinder = $2\pi rh$

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

area of trapezium = $\frac{1}{2}(a+b)h$

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

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

Pythagoras' theorem: $a^2 = b^2 + c^2$

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

sine rule: $\dfrac{a}{\sin A} = \dfrac{b}{\sin B} = \dfrac{c}{\sin C}$

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

$\log(AB) = \log(A) + \log(B)$ (Note: $\lg = \log_{10}$ and $\ln = \log_e$)

$\log\left(\dfrac{A}{B}\right) = \log(A) - \log(B)$

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

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

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Formulae and relationships

Module 2 – Foundations of physics	
vectors	$F_x = F\cos\theta$ $F_y = F\sin\theta$

Module 3 – Forces and motion	
uniformly accelerated motion	$v = u + at$ $s = \frac{1}{2}(u+v)t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
force	$F = \frac{\Delta p}{\Delta t}$ $p = mv$
turning effects	$moment = Fx$ $torque = Fd$
density	$p = \frac{m}{V}$
pressure	$p = \frac{F}{A}$ $p = h\rho g$
work, energy and power	$W = Fx\cos\theta$ $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$ $P = \frac{W}{t}$ $P = Fv$
springs and materials	$F = kx$ $E = \frac{1}{2}Fx;\ E = \frac{1}{2}kx^2$ $\sigma = \frac{F}{A}$ $\varepsilon = \frac{x}{L}$ $E = \frac{\sigma}{\varepsilon}$

Module 4 – Electrons, waves and photons	
charge	$\Delta Q = I\Delta t$
current	$I = Anev$
work done	$W = VQ$; $W = \mathcal{E}Q$; $W = VIt$
resistance and resistors	$R = \frac{\rho L}{A}$ $R = R_1 + R_2 + \dots$ $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$
power	$P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$
internal resistance	$\mathcal{E} = I(R + r)$; $\mathcal{E} = V + Ir$
potential divider	$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$ $\frac{V_1}{V_2} = \frac{R_1}{R_2}$
waves	$v = f\lambda$ $f = \frac{1}{T}$ $I = \frac{P}{A}$ $\lambda = \frac{ax}{D}$
refraction	$n = \frac{c}{v}$ $n \sin\theta = \text{constant}$ $\sin C = \frac{1}{n}$
quantum physics	$E = hf \quad E = \frac{hc}{\lambda}$ $hf = \phi + KE_{max}$ $\lambda = \frac{h}{p}$

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Module 5 – Newtonian world and astrophysics	
thermal physics	$E = mc\Delta\theta$ $E = mL$
ideal gases	$pV = NkT$; $pV = nRT$ $pV = \frac{1}{3}Nm\overline{c^2}$ $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ $E = \frac{3}{2}kT$
circular motion	$\omega = \frac{2\pi}{T}$; $\omega = 2\pi f$ $v = \omega r$ $a = \frac{v^2}{r}$; $a = \omega^2 r$ $F = \frac{mv^2}{r}$; $F = m\omega^2 r$
oscillations	$\omega = \frac{2\pi}{T}$; $\omega = 2\pi f$ $a = -\omega^2 x$ $x = A\cos\omega t$; $x = A\sin\omega t$ $v = \pm\omega\sqrt{A^2 - x^2}$
gravitational field	$g = \frac{F}{m}$ $F = -\frac{GMm}{r^2}$ $g = -\frac{GM}{r^2}$ $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ $V_g = -\frac{GM}{r}$ $\text{energy} = -\frac{GMm}{r}$
astrophysics	$hf = \Delta E$; $\frac{hc}{\lambda} = \Delta E$ $d\sin\theta = n\lambda$ $\lambda_{max} \propto \frac{1}{T}$ $L = 4\pi r^2 \sigma T^4$

cosmology	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ $p = \frac{1}{d}$ $v = H_0 d$ $t = H_0^{-1}$

