Pearson Edexcel

INTERNATIONAL ADVANCED LEVEL

PHYSICS

SPECIFICATION

Pearson Edexcel International Advanced Subsidiary in Physics (XPH11)
Pearson Edexcel International Advanced Level in Physics (YPH11)
First teaching September 2018
First examination from January 2019
First certification from August 2019 (International Advanced Subsidiary) and August 2020 (International Advanced Level)
Issue 3

Edexcel, BTEC and LCCI qualifications

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Acknowledgements

This specification has been produced by Pearson on the basis of consultation with teachers, examiners, consultants and other interested parties. Pearson would like to thank all those who contributed their time and expertise to the specification's development.

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Summary of Pearson Edexcel International Advanced Subsidiary/Advanced Level in Physics specification Issue 3 changes

Summary of changes made between previous issue and this current issue	**Page number**
These sentences have been added to ensure that thorough information on assessment criteria is provided:	
This paper may contain some synoptic questions which require knowledge and understanding from Units 1 and 2.	9, 27
This paper may contain some synoptic questions which require knowledge and understanding from Units 1, 2 and 4.	10, 33

Earlier issue shows previous changes.

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

Contents

About this specification

The Pearson Edexcel International Advanced Subsidiary in Physics and the Pearson Edexcel International Advanced Level in Physics are part of a suite of International Advanced Level qualifications offered by Pearson.

These qualifications are not accredited or regulated by any UK regulatory body.

Key features

This specification includes the following key features:

Structure

The Pearson Edexcel International Advanced Subsidiary in Physics and the Pearson Edexcel International Advanced Level in Physics are modular qualifications. The Advanced Subsidiary can be claimed on completion of the International Advanced Subsidiary (IAS) units.

The International Advanced Level can be claimed on completion of all the units (IAS and IA2 units).

Content

The content is relevant for learners who have achieved an International GCSE in Physics and who want to study this subject at a higher level. The content has been updated from the previous Pearson Edexcel International Advanced Subsidiary in Physics and the previous Pearson Edexcel International Advanced Level in Physics qualifications. It covers the major topics in physics, including mechanics, materials, waves, electricity, fields, thermodynamics, radiation, particles, oscillations and cosmology.

Assessment

Assessment consists of three written papers at IAS level that are externally assessed. The International A level consists of three further written papers that are externally assessed.

Approach

Learners will develop their knowledge and understanding of physics by applying the concepts in this specification to a range of different problems that include a variety of contexts. Problems will require the application of mathematical skills.

Learners will also develop their practical skills. The specification includes 16 core practical activities. This is the minimum number of practical activities that learners will carry out; centres are encouraged to enable learners to carry out additional practical activities to further develop practical skills.

Specification updates

This specification is Issue 3 and is valid for first teaching from September 2018. If there are any significant changes to the specification, we will inform centres in writing. Changes will also be posted on our website.

For more information please visit qualifications.pearson.com

Using this specification

This specification has been designed to give guidance to teachers and encourage effective delivery of these qualifications. The following information will help you get the most out of the content and guidance.

Compulsory content: as a minimum, all the items in the content must be taught. The word ‘including’ in content specifies the detail of what must be covered.

Assessments: use a range of material and are not limited to the examples given. Teachers should deliver these qualifications using a good range of examples to support the assessment of the content.

Depth and breadth of content: teachers should use the full range of content and all the assessment objectives given in the subject content section.

Qualification aims and objectives

The aims and objectives of these qualifications are to enable students to develop:

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

Qualification abbreviations used in this specification

The following abbreviations appear in this specification:

- International Advanced Subsidiary – IAS
- International A2 – IA2 (the additional content required for an IAL)
- International Advanced Level – IAL.

Why choose Pearson Edexcel qualifications?

Pearson – the world's largest education company

All Edexcel's academic qualifications, including our new International AS and A level suite, are produced by Pearson, the UK's largest awarding organisation. With over 3.4 million students studying our academic and vocational qualifications worldwide, we offer internationally recognised qualifications to schools, colleges and employers globally.

Pearson is recognised as the world's largest education company, allowing us to drive innovation and provide comprehensive support for Pearson Edexcel students in acquiring the knowledge and skills they need for progression in study, work and life.

A heritage you can trust

The background to Pearson becoming the UK's largest awarding organisation began in 1836, when a royal charter gave the University of London its first powers to conduct exams and confer degrees on its students. Pearson Edexcel qualifications build on experience of over 150 years in international education, and have a firm academic foundation, built on the traditions and rigour associated with Britain's educational system.

Results you can trust

Pearson's leading online marking technology has been shown to produce exceptionally reliable results, demonstrating that at every stage, Pearson Edexcel qualifications maintain the highest standards.

Developed to Pearson's world-class qualifications standards

Pearson's world-class standards mean that all Pearson Edexcel qualifications are developed to be rigorous, demanding, inclusive and empowering. We work collaboratively with a panel of educational thought leaders and assessment experts to ensure that Pearson Edexcel qualifications are globally relevant, represent world-class best practice and maintain a consistent standard.

For more information on the world-class qualification process and principles please go to *Appendix 2: Pearson World Class Qualification design principles* or visit our website: uk.pearson.com/world-class-qualifications.

Why choose Pearson Edexcel International Advanced Subsidiary/Advanced Level qualifications in Physics?

We have listened to feedback from all parts of the international school education community, including a large number of teachers. Our International Advanced Subsidiary and Advanced Levels have been developed to be engaging for international learners; and to give them the necessary skills to support progression to further study in Physics, as well as to a wide range of other subjects.

Key qualification features – using feedback from teachers, we've retained several key features which we know you value. These include:

- modular assessment, offered at different times of year to suit your delivery model
- practical skills assessed through a dedicated examination Unit both at AS (Unit 3) and at A Level Unit 6) to ensure key practical skills are developed and assessed in an accessible way
- comparable content with the UK GCE AS and A Level – giving confidence to students, teachers and universities about the comparability between specifications
- range of types of questions in exams – to test breadth of subject knowledge, as well as allowing depth of understanding to be examined.

Clear and straightforward question papers – our question papers are clear and accessible for students of all ability ranges, and use a series of well-defined command words. Our mark schemes are straightforward so that the assessment requirements are clear.

Broad and deep development of learners' skills – we designed the Advanced Subsidiary and International Advanced Level qualifications to extend learners' knowledge by broadening and deepening skills. For example learners will:

- develop and use a range of mathematical skills which support their knowledge and understanding of Physics
- gain experience in a variety of practical techniques and procedures, which will be assessed separately within Unit 3 and Unit 6
- widen their learning through a number of key transferable skills, which may be cognitive, intrapersonal or interpersonal (see *Appendix 3: Transferable skills*).

Progression – these qualifications enable successful progression to further education courses in physical sciences. Through our world-class qualification development process we have consulted with a number of universities in the UK, as well as internationally, to validate the appropriateness of these qualifications, including content, skills and the assessment structure.

Our International Advanced Subsidiary and Advanced Levels in Physics sits within our wider subject offer for sciences. We also offer International Advanced Subsidiary and Advanced Levels in Biology, Chemistry and Psychology; and well as in Mathematics and Further Mathematics.

More information can be found on our website (qualifications.pearson.com) on the Pearson Edexcel International Advanced Level pages.

Supporting you in planning and implementing these qualifications

Planning

- Our *Getting Started Guide* gives you an overview of the Pearson Edexcel International Advanced Subsidiary and Advanced Levels in Physics qualifications to help you understand the changes to content and assessment, and what these changes mean for you and your students.
- We will provide you with an editable course planner and scheme of work to save you time in planning and help you to put together teaching strategies for delivering the specification content.
- Our mapping documents highlight key differences between the new and legacy qualifications to help you understand the changes made to the new specifications.

Teaching and learning

There will be a variety of teaching and learning support to help you deliver the new specifications, including:

- Practical Skills Guides and Mathematical Skills Guides - to help you ensure that students are developing these skills, both of which form a key part of the assessment of the new International Advanced Subsidiary and Advanced Levels
- Getting Ready to Teach and other training events - available locally, as well as online – to support you as you prepare to teach the new specification
- Printed textbooks and digital teaching resources - promote any time, any place learning to improve student motivation and encourage new ways of working.

Preparing for exams

We will also provide a range of resources to help you prepare your students for the assessments, including:

- specimen assessment materials to support formative assessments and mock exams
- examiner commentaries on questions following each examination series.

ResultsPlus

ResultsPlus provides the most detailed analysis available of your students' examination performance. It can help you identify the topics and skills where further learning would benefit your students.

examWizard

A free online resource is available, designed to support students and teachers with examination preparation and assessment.

Training events

In addition to online training, we host a series of training events each year for teachers to deepen their understanding of our qualifications.

Get help and support

Our Subject Advisor service will ensure that you receive help and guidance from us. You can sign up to receive Pearson Edexcel newsletter for qualification updates and product and service news.

