INTERNATIONAL AS AND A-LEVEL PHYSICS

(9630)

Practical handbook

Version 2

This is the **Physics** version of this practical handbook.

The sections on tabulating data, significant figures, uncertainties, graphing and subject specific vocabulary are particularly useful for students and could be printed as a student booklet by schools.

The information in this document is correct, to the best of our knowledge as of September 2018.

CONTENTS

INTRODUCTION

Practical work brings science to life, helping students make sense of the universe around them. That's why we've put practical work at the heart of our Biology, Chemistry and Physics International AS and A-levels. Practical science allows scientific theory to transform into deep knowledge and understanding – scientific thinking. Through investigation, students uncover the important links between their personal observations and scientific ideas.

> "In the best schools visited, teachers ensured that pupils understood the 'big ideas' of science. They made sure that pupils mastered the investigative and practical skills that underpin the development of scientific knowledge and could discover for themselves the relevance and usefulness of those ideas."
>
> Ofsted report
>
> Maintaining curiosity in science
>
> November 2013, No. 130135

THE PURPOSE OF THIS PRACTICAL HANDBOOK

This handbook has been developed to support you in advancing your students to fluency in science.

Over the years, there have been many rules developed for practical work in Biology, Chemistry and Physics. Some have been prescriptive, some have been intended as guidance. Although we have always attempted to be consistent within subjects, differences have emerged over time. For example, students taking Physics may also be taking Biology and find themselves confronted with contradictory rules and guidance.

This practical handbook is an attempt to harmonise the rules and guidance for International Biology, Chemistry and Physics. There are occasions where these will necessarily be different, but we will try to explain why on the occasions where that happens.

We have worked with teachers, technicians and examiners to produce this handbook. This has been an evolving document, but one that we hope you will be able to use with your students, whether they're doing International AS or A-level Biology, Chemistry or Physics, or a combination of subjects, to improve their practical skills: in the classroom, in the laboratory, in exams, and on to university or the workplace.

Unless specified, all guidance is common to Biology, Chemistry and Physics at both International AS and A-level and subject-specific examples are for illustration only. However, the extent to which a particular aspect is assessed will differ. Teachers should refer to the specifications and specimen materials on our website for more information.

THE PURPOSE OF PRACTICAL WORK

There are three interconnected, but separate reasons for doing practical work in schools and colleges. They are:

1. To support and consolidate **scientific concepts** (knowledge and understanding).

   This is done by applying and developing what is known and understood of abstract ideas and models. Through practical work we are able to make sense of new information and observations, and provide insights into the development of scientific thinking.

2. To develop **investigative skills**. These transferable skills include:
   - devising and investigating testable questions
   - identifying and controlling variables
   - analysing, interpreting and evaluating data.

3. To build and master **practical skills** such as:
   - using specialist equipment to take measurements
   - handling and manipulating equipment with confidence and fluency
   - recognising hazards and planning how to minimise risk.