Module 6 - Particles and medical physics

capacitance and capacitors	$C = \frac{Q}{V}$ $C = \frac{\varepsilon_0 A}{d}$ $C = 4\pi\varepsilon_0 R$ $C = C_1 + C_2 + \ldots$ $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots.$ $W = \frac{1}{2}QV;\ W = \frac{1}{2}\frac{Q^2}{C};\ \ W = \frac{1}{2}V^2C$ $\tau = CR$ $x = x_0 e^{-\frac{t}{CR}}$ $x = x_0(1 - e^{-\frac{t}{CR}})$
electric field	$E = \frac{F}{Q}$ $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ $E = \frac{V}{d}$ $V = \frac{Q}{4\pi\varepsilon_0 r}$ energy = $\frac{Qq}{4\pi\varepsilon_0 r}$
magnetic field	$F = BIL sin\theta$ $F = BQv$

electromagnetism	$\phi = BA\cos\theta$ $\varepsilon = -\frac{\Delta(N\phi)}{\Delta t}$ $\frac{n_s}{n_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$
radius of nucleus	$R = r_0 A^{\frac{1}{3}}$
radioactivity	$A = \lambda N;\ \frac{\Delta N}{\Delta t} = -\lambda N$ $\lambda t_{\frac{1}{2}} = \ln(2)$ $A = A_0 e^{-\lambda t}$ $N = N_0 e^{-\lambda t}$
Einstein's mass-energy equation	$\Delta E = \Delta mc^2$
attenuation of X-rays	$I = I_0 e^{-\mu x}$
ultrasound	$Z = \rho c$ $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ $\frac{\Delta f}{f} = \frac{2v\cos\theta}{c}$

5d. How Science Works (HSW)

How Science Works (HSW) was conceived as being a wider view of science in context, rather than just straightforward scientific enquiry. It was intended to develop learners as critical and creative thinkers, able to solve problems in a variety of contexts.

Developing ideas and theories to explain the operation of the entirety of our existence, from the sub-atomic particles to the Universe, is the basis of Physics. How Science Works develops the critical analysis and linking of evidence to support or refute ideas and theories. Learners should be aware of the importance that peer review and repeatability have in giving confidence to this evidence.

Learners are expected to understand the variety of sources of data available for critical analysis to provide evidence and the uncertainty involved in its measurement. They should also be able to link that evidence to contexts influenced by culture, politics and ethics.

Understanding How Science Works requires an understanding of how scientific evidence can influence ideas and decisions for individuals and society, which is linked to the necessary skills of communication for audience and for purpose with appropriate scientific terminology.

The examples and guidance within the specification are not exhaustive but give a flavour of opportunities for integrating HSW within the course. These references, written in the form HSW1, link to the statements as detailed below:

- **HSW1** Use theories, models and ideas to develop scientific explanations
- **HSW2** Use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
- **HSW3** Use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems
- **HSW4** Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- **HSW5** Analyse and interpret data to provide evidence, recognising correlations and causal relationships
- **HSW6** Evaluate methodology, evidence and data, and resolve conflicting evidence
- **HSW7** Know that scientific knowledge and understanding develops over time
- **HSW8** Communicate information and ideas in appropriate ways using appropriate terminology
- **HSW9** Consider applications and implications of science and evaluate their associated benefits and risks
- **HSW10** Consider ethical issues in the treatment of humans, other organisms and the environment
- **HSW11** Evaluate the role of the scientific community in validating new knowledge and ensuring integrity
- **HSW12** Evaluate the ways in which society uses science to inform decision making.

5e. Mathematical requirements

In order to be able to develop their skills, knowledge and understanding in A Level Physics, learners 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 40% Level 2 (or above) mathematical skills for physics (see later for a definition of Level 2 mathematics).

These skills will be applied in the context of the relevant physics.

All mathematical content will be assessed within the lifetime of the specification. Skills shown in **bold** type will only be tested in the full A level course, not the standalone AS level course.

This list of examples is not exhaustive and is not limited to Level 2 examples. These skills could be developed in other areas of specification content from those indicated.

