Qualification Accredited

OCR
Oxford Cambridge and RSA

AS and A Level

Practical skills handbook

PHYSICS A
PHYSICS B
(ADVANCING PHYSICS)

H156/H556
H157/H557
For first teaching in 2015

OCR Advanced Subsidiary and Advanced GCE in Physics

Version 2.0

Contents

Version 2.0 – January 2024

Version 1.3 (May 2018)

One change of note made between Version 1.2 and Version 1.3:

1. Guidance on Appendix 3: Measurements - Uncertainties

Version 1.2

One change of note made between Version 1.1 and Version 1.2:

1. Guidance on arrangements of visits and standardisation.

Version 2.0 (January 2024)

Changes to wording to improve accessibility and clarity. Minor changes to the guidance for practical skills 1.2.1 (d), (e) and (f) to better support teacher assessment.

1 Introduction

During their study of Physics, students are expected to acquire experience of planning, implementation, use of apparatus and techniques, analysis and evaluation. These skills will be indirectly assessed in the written examinations at both AS and A Level. In addition, certain planning and implementation skills will be directly assessed at A Level only, through the Practical Endorsement.

This Handbook offers guidance on the skills required for both assessments, clarifies the arrangements for the Practical Endorsement, and gives suggestions towards planning a practical scheme of work that will cover all requirements.

The specification is the document on which assessment is based and this Handbook is intended to elaborate on the content of the specification to clarify how practical skills are assessed and what practical experience is necessary to support an assessment. The Practical Skills Handbook should therefore be read in conjunction with the specification.

How to use this handbook

Sections 2–4 of this handbook describe the assessment of practical skills in the AS and A Level qualifications. These sections elaborate on the information provided in the specification. Teachers are particularly advised to carefully read **Section 4**, which sets out the requirements for the Practical Endorsement – the direct assessment of practical skills in the A Level qualifications.

Section 5 provides guidance on planning the practical scheme of work, bringing together the various aspects that should be taken into account. The guidance in this section is intended to be supportive rather than prescriptive.

Section 6 gives some further guidance on the practical skills set out in specification Section 1.2.1, which are covered in the Practical Endorsement. This section is intended to support centres in planning how they will develop these skills.

The **Appendices** provide reference information on various topics:

- **Appendices 1 and 2** provide information on health and safety and apparatus requirements, and may be useful to share with technicians.
- **Appendices 3–6** give additional information on skills related to recording and presenting experimental data, covering measurements, units, graphs and referencing respectively. This content could be shared with students to help them develop an appropriate level of skill.
- **Appendix 7** lists a number of useful resources, including additional resources and support provided by OCR.

2 Overview of practical skills requirements

Summary of the assessment model

The practical skills assessment model consists of a theoretical and a practical component.

- The 'theoretical' component is an ***indirect*** assessment of practical skills through the written examination at the end of the course.
- The 'practical' component is a ***direct*** assessment of practical skills displayed by students as they are performing practical work. This is assessed by the teacher across the whole of the course.

The indirect, written assessment is a component of both AS and A Level Physics. The direct assessment, known as the Practical Endorsement, is a component of A Level Physics only.

The skills required for the practical skills assessments are set out in Module 1. Development of practical skills in physics. Module 1 is divided into two sections:

- ***Section 1.1*** of the specification covers skills that are assessed indirectly in a written examination. These skills may be assessed in any of the written papers that constitute the written assessment, at both AS and A Level.
  Assessment of practical skills forms a minimum of 15% of the written assessment at both AS and A Level.
- ***Section 1.2*** of the specification covers skills that are assessed directly through the Practical Endorsement. Student performance is teacher-assessed against the Common Practical Assessment Criteria (CPAC).

The Practical Endorsement is a component of the assessment at A Level only. There is no direct assessment of practical skills at AS Level.
Performance in the Practical Endorsement is reported separately to the performance in the A Level as measured through the externally assessed components.

Summary of the practical skills required

Skills assessed in the written examinations

The skills assessed in the written examination cover the following areas:

- Planning
- Implementing
- Analysis
- Evaluation

Questions assessing these practical skills will be embedded in contexts relating to the content of the specification.

Skills assessed through the Practical Endorsement

The skills assessed through the Practical Endorsement cover the areas of Planning and Implementing, specifically the following:

- Independent thinking
- Use and application of scientific methods and practices
- Research and referencing
- Instruments and equipment

Students must exemplify their skill in these areas through use of the apparatus and techniques listed in the specification, Section 1.2.2.

Centres can assess a wider range of practical activities for the Practical Endorsement, which may include our suggested practical activities, centre developed practicals or practicals from other publishers as long as these are appropriately mapped to CPAC.

AS Level students and the Practical Endorsement

There is no direct assessment of practical skills within the AS Level qualification. However, AS Level students will benefit from completing the type of practical activities recommended within the Practical Endorsement, as well as others, for the following reasons:

- completing practical activities will help to develop the practical skills that are assessed in the written examination
- completing practical activities will support understanding of the content of the specification
- students who decide to continue to take the A Level qualification after completing AS Level will be able to use their performance on Practical Endorsement activities completed in their first year towards the Practical Endorsement, as long as appropriate records have been kept.

3 Practical skills assessed in a written examination

Planning

Specification Section 1.1.1.

Learners should be able to demonstrate and apply their knowledge and understanding of:

- experimental design, including to solve problems set in a practical context
- identification of variables that must be controlled, where appropriate
- evaluation that an experimental method is appropriate to meet the expected outcomes.

Experimental design should include selection of suitable apparatus, equipment and techniques for the proposed experiment.

Students will benefit from having been given the opportunity to design simple experiments, and receiving feedback on their plans. Additionally, they should routinely be asked to consider why experiments are performed in the way they are, and how the experimental set-up contributes to being able to achieve the expected outcome. Students could be asked what might be the effect of changing aspects of the method.

Implementing

Specification Section 1.1.2.

Learners should be able to demonstrate and apply their knowledge and understanding of:

- how to use a wide range of practical apparatus and techniques correctly
- appropriate units for measurements
- presenting observations and data in an appropriate format.

The practical apparatus and techniques that may be assessed are those outlined in the specification statements related to practical techniques and procedures and, for A Level only, those covered in the Practical Endorsement

Students will be expected to understand the units used for measurements taken using common laboratory apparatus. See Appendix 4 for units commonly used in practical work in physics.

Appropriate presentation of data includes use of correct units and correct number of decimal places for quantitative data. This skill also includes appropriate use of tables and graphs for presentation of data.

Further information on recording measurements and the use of graphs is given in Appendices 3 and 5, respectively.

Analysis

Specification Section 1.1.3.

Learners should be able to demonstrate and apply their knowledge and understanding of:

- processing, analysing and interpreting qualitative and quantitative experimental results
- use of appropriate mathematical skills for analysis of quantitative data
- appropriate use of significant figures
- plotting and interpreting suitable graphs from experimental results, including:

  (i) selection and labelling of axes with appropriate scales, quantities and units

  (ii) measurement of gradients and intercepts.

Students will benefit from having practised these skills in a range of practical contexts. Many of the skills and techniques that form part of the Practical Endorsement will also be suitable for practising these skills.

Appendix 3 gives further information about the use of significant figures. Appendix 5 gives further information about the plotting of graphs. See also the Mathematical Skills Handbook for further guidance on the mathematical skills required in analysing experimental results, and in other areas of quantitative physics.

Evaluation

Specification Section 1.1.4.

Learners should be able to demonstrate and apply their knowledge and understanding of:

- how to evaluate results and draw conclusions
- the identification of anomalies in experimental measurements
- the limitations in experimental procedures
- precision and accuracy of measurements and data, including margins of error, percentage errors and uncertainties in apparatus
- refining experimental design by suggestion of improvements to the procedures and apparatus.

Students will benefit from having practised these skills in a range of practical contexts. As a matter of course, students should be encouraged to think carefully about the procedure they are performing and how it relates to the content of the specification; this will better place them to draw appropriate conclusions, identify anomalous and unexpected results, and identify limitations in procedures. Many activities included in the Practical Endorsement, as well as others, can be extended to allow students to consider errors and uncertainties, and suggest improvements to procedures.

Appendix 3 provides further information on precision, accuracy and errors, as well as identifying anomalous results.

4 Practical skills assessed in the Practical Endorsement

Introduction to the OCR Practical Endorsement

In order to pass the Practical Endorsement, students must demonstrate by the end of the two-year A Level course that they consistently and routinely exhibit the competencies described in the Common Practical Assessment Criteria (CPAC), listed in Section 5 of the specification. These competencies must be developed through a practical programme that encompasses the skills, apparatus and techniques listed in section 1.2 of the specification and must comprise a minimum of 12 practical activities.

In our specifications, 12 Practical Activity Groups (PAGs) are presented, which provide opportunities for demonstrating competency in all required apparatus and techniques. Additionally, all of the required skills can be developed through the PAGs. Some of the required skills are explicitly included in the requirements for individual practical activities, while others can be developed across the full range of activities.

The PAGs have been designed so that activities can be chosen that directly support the specification content. PAG1–5 support concepts that are likely to be taught in the first year of A Level, while PAG6–9 support concepts from the second year of A Level. PAG10 and PAG11 are less scaffolded activities, designed for development of the investigative skills covered in Module 1.2.1, and can be used to bring together knowledge from across the course. Finally, PAG12 allows students to demonstrate research skills and apply investigative approaches and may link in with any content from the course or beyond.

Planning activities to cover the Endorsement requirements

The Practical Activity Groups

Table 1 on the next page lists the 12 Practical Activity Groups (PAGs) with the minimum of skills and use of apparatus and techniques to be covered in each. We have designed the groups to include the types of activities that will support the requirements of the Practical Endorsement, as well as the assessment of practical skills within the written examinations.

You can use Table 1 to construct a practical scheme of work that covers all requirements. Centres are not required to stick rigidly to this table, as long as overall all the requirements are covered. For example, the skills included in PAG12 could be covered as part of an activity described for another PAG, rather than as a separate activity. That is fine, as long as at least 12 activities are completed overall.

Centres are not required to cover the skills and techniques for each PAG in a single activity. Some PAGs cover a range of skills, and centres may prefer to split these out. For example, PAG5 could be covered through a series of stand-alone activities, focusing on light waves, water waves or microwaves as stand-alone practicals. Risk assessments could be completed for any or all of these.

The Common Practical Assessment Criteria (CPAC) can be applied to student performance across all practical work performed throughout the A Level course. It is not the intention that assessment of the Practical Endorsement should only be based on performance in 12 activities, one from each PAG. For example, if you run multiple activities involving the construction of electric circuits, you can take into account students' performance across all these activities, not just their performance in an activity selected explicitly to cover PAG3.