Qualification at a glance

Qualification overview

Pearson Edexcel International Advanced Subsidiary in Physics

This qualification consists of three externally examined units.

The International Advanced Subsidiary is the first half of the International Advanced Level qualification and consists of three IAS units, Units 1, 2 and 3. This qualification can be awarded as a discrete qualification or can contribute 50 percent towards the International Advanced Level qualification.

The qualification will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 40% of the marks across the papers will be awarded for mathematics at Level 2 or above.

Pearson Edexcel International Advanced Level in Physics

This qualification consists of six externally examined units.

The International Advanced Level consists of the three IAS units (Units 1, 2 and 3) plus three IA2 units (Units 4, 5 and 6). Candidates wishing to take the International Advanced Level must, therefore, complete all six units.

The qualification will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 40% of the marks across the papers will be awarded for mathematics at Level 2 or above.

Course of study

The structure of these qualifications allows teachers to construct a course of study that can be taught and assessed as either:

- distinct modules of teaching and learning with related units of assessment taken at appropriate stages during the course; or
- a linear course assessed in its entirety at the end.

Content and assessment overview

IAS **Unit 1: Mechanics and Materials**	***Unit code: WPH11/01**	
Externally assessed Written examination: 1 hour and 30 minutes Availability: January, June and October First assessment: January 2019 80 marks	40% of the total IAS	20% of the total IAL
Content overview • Mechanics • Materials		
Assessment overview The paper may include multiple-choice, short open, open-response, calculations and extended-writing questions. The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). A minimum of 32 marks will be awarded for mathematics at Level 2 or above. Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.		

IAS **Unit 2: Waves and Electricity**	***Unit code: WPH12/01**	
Externally assessed Written examination: 1 hour and 30 minutes Availability: January, June and October First assessment: June 2019 80 marks	40% of the total IAS	20% of the total IAL
Content overview • Waves and Particle Nature of Light • Electric Circuits		
Assessment overview The paper may include multiple-choice, short-open, open-response, calculations and extended-writing questions. The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). A minimum of 32 marks will be awarded for mathematics at Level 2 or above. Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.		

<table>
<tr><th colspan="2">IAS
Unit 3: Practical Skills in Physics I</th><th colspan="2">*Unit code: WPH13/01</th></tr>
<tr><td colspan="2">Externally assessed
Written examination: 1 hour and 20 minutes
Availability: January, June and October
First assessment: June 2019
50 marks</td><td>20% of the total IAS</td><td>10% of the total IAL</td></tr>
<tr><td colspan="4">Content overview
Students are expected to develop experimental skills, and a knowledge and understanding of experimental techniques, by carrying out a range of practical experiments and investigations while they study Units 1 and 2.
This unit will assess candidates' knowledge and understanding of experimental procedures and techniques that were developed in Units 1 and 2.</td></tr>
<tr><td colspan="4">Assessment overview
The paper may include short-open, open-response, calculations and extended-writing questions.
The paper will include questions that target mathematics at Level 2 or above (see Appendix 6: Mathematical skills and exemplifications). A minimum of 20 marks will be awarded for mathematics at Level 2 or above.
Candidates will be expected to apply their knowledge and understanding of practical skills to familiar and unfamiliar situations.</td></tr>
</table>

<table>
<tr><th colspan="1">IA2
Unit 4: Further Mechanics, Fields and Particles</th><th colspan="2">*Unit code: WPH14/01</th></tr>
<tr><td>Externally assessed
Written examination: 1 hour and 45 minutes
Availability: January, June and October
First assessment: January 2020
90 marks</td><td>40% of the total IA2</td><td>20% of the total IAL</td></tr>
<tr><td colspan="3">Content overview
Further Mechanics
Electric and Magnetic Fields
Nuclear and Particle Physics</td></tr>
<tr><td colspan="3">Assessment overview
The paper may include multiple-choice, short-open, open-response, calculations and extended-writing questions.
The paper will include questions that target mathematics at Level 2 or above (see Appendix 6: Mathematical skills and exemplifications). A minimum of 36 marks will be awarded for mathematics at Level 2 or above.
Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.
This paper may contain some synoptic questions which require knowledge and understanding from Units 1 and 2.</td></tr>
</table>

<table>
<tr><td>IA2
Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology</td><td colspan="2">*Unit code: WPH15/01</td></tr>
<tr><td>Externally assessed
Written examination: 1 hour and 45 minutes
Availability: January, June and October
First assessment: June 2020
90 marks</td><td>40% of the total IA2</td><td>20% of the total IAL</td></tr>
<tr><td colspan="3">Content overview
• Thermodynamics
• Nuclear Decay
• Oscillations
• Astrophysics and Cosmology</td></tr>
<tr><td colspan="3">Assessment overview
The paper may include multiple-choice, short-open, open-response, calculations and extended-writing questions.
The paper will include questions that target mathematics at Level 2 or above (see Appendix 6: Mathematical skills and exemplifications). A minimum of 36 marks will be awarded for mathematics at Level 2 or above.
Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.
This paper may contain some synoptic questions which require knowledge and understanding from Units 1, 2 and 4.</td></tr>
</table>

<table>
<tr><th>IA2
Unit 6: Practical Skills in Physics II</th><th colspan="2">*Unit code: WPH16/01</th></tr>
<tr><td>Externally assessed
Written examination: 1 hour and 20 minutes
Availability: January, June and October
First assessment: June 2020
50 marks</td><td>20% of the total IA2</td><td>10% of the total IAL</td></tr>
<tr><td colspan="3">Content overview
Students are expected to further develop the experimental skills and the knowledge and understanding of experimental techniques that they acquired in Units 1 and 2 by carrying out a range of practical experiments and investigations while they study Units 4 and 5.
This unit will assess candidates' knowledge and understanding of the experimental procedures and techniques that were developed in Units 4 and 5.</td></tr>
<tr><td colspan="3">Assessment overview
The paper may include short-open, open-response, calculations and extended-writing questions.
The paper will include questions that target mathematics at Level 2 or above (see Appendix 6: Mathematical skills and exemplifications). A minimum of 20 marks will be awarded for mathematics at Level 2 or above.
Candidates will be expected to apply their knowledge and understanding of practical skills to familiar and unfamiliar situations.</td></tr>
</table>

*See *Appendix 1: Codes* for a description of this code and all other codes relevant to these qualifications.

Calculators

Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

Physics content

Content overview

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

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

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

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

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

Questions in examination papers for Units 1, 2, 4 and 5 will aim to assess the knowledge and understanding that students gain while carrying out practical activities, within the context of the 16 core practical activities, as well as in novel practical scenarios. Success in questions that indirectly assess practical skills will come more naturally to those candidates who have a solid foundation of laboratory practice and who, having carried them out, have a thorough understanding of practical techniques. Therefore, where possible, teachers should consider adding additional experiments to the core practical activities.

Candidates will be assessed on their practical skills in Papers 3 and 6. These papers will include testing candidates' skills in planning practical work – both in familiar and unfamiliar applications – including risk management and the selection of apparatus, with reasons.

When data handling, candidates will be expected to use significant figures appropriately, to process data and to plot graphs. In analysing outcomes and drawing valid conclusions, students should critically consider methods and data, including assessing measurement uncertainties and errors. *Appendix 10: Uncertainties and practical work* provides guidance on this.

Students should be encouraged to use information technology throughout the course.

Units

Unit 1: Mechanics and Materials

IAS compulsory unit

Externally assessed

1.1 Unit description

Introduction	This unit covers mechanics and materials. This topic may be studied using applications that relate to mechanics, for example sports and to materials, for example spare-part surgery. This topic also enables students to develop practical and mathematical skills.
Practical skills	In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include strobe photography or the use of a video camera to analyse projectile motion, determine the centre of gravity of an irregular rod, investigate the conservation of momentum using light gates and air track, Hooke's law and the Young modulus experiments for a variety of materials.
Mathematical skills	Mathematical skills that could be developed in this topic include: plotting two variables from experimental data; calculating rate of change from a graph showing a linear relationship; drawing and using the slope of a tangent to a curve as a measure of rate of change; calculating or estimating, by graphical methods as appropriate, the area between a curve and the x-axis and realising the physical significance of the area that has been determined; distinguishing between instantaneous rate of change and average rate of change and identifying uncertainties in measurements; using simple techniques to determine uncertainty when data are combined; using angles in regular 2D and 3D structures with force diagrams and using sin, cos and tan in physical problems.