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
***M0* – Arithmetic and numerical computation**			
M0.1	Recognise and make use of appropriate units in calculations	Learners 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.	1.1.2(b), 2.1.1(a), 3.1.1(a), 3.2.4(a)
M0.2	Recognise and use expressions in decimal and standard form	Learners may be tested on their ability to: • use physical constants expressed in standard form such as $c = 3.00 \times 10^8\ \text{m s}^{-1}$.	1.1.3(c), 4.1.2(b)
M0.3	Use ratios, fractions and percentages	Learners may be tested on their ability to: • calculate efficiency of devices; • calculate percentage uncertainties in measurements.	3.3.3(c), 6.3.3(f), 6.5.3(e)

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M0.4	Estimate results	Learners may be tested on their ability to: • estimate the effect of changing experimental parameters on measurable values.	2.1.1(b), 6.4.1(c)
M0.5	Use calculators to find and use power, **exponential and logarithmic functions**	Learners may be tested on their ability to: • **solve for unknowns in decay problems such as** $\boldsymbol{N = N_0 e^{-\lambda t}}$.	3.3.2(a), 3.4.2(b), **6.1.3(c)** **6.4.3(g)**, **6.5.1(d)**
M0.6	Use calculators to handle sin *x*, cos *x* and tan *x* when *x* is expressed in degrees or radians	Learners may be tested on their ability to: • calculate the direction of resultant vectors.	2.3.1(c)(d), 3.1.3(b)
***M1* – Handling data**			
M1.1	Use an appropriate number of significant figures	Learners 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.	1.1.3(c), 3.2.1(a)
M1.2	Find arithmetic means	Learners may be tested on their ability to: • calculate a mean value for repeated experimental readings.	1.1.3(a)
M1.3	Understand simple probability	Learners may be tested on their ability to: • understand probability in the context of radioactive decay.	1.1.4(d), 6.4.3(a)

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	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M1.4	Make order of magnitude calculations	Learners may be tested on their ability to: • evaluate equations with variables expressed in different orders of magnitude.	3.1.1(a), 5.5.3(m), 6.4.1(c)
M1.5	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers	Learners may be tested on their ability to: • determine the uncertainty where two readings for length need to be added together.	1.1.4(d), 2.2.1(c)(d)
M2 **– Algebra**			
M2.1	Understand and use the symbols: $=, <, \ll, \gg, >, \propto, \approx, \Delta$	Learners may be tested on their ability to: • recognise the significance of the symbols in the expression $F \propto \Delta p/\Delta t$.	3.2.4(c), 3.5.1(c)
M2.2	Change the subject of an equation, including non-linear equations	Learners may be tested on their ability to: • rearrange $E = mc^2$ to make m the subject.	3.1.2(a), 4.2.5(a), 5.3.1(e)
M2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Learners 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 $p = mv$.	4.3.3(c), 4.5.2(c), 5.4.2(a)
M2.4	Solve algebraic equations, including quadratic equations	Learners may be tested on their ability to: solve kinematic equations for constant acceleration such as $v = u + at$ and $s = ut + \frac{1}{2}at^2$.	3.1.2(a), 5.2.2(c)

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M2.5	**Use logarithms in relation to quantities that range over several orders of magnitude**	**Learners may be tested on their ability to:** • **recognise and interpret real world examples of logarithmic scales.**	**6.1.3(c), 6.4.3(g)**
***M3* – Graphs**			
M3.1	Translate information between graphical, numerical and algebraic forms	Learners may be tested on their ability to: • calculate Young modulus for materials using stress–strain graphs.	1.1.3(d), 1.2.1(g), 3.4.2(a)(d)
M3.2	Plot two variables from experimental or other data	Learners may be tested on their ability to: • plot graphs of extension of a wire against force applied.	1.1.3(d), 3.4.1(d)(i), 3.4.2(d)
M3.3	Understand that $y = mx + c$ represents a linear relationship	Learners may be tested on their ability to: • rearrange and compare $v = u + at$ with $y = mx + c$ for velocity–time graphs in constant acceleration problems.	1.1.3(d), 3.1.2(a)
M3.4	Determine the slope and intercept of a linear graph	Learners 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.	1.1.3(d), 3.1.1(c)
M3.5	Calculate rate of change from a graph showing a linear relationship	Learners may be tested on their ability to: • calculate acceleration from a linear velocity–time graph.	3.1.1(d)
M3.6	Draw and use the slope of a tangent to a curve as a measure of rate of change	Learners 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.	3.1.1(b)