Table 1 Practical requirements for the OCR Physics Practical Endorsement

Practical activity group (PAG)	Techniques/skills covered (minimum)
1 Investigating motion	• Use of appropriate analogue apparatus to measure distance, angles[1], mass[2] and to interpolate between scale markings[3] • Use of a stopwatch or light gates for timing • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4] • Use of methods to increase accuracy of measurements, such as set square or plumb line
2 Investigating properties of materials	• Use of calipers and micrometers for small distances, using digital or vernier scales[5] • Use of appropriate analogue apparatus to measure length[6] and to interpolate between scale markings[3] • Use of appropriate digital instruments to measure mass[2]
3 Investigating electrical properties	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9] and resistance[10] • Use calipers and micrometers for small distances, using digital or vernier scales[5] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components
4 Investigating electrical circuits	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9] and resistance[10] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important • Designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components
5 Investigating waves	• Use of appropriate analogue apparatus to measure length[6], angles[1] and to interpolate between scale markings[3] • Use of a signal generator and oscilloscope, including volts/division and time-base • Generating and measuring waves, using microphone and loudspeaker, ripple tank, vibration transducer or microwave/radio wave source • Use of a laser or light source to investigate characteristics of light, including interference and diffraction • Use of ICT such as computer modelling
6 Investigating quantum effects	• Use of appropriate digital instruments, including multimeters[7], to measure current[8] and voltage[9] • Correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important • Use of a laser or light source to investigate characteristics of light, including interference and diffraction • Use of methods to increase accuracy of measurements
7 Investigating ionising radiation	• Safe use of ionising radiation, including detectors • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data or use of software to process data[4]
8 Investigating gases	• Use of appropriate analogue apparatus to measure pressure, volume, temperature and to interpolate between scale markings[3]

Practical activity group (PAG)	Techniques/skills covered (minimum)
9 Investigating capacitors	• Use of appropriate digital instruments, including multimeters[7], to measure current[8], voltage[9] and resistance[10] • Use of appropriate digital instruments to measure time • Designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data[4]
10 Investigating simple harmonic motion	• Use of appropriate digital instruments to measure time • Use of appropriate analogue apparatus to measure distance and to interpolate between scale markings[3] • Use of methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiduciary marker, set square or plumb line • Use of ICT such as computer modelling, or data logger with a variety of sensors to collect data or use of software to process data[4]
11 Investigation	• Apply investigative approaches and methods to practical work
12 Research skills	• Use online and offline research skills • Correctly cite sources of information

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

Table 1 refers mainly to learning outcomes in Section 1.2 of the specification. In a few instances, references are included to the Common Practical Assessment Criteria (CPAC), to ensure coverage of criteria that are not explicitly stated in the learning outcomes.

Some of the learning outcomes in Section 1.2 are generic and they could be covered in many different activities.

The learning outcome ‘designing, constructing and checking circuits using DC power supplies, cells and a range of electronic components’, 1.2.2(g), needs to be covered across the selection of activities.

It is expected that there will be ample opportunities to develop and demonstrate the following skills across the whole practical course, regardless of the exact selection of activities:

- safely and correctly use a range of practical equipment and materials, 1.2.1(b)
- follow written instructions, 1.2.1(c)
- make and record observations/measurements, 1.2.1(d)
- keep appropriate records of experimental activities, 1.2.1(e)
- present information and data in a scientific way, 1.2.1(f)
- use appropriate tools to process data, carry out research and report findings, 1.2.1(g)
- use a wide range of experimental and practical instruments, equipment and techniques, 1.2.1(j).

Practical Activity Support Service

We do not require specific activities to be completed for the Practical Endorsement. Centres may select activities of their own, or provided by third parties, and map these against the requirements.

If you have any queries regarding selection of activities for the Practical Endorsement please contact us by email: science@ocr.org.uk.

Our activities

We have produced three example activities for each PAG, comprising student sheets and teacher/technician guidance. You may use them directly, adapt them to your requirements, or merely use them as reference for the types of activity that would satisfy the criteria for each PAG and the Endorsement as a whole.

The example activities are available on Teach Cambridge.

Table 2 lists the activity titles of the OCR suggested activities for A Level Physics. Our Practical Activity Support Guide provides more detailed guidance on these suggested activities and how you may adapt them.

Table 2 Our PAG activities

PAG1	PAG7
1.1 Comparing methods of determining *g* 1.2 Investigating terminal velocity 1.3 Investigating the effect of initial speed on stopping distance	7.1 Observing the random nature of radioactive decay 7.2 Investigate the absorption of alpha, beta & gamma by differing materials 7.3 Determine half-life (using an ionisation chamber)
PAG2	**PAG8**
2.1 Determining the Young Modulus for a metal 2.2 Force/extension characteristics for arrangements of springs 2.3 Investigating a property of plastic	8.1 Estimate a value for absolute zero from gas pressure and volume 8.2 Investigating the relationship between pressure and volume 8.3 Estimating the work done by a gas as its temperature increases
PAG3	**PAG9**
3.1 Determining the resistivity of a metal 3.2 Investigating electrical characteristics 3.3 Determining the internal resistance and maximum power available from a cell	9.1 Investigating the charging and discharging of capacitors 9.2 Investigating capacitors in series and parallel 9.3 Investigating the factors affecting the capacitance of a capacitor
PAG4	**PAG10**
4.1 Investigating resistance 4.2 Investigating circuits with more than one source of e.m.f. 4.3 Investigating potential divider circuits including a non-ohmic device	10.1 Investigate the factors affecting simple harmonic motion 10.2 Observing forced and damped oscillations 10.3 Comparison of static and dynamic methods of determining spring stiffness
PAG5	**PAG11**
5.1 Determining the wavelength of light with a diffraction grating 5.2 Determining the speed of sound in air using a resonance tube 5.3 Determining frequency and amplitude of a wave using an oscilloscope	11.1 Investigating transformers 11.2 Determining the specific heat capacity of a material 11.3 Determining the magnetic field of a magnet
PAG6	**PAG12**
6.1 Determining the Planck constant 6.2 Experiments with light 6.3 Experiments with polarisation	12.1 Materials presentation 12.2 Research report 12.3 An appreciation of an aspect of How Science Works

Tracking achievement

You need to keep the following records:

1. Plans to cover all practical requirements, such as a scheme of work to show how sufficient practical activities will be carried out to meet the requirements of the CPAC, incorporating all the skills and techniques required over the course of the A Level.
2. A record of each practical activity that is carried out and the date it was done.
3. A record of the criteria assessed in each practical activity.
4. A record of student attendance.
5. A record of which students met which criteria and which did not.
6. Evidence of students' work associated with particular activities.
7. Any associated materials provided e.g. written instructions.

You are free to choose the method of evidencing students' work that best suits them. Possible suitable methods include the use of a lab book, a folder of relevant sheets or a collection of digital files.

Our PAG trackers

We have developed spreadsheets that can be used to track the progress of a class through the Practical Endorsement. These trackers and guides on using them can be found on Teach Cambridge.

You can use our trackers as evidence for items 2–5 of the list of record keeping requirements above. Therefore by using these trackers, along with a scheme of work, any student sheets used and the students' evidence, the internal monitoring of the Practical Endorsement should be very easy to administer.

Monitoring arrangements

Monitoring visits

Monitoring runs in two-year cycles, with large centres (more than 140 students in any science subject) receiving visits for each science subject in each cycle. Other centres receive a visit for a single science subject in each monitoring cycle.

The purpose of the monitoring process is to ensure that centres are planning and delivering appropriate practical work, and making and recording judgements on student competences to meet the required standards.

On the day of the visit the monitor will:

- observe a practical activity
- review the records kept by the centre and by students (see Tracking achievement above)
- talk with staff and students.

Following the visit, the monitor will complete a record of the visit, which will be copied to the centre. The record will state that the monitor is satisfied whether the centre is meeting the requirements for the Practical Endorsement. The report may additionally offer guidance on improvements that could be made by the centre.

Should a centre dispute the outcome of a monitoring visit, a repeat visit by an alternative monitor may be requested.

Arrangement of visits

Awarding Organisations (AOs) will use information from centre entries for A levels in biology, chemistry and physics in the previous summer examination series to jointly plan monitoring visits.

Centres will be monitored for a different science than that which was monitored in the previous monitoring cycle. The first contact with a centre will be from the AO with which the science to be monitored was previously entered. This first contact will be with the exams officer (or other nominated school contact) before arranging a mutually convenient time for the monitoring visit to take place with the lead teacher for that subject.

AOs publish cross-board messaging at the beginning of each two year monitoring cycle. The latest cross-board messaging can be found on Teach Cambridge.

Standardisation

Lead teachers must complete the free on-line training provided (available and accessible to all teachers at: https://practicalendorsement.ocr.org.uk) on the implementation of the Practical Endorsement. They should also ensure that all other teachers of that science within the centre are familiar with the requirements so that:

- all students are given an adequate opportunity to fulfil the requirements of the Practical Endorsement
- standards are applied appropriately across the range of students within the centre.

Assessing the Practical Endorsement

The Practical Endorsement is directly assessed by teachers. The assessment is certificated Pass or Not-classified.

To achieve a **Pass**, students will need to meet the expectations set out in the Common Practical Assessment Criteria (CPAC) (see Table 2 in the specification, Appendix 5) including demonstrating competence in all the skills, apparatus and techniques in sections 1.2.1 and 1.2.2 of each specification. Students can demonstrate these competencies in any practical activity undertaken throughout the course of study.

Students may work in groups, but must be able to demonstrate and record independent evidence of their competency. This must include evidence of independent application of investigative approaches and methods to practical work.

Teachers who award a Pass need to be confident that the student consistently and routinely exhibits the required competencies before completion of the A Level course.

Access arrangements

There are no formal access arrangements for the Practical Endorsement. The approach of reasonable adjustments for the Practical Endorsement is described in this JCQ document.

Centres may make reasonable adjustments to their planned practical activities to allow students with disabilities to participate in practical work. Where such adjustments allow these students to independently demonstrate the competencies and technical skills required, without giving these students an unfair assessment advantage, centres may award a Pass for the Practical Endorsement.

For example, students who are colour blind can use colour charts to help them identify colour changes. Alternatively, practical activities can be selected that involve changes that such students are able to observe without such assistance.

A student whose impairment restricts their ability to perform some or all of the required practical work independently cannot achieve a Pass in the Practical Endorsement. However, they can access all the marks within the written examinations, and will benefit from having been given the opportunity to experience all practical work, perhaps with the help of a practical assistant. Details of the application process can be found here in this JCQ document.

More information about possible reasonable adjustments is available in our blog.

5 Planning your practical scheme of work

In planning the practical scheme of work, centres need to ensure sufficient opportunities are provided to support students' development of understanding and skill in the following areas:

- practical skills assessed in the written examinations (identified in specification Section 1.1)
- practical techniques and procedures assessed in the written examinations (identified throughout the content modules of the specifications)
- practical skills assessed through the Practical Endorsement (identified in specification Section 1.2, for A Level only)
- conceptual understanding which can be supported through practical work.

This section presents an approach to planning a practical scheme of work that takes into account all of the above. The information in this section is presented for guidance only; there is no prescribed approach.

A possible approach to planning

1. Identify the learning outcomes within the specification that relate to knowledge and understanding of practical techniques and procedures.
2. Identify which of these learning outcomes relate to Practical Activity Groups, so that carrying out practical work in support of these learning outcomes will also meet certain requirements within the Practical Endorsement. For both GCE Physics specifications, PAGs 1–11 relate to activity types that will also directly support learning outcomes assessed in the written examinations.
3. Select practical activities that will adequately cover the requirements identified so far.
4. Consider how to incorporate coverage of PAG12. The research, citation and investigative skills covered in PAG12 may be developed in the context of any topic in the specification (or beyond). You may elect to:
    a. develop these skills in an area not already included in the PAGs
    b. use this type of activity to give additional support in an area of practical activity already covered
    c. run this type of activity as a 'mini-investigation', giving students some freedom of choice of topic.
5. Identify how the chosen practical activities can be used to support development of the practical skills assessed in the written examinations. Modify the choice of activities, or add activities, if more support is required.
6. Identify how the chosen practical activities can be used to support other learning outcomes within the specification. Again, if insufficient opportunities have been identified, consider modifying the choice of activities or adding additional activities.