1.2 Assessment information

Some questions will assess knowledge and understanding of experimental methods.	• First assessment: January 2019. • The assessment is 1 hour and 30 minutes. • The assessment is out of 80 marks. • Candidates must answer all questions. • The paper may include multiple-choice, short open, open-response, calculations and extended-writing questions. • The paper will include questions that target mathematics at Level 2. A minimum of 32 marks will be awarded for mathematics at Level 2 or above in this paper. • Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts. • Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

1.3 Mechanics

This topic covers rectilinear motion, forces, energy and power. It may be studied using applications that relate to mechanics such as sports.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

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

14	know the principle of conservation of linear momentum, understand how to relate this to Newton's laws of motion and understand how to apply this to problems in one dimension
15	be able to use the equation for the moment of a force, moment of force = Fx where x is the perpendicular distance between the line of action of the force and the axis of rotation
16	be able to use the concept of centre of gravity of an extended body and apply the principle of moments to an extended body in equilibrium
17	be able to use the equation for work $\Delta W = F\Delta s$, including calculations when the force is not along the line of motion
18	be able to use the equation $E_k = \frac{1}{2}mv^2$ for the kinetic energy of a body
19	be able to use the equation $\Delta E_{grav} = mg\Delta h$ for the difference in gravitational potential energy near the Earth's surface
20	know, and understand how to apply, the principle of conservation of energy including use of work done, gravitational potential energy and kinetic energy
21	be able to use the equations relating power, time and energy transferred or work done $P = \frac{E}{t}$ and $P = \frac{W}{t}$
22	be able to use the equations $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$ and $\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$

1.4 Materials

This topic covers density, flow of liquids, Hooke’s law, the Young modulus and elastic strain energy.

This topic should be studied using a variety of applications, for example making and testing food, engineering materials, spare-part surgery for joint replacement.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

23	be able to use the equation density $\rho = \frac{m}{V}$
24	understand how to use the relationship upthrust = weight of fluid displaced
25	a be able to use the equation for viscous drag (Stokes’ Law), $F = 6\pi\eta rv$. b understand that this equation applies only to small spherical objects moving at low speeds with *laminar flow* (or in the absence of *turbulent flow*) and that viscosity is temperature dependent
26	**CORE PRACTICAL 2: Use a falling-ball method to determine the viscosity of a liquid**
27	be able to use the Hooke’s law equation, $\Delta F = k\Delta x$, where k is the stiffness of the object
28	understand how to use the relationships • *(tensile or compressive) stress = force/cross-sectional area* • *(tensile or compressive) strain= change in length/original length* *Young modulus = stress/strain.*
29	a be able to draw and interpret force-extension and force-compression graphs b understand the terms limit of proportionality, elastic limit, yield point, elastic deformation and plastic deformation and be able to apply them to these graphs
30	be able to draw and interpret tensile or compressive stress-strain graphs, and understand the term *breaking stress*
31	**CORE PRACTICAL 3: Determine the Young modulus of a material**
32	be able to calculate the elastic strain energy E_{el} in a deformed material sample, using the equation $\Delta E_{el} = \frac{1}{2}F\Delta x$, and from the area under the force-extension graph *The estimation of area and hence energy change for both linear and non-linear force-extension graphs is expected.*

Unit 2: Waves and Electricity

IAS compulsory unit

Externally assessed

2.1 Unit description

Introduction	This topic covers waves and the particle nature of light and electric currents. This topic may be studied using applications that relate to electricity, for example space technology and to waves, for example medical physics. This topic also enables students to develop practical and mathematical skills.
Practical skills	In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include estimating power output of an electric motor, using a digital voltmeter to investigate the output of a potential divider and investigating current/voltage graphs for a filament bulb, thermistor and diode, determining the refractive index of solids and liquids, demonstrating progressive and stationary waves on a slinky.
Mathematical skills	Mathematical skills that could be developed in this topic include substituting numerical values into algebraic equations using appropriate units for physical quantities and applying the equation $y = mx + c$ to experimental data, using calculators to handle *sin x*, identifying uncertainties in measurements and using simple techniques to determine uncertainty when data are combined.

2.2 Assessment information

- First assessment: June 2019.
- The assessment is 1 hour and 30 minutes.
- The assessment is out of 80 marks.
- Candidates must answer all questions.
- The paper may include multiple-choice, short open, open-response, calculations and extended-writing questions.
- The paper will include questions that target mathematics at Level 2. A minimum of 32 marks will be awarded for mathematics at Level 2 or above in this paper.
- Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.
- Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

2.3 Waves and Particle Nature of Light

This topic covers the properties of different types of wave, including standing waves. Refraction, polarisation and diffraction are also included and the wave/particle nature of light. This topic should be studied by exploring the applications of waves, for example applications in medical physics or music.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

33	understand the terms amplitude, frequency, period, speed and wavelength
34	be able to use the wave equation $v = f\lambda$
35	be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules
36	be able to describe transverse waves
37	be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves
38	**CORE PRACTICAL 4: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone**
39	know and understand what is meant by *wavefront, coherence, path difference, superposition, interference* and *phase*
40	be able to use the relationship between *phase difference* and *path difference*
41	know what is meant by a *standing*/*stationary* wave and understand how such a wave is formed, know how to identify nodes and antinodes
42	be able to use the equation for the speed of a transverse wave on a string $v = \sqrt{\frac{T}{\mu}}$
43	**CORE PRACTICAL 5: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire**
44	be able to use the equation for the intensity of radiation $I = \frac{P}{A}$
45	know and understand that at the interface between medium 1 and medium 2 $n_1 \sin \theta_1 = n_2 \sin \theta_2$ where refractive index is $n = \frac{c}{v}$
46	be able to calculate critical angle using $\sin C = \frac{1}{n}$

47	be able to predict whether total internal reflection will occur at an interface
48	understand how to measure the refractive index of a solid material
49	understand what is meant by plane polarisation
50	understand what is meant by diffraction and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle
51	be able to use $n\lambda = d\sin\theta$ for a diffraction grating
52	**CORE PRACTICAL 6: Determine the wavelength of light from a laser or other light source using a diffraction grating**
53	understand how diffraction experiments provide evidence for the wave nature of electrons
54	be able to use the de Broglie equation $\lambda = \frac{h}{p}$
55	understand that waves can be transmitted and reflected at an interface between media
56	understand how a pulse-echo technique can provide information about the position of an object and how the amount of information obtained may be limited by the wavelength of the radiation or by the duration of pulses
57	understand how the behaviour of electromagnetic radiation can be described in terms of a wave model and a photon model, and how these models developed over time
58	be able to use the equation $E = hf$, that relates the photon energy to the wave frequency
59	understand that the absorption of a photon can result in the emission of a photoelectron
60	understand the terms 'threshold frequency' and 'work function' and be able to use the equation $hf = \phi + \frac{1}{2}mv^2_{max}$
61	be able to use the electronvolt (eV) to express small energies
62	understand how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation
63	understand atomic line spectra in terms of transitions between discrete energy levels and understand how to calculate the frequency of radiation that could be emitted or absorbed in a transition between energy levels.

2.4 Electric Circuits

This topic covers the definitions of various electrical quantities, for example current, potential difference and resistance, Ohm's law and non-ohmic conductors, potential dividers, e.m.f. and internal resistance of cells and negative temperature coefficient thermistors.

This topic should be studied using applications such as space technology.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

64	understand that electric current is the rate of flow of charged particles and be able to use the equation $I = \frac{\Delta Q}{\Delta t}$
65	understand how to use the equation $V = \frac{W}{Q}$
66	understand that resistance is defined by $R = \frac{V}{I}$ and that Ohm's law is a special case when $I \propto V$ for constant temperature
67	(a) understand how the distribution of current in a circuit is a consequence of charge conservation (b) understand how the distribution of potential differences in a circuit is a consequence of energy conservation
68	be able to derive the equations for combining resistances in series and parallel using the principles of charge and energy conservation, and be able to use these equations
69	be able to use the equations $P = VI$, $W = VIt$ and be able to derive and use related equations, e.g. $P = I^2R$ and $P = \frac{V^2}{R}$
70	understand how to sketch, recognise and interpret current-potential difference graphs for components, including ohmic conductors, filament bulbs, thermistors and diodes
71	be able to use the equation $R = \frac{\rho l}{A}$
72	**CORE PRACTICAL 7: Determine the electrical resistivity of a material**
73	be able to use $I = nqvA$ to explain the large range of resistivities of different materials
74	understand how the potential along a uniform current-carrying wire varies with the distance along it
75	understand the principles of a potential divider circuit and understand how to calculate potential differences and resistances in such a circuit
76	be able to analyse potential divider circuits where one resistance is variable including thermistors and light dependent resistors (LDRs)

77	know the definition of *electromotive force (e.m.f.)* and understand what is meant by *internal resistance* and know how to distinguish between e.m.f. and *terminal potential difference*
78	**CORE PRACTICAL 8: Determine the e.m.f. and internal resistance of an electrical cell**
79	understand how changes of resistance with temperature may be modelled in terms of lattice vibrations and number of conduction electrons and understand how to apply this model to metallic conductors and negative temperature coefficient thermistors
80	understand how changes of resistance with illumination may be modelled in terms of the number of conduction electrons and understand how to apply this model to LDRs.