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M3.7	Distinguish between instantaneous rate of change and average rate of change	Learners 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.	3.1.1(a)(c)
M3.8	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	Learners 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.	3.5.1(e), 6.1.2(a)
M3.9	Apply the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, e.g. $\frac{\Delta x}{\Delta t} = -\lambda x$ using a graphical method or spreadsheet modelling	Learners may be tested on their ability to: • determine *g* from distance–time plot, projectile motion.	3.1.1(a), 3.5.1(c), 5.3.1(d), 6.1.3(d), 6.3.3(d), 6.4.3(g)
M3.10	**Interpret logarithmic plots**	**Learners may be tested on their ability to:** • **obtain time constant for capacitor discharge by interpreting plot of log *V* against time.**	**6.1.3(c)**
M3.11	**Use logarithmic plots to test exponential and power law variations**	**Learners may be tested on their ability to:** • **use logarithmic plots with decay law of radioactivity / charging and discharging of a capacitor.**	**6.1.3(e), 6.5.1(d)**

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M3.12	Sketch relationships which are modelled by $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = kx$, $y = \sin x$, $y = \cos x$, **$y = e^{\pm x}$, and $y = \sin^2 x$, $y = \cos^2 x$ as applied to physical relationships**	Learners may be tested on their ability to: • **sketch relationships between pressure and volume for an ideal gas.**	3.4.2(b), 4.2.3(c), **5.3.1(d), 6.1.3(c), 6.4.3(f)**
***M4* – Geometry and trigonometry**			
M4.1	Use angles in regular 2D and 3D structures	Learners may be tested on their ability to: • interpret force diagrams to solve problems.	3.2.3(f)
M4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Learners may be tested on their ability to: • draw force diagrams to solve mechanics problems.	2.3.1(c), 3.2.3(f)
M4.3	Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres	Learners 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.	3.1.1(d), 3.2.4(a), 3.5.1(e)
M4.4	Use Pythagoras' theorem, and the angle sum of a triangle	Learners may be tested on their ability to: • calculate the magnitude of a resultant vector, resolving forces into components to solve problems.	2.3.1(c), 3.2.3(f)
M4.5	Use sin, cos and tan in physical problems	Learners may be tested on their ability to: • resolve forces into components.	2.3.1(d), 3.1.3(b)
M4.6	Use of small angle approximations including $\sin\theta \approx \theta$, $\tan\theta \approx \theta$, $\cos\theta \approx 1$ for small θ where appropriate	Learners may be tested on their ability to: • calculate fringe separations in interference patterns.	4.4.3(g), 5.5.3(a)

	Mathematical skill to be assessed	Exemplification of the mathematical skill in the context of A Level Physics (assessment is not limited to the examples below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
M4.7	Understand the relationship between degrees and radians and translate from one to the other	Learners may be tested on their ability to: • convert angle in degrees to angle in radians.	5.2.1(a), 5.3.1(a)

Definition of Level 2 mathematics

Within A Level Physics, 40% of the marks available within written examinations will be for assessment of mathematics (in the context of physics) at a Level 2 standard, or higher. Lower level mathematical skills will still be assessed within examination papers but will not count within the 40% weighting for physics.

The following will be counted as Level 2 (or higher) mathematics:

- application and understanding requiring choice of data or equation to be used
- problem solving involving use of mathematics from different areas of maths and decisions about direction to proceed
- questions involving use of A level mathematical content (as of 2012), e.g. use of logarithmic equations.