Note that a much wider range of practical work can be carried out than is suggested by the learning outcomes specifically related to practical techniques and procedures.

The learning outcomes related to techniques and procedures form just one potential starting point for planning the practical scheme of work. It is equally possible to begin by considering the work you wish to carry out to support conceptual understanding, and then checking that other requirements have been covered. Alternatively, you could begin by planning sufficient work to cover the requirements of the Practical Endorsement.

6 Guidance on practical skills

Section 1.2.1 of the specification covers the general practical skills which student should develop and practice during their course.

This section provides guidance which teachers can use to assist how they teach the required skills, as well as things to look out for in assessing whether students are performing the skills competently. This section is not intended as a 'mark scheme', or statement of the minimum standard required for a pass in individual activities.

Practical skills (specification Section 1.2.1)

1.2.1(a) apply investigative approaches and methods to practical work

Students are expected to be able to think independently about solving problems in a practical context. This means that students should develop their own ideas about how to approach a task, before perhaps discussing them with other students and joining together as a group to put an agreed plan into effect.

Demonstrating investigative approaches could include:

- choosing the materials, or amounts of materials, to use
- choosing which variables to measure and which to control
- deciding what measurements or observations to make and when to make them
- choosing apparatus and devising a procedure that is safe and appropriate.

Applying investigative approaches should include completing tasks that do not include complete step by step instructions. However, activities may still be structured in some form. For example:

- providing a basic method, with students asked to modify this to measure the effect of changing a certain variable
- providing a limited range of equipment, with students asked to think about how they can use what they have been given to solve a practical problem
- providing a certain amount of information, allowing students to consider how to use familiar techniques or procedures to investigate and solve a problem.

1.2.1(b) safely and correctly use a range of practical equipment and materials

Students should be shown how to use practical equipment when it is first met, through a demonstration by the teacher or technician. Good quality videos of many techniques are available online which could be used to complement such a demonstration. Teacher demonstration should also include the safe disposal of materials at the end of the laboratory session.

Hazards, and the ways in which risks should be minimised, should be explicitly explained to students whenever equipment is used for the first time, and on subsequent occasions as required. Students should also be shown how to handle equipment and materials safely so they adopt a standard routine whenever they need to use these. Some pieces of equipment or procedures are associated with particular hazards and students should be clearly shown how they need to be handled to minimise the risk involved. In some cases, the hazards may be such that it is good practice for students perform the practical work under the direct supervision of the teacher.

Increasingly, students should be able to use common laboratory equipment safely with minimal prompting. They should be doing this routinely and consistently by the end of the course.

Students will be expected to be able to identify hazards and understand how to minimise risk. This skill can be developed by asking them to devise their own risk assessments. The risk assessment should identify the hazards associated with materials and techniques that students will be using, and describe the steps that they will take to minimise the risks involved. Teachers should always check risk assessments and make sure students are aware of any errors or omissions before they begin the practical activity.

Risk assessments have been included in the OCR Practical Endorsement structure as part of PAG7, as radioactive materials frequently offer a number of different types of hazard to consider. However, students could demonstrate this skill in the context of any type of activity. Performing a risk assessment also gives the opportunity to demonstrate research and citation skills.

More detail about the safe use of equipment and materials is given in Appendix 1: Health and safety.

1.2.1(c) follow written instructions

In many activities students will be asked to follow written instructions. It is helpful if they are first given the aims of the activity so they are clear what is expected of them and what they should expect to learn from the activity. An introduction is also a good idea so that students can fit what they are doing into a bigger picture.

It is quite common for students to be given too much information and be asked to do too many things at the same time. Research suggests that when many students follow complex instructions they are not able to think about the theoretical implications and explanations of their task at the same time. It is probably better to focus on these issues before and after the practical task itself. Providing students with instructions to look through before the practical session allows them to think about what is needed and to visualise what they will do in advance of the practical session.

1.2.1(d) make and record observations and measurements

Each student must individually make measurements for each of the activities and retain a contemporaneous record of these. Appropriate scientific vocabulary should be used when recording **qualitative data**.

Units and format of recording quantitative and qualitative data are not assessed under this skill.

Students need to be able to make measurements using a range of equipment. See Appendix 3 for measurements and Appendix 4 for Units, for more detail about how to record measurements appropriately.

Observations should be recorded using appropriate scientific vocabulary. Examples of ambiguous or incorrect language include:

- mentioning energy conversion, without specifying the type of energy (e.g. 'the ball increases in velocity when dropped due to the conversion of energy' instead of ('when the ball is dropped gravitational potential energy is converted to kinetic energy increasing the velocity of the ball as it drops').
- giving an example of a limitation without sufficient detail (e.g. 'the time wasn't measured very accurately' instead of 'using a stopwatch to measure the oscillation time of the pendulum introduced an error due to the reaction time of the experimenter'.
- giving an example of an improvement without sufficient detail (e.g. 'the accuracy can be improved by making a video' rather than 'by making a video of the swinging pendulum and analysing frame-by-frame, the error in determining the displacement *d* can be greatly reduced over trying to determine *d* while the pendulum is swinging'.

1.2.1(e) keep appropriate records of experimental activities

Each student should have a permanent record of each activity they have completed, and where appropriate with suitable tables and graphs and/or calculated results. These records should be made during the laboratory session and are the primary evidence of the outcomes of experiments. Some errors/inconsistencies in the presentation of data are acceptable.
Where experimental procedures have been provided they do not need to be written out again, but they should be kept as part of the record.

Where the activities are 'investigations' there should be a suitable description of the manner in which these were carried out and why - citing which variables were dependent and which independent, whether or not ranges were adjusted to produce suitable results and how.

There should be enough detail to interpret the results produced.

The record may also show how the student has processed raw data, perhaps by using graphs or calculations, and the conclusions they have drawn. In some cases students may also evaluate their practical activity by calculating errors and/or commenting on the limitations of experimental procedures. These skills are not assessed in the Practical Endorsement, but are valuable in understanding the purpose of a practical activity, and will be assessed in the written examinations.

Records may be kept in a laboratory notebook, in a loose-leaf file or electronically. Students should record measurements and observations during laboratory sessions immediately, but these could be transferred to the permanent record later; for example, if there is no means of entering data into an electronic record in the lab.

1.2.1(f) present information and data in a scientific way

Students should present information and data in ways that are appropriate for that information or data. In many cases this will involve the use of tables. These should include an explanatory title, clear headings for columns and relevant units for measurements (see Appendix 3: Measurement and Appendix 4: Units for further details).

Graphs should be of an appropriate type for the information or data involved. Further detail about drawing and using graphs is given in Appendix 5: Tables and Graphs.

Some information is best presented by using clear, well labelled diagrams or potentially using annotated photographs.

1.2.1(g) use appropriate software and tools to process data, carry out research and report findings

The most obvious tools and software used for processing data are calculators and spreadsheets. Spreadsheets provide a very effective way of processing data, particularly when the amount of data is large. They can be used to sort data, carry out calculations and generate graphs. Graphs drawn using spreadsheets should not be too small, should have a clear title and the axes should be clearly labelled. Where more than one graph is drawn using the same axes it should be clear what each graph refers to.

If records are kept electronically, students will routinely make use of a word processing package to report their findings. Short video clips can be used to show changes over time. Digital images, podcasts and PowerPoint presentations also provide creative ways in which students can personalise their individual record of practical activities.

Experiments with very short or very long timescales of data collection lend themselves to the use of a data logger. Examples are fast motions, the charging of a capacitor or calorimetry. Students need training in how to use both the hardware and associated software to collect data, particularly if choices need to be made about measurement scales or when a trigger is used to start data collection. In a report or in a lab book it is usually better to present collected data graphically rather than recording a large amount of raw data on paper.

1.2.1(h) use online and offline research skills including websites, textbooks and other printed scientific sources of information

Students should be given opportunities to use both online and offline research skills in the context of practical activities. A useful starting point might be finding reliable information to devise a risk assessment for an experiment. Safety data sheets, such as the CLEAPSS Student Safety Sheets (accessible without a login) are a good place to start. More detail about sources of information is given in Appendix 1: Health and safety.

In other situations students might consult websites, textbooks or scientific journals to clarify or suggest experimental techniques and/or to provide supporting background theory to practical activities.

1.2.1(i) correctly cite sources of information

Where a student records information that they have looked up they should provide an accurate reference so that readers can find the information. Examples of how to do this are given in Appendix 6: Referencing.

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

It is expected that students will carry out practical work throughout their course and will therefore use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification. The minimum of apparatus and techniques that each student must use is listed in specification Section 1.2.2. Suggested apparatus for use during the course is also provided in Appendix 2: Apparatus list.

Appendix 1: Health and safety

This appendix provides information on Health and Safety issues while carrying out practical experiments.

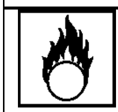
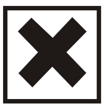
Before carrying out any experiment or demonstration based on this guidance, it is the responsibility of teachers to ensure that they have undertaken a risk assessment in accordance with their employer's requirements, making use of up-to-date information and taking account of their own particular circumstances. Any local rules or restrictions issued by the employer must always be followed.

Useful information can be found at www.cleapss.org.uk (available to CLEAPSS members only).

Hazard labelling systems

The CLP regulations were launched in 2010, and fully implemented across the EU in 2015. The 'CHIP' system is no longer in active use, but some older containers may still carry the CHIP symbols, and students may come across them in older reference works. It is important that students are taught to use both systems, particularly if centres are still using chemicals carrying CHIP hazard symbols. While in the physics classroom (dangerous) chemicals are not routinely used, it is important for both staff and students to be familiar with the hazard labels.

OCR recognises the CLP system as the default system in current use. OCR resources indicate hazards using the CLP system.

	**Oxidising**		**Toxic**	**CLP pictograms are also accompanied by a 'signal word' to indicate the severity of the hazard.**
	**Highly flammable**		**Indicates that the chemical could cause serious *long term* health effects.**	**'DANGER' for more severe; 'WARNING 'for less severe.**
	**Corrosive**		**Indicates less serious health hazards (e.g. skin irritants).**	
	**Oxidising**		**Toxic**	**'CHIP' system** **(being phased out)**
	**Highly Flammable**		**Harmful or Irritant**	
	**Corrosive**			

Non-Ionising Radiation

The light from lasers and high-power LEDs is classed as non-ionising radiation and the use of these light sources may cause significant risk of serious, irreversible eye or skin damage. In the UK, according to BS EN 60825-1:2007, there are 7 classes of lasers: 1, 1M, 2, 2M, 3R, 3B and 4. A class 1 laser poses the lowest risk, class 4 the highest. In the USA and other countries different standards are used, and these lasers are not recommended for use in the UK classroom.

Lasers should only be acquired from reputable suppliers and have all relevant warning labels and certifications. Laser pointers sold online may have a power greatly exceeding their labelling and may lack essential safety features and may be especially dangerous.

CLEAPSS publishes guidance on the use of lasers in the classroom on their website, https://science.cleapss.org.uk/resource-info/ps052-lasers-laser-devices-and-leds.aspx and strongly advises only Class 1 or 2 lasers are used in a classroom setting. Other classes including Class 1M and 2M present an unacceptable risk.