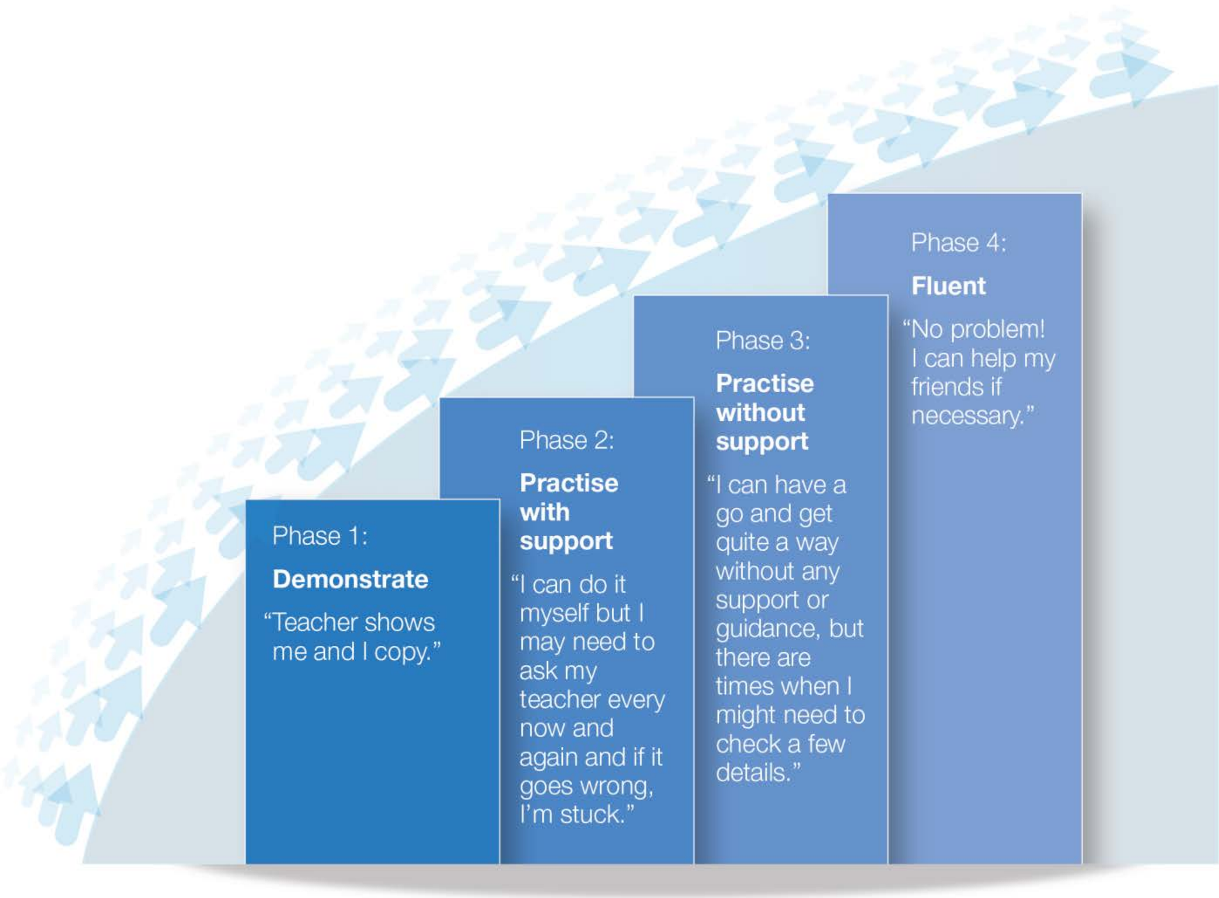
By focusing on the reasons for carrying out a particular practical, teachers will help their students understand the subject better, to develop the skills of a scientist and to master the manipulative skills required for further study or jobs in STEM subjects.

The International AS and A-levels in Biology, Chemistry and Physics separate the ways in which practical work is assessed. This is discussed in the next section.

FLUENCY IN SCIENCE PRACTICAL WORK

At the beginning of a year 12 course, students will need support and guidance to build their confidence. This could involve, for example, breaking down practicals into discrete sections or being more explicit in instructions. Alternatively, a demonstration of a key technique followed by students copying may support students' development. This could be a better starting point than 'setting students loose' to do it for themselves.

Progression in the mastery of practical skills and techniques shows increasing independence and confidence.



Safety is always the responsibility of the teacher. No student should be expected to assess risks and then carry out their science practical without the support and guidance of their teacher.