Unit 3: Practical Skills in Physics I

IAS compulsory unit

Externally assessed

3.1 Unit description

Introduction	Students are expected to develop experimental skills, and a knowledge and understanding of experimental techniques, by carrying out a range of practical experiments and investigations while they study Units 1 and 2. This unit will assess students' knowledge and understanding of experimental procedures and techniques that were developed when they conducted these experiments.
Development of practical skills, knowledge and understanding	Students should carry out a variety of practical work during the IAS course to develop their practical skills. This should help them to gain an understanding and knowledge of the practical techniques that are used in experimental work. In order to prepare students for the assessment of this unit, centres should give students opportunities to plan experiments, implement their plans, collect data, analyse their data and draw conclusions. Experiments should cover a range of different topic areas and require the use of a variety of practical techniques.

3.2 Assessment information

- First assessment: June 2019.
- The assessment is 1 hour and 20 minutes.
- The assessment is out of 50 marks.
- Candidates must answer all questions.
- The paper may include short-open, open-response, calculations and extended-writing questions.
- The paper will include questions that target mathematics at Level 2. A minimum of 20 marks will be awarded for mathematics at Level 2 or above in this paper.
- Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

3.3 Planning

Students will be expected to plan an experiment set by Pearson, although they will not be expected to carry it out.

Candidates will be assessed on their ability to:

Plan an experiment	• identify the apparatus required • the range and resolution of measuring instruments including Vernier calipers (0.1mm) and micrometer screw gauge (0.01mm) • discuss calibration of instruments, e.g. whether a meter reads zero before measurements are made • describe how to measure relevant variables using the most appropriate instrument and correct measuring techniques • identify and state how to control all other relevant variables to make it a fair test • discuss whether repeat readings are appropriate • identify health and safety issues and discuss how these may be dealt with • discuss how the data collected will be used • identify possible sources of uncertainty and/or systematic error and explain how these may be reduced or eliminated • comment on the implications of physics (e.g. benefits/risks) and on its context (e.g. social/environmental/historical).

3.4 Implementation and measurements

Students will be given details of an experiment carried out by an inexperienced student. Results may be included.

Candidates will be assessed on their ability to:

Implementation and measurements	• comment on the number of readings taken • comment on the range of measurements taken • comment on significant figures • check a reading that is inconsistent with other readings, e.g. a point that is not on the line of a graph – students may be shown a diagram of a micrometer that is being used to measure the diameter of a wire and be expected to write down the reading to the correct number of significant figures • comment on how the experiment may be improved, possibly by using additional apparatus (e.g. to reduce errors) – examples may include using a set square to determine whether a ruler is vertical to aid the measurement of the extension of a spring.

3.5 Processing Results

Students will be provided with a set of experimental results that were obtained by a more-experienced student conducting an experiment.

Candidates will be assessed on their ability to:

Process results	• perform calculations, using the correct number of significant figures • plot results on a graph using an appropriate scale • use the correct units throughout • comment on the relationship obtained from the graph • determine the relationship between two variables or determine a constant with the aid of a graph, e.g. by determining the gradient using a large triangle • suggest realistic modifications to reduce errors • suggest realistic modifications to improve the experiment • discuss uncertainties, qualitatively and quantitatively • determine the percentage uncertainty in measurements for a single reading using **half** the resolution of the instrument **and** from multiple readings using the **half** range (students are **not** expected to compound percentage uncertainties).

Unit 4: Further Mechanics, Fields and Particles

IA2 compulsory unit

Externally assessed

4.1 Unit description

Introduction	This topic covers further mechanics, electric and magnetic fields, and nuclear and particle physics. This topic may be studied using applications that relate to mechanics, for example transportation and fields, for example communications and display techniques. This topic also enables students to develop practical and mathematical skills.
Practical skills	In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the effect of mass, velocity and radius of orbit on centripetal force, using a coulomb meter to measure charge stored and using an electronic balance to measure the force between two charges.
Mathematical skills	Mathematical skills that could be developed in this topic include translating between degrees and radians and using trigonometric functions, sketching relationships that are modelled by $y = k/x$, and $y = k/x^2$, using logarithmic plots to test exponential and power law variations, interpreting logarithmic plots and sketching relationships that are modelled by $y = e^{-x}$.

4.2 Assessment information

- First assessment: January 2020.
- The assessment is 1 hour and 45 minutes.
- The assessment is out of 90 marks.
- Candidates must answer all questions.
- The paper may include multiple-choice, short open, open-response, calculations and extended-writing questions.
- The paper will include questions that target mathematics at Level 2. A minimum of 36 marks will be awarded for mathematics at Level 2 or above in this paper.
- Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.
- This paper may contain some synoptic questions which require knowledge and understanding from Units 1 and 2.
- Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

4.3 Further Mechanics

This topic covers impulse, conservation of momentum in two dimensions and circular motion.

It can be studied using applications that relate to, for example, a modern rail transportation system.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

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

4.4 Electric and Magnetic Fields

This topic covers Coulomb's law, capacitors, magnetic flux density and the laws of electromagnetic induction.

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

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiment.

Candidates will be assessed on their ability to:

92	understand that an electric field (force field) is defined as a region where a charged particle experiences a force
93	understand that electric field strength is defined as $E = \frac{F}{Q}$ and be able to use this equation
94	be able to use the equation $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ for the force between two charges
95	be able to use the equation $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the electric field due to a point charge
96	know and understand the relation between electric field and electric potential
97	be able to use the equation $E = \frac{V}{d}$ for an electric field between parallel plates
98	be able to use $V = \frac{Q}{4\pi\varepsilon_0 r}$ for a radial field
99	be able to draw and interpret diagrams using field lines and equipotentials to describe radial and uniform electric fields
100	understand that capacitance is defined as $C = \frac{Q}{V}$ and be able to use this equation
101	be able to use the equation $W = \frac{1}{2}QV$ for the energy stored by a capacitor, be able to derive the equation from the area under a graph of potential difference against charge stored and be able to derive and use the equations $W = \frac{1}{2}CV^2$ and $W = \frac{\frac{1}{2}Q^2}{C}$

102	be able to draw and interpret charge and discharge curves for resistor capacitor circuits and understand the significance of the time constant *RC*
103	**CORE PRACTICAL 11: Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through a resistor**
104	be able to use the equation $Q = Q_0 e^{-t/RC}$ and derive and use related equations for exponential discharge in a resistor-capacitor circuit, $I = I_0 e^{-t/RC}$, and $V = V_0 e^{-t/RC}$ and the corresponding log equations $\ln Q = \ln Q_0 - \frac{t}{RC}$, $\ln I = \ln I_0 - \frac{t}{RC}$ and $\ln V = \ln V_0 - \frac{t}{RC}$
105	understand and use the terms *magnetic flux density B, flux* ϕ and *flux linkage N*ϕ
106	be able to use the equation $F = Bqv \sin\theta$ and apply Fleming's left-hand rule to charged particles moving in a magnetic field
107	be able to use the equation $F = BIl \sin\theta$ and apply Fleming's left-hand rule to current carrying conductors in a magnetic field
108	understand the factors affecting the e.m.f. induced in a coil when there is relative motion between the coil and a permanent magnet
109	understand the factors affecting the e.m.f. induced in a coil when there is a change of current in another coil linked with this coil
110	understand how to use Faraday's law to determine the magnitude of an induced e.m.f. and be able to use the equation that combines Faraday's and Lenz's laws $\mathscr{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$.

4.5 Nuclear and Particle Physics

This topic covers atomic structure, particle accelerators and the standard quark-lepton model.

This topic is the subject of current research, involving the acceleration and detection of high-energy particles. It may be taught by exploring a range of experiments such as

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

Candidates will be assessed on their ability to:

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

Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology

IA2 compulsory unit

Externally assessed

5.1 Unit description

Introduction	This topic covers thermal energy, nuclear decay, oscillations and astrophysics and cosmology. This topic may be studied using applications that relate to thermodynamics, for example space technology, and to nuclear radiation, for example nuclear power stations and medical physics. This topic also enables students to develop practical and mathematical skills.
Practical skills	In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the relationship between the volume and temperature of a fixed mass of gas, measuring the half-life of a radioactive material, measuring gravitational field strength using a simple pendulum and measuring a spring constant from simple harmonic motion.
Mathematical skills	Mathematical skills that could be developed in this topic include substituting numerical values into algebraic equations using appropriate units for physical quantities, applying the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example. $\Delta x/\Delta t = -\lambda x$ using a graphical method or spreadsheet modelling and understanding probability in the context of radioactive decay, sketching relationships that are modelled by $y = \sin x$, $y = \cos x$, $y = k/x$, $y = k/x^2$

5.2 Assessment information

- First assessment: June 2020.
- The assessment is 1 hour and 45 minutes.
- The assessment is out of 90 marks.
- Candidates must answer all questions.
- The paper may include multiple-choice, short open, open-response, calculations and extended-writing questions.
- The paper will include questions that target mathematics at Level 2. A minimum of 36 marks will be awarded for mathematics at Level 2 or above in this paper.
- Candidates will be expected to apply their knowledge and understanding to familiar and unfamiliar contexts.
- This paper may contain some synoptic questions which require knowledge and understanding from Units 1, 2 and 4.
- Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

5.3 Thermodynamics

This topic covers specific heat capacity, specific latent heat, internal energy and the gas equation.