Ionising Radiation

If radioactive substances are to be used during practicals adequate protection for all students and staff is essential. Guidance is given by CLEAPSS

https://science.cleapss.org.uk/resource/l093-managing-ionising-radiations-and-radioactive-substances-in-schools-and-colleges.pdf

Electrical Safety

The use of electrical equipment poses risks of fatal injury if mishandled. Discussing the full regulations is beyond the scope of the current document. CLEAPSS publishes guidance on this important topic

https://science.cleapss.org.uk/resource-info/handbook-section-6-electrical-hazards.aspx

Risk assessments

In UK law, health and safety is the responsibility of the employer. Employees, i.e. teachers, lecturers and technicians, have a duty to cooperate with their employer on health and safety matters. Various regulations, but especially the COSHH Regulations 2002 and the Management of Health and Safety at Work Regulations 1999, require that before any activity involving a hazardous procedure or harmful micro-organisms is carried out, or hazardous chemicals are used or made, the employer must provide a risk assessment. A useful summary of the requirements for risk assessment in school or college science can be found at

http://www.ase.org.uk/resources/health-and-safety-resources

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

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

  Now out of print but sections are available at

  http://www.ase.org.uk/resources/health-and-safety-resources;

- *Topics in Safety*, 3rd edition, 2001, ASE ISBN 0 86357 316 9;
- *Safeguards in the School Laboratory*, 11th edition, 2006, ASE ISBN 978 0 86357 408 5;

- CLEAPSS *Hazcards*.*

  CLEAPSS are in the process of updating the *Hazcards*, the latest edition being the CLP Edition, 2014. At present, CLP Hazcards have only been published for some chemicals. For other chemicals, the CHIP Hazcard is referenced and should be consulted.

- CLEAPSS Laboratory Handbook*;
- *Hazardous Chemicals*, A Manual for Science Education, 1997, SSERC Limited ISBN 0 9531776 0 2.

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

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

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

*These, and other CLEAPSS publications, are on the CLEAPSS website. Note that CLEAPSS publications are only available to members. For more information about CLEAPSS - go to www.cleapss.org.uk. In Scotland, SSERC (www.sserc.org.uk) has a similar role to CLEAPSS.

Appendix 2: Apparatus list

This appendix lists the apparatus likely to be required in order to complete a practical scheme of work that covers all requirements of the qualification. Teachers and technicians should bear in mind that activities that would support the qualification may require additional apparatus not on this list. Resources provided by OCR detail the apparatus needed for individual activities.

It should be noted that centres are required to carry out a minimum of 12 practical activities over two years. OCR have provided 18 alternatives for the first year and a total of 36 alternatives for the full two years. This list of apparatus incorporates the requirements for all 36 activities.

Standard Equipment

- Beakers (including 1 litre beakers)
- Bench pulley
- Bosses
- Bunsen burner
- Calipers or vernier measurement system
- Clamps
- Conical flasks
- Fibre board mat
- G clamps
- Heatproof mat
- Kettle
- Magnet
- Masses, including 100g and 1kg
- Mass holder
- Material clamps
- Measuring cylinders
- Metal bars including aluminium, copper and steel or iron
- Metal blocks (suitable for determination of shc)
- Metre rules
- Micrometer screw gauge
- Rubber tubing
- Springs
- Stainless steel ruler
- Stands
- Steel ball bearings
- Tube or tall measuring cylinder
- Wooden block

Electronic Equipment

- Ammeter
- Data logging system
- Digital multimeter with capacitance range
- Electric heater (12V)
- Interrupt card
- Light-gates
- Loudspeaker
- Mass balance
- Oscilloscope
- Resistance decade box
- Stop clock

- Signal generator
- Variable power supply
- Voltmeter

Electronic Components

- Capacitors (470 μF and other suitable values)
- Constantan wire (28 swg)
- Crocodile clips
- Diode
- Lamps (1.25 to 2.5V torch bulbs)
- LDR
- Leads
- LEDs, a variety of different coloured light-emitting diodes
- Potentiometer
- Resistors
- Rheostat
- Switch
- Thermistor (NTC)
- Transformer coils with differing numbers of turns
- Transformer cores (laminated)

Optical Components

- Diffraction grating of known lines per mm
- Laser suitable for classroom use
- Lens stands
- Lenses with at least two differing focal lengths
- Microwave emitter and receiver
- Optical pins
- Plain white screen
- Polarising filters (can be lenses from 3D glasses or sunglasses)
- Polarising grid for microwaves
- Ray box or similar light source
- Semi-circular glass or plastic block
- Transparent rectangular block

Consumables

- Bun-cases
- Card or black paper
- D cell batteries and holders
- Drawing pins
- Elastic bands
- Ice
- Paper towels
- Photocopied sheets with protractor scale
- Plastic bags (various types)
- Plasticine
- String
- Viscous liquid

Radioactive materials

- Counter
- Geiger-Műller (GM) tube

- Materials to place between source and detector
- Protactinium generator
- Radioactive object (gas mantle in sealed bag)
- Radioactive sources

Gases

- Barometer
- Boyle's Law apparatus
- Capillary tube
- Mercury
- Mercury in glass thermometer
- Plastic syringe or gas syringe
- Plastic syringe or gas syringe with the outlet sealed or clamped

Capacitors

- Insulating materials
- Metal sheets or aluminium foil covered card
- Multimeter with capacitance range

Simple Harmonic Motion

- Pendulum bob
- Position encoder for data logger
- String
- Ultrasonic distance sensor for data logger
- Vibration generator

Student equipment

- Calculator
- Protractor
- Ruler
- Set square

PPE

- Safety goggles

Additional requirements

In order to fulfil the requirements of the skills set out in Section **1.2.1** of the specification, students will require access to the following.

- Data logging software
- Graph plotting and data analysis software (e.g. Microsoft Excel)
- Textbooks, websites and other sources of scientific information
- A means of recording practical activity undertaken towards the Practical Endorsement, for example a logbook, binder to collect loose sheets, or means to create and store digital files
- Chemical data or hazard sheets

Lab Books

Students can keep their records in any appropriate form including the use of a ring binder or other folder. Should your centre wish to purchase lab books there are educational suppliers who stock a wide variety of these.

Some publishers offer lab book resources which include practical activities and space for students to record results. Take care if using these resources as they are not endorsed and in some cases the level of scaffolding provided for the recording of results could prevent students from being able to independently demonstrate some 1.2.1 skills. You should check the mapping of these activities to the 1.2.1 and 1.2.2 practical skills as in some cases the publisher's mapping is not accurate.

Appendix 3: Measurements

This appendix provides background information on terms used in measurement, and conventions for recording and processing experimental measurements. This information relates to skills assessed both in the written examinations and in the Practical Endorsement, notably 1.1.2(c), 1.1.3(c), 1.1.4(b), 1.1.4(d), 1.2.1(d), 1.2.1(f). Further guidance on the language of measurement is also provided on Language of measurement in context resource available on Teach Cambridge.

Useful terms

Accuracy is a measure of the closeness of agreement between an individual test result and the true value. If a test result is **accurate**, it is in close agreement with the true value. An accepted reference value may be used as the true value, though in practice the true value is usually not known.

Anomaly (outlier) is a value in a set of results that is judged not to be part of the inherent variation.

Confidence is a qualitative judgement expressing the extent to which a conclusion is justified by the quality of the evidence.

Error (of measurement) is the difference between an individual measurement and the true value (or accepted reference value) of the quantity being measured.

Precision is the closeness of agreement between independent measurements obtained under the same conditions. It depends only on the distribution of random errors (*i.e.* the spread of measurements) and does not relate to the true value.

Repeatability is the precision obtained when measurement results are produced over a short timescale by one person (or the same group) using the same equipment in the same place.

Reproducibility is the precision obtained when measurement results are produced over a wider timescale by different people using equivalent equipment in different (but equivalent) places.

Resolution is the smallest change in the quantity being measured that can be detected by an instrument.

Uncertainty is an estimate attached to a measurement which characterises the range of values within which the true value is asserted to lie. This is normally expressed as a range of values such as 44.0 ± 0.4.

Validity can apply to an individual measurement or a whole investigation. A measurement is valid if it measures what it is supposed to be measuring. An investigative procedure is valid if it is suitable to answer the question being asked. Validity will be reduced, for example, if no negative control is included in an investigation into the efficacy of a therapeutic drug.

The ASE booklet *The Language of Measurement* (Campbell 2010) provides information on these and other terms along with examples of their use. In particular please note that **reliability** will no longer be used. As the authors of the booklet say:

> *"The word 'reliability' has posed particular difficulties because it has an everyday usage and had been used in school science to describe raw data, data patterns and conclusions, as well as information sources. On the strong advice of the UK metrology institutes, we avoid using the word 'reliability' because of its ambiguity. For data the terms 'repeatable' and 'reproducible' are clear and therefore better. For conclusions from an experiment, evaluative statements can mention 'confidence' in the quality of the evidence."*

Uncertainties

Whenever a measurement is made, there will always be some doubt about the result that has been obtained. An uncertainty in a measurement is an interval that indicates a range within which we are reasonably confident that the true value lies.

Uncertainties technically depend on a range of factors related to measurements, including both systematic and random errors. Determining uncertainties based on the spread of data obtained is not required within the context of AS and A Level Physics. Rather, an estimation of uncertainty is made based on the characteristics of the equipment used.

Uncertainties in apparatus and equipment

When using any apparatus, students should check whether the apparatus itself is marked with the uncertainty. This is, for example, generally the case in for volumetric glassware used to measure specific volumes of liquid, such as volumetric flasks and pipettes frequently used in A Level Chemistry. The degree of uncertainty in these cases depends on the class of apparatus.

For example, a 100 cm^3 measuring cylinder is graduated in divisions every 1 cm^3.

- A Class A measuring cylinder has an uncertainty of half a division or 0.5 cm^3 in each measurement
- A Class B measuring cylinder has an uncertainty of a whole division or 1 cm^3 in each measurement.

In the absence of information provided on the equipment, the following assumptions are made regarding the uncertainty in each measurement:

- When using apparatus with an analogue graduated scale, the uncertainty is assumed to be ± half the smallest graduation.

  For example a 30 cm rule has divisions of 1 mm and an uncertainty of half a division, or 0.5 mm. When measuring a distance the uncertainty has to be taken into account twice and it is overall 1 mm.

  An analogue meter with scale markings each 0.2 V has an uncertainty of 0.1 V.

- When using digital apparatus, the uncertainty is presumed to be ± the resolution of the apparatus in each measurement.

  For example, a two-decimal place balance has an uncertainty of ±0.01 g in each measurement and a voltmeter with three significant figures which has an uncertainty of ±0.1 V in the 0-20 V range will have an uncertainty of ±1 V in the 0-100 V range.

The basis of the assumption for electronic apparatus is that the electronic circuit is designed to avoid “hunting” which is the rapid cycling from one figure to another in the final digit. This is achieved by programming the equipment to go up to the next value at a level greater than 0.5, and to go to the lower value at a level below 0.5, this could be going up at 0.7 and down at 0.3. As we are not aware of that value we can only assume ±1 digit in the final digit.

Students should be able to calculate a percentage uncertainty for a measurement from the absolute uncertainty for the apparatus used. See worked examples on the next page.

Because of the variability in uncertainties associated with equipment, assessments will frequently state the absolute uncertainty in any measurement given to allow students to calculate the percentage uncertainty. If no information is given, the uncertainty in each reading is derived from the resolution of the apparatus used as explained above.

Measurement of time

Whilst a stopwatch measures time with a resolution of say 0.001 s, the operator reaction time is significantly longer, increasing the total uncertainty in the measurement, in which case a reasonable estimate for the uncertainty would be the reaction time of the operator.