The following will not be counted as Level 2 mathematics:

- simple substitution with little choice of equation or data
- structured question formats using GCSE mathematics (based on 2012 GCSE mathematics content).

Additional guidance on the assessment of mathematics within physics is available on the OCR website as a separate resource, the Maths Skills Handbook.

5f. Health and Safety

In UK law, health and safety is primarily the responsibility of the employer. In a school or college the employer could be a local education authority, the governing body or board of trustees. Employees (teachers/lecturers, technicians etc), have a legal duty to cooperate with their employer on health and safety matters. Various regulations, but especially the COSHH Regulations 2002 (as amended) and the Management of Health and Safety at Work Regulations 1999, require that before any activity involving a hazardous procedure or harmful microorganisms is carried out, or hazardous chemicals are used or made, the employer must carry out a risk assessment. A useful summary of the requirements for risk assessment in school or college science can be found at http://www.ase.org.uk/resources/health-and-safety-resources/risk-assessments/

For members, the CLEAPSS® guide, *PS90*, *Making and recording risk assessments in school science*[1] offers appropriate advice.

Most education employers have adopted nationally available publications as the basis for their Model Risk Assessments.

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

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

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

[1] These, and other CLEAPSS® publications, are on the CLEAPSS® Science Publications website www.cleapss.org.uk. Note that CLEAPSS® publications are only available to members. For more information about CLEAPSS® go to www.cleapss.org.uk.

5g. Practical Endorsement

The Practical Endorsement is common across Chemistry A and Chemistry B (Salters)/Biology A and Biology B (Advancing Biology) /Physics A and Physics B (Advancing Physics). It requires a minimum of 12 practical activities to be completed from the Practical Activity Groups (PAGs) defined below (**Fig. 1**).