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

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

125	be able to use the equations $\Delta E = mc\Delta\theta$ and $\Delta E = L\Delta m$
126	**CORE PRACTICAL 12: Calibrate a thermistor in a potential divider circuit as a thermostat**
127	**CORE PRACTICAL 13: Determine the specific latent heat of a phase change**
128	understand the concept of *internal energy* as the random distribution of potential and kinetic energy amongst molecules
129	understand the concept of *absolute zero* and how the average kinetic energy of molecules is related to the absolute temperature
130	be able to use the equation $pV = N\mathrm{k}T$ for an ideal gas
131	**CORE PRACTICAL 14: Investigate the relationship between pressure and volume of a gas at fixed temperature**
132	be able to derive and use the equation $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}\mathrm{k}T$

5.4 Nuclear Decay

This topic covers radioactive decay.

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

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

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

5.5 Oscillations

This topic covers simple harmonic motion and damping.

This topic may be studied using applications that relate to, for example, the construction of buildings in earthquake zones.

This unit includes many opportunities for developing experimental skills and techniques by carrying out more than just the core practical experiments.

Candidates will be assessed on their ability to:

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

5.6 Astrophysics and Cosmology

This topic covers gravitational fields and the physical interpretation of astronomical observations, the formation and evolution of stars and the history and future of the universe.

Candidates will be assessed on their ability to:

154	understand that a gravitational field (force field) is defined as a region where a mass experiences a force
155	understand that gravitational field strength is defined as $g = \frac{F}{m}$ and be able to use this equation
156	be able to use the equation $F = \frac{Gm_1m_2}{r^2}$ (Newton's law of universal gravitation)
157	be able to derive and use the equation $g = \frac{Gm}{r^2}$ for the gravitational field due to a point mass
158	be able to use the equation $V_{grav} = \frac{-Gm}{r}$ for a radial gravitational field
159	be able to compare electric fields with gravitational fields
160	be able to apply Newton's laws of motion and universal gravitation to orbital motion
161	understand what is meant by a *black body radiator* and be able to interpret radiation curves for such a radiator
162	be able to use the Stefan-Boltzmann law equation $L = \sigma AT^4$ for black body radiators
163	be able to use Wien's law equation $\lambda_{max}T$ = 2.898 x 10^{-3} m K for black body radiators
164	be able to use the equation, intensity $I = \frac{L}{4\pi d^2}$ where L is luminosity and d is distance from the source
165	understand how astronomical distances can be determined using trigonometric parallax
166	understand how astronomical distances can be determined using measurements of intensity received from standard candles (objects of known luminosity)
167	be able to sketch and interpret a simple Hertzsprung-Russell diagram that relates stellar luminosity to surface temperature
168	understand how to relate the Hertzsprung-Russell diagram to the life cycle of stars
169	understand how the movement of a source of waves relative to an observer/detector gives rise to a shift in frequency (Doppler effect)

170	be able to use the equations for redshift $z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer and $v = H_0 d$ for objects at cosmological distances
171	understand the controversy over the age and ultimate fate of the universe associated with the value of the Hubble constant and the possible existence of dark matter.

Unit 6: Practical Skills in Physics II

IA2 compulsory unit

Externally assessed

6.1 Unit description

Introduction	Students are expected to further develop the experimental skills they acquired in Units 1 and 2. Students are expected to develop these skills, and a knowledge and understanding of experimental techniques, by carrying out a range of practical experiments and investigations while they study Units 4 and 5. This unit will assess students' knowledge and understanding of experimental procedures and techniques that were developed when they conducted these experiments.
Development of practical skills, knowledge and understanding	Students should carry out a variety of practical work during the IA2 course to develop their practical skills. In order to prepare students for the assessment of this unit, centres should give students opportunities to plan experiments, implement their plans, collect data, analyse their data and draw conclusions. Experiments should cover a range of different topic areas and use a variety of practical techniques. Students should gain experience of using log graphs to determine the relationship between two variables. The graphs do not always need to be obtained for variables that are related by the exponential function. For example, students could investigate how the pressure of a fixed mass of gas varies with its volume at constant temperature and plot an appropriate log/log graph to determine the relationship between the pressure and volume of the gas.

6.2 Assessment information

- First assessment: June 2020.
- The assessment is 1 hour and 20 minutes.
- The assessment is out of 50 marks.
- Candidates must answer all questions.
- The paper may include short open, open-response, calculations and extended-writing questions.
- The paper will include questions that target mathematics at Level 2. A minimum of 20 marks will be awarded for mathematics at Level 2 or above in this paper.
- Calculators may be used in the examination. Please see *Appendix 11: Use of calculators*.

6.3 Planning

Students will be expected to plan an experiment set by Pearson, although they will not be expected to carry it out.

Candidates will be assessed on their ability to:

Plan an experiment	• identify the most appropriate apparatus, giving details. These may include the range and resolution of instruments and/or relevant dimensions of apparatus (e.g. the length of string used for a pendulum) • discuss calibration of instruments, e.g. whether a meter reads zero before measurements are made • describe how to measure relevant variables using the most appropriate instrument(s) and techniques • identify and state how to control all other relevant variables to make it a fair test • discuss whether repeat readings are appropriate • identify health and safety issues and discuss how these may be dealt with • discuss how the data collected will be used.

6.4 Implementation and Measurements

Students will be given partial details of how an experiment was carried out.
Results may be included.

Candidates will be assessed on their ability to:

Implementation and measurements	• comment on how the experiment could have been improved, possibly by using additional apparatus (e.g. to reduce errors) – examples may include using set squares to measure the diameter of a cylinder and using a marker for timing oscillations • comment on the number of readings taken • comment on the range of measurements taken • comment on significant figures – students may be required to identify and/or round up any incorrect figures in a table of results • identify and/or amend units that are incorrect • identify and check a reading that is inconsistent with other readings, e.g. a point that is not on the line of a graph.

6.5 Analysis

Students may be given a set of experimental results to analyse.

Candidates will be assessed on their ability to:

Analyse data	• perform calculations, using the correct number of significant figures • plot results on a graph using an appropriate scale and units – the graph could be logarithmic in nature • use the correct units throughout • comment on the trend/pattern obtained • determine the relationship between two variables or determine a constant with the aid of the graph, e.g. by determining the gradient using a large triangle • use the terms precision, accuracy and sensitivity appropriately • suggest realistic modifications to reduce errors • suggest realistic modifications to improve the experiment • discuss uncertainties qualitatively and quantitatively • compound percentage uncertainties correctly • determine the percentage uncertainty in measurements for a single reading using **half** the resolution of the instrument **and** from multiple readings using the **half** range.

Assessment information

Assessment requirements

The Pearson Edexcel International Advanced Subsidiary in Physics consists of three externally examined units.

The Pearson Edexcel International Advanced Level in Physics consists of six externally examined units.

Candidates must complete all assessments.

Please see the *Assessment availability and first award* section for information on from when the assessment for each unit will be available.

Unit	**IAS or IA2**	**Assessment information**	**Number of raw marks allocated in the unit**
Unit 1: Mechanics and Materials	IAS	Externally assessed Written examination: 1 hour and 30 minutes Availability: January, June and October First assessment: January 2019	80 marks
Unit 2: Waves and Electricity	IAS	Externally assessed Written examination: 1 hour and 30 minutes Availability: January, June and October First assessment: June 2019	80 marks
Unit 3: Practical Skills in Physics I	IAS	Externally assessed Written examination: 1 hour and 20 minutes Availability: January, June and October First assessment: June 2019	50 marks
Unit 4: Further Mechanics, Fields and Particles	IA2	Externally assessed Written examination: 1 hour and 45 minutes Availability: January, June and October First assessment: January 2020	90 marks

Unit	IAS or IA2	Assessment information	Number of raw marks allocated in the unit
Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology	IA2	Externally assessed Written examination: 1 hour and 45 minutes Availability: January, June and October First assessment: June 2020	90 marks
Unit 6: Practical Skills in Physics II	IA2	Externally assessed Written examination: 1 hour and 20 minutes Availability: January, June and October First assessment: June 2020	50 marks

Sample assessment materials

Sample papers and mark schemes can be found in the *Pearson Edexcel International Advanced Subsidiary/Advanced Level in Physics Sample Assessment Materials (SAMs)* document.

A full list of command words that will be used in the assessment across the IAS/IAL Science qualifications can be found in *Appendix 9: Taxonomy*.