A light gate measures time with the same resolution of 0.001 s, but has a significantly lower total uncertainty as it eliminates the reaction time of the operator.

Examples of uncertainties

Some examples are shown below. Note that the actual uncertainty on a particular item of equipment may differ from the values given below. An item of equipment may have different uncertainties for different range settings.

Ruler

- A ruler with marks every 1mm has an uncertainty of 1mm for a distance measurement
- A caliper has an uncertainty of 0.01 mm when used by a skilled operator

Voltmeter

- A voltmeter has an uncertainty of 0.1V in the 0-20V range
- The same voltmeter has an uncertainty of 1V in the 0-100V range

Time Measurement

- A stopwatch measures time with a resolution of 0.01s, however the operator reaction time is significantly longer, increasing the total uncertainty in the measurement
- A light gate measures time with the same resolution of 0.01s, but has a significantly lower total uncertainty as it eliminates the reaction time

Worked examples

The significance of the uncertainty in a measurement depends upon how large a quantity is being measured. It is useful to quantify this uncertainty as a percentage uncertainty

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{quantity measured}} \times 100\%$$

For example, a two-decimal place balance may have an uncertainty of 0.005 g.

For a mass measurement of 2.56 g

- percentage uncertainty = $\frac{0.005}{2.56} \times 100\%$ = 0.20%

For a mass measurement of 0.12 g, the percentage uncertainty is much greater

- percentage uncertainty = $\frac{0.005}{0.12} \times 100\%$ = 4.2%

Multiple measurements

Where quantities are measured by difference, there will be an uncertainty in each measurement, which must be combined to give the uncertainty in the final value. The principle of the following example can be applied to other quantities measured by difference.

The difference in length of a rod due to a change in temperature is to be found. The absolute uncertainties of both measurements are summed up to give the uncertainty in the change in length.

Using a rule to determine the elongation of a metal rod due to thermal expansion

Length when cold = 54.3 cm uncertainty = 0.1 cm

Length when hot = 55.2 cm uncertainty = 0.1 cm

Increase in length = 0.9 cm overall uncertainty = 2 × 0.1 cm

percentage uncertainty in the elongation = $\frac{2 \times 0.1}{0.9} \times 100\%$ = 22%

While there is a negligible percentage uncertainty in each length measurement, the overall percentage uncertainty in the elongation is much greater and care should be taken to ensure the measurement technique and apparatus are appropriate.

Note

We are aware that some textbooks available do not give a consistent message regarding the treatment of uncertainties. In OCR Physics A and B we will therefore allow both half the smallest division as the absolute uncertainty for a measuring instrument and the smallest division itself as the absolute uncertainty. This will ensure that we do not penalise students in any examination - since this ambiguity is not their fault.

The guidance on electronic instruments differs from guidance previously provided by OCR and other sources which state that the uncertainty for digital apparatus is half the resolution, e.g. ±0.005 g for a two-decimal place balance. The guidance here has been updated for consistency across the OCR suite of A level sciences. For assessment purposes, approaches correctly using either the resolution or half the resolution as the uncertainty will be considered acceptable.

Recording measurements

When using a digital measuring device (such as a modern top pan balance or ammeter),

- record *all* the digits shown (Note: when using a digital timer such as a stopwatch, do not record to more than two decimal places.)

When using a non-digital device (such as a ruler or a measurement cylinder),

- record all the figures that are known and, where appropriate, an additional estimated figure may be allowed

Reading a ruler

A ruler is graduated in divisions every 1 mm. A ruler is a non-digital device, so we record all figures that are known for certain. We can estimate a further figure.

Using the half-division rule, the estimation is 0.5 mm. The overall uncertainty in any distance measured always comes from two measurements, so the overall uncertainty = 2 × 0.5 mm = 1 mm.

In a distance measurement covering the entire 300 mm length of the ruler, the uncertainty is small

percentage uncertainty = $\frac{2 \times 0.5}{300.0} \times 100\%$ = 0.3%

For shorter distances, the percentage uncertainty becomes more significant. For measuring a distance of 25 mm:

percentage uncertainty = $\frac{2 \times 0.5}{25.0} \times 100\%$ = 4%

Mean values

When calculating the mean value of measurements, it is *acceptable* to increase the number of significant figures by 1.

Presentation of results

Table headings

It is expected that **all** table column (or row) headings will consist of a quantity **and** a unit.

The quantity may be represented by a symbol or written in words. There must be some kind of distinguishing notation between the quantity and the unit. Students should be encouraged to use solidus notation, but a variety of other notations are accepted. Quantities should be represented with a symbol in italics, while units are upright. For example:

T / °C   *T* (°C)   *T* in °C $\frac{T}{°\mathrm{C}}$ are all **acceptable** as column headings.

Students should avoid notations that do not distinguish between the quantity and the unit, such as

T cm T_{cm} just 'cm'

The logarithm of a quantity can only be taken if a quantity has no units. Therefore, the quantity is divided by an initial value or its unit before taking the logarithm. The resulting logarithm then has no units.

Consistency of presentation of raw data

All raw readings of a particular quantity should, where possible, be recorded to the same number of decimal places. These should be consistent with the apparatus used to make the measurement (see above).

Significant figures

How many significant figures should be used?

The result of a calculation that involves measured quantities cannot be more certain than the *least* certain of the information that is used. So the result should contain the same number of significant figures as the measurement that has the *smallest* number of significant figures.

A common mistake by students is to simply copy down the final answer from the display of a calculator. This often has far more significant figures than the measurements justify.

Rounding off

When rounding off a number that has more significant figures than are justified (as in the example above), if the last figure is between 5 and 9 inclusive round up; if it is between 0 and 4 inclusive round down.

For example, the number 3.5099 rounded to:

4 sig. figs. is 3.510   3 sig. figs. is 3.51   2 sig. figs. is 3.5   1 sig. fig. is 4

Notice that when rounding you only look at the one figure beyond the number of figures to which you are rounding, *i.e.* to round to three sig. fig. you only look at the fourth figure.

How do we know the number of significant figures?

When rounding 228.5 to 2 significant figures, an incorrect approach would be to round to 230.

When seen in isolation, it would be impossible to know whether the final zero in 230 is significant (and the value to 3 sig. figs.) or insignificant (and the value to 2 sig. figs.).

In such cases, standard form should be used and is unambiguous:

- 2.3×10^2 is to 2 sig. figs.
- 2.30×10^2 is to 3 sig. figs.

When to round off

It is important to be careful when rounding off in a calculation with two or more steps.

- Rounding off should be left until the very end of the calculation.
- Rounding off after each step, and using this rounded figure as the starting figure for the next step, is likely to make a difference to the final answer. This introduces a **rounding error**. ***Students often introduce rounding errors in multi-step calculations.***

Example

The resistance of a resistor is determined by measuring the potential difference and current. The voltmeter reads 12.0 V and the ammeter 1.3 mA.

The resistance can be found using $R=V/I$.

Using a calculator the resistance is then $12.0/(1.3 \times 10^{-3})=9.2307$ kΩ.

> *Since the least certain measurement (the current) is only to 2 significant figures, the answer should also be quoted to 2 significant figures.*

Therefore, the resistance to the correct number of significant figures is $R = 9.2$ kΩ

> *It should be noted however, that if this figure is to be used in subsequent calculations then the rounding off should **not** be applied until the final answer has been obtained.*

For example, the resistor is used in a circuit to determine the capacitance of a capacitor. The circuit was found to have a time constant $\tau = RC = 0.31$ s

Using the calculator value of 9.2307 k Ω

- $C = 3.3584 \times 10^{-5}$ F
- rounding to 2 sig. figs. gives $C = 3.36 \times 10^{-5}$ F

Using the rounded value of 9.2 kΩ to determine the capacitance

- $C = 3.3696 \times 10^{-5}$ F
- rounding to 2 sig. figs. gives $C = 3.37 \times 10^{-5}$ F and we have a ‘rounding error’.

Logarithms

Significant figures in logarithmic quantities often pose difficulties for students. Often it is not appreciated by students that the characteristic is a place value and is not ‘significant’ in relation to the precision of the data. The table below illustrates this. All values for *x* are given to three significant figures.

x	log(x)
2.53	0.403
25.3	1.403
253	2.403
2.53×10^6	6.403
2.52×10^6	6.401
2.54×10^6	6.405

Clearly the characteristic must be given, but it can be seen that changes to the last figure in the value of x will change the third decimal place in the value of log(*x*). Therefore it would be sensible to quote log(x) to three decimal places if the values of *x* are correct to three significant figures. The characteristic fulfils the same role as $\times\ 10^n$ in the standard notation, which is also not considered part of the number of significant figures.

Errors in procedure

The accuracy of a final result also depends on the procedure used. For example, in a calorimetry experiment, the measurement of a temperature change may be precise but there may be large heat losses to the surroundings which affect the accuracy of the overall result.

When determining the acceleration of free fall g by dropping objects, ignoring air resistance may significantly affect the accuracy. Compare dropping an inflated balloon and a stone of a similar shape and volume from the same height: air resistance will cause the balloon to fall much slower than the stone. The value for g found with the balloon will thus have a much lower accuracy than the one found using the stone.

A more trivial example is using the wrong scale on a measurement device, such as using inches instead of centimetres on a rule.

Anomalous readings

If a piece of data was produced due to a failure in the experimental procedure, or by human error, it would be justifiable to remove it before analysing the data. For example if a time lapse measurement is clearly different to the other readings taken for that particular data point it might be judged as being an outlier and should be ignored when the mean time is calculated.

However, data must never be discarded simply because it does not correspond with expectation.

Percentage Difference

Students may be asked to determine the difference between experimental values and accepted values. ‘Experimental values’ are those that are derived from measurement or calculation, whereas ‘accepted’ or ‘theoretical’ values are values that are accepted by the scientific community. The percentage difference between an experimental and accepted value is determined as follows:

$$\text{percentage difference} = \frac{\text{experimental value} - \text{accepted value}}{\text{accepted value}} \times 100\%$$

In many cases there will be no ‘accepted value’, especially since most experiments are performed to find out something ‘new’. However, it is considered good practice when developing a new experiment to first try to perform a measurement that does have an accepted value the result can be compared to. The scientist can then assess if their experiment is accurate.

References

The ASE booklet *The Language of Measurement* (ISBN 9780863574245) provides additional guidance on many of the matters discussed in this section.

Appendix 4: Units

Students are expected to use the following units for measurements made and in associated calculations during the course of the practical work carried out to support the GCE Physics qualifications. Records of measurements should always include the relevant units. There are seven SI base units, all other units are derived from the seven base units. Practicals and other assessed work may require the derivation of units by the student and may include derived units not included below.