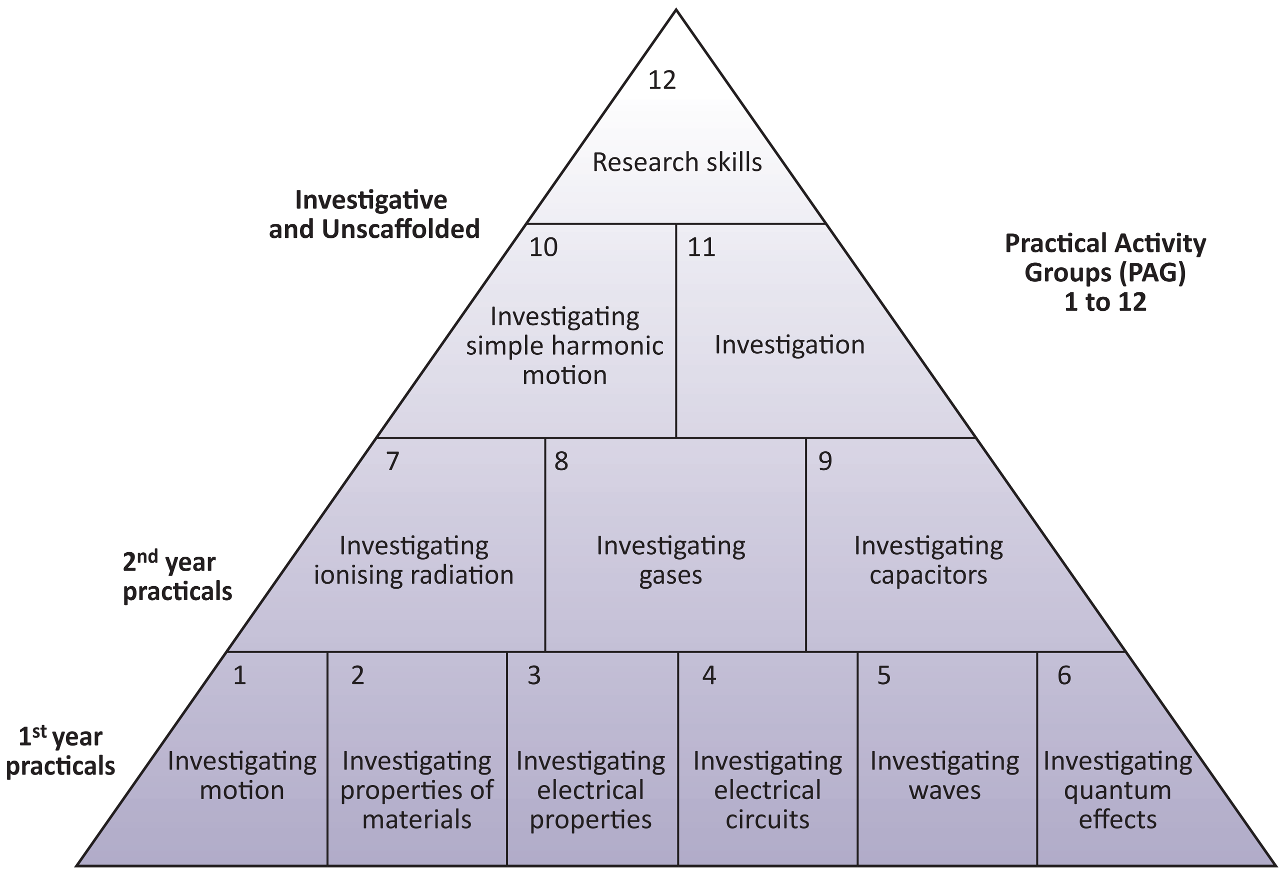

Fig. 1 OCR's Practical Activity Groups (PAGs), also see **Table 1**

Table 1 Practical requirements for the OCR Physics Practical Endorsement

Practical activity group (PAG)	Techniques/skills covered (minimum)	Example of a suitable practical activity (a range of examples will be available from the OCR website and centres can devise their own activity)	Specification reference (examples)
1 Investigating motion	• Use of appropriate analogue apparatus to measure distance, angles[1], mass[2] and to interpolate between scale markings[3] • Use of a stopwatch or light gates for timing • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4] • Use of methods to increase accuracy of measurements, such as set square or plumb line	Acceleration of free fall	3.1.2(b)(ii)
2 Investigating properties of materials	• Use of calipers and micrometers for small distances, using digital or vernier scales[5] • Use of appropriate analogue apparatus to measure length[6] and to interpolate between scale markings[3] • Use of appropriate digital instruments to measure mass[2]	Determining Young's Modulus for a metal	3.4.2(d)(ii)
3 Investigating electrical properties	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9], resistance[10] • Use calipers and micrometers for small distances, using digital or vernier scales[5] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components	Determining the resistivity/ conductivity of a metal	4.2.4(a)(ii)

Practical activity group (PAG)	Techniques/skills covered (minimum)	Example of a suitable practical activity	Specification Reference
4 Investigating electrical circuits	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9], resistance[10] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important • Designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components	Investigation of potential divider circuits	4.3.3(c)(i), 4.3.3(c)(ii)
5 Investigating waves	• Use of appropriate analogue apparatus to measure length[6], angles[1] and to interpolate between scale markings[3] • Use of a signal generator and oscilloscope, including volts/division and time-base • Generating and measuring waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source • Use of a laser or light source to investigate characteristics of light, including interference and diffraction • Use of ICT such as computer modelling	Determination of the wavelength of light and sound by two source superposition with a double-slit and diffraction grating	4.4.3(a)(ii), 4.4.3(h)(ii)