PRACTICAL SKILLS ASSESSMENT IN QUESTION PAPERS

The International AS and A-level papers will contain the following types of questions which relate to practical work:

1. Questions set in a practical context, where the question centres on the science, not the practical work.

EXAMPLE (A-LEVEL BIOLOGY SPECIMEN PAPER 1)

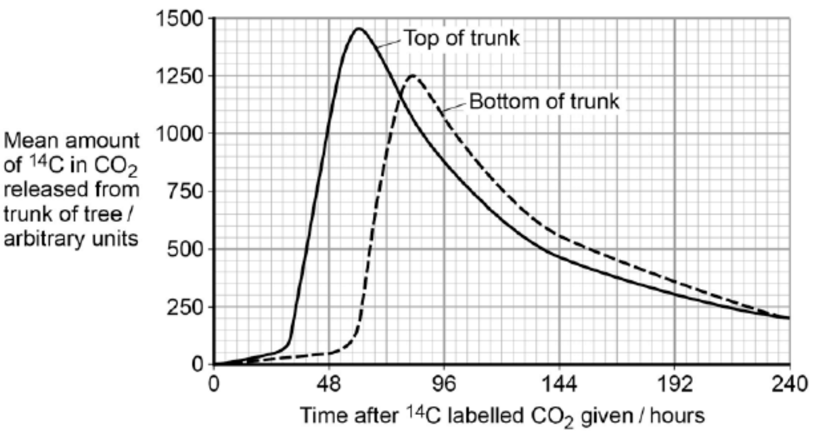
Scientists measured translocation in the phloem of trees. They used carbon dioxide labelled with radioactive ^{14}C.

They put a large, clear plastic bag over the leaves and branches of each tree and added $^{14}CO_2$. The main trunk of the tree was not in the plastic bag.

At regular intervals after adding the $^{14}CO_2$ to the bag, the scientists measured the amount of $^{14}CO_2$ released from the top and bottom of the main trunk of the tree. On the surface of the trunk of these trees, there are pores for gas exchange.

Figure 7 shows the scientists' results.

Figure 7



0 9 . 2 Name the process that produced the $^{14}CO_2$ released from the trunk.

[1 mark]

____

0 9 . 3 How long did it take the ^{14}C label to get from the top of the trunk to the bottom of the trunk? Explain how you reached your answer.

[2 marks]

____

____

0 9 . 4 What other information is required in order to calculate the mean rate of movement of the ^{14}C down the trunk?

[1 mark]

____

These questions are set in the context of practical work that has been carried out.

However, the questions relate more to the basic Biology behind the situation, or mathematical skills.

EXAMPLE (AS CHEMISTRY SPECIMEN PAPER 1)

4 Colourless solutions of **X**(aq) and **Y**(aq) react to form an orange solution of **Z**(aq) according to the following equation.

$$\mathbf{X}(aq) + 2\mathbf{Y}(aq) \rightleftharpoons \mathbf{Z}(aq) \qquad \Delta H = -20 \text{ kJ mol}^{-1}$$

A student added a solution containing 0.50 mol of **X**(aq) to a solution containing 0.50 mol of **Y**(aq) and shook the mixture.
After 30 seconds, there was no further change in colour.
The amount of **Z**(aq) at equilibrium was 0.20 mol.

0 4 . 1 Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

[2 marks]

Amount of **X**(aq) = ____________ mol Amount of **Y**(aq) = ____________ mol

This question requires an understanding of the underlying chemistry, not the practical procedure undertaken.

EXAMPLE (A-LEVEL PHYSICS SPECIMEN PAPER 3)

0 2 . 6 The experiment is performed with a capacitor of nominal value 680 μF and a manufacturing tolerance of ± 5 %. In this experiment the charging current is maintained at 65 μA. The data from the experiment produces a straight-line graph for the variation of pd with time. This shows that the pd across the capacitor increases at a rate of 98 mV s^{-1}.

Calculate the capacitance of the capacitor.

[2 marks]

capacitance = ____________ μF

This question is set in a practical context, and particular readings need to be used to calculate the answer, but the specific practical set-up is not important.

2. Questions that require specific aspects of a practical procedure to be understood in order to answer a question about the underlying science.