Base Units

length	m
mass	kg
time	s
electric current	A
temperature	K
luminous intensity	cd (not part of OCR A Level Physics Specification)
amount of substance	mole

Derived Units

area	m^2
volume	m^3
velocity	ms^{-1}
speed	ms^{-1}
acceleration	ms^{-2}
momentum	$kg\ ms^{-1}$
density	$kg\ m^{-3}$
force	N
torque	Nm *(not to be confused with energy!)*
momentum	Ns
energy	J
work	J
power	$W=Js^{-1}$
pressure	Pa
gravitational constant	$N\ m^2\ kg^{-2}$

gravitational field strength	N kg^{-1}
angle	°, rad
angular displacement	rad
angular velocity	rad s^{-1}
frequency	Hz = s^{-1}
potential difference	V
electromotive force (e.m.f.)	V
capacitance	F
electric resistance	Ω
electric conductance	S
electric resistivity	Ωm
electric conductivity	Sm^{-1}
electric charge	C
electric field strength	N C^{-1}, V m^{-1}
permittivity of free space	F m^{-1}
magnetic flux	Wb
magnetic flux density	T
permittivity of free space	Hm^{-1}
stress	Pa
strain	fraction or percent
Young modulus	Pa
spring constant	N m^{-1}
temperature	K, °C
specific heat capacity	J kg^{-1} K^{-1}
specific latent heat	J kg^{-1}
activity radioactive source	Bq
radiation dose	Gy=J kg^{-1}
radiation dose equivalent	Sv= J kg^{-1}

Appendix 5: Tables and Graphs

Tables

The following guidelines should be followed when presenting results in tables.

- All raw data in a single table with ruled lines and border.
- Independent variable (IV) in the first column; dependent variable (DV) in columns to the right (for quantitative observations) OR descriptive comments in columns to the right (for qualitative observations).
- Processed data (e.g. means, rates, standard deviations) in columns to the far right.
- No calculations in the table, only calculated values.
- Each column headed with informative description (for qualitative data) or physical quantity **and** correct units (for quantitative data); units separated from physical quantity using either brackets or a solidus (slash).
- No units in the body of the table, only in the column headings.
- Raw data recorded to a number of decimal places appropriate to the resolution of the measuring equipment.
- All raw data of the same type recorded to the same number of decimal places.
- Processed data recorded to up to one significant figure more than the raw data.

Graphs

The following general guidelines should be followed when presenting data in graphs.

There should be an informative title.

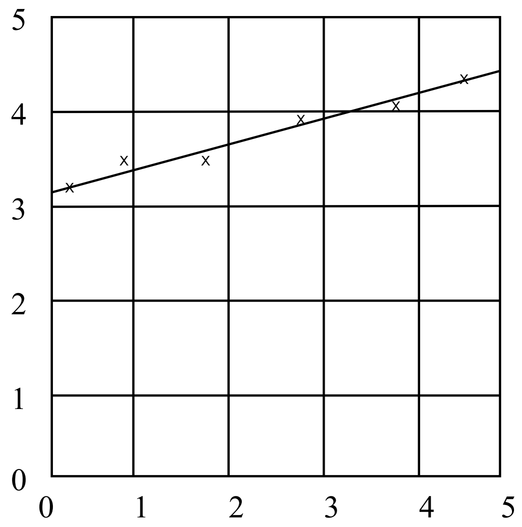
Range bars may be used to show the highest and lowest readings for each set of data.

This appendix provides background information on the following graphical skills:

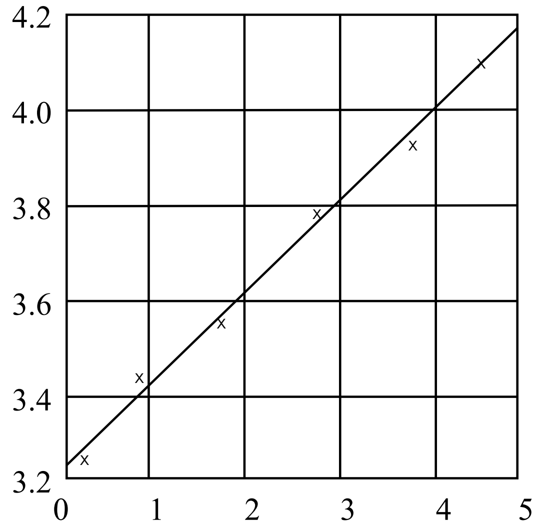
- choice of scale
- plotting of points
- line of best fit
- calculation of gradient
- determination of the *y*-intercept.

This information relates to skills assessed both in the written examinations and in the Practical Endorsement, notably 1.1.3(d) and 1.2.1(f).

Scales should be chosen so that the plotted points occupy at least half the graph grid in both the *x* and *y* directions.



Not acceptable - scale in the *y*-direction is compressed



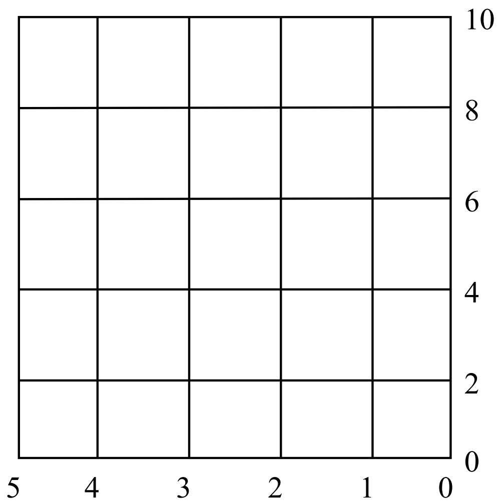
Acceptable - points fill more than half the graph grid in both the *x* and *y* directions

It is expected that each axis will be labelled with the quantity (including unit) which is being plotted. The quantity may be represented by a symbol or written in words. There must be some kind of distinguishing notation between the quantity and the unit. Students should be encouraged to use solidus notation, but a variety of other notations are accepted. For example:

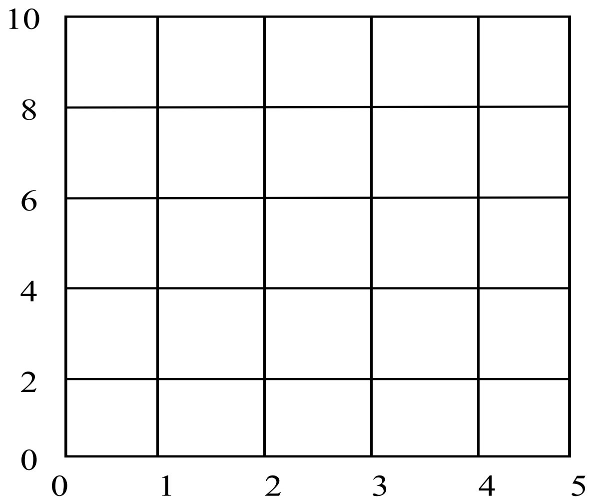
T / °C *T* (°C) *T* in °C $\frac{T}{°C}$ are all **acceptable** as axis labels.

The logarithm of a quantity has no units. Therefore, the axis label for e.g. pH measurements can be written simply as 'pH'.

The scale direction must be conventional (i.e. increasing from left to right).



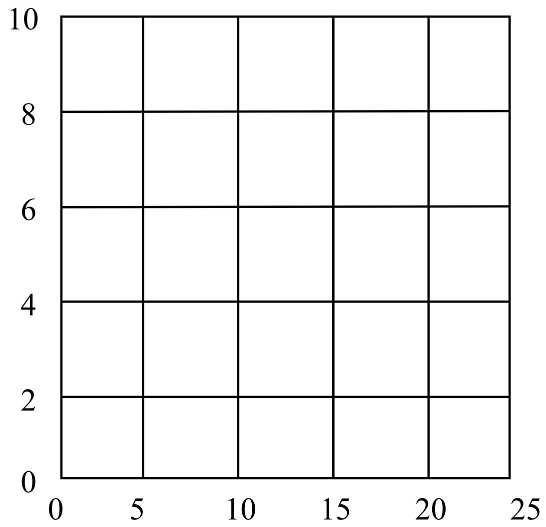
Not acceptable - unconventional scale direction



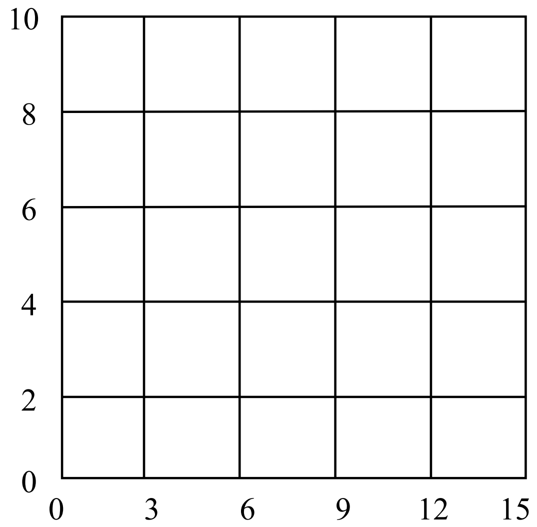
Acceptable - conventional scale direction

This problem often occurs when scales are used with negative numbers.

Students should be encouraged to choose scales that are easy to work with.



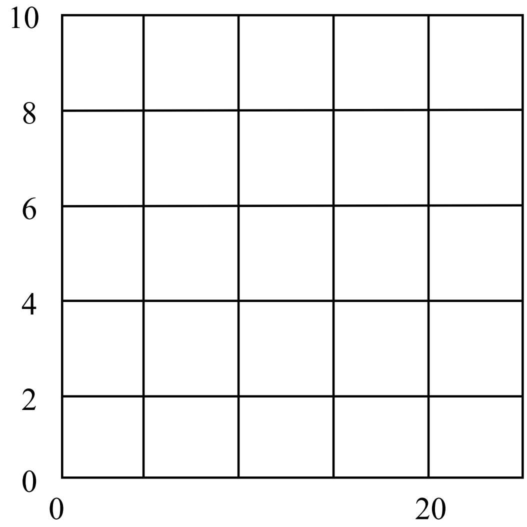
Acceptable scale divisions.



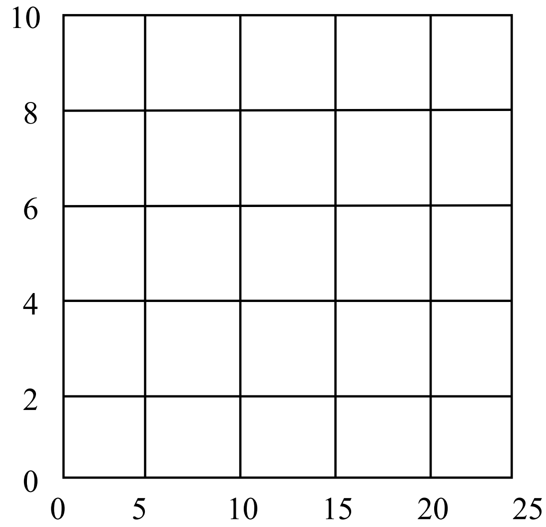
Not acceptable - awkward scale on the *x*-axis.

Students who choose awkward scales in examinations often lose marks for plotting points (as they cannot read the scales correctly) and calculation of gradient (Δx and Δy often misread – again because of poor choice of scale).

Scales should be labelled reasonably frequently (i.e. there should not be more than three large squares between each scale label on either axis).