Practical activity group (PAG)	Techniques/skills covered (minimum)	Example of a suitable practical activity	Specification Reference
6 Investigating quantum effects	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important • Use of a laser or light source to investigate characteristics of light, including interference and diffraction • Use of methods to increase accuracy of measurements	Determination of Planck's constant using LEDs	4.5.1(e)(ii)
7 Investigating ionising radiation	• Safe use of ionising radiation, including detectors • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4]	Absorption of α or β or γ radiation	6.4.3(b)(ii)
8 Investigating gases	• Use of appropriate analogue apparatus to measure pressure, volume, temperature and to interpolate between scale markings[3]	Determining an estimate of absolute zero using variation of gas temperature with pressure	5.1.4(d)(iii)
9 Investigating capacitors	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9], resistance[10] • Use of appropriate digital instruments to measure time • Designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4]	Determining time constant using the gradient of ln *V* or ln *I*–time graph	6.1.3(a)(ii), 6.1.3(c)

Practical activity group (PAG)	Techniques/skills covered (minimum)	Example of a suitable practical activity	Specification Reference
10 Investigating simple harmonic motion	• Use of appropriate digital instruments to measure time • Use of appropriate analogue apparatus to measure distance and to interpolate between scale markings[3] • Use of methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4]	Investigating the factors affecting the period of a simple harmonic oscillator	5.3.1(c)(ii)
11 Investigation	• Apply investigative approaches and methods to practical work	Determination of the specific heat capacity of a material	5.1.3(b)(i)
12 Research skills	• Use online and offline research skills • Correctly cite sources of information	The principles behind the operation of the Global Positioning System The use of radioactive materials as tracers in medical imaging	Opportunities throughout specification

[1,2,3,4,5,6,7,8,9,10] These techniques/skills may be covered in any of the groups indicated.

It is expected that the following skills will be developed across all activities, regardless of the exact selection of activities. The ability to:

- safely and correctly use a range of practical equipment and materials **(1.2.1 b)**
- follow written instructions **(1.2.1 c)**
- make and record observations/measurements **(1.2.1 d)**
- keep appropriate records of experimental activities **(1.2.1 e)**
- present information and data in a scientific way **(1.2.1 f)**
- use a wide range of experimental and practical instruments, equipment and techniques **(1.2.1 j)**

5

The practical activities can be completed at any point during the two year A level course at the discretion of the centre. Candidates starting from a standalone AS can count A level practical activities carried out during the AS year towards the A level Practical Endorsement provided that they are appropriately recorded. It is recommended therefore that candidates starting AS maintain a record of practical activities carried out (e.g. this could be in the form of a 'log book' or 'practical portfolio') that could be counted towards the Practical Endorsement. For candidates who then decide to follow a full A level, having started from AS, they can carry this record with them into their A level study.

The assessment of practical skills is a compulsory requirement of the course of study for A level qualifications in 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 are 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,* covered in Section **1.2.1**) and 5c (*Use of apparatus and techniques*, covered in Section **1.2.2**) from the prescribed subject content, published by the Department for Education. The required practical activities are defined by each awarding organisation (see **Fig. 1** and **Table 1**)
- Teachers will assess students against Common Practical Assessment Criteria (CPAC) issued by the awarding organisations. The CPAC (see **Table 2**) 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, incorporating all the skills, apparatus and techniques (as defined in Sections 1.2.1 and 1.2.2), will receive a 'Pass' grade (note that the practical activity tracker available from OCR allows confirmation that the activities selected cover all the requirements).
- There will be no direct 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*, covered in Section **1.1**) 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.

In order to achieve a pass, students will need to:

- develop these competencies by carrying out a minimum of 12 practical activities (**PAG1** to **PAG12**), which allow acquisition of all the skills, apparatus and techniques outlined in the requirements of the specification (Sections 1.2.1 and 1.2.2)
- consistently and routinely exhibit the competencies listed in the CPAC (**Table 2**) before the completion of the A-level course
- keep an appropriate record of their practical work, including their assessed practical activities
- be able to demonstrate and/or record independent evidence of their competency, including evidence of independent application of investigative approaches and methods to practical work.

The practical activities prescribed in the subject specification (**PAG1** to **PAG12**) will 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 5b and 5c (covered in Sections 1.2.1 and 1.2.2).