Assessment objectives and weightings

		% in IAS	% in IA2	% in IAL
AO1	Demonstrate knowledge and understanding of science.	34–36	29–31	32–34
AO2	(a) Application of knowledge and understanding of science in familiar and unfamiliar contexts.	34–36	33–36	34–36
	(b) Analysis and evaluation of scientific information to make judgements and reach conclusions.	9–11	14–16	11-14
AO3	Experimental skills in science, including analysis and evaluation of data and methods.	20	20	20

Relationship of assessment objectives to units for the International Advanced Subsidiary qualification

Unit number	Assessment objective (%)			
	AO1	AO2(a)	AO2(b)	AO3
Unit 1	17–18	17–18	4.5–5.5	0.0
Unit 2	17–18	17–18	4.5–5.5	0.0
Unit 3	0.0	0.0	0.0	20
Total for International Advanced Subsidiary	34–36	34–36	9–11	20

Relationship of assessment objectives to units for the International Advanced Level qualification

Unit number	Assessment objective (%)			
	AO1	AO2(a)	AO2(b)	AO3
Unit 1	8.5–9.0	8.5–9.0	2.25–2.75	0
Unit 2	8.5–9.0	8.5–9.0	2.25–2.75	0
Unit 3	0	0	0	10
Unit 4	7.3–7.8	8.4–8.9	3.6–4.0	0
Unit 5	7.3–7.8	8.4–8.9	3.6–4.0	0
Unit 6	0	0	0	10
Total for International Advanced Level	32–34	34-36	11-14	20

Assessment availability and first award

Unit	January 2019	June 2019	October 2019	January 2020	June 2020
1	✓	✓	✓	✓	✓
2	×	✓	✓	✓	✓
3	×	✓	✓	✓	✓
4	×	×	×	✓	✓
5	×	×	×	×	✓
6	×	×	×	×	✓
IAS award	×	✓	✓	✓	✓
IAL award	×	×	×	×	✓

From June 2020, **all six units will be assessed** in January, June and October for the lifetime of the qualifications.

From June 2020, **IAL and IAS will both be awarded** in January, June and October for the lifetime of the qualifications.

Administration and general information

Entries, resitting of units

Entries

Details of how to enter students for the examinations for these qualifications can be found in our *International Information Manual*. A copy is made available to all examinations officers and is available on our website, qualifications.pearson.com

Resitting of units

Candidates can resit any unit irrespective of whether the qualification is to be cashed in. If a candidate resits a unit more than once, only the better of the two most recent attempts of that unit will be available for aggregation to a qualification grade.

Access arrangements, reasonable adjustments, special consideration and malpractice

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

We are committed to making sure that:

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

Language of assessment

Assessment of these qualifications will be available in English only. All student work must be in English.

We recommend that students are able to read and write in English at Level B2 of the Common European Framework of Reference for Languages.

Access arrangements

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

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

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

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

Reasonable adjustments

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

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

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

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

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

Special consideration

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

Further information

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

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

Candidate malpractice

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

Candidate malpractice in examinations **must** be reported to Pearson using a *JCQ Form M1* (available at www.jcq.org.uk/exams-office/malpractice). The form should be emailed to candidatemalpractice@pearson.com. Please provide as much information and supporting documentation as possible. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report malpractice constitutes staff or centre malpractice.

Staff/centre malpractice

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

All cases of suspected staff malpractice and maladministration **must** be reported immediately, before any investigation is undertaken by the centre, to Pearson on a *JCQ Form M2(a)* (available at www.jcq.org.uk/exams-office/malpractice).

The form, supporting documentation and as much information as possible should be emailed to pqsmalpractice@pearson.com. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report malpractice itself constitutes malpractice.

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

Awarding and reporting

The Pearson Edexcel International Advanced Subsidiary in Physics will be graded on a five-grade scale from A to E. The Pearson Edexcel International Advanced Level in Physics will be graded on a six-point scale A* to E. Individual unit results will be reported. Only Units 1, 2 and 3 will contribute to the International Advanced Subsidiary grade. All six units will contribute to the International Advanced Level grade.

The first certification opportunity for the Pearson Edexcel International Advanced Subsidiary in Physics will be in August 2019. The first certification opportunity for the Pearson Edexcel International Advanced Level in Physics will be in August 2020. A pass in an International Advanced Subsidiary subject is indicated by one of the five grades A, B, C, D, E, of which grade A is the highest and grade E the lowest. A pass in an International Advanced Level subject is indicated by one of the six grades A*, A, B, C, D, E, of which grade A* is the highest and grade E the lowest. Candidates whose level of achievement is below the minimum judged by Pearson to be of sufficient standard to be recorded on a certificate will receive an unclassified U result.

Unit results

Candidates will receive a uniform mark between 0 and the maximum uniform mark for each unit.

The uniform marks at each grade threshold for each unit are:

Units 1, 2, 4 and 5

Unit grade	Maximum uniform mark	A	B	C	D	E
	120	**96**	**84**	**72**	**60**	**48**

Units 3 and 6

Unit grade	Maximum uniform mark	A	B	C	D	E
	60	**48**	**42**	**36**	**30**	**24**

Qualification results

The minimum uniform marks required for each grade:

International Advanced Subsidiary (cash-in code: XPH11)

Qualification grade	Maximum uniform mark	A	B	C	D	E
	300	**240**	**210**	**180**	**150**	**120**

Candidates with a uniform mark in the range 0–119 will be Unclassified (U).

International Advanced Level (cash-in code: YPH11)

Qualification grade	Maximum uniform mark	A	B	C	D	E
	600	**480**	**420**	**360**	**300**	**240**

Candidates with a uniform mark in the range 0–239 will be Unclassified (U).

To be awarded an A*, Candidates will need to achieve an A for the International Advanced Level qualification (at least 480 uniform marks) **and** at least 90 percent of the total uniform marks available across the IA2 units combined (at least 270 uniform marks).

Student recruitment and progression

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

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

Prior learning and other requirements

Students who would benefit most from studying these qualifications are likely to have a Level 2 qualification in this subject such as a GCSE in Physics and also a GCSE in mathematics (or equivalent).

Progression

Students can progress from these qualifications to:

- a range of different, relevant academic or vocational higher education qualifications, e.g. degrees in physics or related subjects including engineering and environmental science or equivalent qualifications such as BTEC Higher Nationals in Engineering
- employment
- further training.

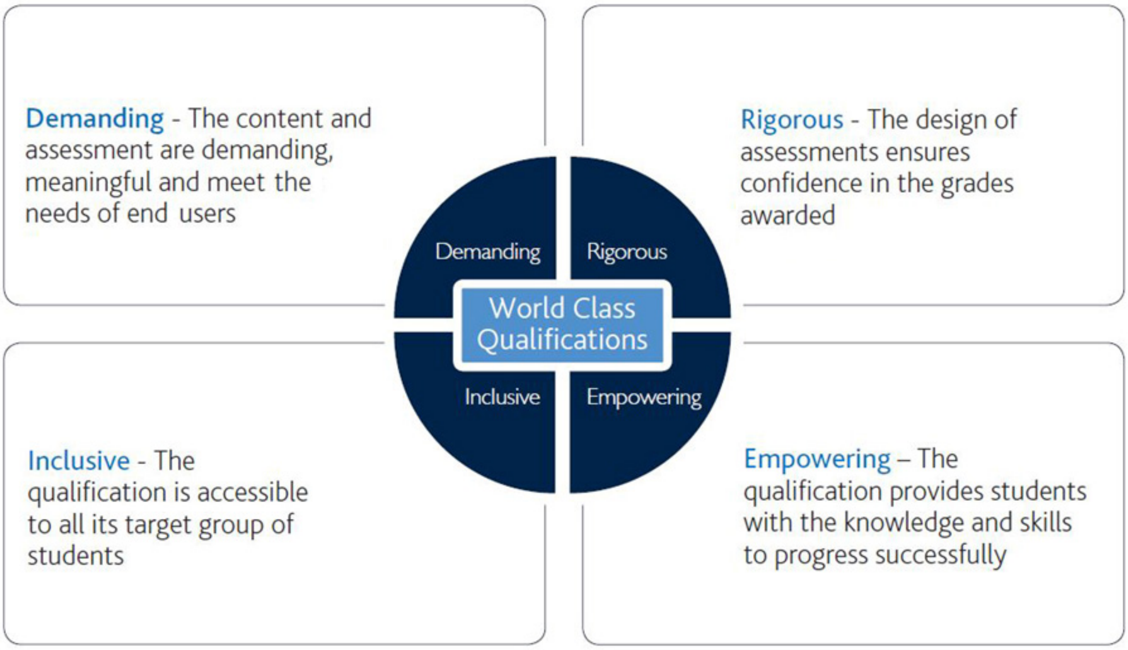
Appendices

Appendix 1: Codes

Type of code	Use of code	Code
Unit codes	Each unit is assigned a unit code. This unit code is used as an entry code to indicate that a student wishes to take the assessment for that unit. Centres will need to use the entry codes only when entering students for their examination.	Unit 1: WPH11/01 Unit 2: WPH12/01 Unit 3: WPH13/01 Unit 4: WPH14/01 Unit 5: WPH15/01 Unit 6: WPH16/01
Cash-in codes	The cash-in code is used as an entry code to aggregate the student's unit scores to obtain the overall grade for the qualification. Centres will need to use the entry codes only when entering students for their qualification.	International Advanced Subsidiary – XPH11 International Advanced Level – YPH11
Entry codes	The entry codes are used to: • enter a student for the assessment of a unit • aggregate the student's unit scores to obtain the overall grade for the qualification.	Please refer to the *Pearson Information Manual*, available on our website.