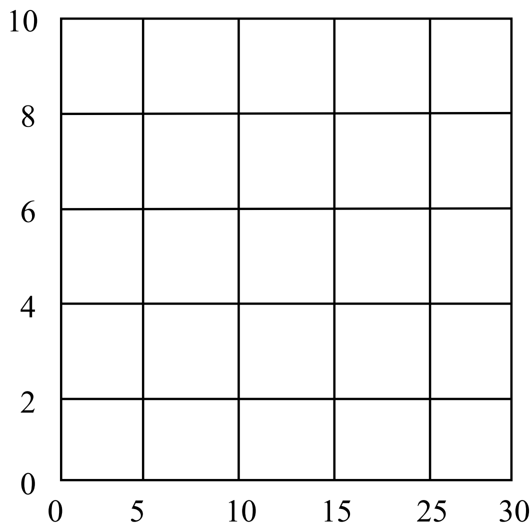


Not acceptable - too many large squares with no label

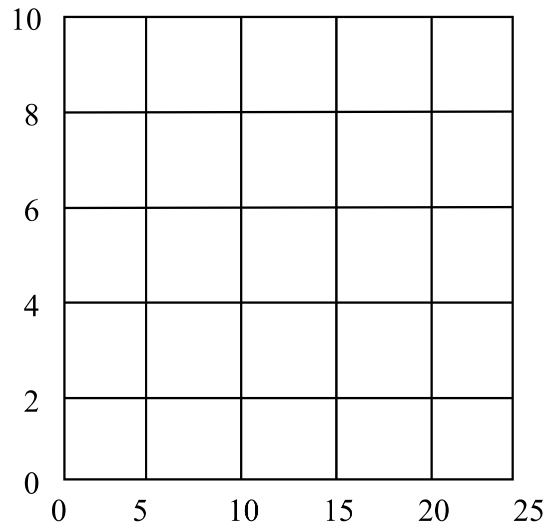


Acceptable - scales have regular labels

There should be no 'holes' in the scale.



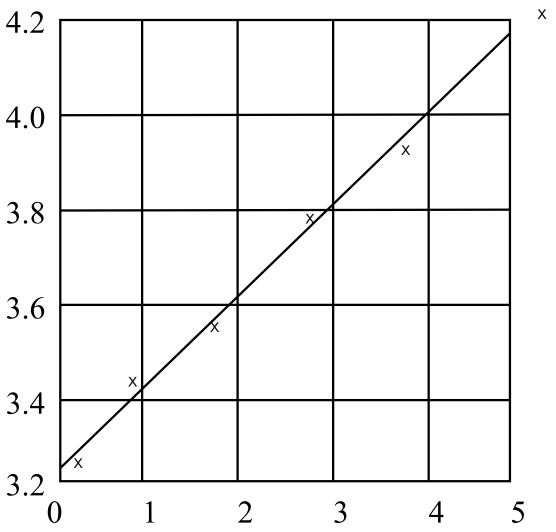
Not acceptable - non-linear scale on the *x*-axis



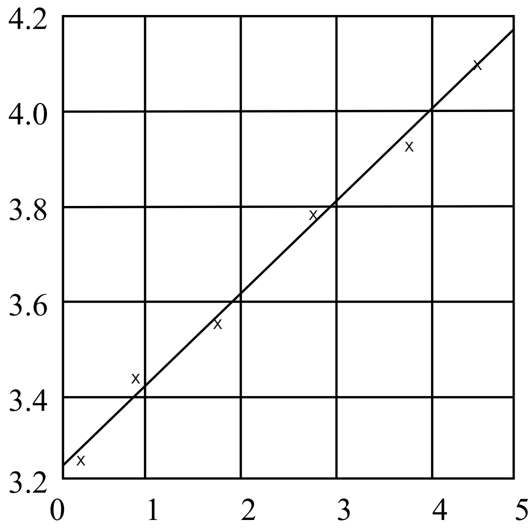
Acceptable - scale labelling is regular

Plotting of points

Plots in the margin area are not allowed, and will be ignored in examinations. Sometimes students (realising they have made a poor choice of scale) will attempt to draw a series of lines in the margin area so that they can plot the 'extra' point in the margin area. This is considered to be bad practice and would not be credited.



Not acceptable - the last point has been plotted in the margin area



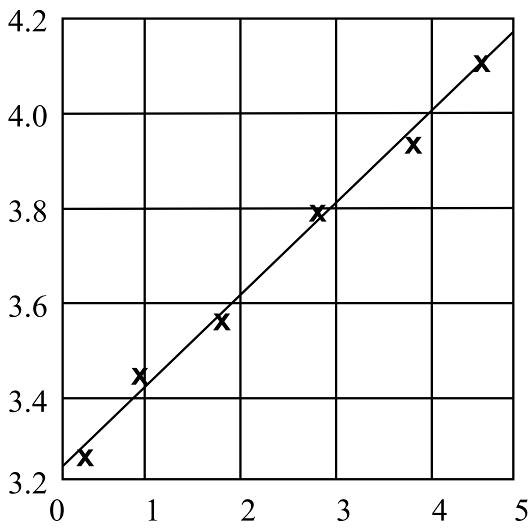
Acceptable - all plotted points are on the graph grid

It is expected that all observations will be plotted (e.g. if six observations have been made then it is expected that there will be six plots).

Plotted points must be accurate to half a small square.

Plots must be clear (and not obscured by the line of best fit or other working).

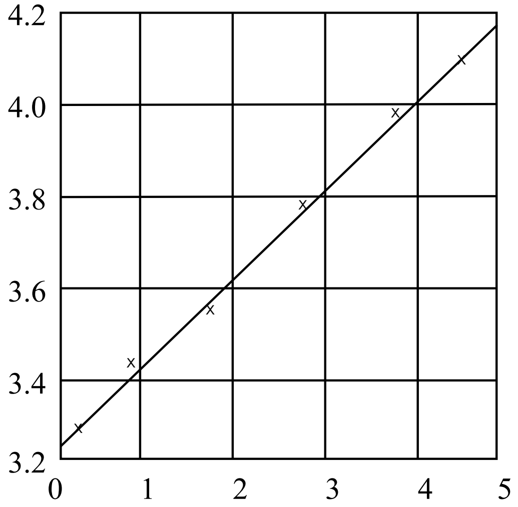
Thick plots are not acceptable. If it cannot be judged whether a plot is accurate to half a small square (because the plot is too thick) then the plotting mark will not be awarded.



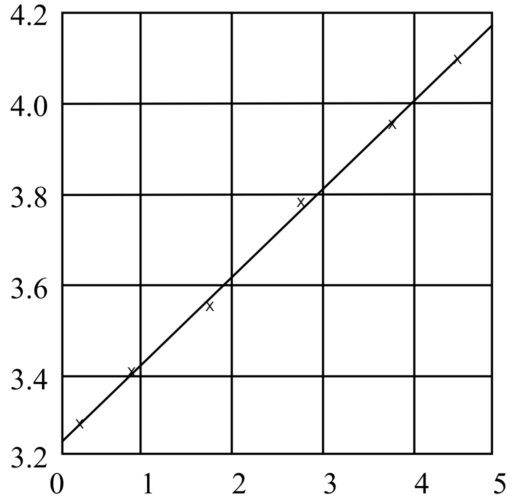
Thick plots not acceptable

Line (or curve) of best fit

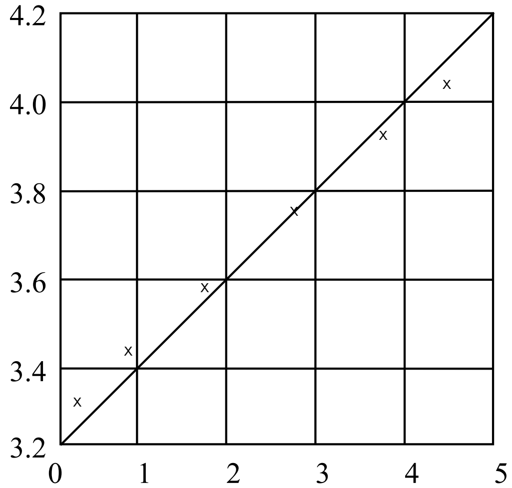
There must be a reasonable balance of points about the line. It is often felt that students should do better if they were able to use a clear plastic rule so that points can be seen which are on both sides of the line as it is being drawn.



Not acceptable - too many points above the line

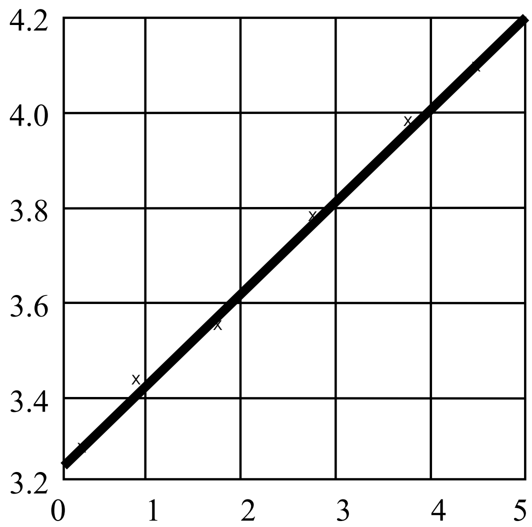


Acceptable balance of points about the line

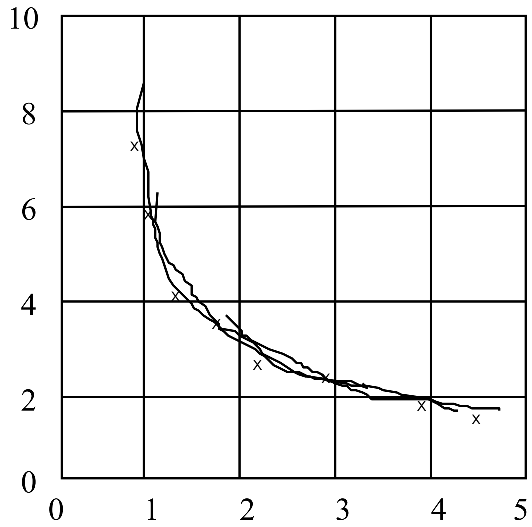


Not acceptable - forced line through the origin (not appropriate in this instance)

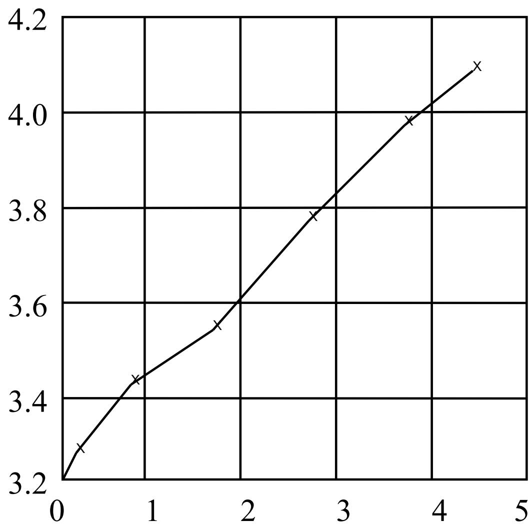
The line must be thin and clear. Thick/hairy/point-to-point/kinked lines are not credited.