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

Table 2 Common Practical Assessment Criteria (CPAC) for the assessment of practical competency in A Level sciences

Competency	Practical Mastery
	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 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 instructions to carry out 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.
(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.

Choice of activity

Centres can include additional skills, apparatus and techniques within an activity (PAG) beyond those listed as the minimum in **Table 1** or in the published practical activities. They may also carry out more than the minimum 12 practical activities required to meet the Practical Endorsement.

To achieve a Pass within the Practical Endorsement, candidates must have demonstrated competence in all the skills, apparatus and techniques detailed in Sections 1.2.1 and 1.2.2 of the specification by carrying out a minimum of 12 assessed practical activities (covering all of **PAG1** to **PAG12**) and achieved the level of competence defined within the Common Practical Assessment Criteria (**Table 2**).

The minimum of 12 activities can be met by:

(i) using OCR suggested activities (provided as resources from Interchange, or by contacting pass@ocr.org.uk should you be unable to access Interchange)

(ii) modifying OCR suggested activities to match available equipment whilst fulfilling the same skills, apparatus and techniques and CPAC

(iii) using activities devised by the centre and mapped against Section 1.2 of the specification and the CPAC

(iv) using activities from external sources such as the learned societies, mapped against Section 1.2 of the specification and the CPAC

Centres can receive guidance on the suitability of their own practical activities or against any of the options within **(ii)** to **(iv)** above through our free practical assessment support service by emailing pass@ocr.org.uk.

Where centres devise their own practical activity or use an alternative activity, that practical activity must be of a level of demand appropriate for A level.

Practical Activity Groups 1 to 12 can be achieved through more than one centre devised practical activity, and centres are not limited to 12 practical activities such that a centre could, for instance, split **PAG3** into two activities of their own (rather than one) with the two activities fulfilling the requirements. Alternatively it could be possible that an extended activity may cover the requirements of more than one group, in which case the centre could then select an additional activity from another group to achieve the required minimum of 12 practical activities.

5h. Revision of the requirements for practical work

OCR will review the Practical Endorsement detailed in Section 5g of this specification following any revision by the Secretary of State of the skills, apparatus or techniques specified in respect of A Level Physics A.

OCR will revise the Practical Endorsement if appropriate.

If any revision to the Practical Endorsement is made, OCR will produce an amended specification which will be published on the OCR website. OCR will then use the following methods to communicate the amendment to centres: subject information update emailed sent to all Examinations Officers, e-alerts to centres that have registered to teach the qualification and social media.

Your checklist

Our aim is to provide you with all the information and support you need to deliver our specifications.

- ☐ Bookmark **ocr.org.uk/alevelphysicsa** for all the latest resources, information and news on AS and A Level Physics A
- ☐ Be among the first to hear about support materials and resources as they become available – register for Physics updates at **ocr.org.uk/updates**
- ☐ Find out about our professional development at **cpdhub.ocr.org.uk**
- ☐ View our range of skills guides for use across subjects and qualifications at **ocr.org.uk/skillsguides**
- ☐ Discover our new online past paper service at **ocr.org.uk/examcreator**
- ☐ Learn more about Active Results at **ocr.org.uk/activeresults**
- ☐ Join our Physics social network community for teachers at **social.ocr.org.uk**

Download high-quality, exciting and innovative AS and A Level Physics resources from ocr.org.uk/alevelphysicsa

Free resources and support for our A Level Physics qualification, developed through collaboration between our Physics Subject Specialists, teachers and other subject experts, are available from our website. You can also contact our Physics Subject Specialists for specialist advice, guidance and support, giving you individual service and assistance whenever you need it.

Meet the team at ocr.org.uk/scienceteam and contact them at:
01223 553998
scienceGCE@ocr.org.uk
@OCR_science

To stay up to date with all the relevant news about our qualifications, register for email updates at ocr.org.uk/updates

Science community

The social network is a free platform where teachers can engage with each other – and with us – to find and offer guidance, discover and share ideas, best practice and a range of Science support materials.
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