EXAMPLE (A-LEVEL BIOLOGY SPECIMEN PAPER 2)

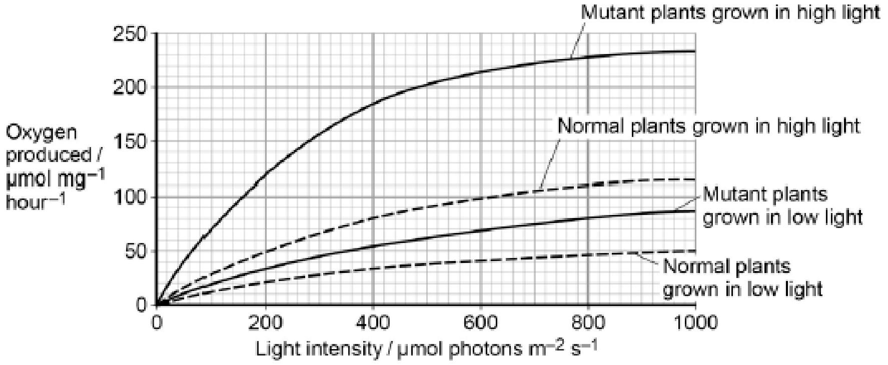
8 Chloroplasts contain chlorophyll a and chlorophyll b. Scientists found tobacco plants with a mutation that caused them to make more chlorophyll b than normal tobacco plants. They investigated the effect of this mutation on the rate of photosynthesis.

The scientists carried out the following investigation.

- They grew normal and mutant tobacco plants. They grew some of each in low light intensity and grew others in high light intensity.
- They isolated samples of chloroplasts from mature plants of both types.
- Finally, they measured oxygen production by the chloroplasts they had isolated from the plants.

Figure 7 shows the scientists' results.

Figure 7



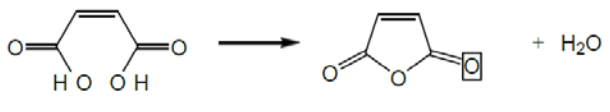
0 8 . 1 Explain why the scientists measured the rate of production of oxygen in this investigation.

[2 marks]

This question requires the students to understand how oxygen production can be used as a proxy measure for photosynthesis, but no other details of the practical procedure are important.

EXAMPLE (AS CHEMISTRY SPECIMEN PAPER 2)

0 1 . 4 The effect of gentle heat on maleic acid is shown below.



A student predicted that the yield of this reaction would be greater than 80%.

In an experiment, 10.0 g of maleic acid were heated and 6.53 g of organic product were obtained.

Is the student correct? Justify your answer with a calculation using these data.

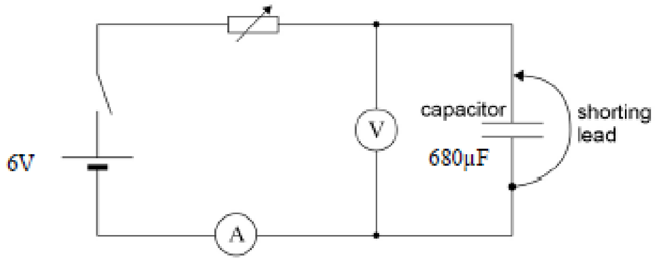
[2 marks]

To answer this question, the student must understand the process of yield calculation (which will have been gained through practical work), but again the details of the practical procedure are unimportant.

EXAMPLE (A-LEVEL PHYSICS SPECIMEN PAPER 5)

0 2 This question is about capacitor charging and discharging.
A student designs an experiment to charge a capacitor using a constant current as shown in **Figure 3**.

Figure 3



The variable resistor is then adjusted to give a suitable ammeter reading. The shorting lead is removed and the stop clock is started at the same instant.

A student measured the potential difference (pd) across the capacitor at 10 s intervals while adjusting the variable resistor to keep the charging current constant.

The power supply has a negligible internal resistance and the variable resistor has a maximum resistance of 100 kΩ.

0 2 . 1 The student chooses a digital voltmeter for the experiment. A digital voltmeter has a very high resistance.

Explain why it is important to use a voltmeter with very high resistance.

[1 mark]

To answer this question, the student must understand why a voltmeter needs to have a very high resistance.