Not acceptable - thick line



Not acceptable - 'hairy' curve

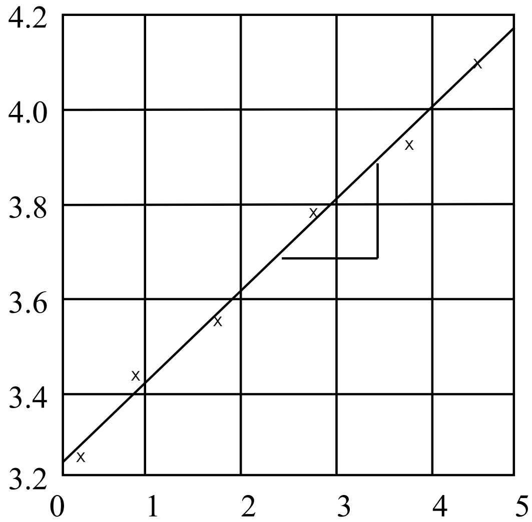


Not acceptable – joining point-to-point

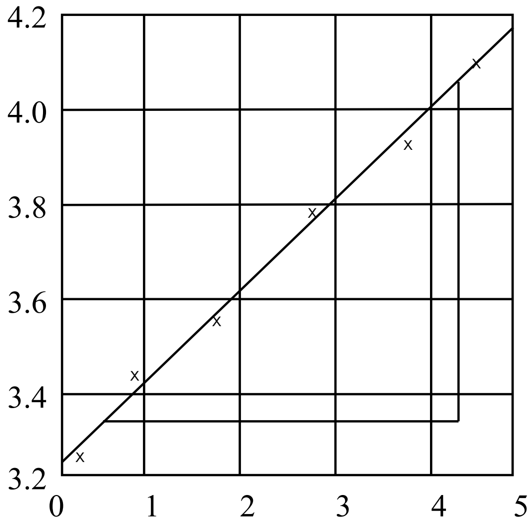
Determining gradients

All the working must be shown. A 'bald' value for the gradient may not be credited. It is helpful to both students and examiners if the triangle used to find the gradient were to be drawn on the graph grid and the co-ordinates of the vertices clearly labelled.

The length of the hypotenuse of the triangle should be greater than half the length of the line which has been drawn.



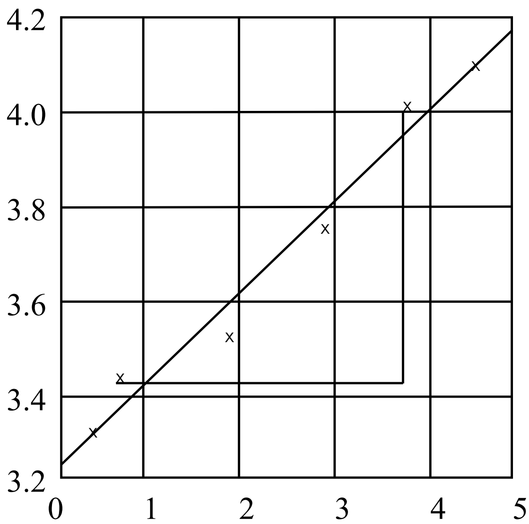
Not acceptable - the 'triangle' used is too small



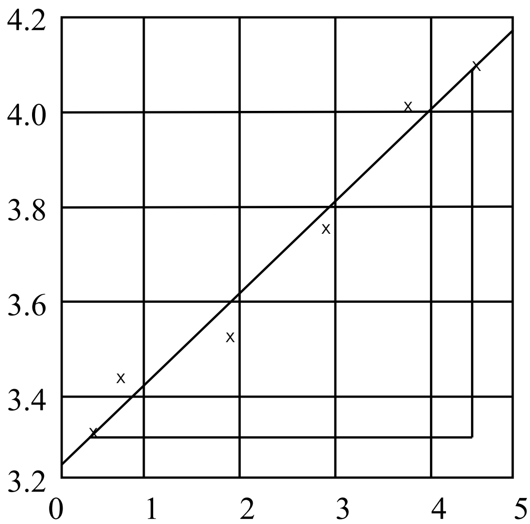
Acceptable – a large 'triangle' used

The values of Δx and Δy must be given to an accuracy of at least one small square (i.e. the 'read-off' values must be accurate to half a small square).

If plots are used which have been taken from the table of results then they must lie on the line of best fit (to within half a small square).



Not acceptable - the data points used which do not lie on the line of best fit

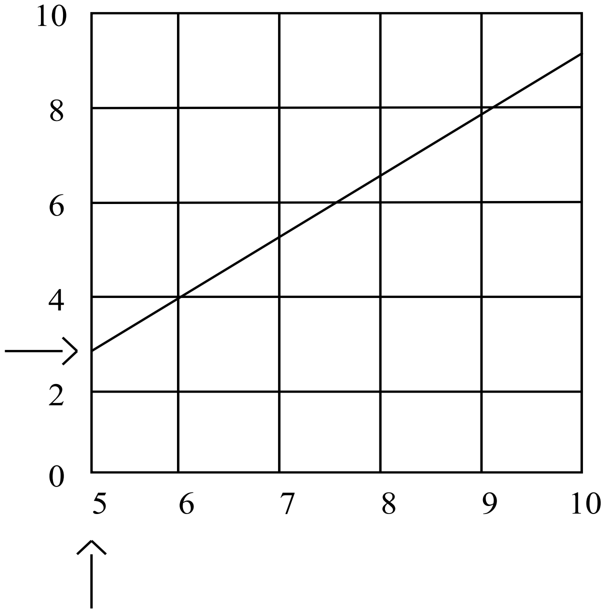


Acceptable - plots on line

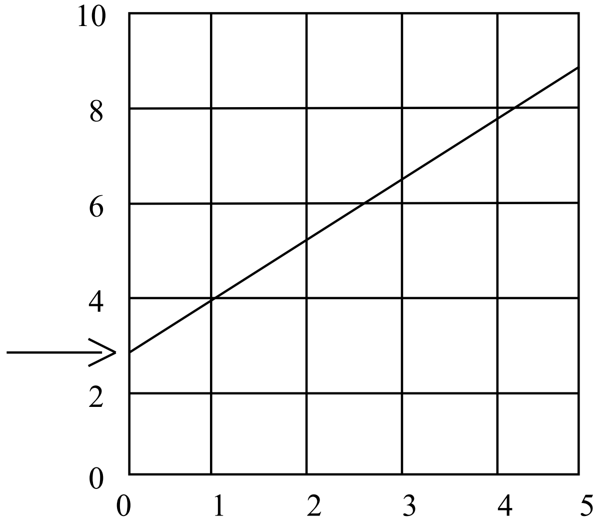
Students should remember to use appropriate units when reporting gradient values.

Intercept

The y-intercept must be read from an axis where $x = 0$. It is often the case that students will choose scales so that the plotted points fill the graph grid (as they should do) but then go on to read the y-intercept from a line other than $x = 0$.



Not acceptable – the y-intercept is found from the line $x = 5$



Acceptable – the value taken from the line $x = 0$

Alternatively, the intercept value can be calculated, recognising that a straight-line graph has the basic formula $y = mx + c$. Substituting the gradient value and a set of coordinates on the line of best fit and solving the equation will give the intercept.

Appendix 6: Referencing

One of the requirements of the Practical Endorsement is that students demonstrate that they can appropriately cite sources of information. The point of referencing is to provide the sources of information that have been used to produce the document, and to enable readers to find that information. There are many different systems of reference in use; the most important thing for students to appreciate at this level is that they should be consistent in how they reference, and that they provide sufficient information for the reader to find the source.

Systems of citation

Wherever a piece of information that has been retrieved from a source is provided in a text, an in-text citation should be included that links to the full original source in the reference list.

Use of a specific referencing system for the Practical Endorsement is not expected. However, students' referencing should be complete and consistent and allowing you to accurately find the original source. If students are already using a particular referencing system in another area of study, for example for an Extended Project qualification, it would make sense if they use the same system within their Physics studies.

There are two main systems of in-text citation: the Vancouver system, which uses numerical citations, and the parenthetical system (of which the Harvard system is the best known version), in which limited reference information is given in brackets in the text.

Students are likely to find the Harvard system easier to handle. However, students should be aware of the Vancouver system as they may come across this system in their secondary research.

Vancouver system

The Vancouver system looks like this:

> The first laser was successfully operated in 1960 by a team lead by Theodore Maiman[1].

The full references are given in a numbered list at the end of the document, with each number linked to the appropriate reference, e.g.:

1. Hecht, E. (1987) *Hecht Optics,* 2nd ed. Addison Wesley

   The references are ordered in the sequence in which they are first cited in the text. The numbers are repeated in the in-text citations as required, so the same number is always used to cite a given reference.

Parenthetical (Harvard) system

The parenthetical system looks like this:

> The first laser was successfully operated in 1960 by a team lead by Theodore Maiman (Hecht, 1987)

The author(s) and date of the work are included in brackets at the appropriate point in the text. In this case, the list of full references at the end of the document is ordered alphabetically, and the references are not numbered.

For multi-author works, the full list of names is usually not given in in-text references. Rather, the first name is given followed by 'et al.'. This is commonly done for works with more than three authors.

References

While different referencing systems have minor variations in how they present complete references, the basic information provided is always very similar, and based on the principle of providing sufficient information so that the reader can find the information source.

An overview is given below of standard referencing formats for the types of sources that students are likely to cite.

Books

General reference format:

> Authors (year), *Title*, edition (if relevant), publisher's location, publisher

For example:

> Young, H., Freedman, R. (2004). *University Physics with modern physics*, 12th ed., Boston, Addison Wesley

For books that have an editor or editors, include (ed.) or (eds) after the names.

If a book does not have named authors or editors, the reference begins with the title, e.g.:

> *CLEAPSS Laboratory Handbook* (2001), Uxbridge, CLEAPSS School Science Service

Journal articles

General reference format:

> Authors (year), 'Article title', *Journal title*, vol. no, issue no, pp. xxx–xxx

For example:

> Aad, G, et al (2012), 'Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC' *Physics Letters B* vol. 716, no. 1, pp. 1-29

Websites

General reference format:

> Authors (year), *Title*. [online] Last accessed date: URL

For example:

> Dianna Cowern (2015), *Crazy pool vortex* [online] Last accessed 22 April 2015: https://www.youtube.com/watch?v=pnbJEg9r1o8

Webpages and online resources frequently do not have individual authors. In that case, the name of the organisation is given.

Similarly, it is often not possible to find the year in which online material or documents were produced. In that case, use the year in which the information was sourced.

> Institute of Physics (2015), *Three alternative ways to charge your iPod* [online] Last accessed 22 April 2015: http://www.physics.org/featuredetail.asp?id=34

If no author or organisation can be found, reference the website by title. However, in that case due consideration should be given as to whether the website is a trustworthy source!

Appendix 7: Resources

General resources

There are many resources available to help teachers provide support to students. These include both books and websites.

Useful websites are:

- CLEAPSS at www.cleapss.org.uk
- the Institute of Physics (IoP) at http://www.iop.org/
- American Physical Society (APS) at http://www.aps.org/
- National Institute of Standards and Technology at http://www.nist.gov/index.html
- the ASE at www.schoolscience.co.uk

Professional Development

OCR runs professional development courses every year, and these include sessions to support the Practical Endorsement. More details about professional development provision are available at https://teachcambridge.org/.

Subject advisor support

OCR Subject advisors are available to offer support and guidance on all aspects of the Practical Endorsement. Direct queries regarding the Practical Endorsement to the OCR Science Team through: science@ocr.org.uk

Need to get in touch?

If you ever have any questions about OCR qualifications or services (including administration, logistics and teaching) please feel free to get in touch with our customer support centre.

Call us on
01223 553998

Alternatively, you can email us on
support@ocr.org.uk

For more information visit
- **ocr.org.uk/qualifications/resource-finder**
- **ocr.org.uk**
- **facebook.com/ocrexams**
- **twitter.com/ocrexams**
- **instagram.com/ocrexaminations**
- **linkedin.com/company/ocr**
- **youtube.com/ocrexams**

We really value your feedback

Click to send us an autogenerated email about this resource. Add comments if you want to.
Let us know how we can improve this resource or what else you need. Your email address will not be used or shared for any marketing purposes.

I like this **I dislike this**

Please note – web links are correct at date of publication but other websites may change over time. If you have any problems with a link you may want to navigate to that organisation's website for a direct search.

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UNIVERSITY PRESS & ASSESSMENT