Appendix 2: Pearson World Class Qualification design principles

Pearson's World Class Qualification design principles mean that all Pearson Edexcel qualifications are developed to be **rigorous, demanding, inclusive and empowering**.



We work collaboratively to gain approval from an external panel of educational thought leaders and assessment experts from across the globe. This is to ensure that Pearson Edexcel qualifications are globally relevant, represent world-class best practice in qualification and assessment design, maintain a consistent standard and support learner progression in today's fast-changing world.

Pearson's Expert Panel for World-Class Qualifications is chaired by Sir Michael Barber, a leading authority on education systems and reform. He is joined by a wide range of key influencers with expertise in education and employability.

"I'm excited to be in a position to work with the global leaders in curriculum and assessment to take a fresh look at what young people need to know and be able to do in the 21st century, and to consider how we can give them the opportunity to access that sort of education." Sir Michael Barber.

Endorsement from Pearson's Expert Panel for World Class Qualifications for the International Advanced Subsidiary (IAS)/International Advanced Level (IAL) development process

May 2014

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

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

- extensive international comparability of subject content against the highest-performing jurisdictions in the world
- benchmarking assessments against UK and overseas providers to ensure that they are at the right level of demand
- establishing External Subject Advisory Groups, drawing on independent subject-specific expertise to challenge and validate our qualifications.

Importantly, we have worked to ensure that the content and learning is future oriented, and that the design has been guided by Pearson's Efficacy Framework. This is a structured, evidenced process which means that learner outcomes have been at the heart of this development throughout.

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

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

Professor Lee Sing Kong
Dean and Managing Director, National Institute of Education International, Singapore

Dr Peter Hill
Former Chief Executive ACARA

Bahram Bekhradnia
President, Higher Education Policy Institute

Professor Jonathan Osborne
Stanford University

Dame Sally Coates
Director of Academies (South), United Learning Trust

Professor Dr Ursula Renold
Federal Institute of Technology, Switzerland

Professor Bob Schwartz
Harvard Graduate School of Education

Professor Janice Kay
Provost, University of Exeter

Jane Beine
Head of Partner Development, John Lewis Partnership

Jason Holt
CEO, Holts Group

All titles correct as at May 2014.

Appendix 3: Transferable skills

The need for transferable skills

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

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

To support the design of our qualifications, the Pearson Research Team selected and evaluated seven global 21st-century skills frameworks. Following on from this process, we identified the National Research Council's (NRC) framework [2] as the most evidence-based and robust skills framework, and have used this as a basis for our adapted skills framework.

The framework includes cognitive, intrapersonal skills and interpersonal skills.

The skills have been interpreted for this specification to ensure they are appropriate for the subject. All of the skills listed are evident or accessible in the teaching, learning and/or assessment of the qualifications. Some skills are directly assessed. Pearson materials will support you in identifying these skills and developing these skills in students.

The table overleaf sets out the framework and gives an indication of the skills that can be found in physics and indicates the interpretation of the skill in this area. A full subject interpretation of each skill, with mapping to show opportunities for student development is given on the subject pages of our website: qualifications.pearson.com

[1] OECD – *Better Skills, Better Jobs, Better Lives* (OECD Publishing, 2012)
[2] Koenig J A, National Research Council – *Assessing 21st Century Skills: Summary of a Workshop* (National Academies Press, 2011)

Cognitive skills	Cognitive processes and strategies	• Critical thinking • Problem solving • Analysis • Reasoning/argumentation • Interpretation • Decision making • Adaptive learning • Executive function
	Creativity	• Creativity • Innovation
Intrapersonal skills	Intellectual openness	• Adaptability • Personal and social responsibility • Continuous learning • Intellectual interest and curiosity
	Work ethic/ conscientiousness	• Initiative • Self-direction • Responsibility • Perseverance • Productivity • Self-regulation (metacognition, forethought, reflection) • Ethics • Integrity
	Positive core self-evaluation	• Self-monitoring/self-evaluation/self-reinforcement
Interpersonal skills	Teamwork and collaboration	• Communication • Collaboration • Teamwork • Cooperation • Empathy/perspective taking • Negotiation
	Leadership	• Responsibility • Assertive communication • Self-presentation

Developing the ability to solve physics problems, including those of a mathematical nature.

Taking responsibility for carrying out practical work in a safe manner, following all safety requirements.

Presenting practical results in a standard scientific format; presenting problems to solutions in a clear and coherent fashion.

Appendix 4: Level 3 Extended Project qualification

What is the Extended Project?

The Extended Project is a stand-alone qualification that can be taken alongside International Advanced Level (IAL) qualifications. It supports the development of independent learning skills and helps to prepare students for their next step – whether that be higher education or employment. The qualification:

- is recognised by higher education institutions for the skills it develops
- is worth half of an International Advanced Level (IAL) qualification at grades A*–E
- carries UCAS points for university entry.

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

Students can choose from one of four approaches to produce:

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

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

The Extended Project has 120 guided learning hours (GLH) consisting of a 40-GLH taught element that includes teaching the technical skills (for example, research skills) and an 80-GLH guided element that includes mentoring students through the project work. The qualification is 100% internally assessed and externally moderated.

How to link the Extended Project with physics

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

Through the Extended Project, students will develop skills that support their study of physics, including:

- conducting, organising and using research
- independent reading in the subject area
- planning, project management and time management
- stating a proposal to be tested in investigations
- collecting, handling and interpreting data and evidence
- evaluating arguments and processes, including arguments in favour of alternative interpretations of data and evaluation of experimental methodology
- critical thinking.

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

Types of Extended Project related to physics

Students may produce a dissertation on any topic that can be researched and argued. A dissertation might involve an investigation such as:

- Are wind turbines a good solution to the energy crisis?
- Can we justify human space exploration?
- How did the Copernican paradigm shift affect subsequent developments in cosmology?

The dissertation uses secondary research sources to provide a reasoned defence or a point of view, with consideration of counterarguments.

An alternative might be an investigative project or field study involving the collection of data from primary research, for example:

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

Using the Extended Project to support breadth and depth

In the Extended Project, students are assessed on the quality of the work they produce and the skills they develop and demonstrate through completing this work. Students should demonstrate that they have extended themselves in some significant way beyond what they have been studying in physics. Students can demonstrate extension in one or more dimensions:

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

A wide range of information to support the delivery and assessment of the Extended Project, including the specification, teacher guidance for all aspects, an editable scheme of work and exemplars for all four approaches, can be found on our website.

Appendix 5: Glossary

Term	Definition
Assessments objectives	The requirements that students need to meet to succeed in the qualification. Each assessment objective has a unique focus, which is then targeted in examinations or coursework. Assessment objectives may be assessed individually or in combination.
External assessment	An examination that is held at the same time and place in a global region.
International Advanced Subsidiary	Abbreviated to IAS.
International Advanced Level	Abbreviated to IAL.
International A2 (IA2)	The additional content required for an IAL.
Linear	Linear qualifications have all assessments at the end of a course of study. The final qualification grade is worked out from the combined unit results.
Modular	Modular qualifications contain units of assessment. These units can be taken during the course of study. The final qualification grade is worked out from the combined unit results.
Non-examined assessment (NEA)	This is any assessment that is not sat in examination conditions at a fixed time and place. It includes coursework, oral examinations and practical examinations.
Raw marks	Raw marks are the actual marks that students achieve when taking an assessment. When calculating an overall grade, raw marks often need to be converted so that it is possible to see the proportionate achievement of a student across all units of study.
Uniform Mark Scale (UMS)	Candidate's actual marks (or raw marks) will be converted into a UMS mark so that it is possible to see the proportionate result of a candidate. Two units may each be worth 25 percent of a total qualification. The raw marks for each unit may differ, but the uniform mark will be the same.
Unit	A modular qualification will be divided into a number of units. Each unit will have its own assessment.

Appendix 6: Mathematical skills and exemplifications

In order to be able to develop their skills, knowledge and understanding in physics, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics relevant to the subject as indicated in the table on the following pages[3].