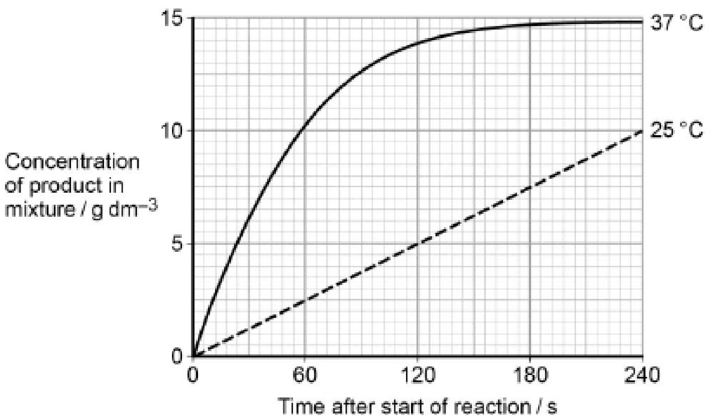
3. Questions directly on the required practical procedures.

EXAMPLE (AS BIOLOGY SPECIMEN PAPER 1)

2 A technician investigated the effect of temperature on the rate of an enzyme-controlled reaction. At each temperature, he started the reaction using the same volume of substrate solution and the same volume of enzyme solution.

Figure 2 shows his results.

Figure 2



0 2 . 1 Give one other factor the technician would have controlled.

[1 mark]

0 2 . 2 Calculate the rate of reaction at 25 °C.

[2 marks]

Similarly, in this example, the students should have done a very similar experiment.

The first question is simple recall of the factors involved in the rate of enzyme controlled reactions.

The second requires the calculation of a gradient, which is a skill students will have learned through their practical and other work.

EXAMPLE (A-LEVEL CHEMISTRY SPECIMEN PAPER 3)

3 A peptide is hydrolysed to form a solution containing a mixture of amino acids. This mixture is then analysed by silica gel thin-layer chromatography (TLC) using a toxic solvent. The individual amino acids are identified from their R_f values.

Part of the practical procedure is given below.

1. **Wearing plastic gloves to hold a TLC plate**, draw a pencil line 1.5 cm from the bottom of the plate.
2. Use a capillary tube to apply a very small drop of the solution of amino acids to the mid-point of the pencil line.
3. Allow the spot to dry completely.
4. In the developing tank, add the developing solvent to **a depth of not more than 1 cm**.
5. Place your TLC plate in the developing tank.
6. Allow the developing solvent to rise up the plate **to the top**.
7. Remove the plate and quickly mark the position of the solvent front with a pencil.
8. Allow the plate to dry **in a fume cupboard**.

0 3 . 1 Parts of the procedure are in bold text.

For each of these parts, consider whether it is essential and justify your answer.

[4 marks]

Students who have completed the related required practical will have a greater understanding of each of the steps in the procedure and will be able to explain each in turn.

This type of question is likely to be fairly rare, to avoid predictable assessments.

EXAMPLE (A-LEVEL PHYSICS SPECIMEN PAPER 5)

0 2 . 6 The student decides to confirm the value of the capacitance by first determining the time constant of the circuit when the capacitor discharges through a fixed resistor.

Describe an experiment to do this. Include in your answer:

- a circuit diagram
- an outline of a procedure
- an explanation of how you would use the data to determine the time constant.

[4 marks]

This question focuses on a particular aspect of one of the required practicals, and is related to the discharging of a capacitor through a fixed resistor.

4. Questions applying the skills from the required practical procedures and the apparatus and techniques list.

EXAMPLE (A-LEVEL BIOLOGY SPECIMEN PAPER 5)

2 Fibrin is a protein.
Congo red is a dye that binds to fibrin molecules and colours them red. When a suspension of Congo-red fibrin is digested, the dye goes into solution.

You are provided with

- fibrin powder that has been dyed with Congo red
- trypsin, an enzyme that hydrolyses fibrin
- any other laboratory apparatus that you might need.

Plan an investigation to the find effect of pH on the rate of hydrolysis of fibrin by Trypsin.

0 2 . 1 Describe how you would change the independent variable. Include the steps that you would take to ensure that confounding variables were kept constant and any controls that you would set up.

[4 marks]

This question expects students to understand enzyme controlled reactions, which is one of the required practicals. It is not necessary for students to have used Congo Red to understand the requirements.

EXAMPLE (A-LEVEL CHEMISTRY SPECIMEN PAPER 3)

0 1 . 3 The boiling points of the organic compounds in a reaction mixture are shown in **Table 1**.

Table 1

Compound	ethanol	ethanal	ethanoic acid
Boiling point / °C	78	21	118

Use these data to describe how you would obtain a sample of ethanal from a mixture of these three compounds. Include in your answer a description of the apparatus you would use and how you would minimise the loss of ethanal. Your description of the apparatus can be either a description in words or a labelled sketch.

[5 marks]

This question expects students to understand distillation which is one of the required practicals. It is not necessary for students to have carried out this precise experiment to understand the requirements.

EXAMPLE (AS PHYSICS SPECIMEN PAPER 2)

0 2 **Data analysis question**

Capillary action can cause a liquid to rise up a hollow tube. **Figure 3** shows water that has risen to a height h in a narrow glass tube because of capillary action.

Figure 3

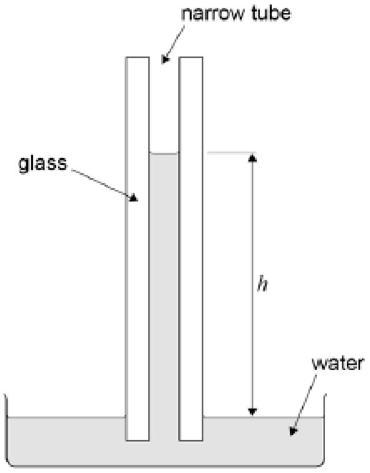
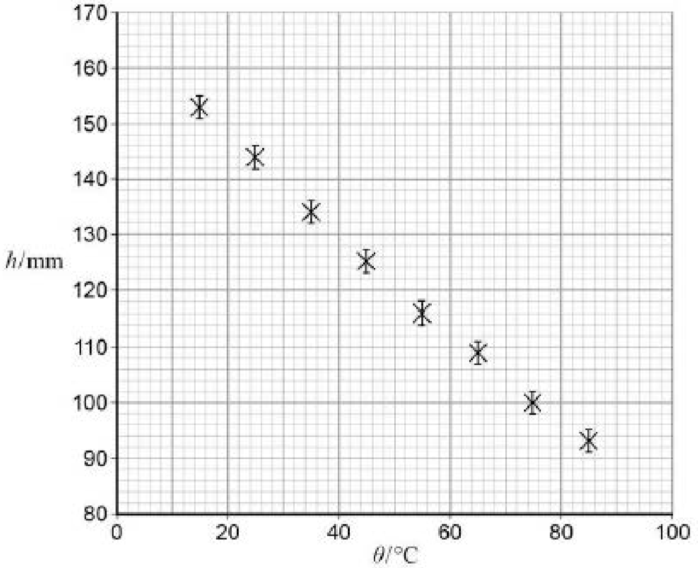


Figure 4 shows the variation of h with temperature θ for this particular tube.

Figure 4



The uncertainty in the measurement of h is shown by the error bars. Uncertainties in the measurements of temperature are negligible.

0 2 . 1 Draw a best-fit straight line for these data (**Figure 4**).

[1 mark]

0 2 . 2 It is suggested that the relationship between h and θ is

$$h = h_0 - (h_0 k)\theta$$

where h_0 and k are constants.
Determine h_0.

[1 mark]

This question requires students to apply the skills of data analysis that they will have gained through their practical work in the required practicals and apply it to an unusual situation.

GUIDELINES TO SUPPORTING STUDENTS IN PRACTICAL WORK

Developed in collaboration with National Foundation for Educational Research (NFER) and CLEAPSS.