The assessment of quantitative skills will include at least 40 percent Level 2 or above mathematical skills. These skills will be applied in the context of physics.

All mathematical content will be assessed within the lifetime of the qualifications.

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

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

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

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

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

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

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

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

Appendix 7: Equations

Students need not memorise formulae for these qualifications.

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

Unit 1: Mechanics and Materials

Mechanics

Kinematic equations of motion

$$s = \frac{(u+v)t}{2}$$

$$v = u + at$$

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

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

Momentum

$$p = mv$$

Moment of force

$$= Fx$$

Materials

Density

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

Stokes' law

$$F = 6\pi \eta r v$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

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

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

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

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

Unit 2: Waves and Electricity

Waves and particle nature of light

Wave speed $v = f\lambda$

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

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

Refractive index $n_1 \sin \theta_1 = n_2 \sin \theta_2$

$$n = \frac{c}{v}$$

Critical angle $\sin C = \frac{1}{n}$

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

de Broglie wavelength $\lambda = \frac{h}{p}$

Photon model $E = hf$

Einstein's photoelectric equation $hf = \phi + \frac{1}{2} m v_{\max}^2$

Electricity

Current	$I = \frac{\Delta Q}{\Delta t}$
Potential difference	$V = \frac{W}{Q}$
Resistance	$R = \frac{V}{I}$
Electrical power, energy and efficiency	$P = VI$ $P = I^2R$ $P = \frac{V^2}{R}$ $W = VIt$
Resistivity	$R = \frac{\rho l}{A}$ $I = nqvA$

Unit 4: Further Mechanics, Fields and Particles

Further mechanics

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

Centripetal force

$$F = ma = \frac{mv^2}{r}$$

$$F = mr\omega^2$$

Electric and magnetic fields

Electric field

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

Coulomb's law

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

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

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

Electric potential

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

Capacitance

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

Energy stored in capacitor

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

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

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

Capacitor discharge

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

Resistor-capacitor discharge

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

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

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

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

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

In a magnetic field

$$F = Bqv \sin \theta$$

$$F = BIl \sin \theta$$

Faraday and Lenz's laws

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

Nuclear and particle physics

In a magnetic field

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

Mass-energy

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

Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology

Thermodynamics

Heating

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

$$\Delta E = L\Delta m$$

Ideal gas equation

$$pV = N\mathrm{k}T$$

Molecular kinetic theory

$$\tfrac{1}{2} m\langle c^2\rangle = \tfrac{3}{2}\mathrm{k}T$$

Nuclear decay

Mass-energy

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

Radioactive decay

$$A = \lambda N$$

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

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

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

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

Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos \omega t$$

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

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

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

$$\omega = 2\pi f$$

Simple harmonic oscillator

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

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

Astrophysics and cosmology

Gravitational field strength $g = F/m$

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field

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

Gravitational potential

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

Stefan-Boltzmann law	$L = \sigma T^4 A$
Wien's law	$\lambda_{max} T = 2.898 \times 10^{-3}$ m K
Intensity of radiation	$I = \frac{L}{4\pi d^2}$
Redshift of electromagnetic radiation	$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$
Cosmological expansion	$v = H_o d$

Appendix 8: Data sheet

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

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

Appendix 9: Taxonomy

The following table lists the command words used across the IAS/IAL Science qualifications in the external assessments.

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

Term	Definition
Draw	Produce a diagram either using a ruler or freehand.
Estimate	Give an approximate value for a physical quantity, or measurement, or uncertainty.
Evaluate	Review information, then bring it together to form a conclusion, drawing on evidence including strengths, weaknesses, alternative actions, relevant data or information. Come to a supported judgement of a subject's qualities and relation to its context.
Explain	An explanation requires a justification/exemplification of a point. The answer must contain some element of reasoning/justification, this can include mathematical explanations.
Give/State/Name	All of these command words are really synonyms. They generally all require a recall of one or more pieces of information.
Give a reason/reasons	When a statement has been made and the requirement is only to give the reasons why.
Identify	Usually requires some key information to be selected from a given stimulus/resource.
Justify	Give evidence to support (either the statement given in the question or an earlier answer).
Plot	Produce a graph by marking points accurately on a grid from data that is provided and then drawing a line of best fit through these points. A suitable scale and appropriately labelled axes must be included if these are not provided in the question.
Predict	Give an expected result or outcome.
Show that	Prove that a numerical figure is as stated in the question. The answer must be to at least one more significant figure than the numerical figure in the question.
Sketch	Produce a freehand drawing. For a graph this would need a line and labelled axes with important features indicated; the axes are not scaled.
State what is meant by	When the meaning of a term is expected but there are different ways of how these can be described.
Suggest	Use your knowledge and understanding in an unfamiliar context. May include material or ideas that have not been learnt directly from the specification.
Write	When the questions ask for an equation.

Appendix 10: Uncertainties and practical work

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

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

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

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

Glossary

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

Uncertainties in practice

What are uncertainties and why are they important?

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

Recording data

Results should be recorded to the resolution of the measuring instrument which means there will be a consistent number of decimal places for the readings for any one variable.
If data has to be processed, these values should be recorded to a consistent number of significant figures which is usually 3 as this is what we can usually confidently plot on a graph. If data goes over a power of ten we would not penalise a mixture of 3 and 4 sf.

Calculating uncertainties

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

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

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

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

a. Using the half range

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

Uncertainty in the mean diameter = (66 mm − 61 mm)/2 = 2.5 mm.

Therefore, the diameter of the metal canister is 64 mm ± 2.5 mm.

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

b. Using the reading furthest from the mean

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

Uncertainty in the mean diameter= 64 mm − 61mm = 3 mm.

Therefore, the diameter of the metal canister is 64 mm ± 3 mm.

c. Using the resolution of the instrument

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

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

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

Calculating percentage uncertainties

The percentage uncertainty in a measurement can be calculated using:

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

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

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

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

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

Compounding uncertainties

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

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

a. Raising a measurement to a power

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

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

Length of one side = 84 mm ± 0.5mm

Length of perpendicular side = 84 mm ± 0.5mm.

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

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

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

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

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

Percentage uncertainty in $A = 2 \times 0.6\% = 1.2\%$

Therefore the uncertainty in $A = 7100 \times 1.2\% = 85\ \text{mm}^2$

So $A = 7100\ \text{mm}^2 \pm 1.2\%$ or $A = 7100\ \text{mm}^2 \pm 85\ \text{mm}^2$

b. Multiplying or dividing measurements

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

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

The following readings are taken:

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

Mass of cube = 48.23 g ± 0.05 g

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

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

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

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

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

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

Therefore, the density of the material = $3490\ \text{kg m}^{-3} \pm 6\%$ or $3490\ \text{kg m}^{-3} \pm 210\ \text{kg m}^{-3}$

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

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

$A = \pi r^2 = \pi\ (33)^2 = 3.4 \times 10^3\ \text{mm}^2 \pm 2\%$

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

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

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

The volume V of the can is:

$V = 3.4 \times 103\ \text{mm}^2 \times 115\ \text{mm} = 3.9 \times 105\ \text{mm}^3 = 3.9 \times 10^{-4}\ \text{m}^3$

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

Percentage uncertainty in $L = (2/115) \times 100\% = 1.7$

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

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

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

c. Adding or subtracting measurements

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

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

Internal diameter = 101.4 mm ± 0.1 mm

External diameter = 102.8 mm ± 0.3 mm.

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

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

Using uncertainties in drawing conclusions

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

a. Calculating maximum and minimum values

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

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

Minimum value of g = 10.1 − (10.1 × 4%) = 9.7 m s^{-2}

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

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

b. Calculating a percentage difference

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

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

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

c. Observations from graphs

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

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

Appendix 11: Use of calculators

Candidates may use a calculator in assessments for these qualifications. Centres are responsible for making sure that calculators used by their students meet the requirements given in the table below.

Candidates must be familiar with the requirements before their assessments for these qualifications.

<table>
<tr>
<td>Calculators must be:
• of a size suitable for use on a desk
• battery- or solar-powered
• free of lids, cases and covers that contain printed instructions or formulae.</td>
<td rowspan="2">Calculators must not:
• be designed or adapted to offer any of these facilities:
○ language translators
○ symbolic algebraic manipulation
○ symbolic differentiation or integration
○ communication with other machines or the internet
• be borrowed from another candidate during an examination for any reason*
• have retrievable information stored in them. This includes:
○ databanks
○ dictionaries
○ mathematical formulae
○ text.</td>
</tr>
<tr>
<td>The candidate is responsible for the following:
• the calculator’s power supply
• the calculator’s working condition
• clearing anything stored in the calculator.</td>
</tr>
</table>

*An invigilator may give a candidate a calculator.

Further information can be found in the JCQ documents *Instructions for conducting examinations* and *Information for candidates - written exams,*, available at www.jcq.org.uk/exams-office.

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