CLARIFY THE IMPORTANCE OF KEEPING A LAB BOOK OR OTHER RECORDS OF PRACTICAL WORK

Explain that students need a record of their achievements to guide their learning. Lab books also can be an opportunity to develop a skill used both by scientists and in business. They allow students to accurately and clearly record information, ideas and thoughts for future reference which is a very useful life skill.

WARN STUDENTS AGAINST PLAGIARISM AND COPYING

Explain the meaning of the term plagiarism and that the use of acknowledged sources is an encouraged and acceptable practice, but trying to pass off other people's work as their own is not, and will not help them learn. Show students how sources should be cited.

EXPLAIN THE LEARNING CRITERIA FOR EACH SKILL

This will help students learn and allow them to know when they have met the criteria. The student lab book contains the criteria, but they own the process and have the responsibility for collecting appropriate evidence of success.

USE CLEARLY DEFINED LEARNING OUTCOMES

For example, if you are running a practical session to teach students how to use a microscope and staining techniques safely and efficiently, then make sure they know why they are learning this. This will also make it much easier for them to know when they have met the criteria.

START WITH SIMPLE TASKS INITIALLY

Students need to become confident with the apparatus and concepts of practical work before they can proceed to more complicated experiments. It may be more effective to start with simple manipulation skills and progress to the higher order skills.

TEACH PRACTICAL WORK IN YOUR PREFERRED ORDER

Teach the skills as you see fit and that suit your circumstances – the assessment process is aimed to be flexible and help you teach practical work, not to dictate how it should be done.

USE FEEDBACK AND PEER ASSESSMENT

Feedback is essential to help students develop skills effectively. Allowing self and peer review will allow time for quality feedback as well as provide powerful learning tools. However, this is a decision for teachers. The scheme is designed to be flexible while promoting best practice.

Research shows that feedback is the best tool for learning in practical skills. Students who normally only receive numerical marks as feedback for work will need to be trained in both giving and receiving comment-based feedback. Provided it is objective, focused on the task and meets learning outcomes, students will quickly value this feedback.

Feedback does not need to be lengthy, but it does need to be done while the task is fresh in the students' mind. Not everything needs written feedback but could be discussed with students, either individually or as a class. For example, if a teacher finds that many students cannot calculate percentage change, the start of the next lesson could be used for a group discussion about this.

The direct assessment of practical work is designed to allow teachers to integrate student-centred learning (including peer review), into day-to-day teaching and learning. This encourages critical skills. Research indicates these are powerful tools for learning. For example, teachers could ask students to evaluate each other's data objectively. The students could identify why some data may be useful and some not. This can be a very good way of getting students to understand why some conventions are used, and what improves the quality of results. This also frees up marking time to concentrate on teaching.

DON'T GIVE MARKS

We have deliberately moved away from banded criteria and marks to concentrate on the mastery of key practical competencies. The purpose of marking should be changed to emphasise learning. Students should find it easier to understand and track their progress, and focus their work. We would expect most students, with practice and the explicit teaching of skills and techniques, to have confidence to approach practical work related exam questions.

USE GROUP WORK

This is a very useful skill, allowing students to build on each other's ideas. For example, planning an experiment can be done as a class discussion. Alternatively, techniques such as snowballing can be used, in which students produce their own plan then sit down in a small group to discuss which are the best collective ideas. From this, they revise their plan which is then discussed to produce a new 'best' plan.

USE OF LAB BOOKS

Students do **not** need to write up every practical that they do in detail. However, it is good practice to have a record of all they do. A lab book could contain this record. It is a student's personal book and may contain a range of notes, tables, jottings, reminders of what went wrong, errors identified and other findings. It is a live document that can function as a learning journal.

Lab books are **not** a requirement of the OxfordAQA International AS and A-level specifications in Biology, Chemistry or Physics. They are, however, highly valued by colleagues in higher education.

Each institution has its own rules on lab book usage. The following guidelines are based on those from a selection of companies and universities that use lab books. They are designed to help students and teachers in preparing to use lab books for university but do not represent the only way that books could be used for International AS and A-level sciences. Teachers may wish to vary or ignore the following points to suit their purposes.

THE PURPOSE OF A LAB BOOK

A lab book is a complete record of everything that has been done in the laboratory. As such, it becomes important both to track progress of experiments, and also, in industry and universities, to prove who developed an idea or discovered something first.

A lab book is a:

- source of data that can be used later by the experimenter or others
- complete record of what has been done so that experiments could be understood or repeated by a competent scientist at some point in the future
- tool that supports sound thinking and helps experimenters to question their results to ensure that their interpretation is the same one that others would come to
- record of why experiments were done.

TYPE OF BOOK

A lab book is often a hard-backed book with bound pages. Spiral bound notebooks are not recommended as it is too easy to rip a page out and start again. It is generally advisable that a lab book has a cover that won't disintegrate the moment it gets slightly wet.

STYLE

Notes should be recorded as experiments are taking place. They should not be a "neat" record written at a later date from scraps of paper. However, they should be written clearly, in legible writing and in language which can be understood by others.

Many lab books are used in industry as a source of data, and so should be written in indelible ink.

To ensure that an observer can be confident that all data are included when a lab book is examined, there should be no blank spaces. Mistakes should be crossed out and re-written. Numbers should not be overwritten, erased, nor should Tippex be used. Pencil should not be used for anything other than graphs and diagrams.

EACH PAGE SHOULD BE DATED

Worksheets, graphs, printed information, photographs and even flat "data" such as chromatograms or TLC plates can all be stuck into a lab book. They should not cover up any information so that photocopying the page shows all information in one go. Anything glued in should lie flat and not be folded.

CONTENT

Generally, lab books will contain:

- title and date of experiment
- notes on the objectives of the experiment
- notes on the method, including all details (eg temperatures, volumes, settings of pieces of equipment) with justification where necessary
- estimates of the uncertainty of measurements
- sketches of how equipment has been set up can be helpful. Photographs pasted in are also acceptable
- data and observations input to tables (or similar) while carrying out the experiment
- calculations – annotated to show thinking
- graphs and charts
- summary, discussions and conclusions
- cross-references to earlier data and references to external information.

This list and its order are not prescriptive. Many experiments change as they are set up and trials run. Often a method will be given, then some data, then a brief mention of changes that were necessary, then more data and so on.

REQUIRED PRACTICAL ACTIVITIES

The OxfordAQA Exams required practicals have been designed to give students a range of practical experience. Carrying out the required practicals will mean that students will have experienced the use of most of the standard pieces of equipment and techniques expected when students move to further study in the subject at university. Teachers are encouraged to develop students' abilities by inclusion of other opportunities for skills development, as exemplified in the schemes of work for each subject.

Teachers are encouraged to vary their approach to the required practical activities. Some are more suitable for highly structured approaches that develop key techniques. Others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the required practical activities. The explicit teaching of practical skills builds students' competence. Many teachers will also use practical approaches to the introduction of content knowledge in the course of their normal teaching.

STUDENTS WHO MISS A REQUIRED PRACTICAL ACTIVITY

The required practical activities are part of the specification. As such, exam papers will test knowledge and understanding of the procedures involved and require evaluation of the techniques adopted. Students may need to interpret specimen results.

A student who misses a particular practical activity may be at a disadvantage when answering questions in the exams. It will often be difficult to set up a practical a second time for students to catch up, although if at all possible an attempt should be made. Teachers will need to decide on a case by case basis whether they feel it is important for the student to carry out that particular practical. This is no different from when teachers make decisions about whether to re-teach a particular topic if a student is away from class when it is first taught.

PHYSICS REQUIRED PRACTICAL ACTIVITIES

AS practical activities	A2 practical activities
Students must carry out the practical activities listed below. The AS written papers test knowledge and understanding of the procedures as well as evaluation of the techniques adopted. They may require students to interpret specimen results.	Students must carry out the practical activities below. The A2 written papers test knowledge and understanding of the procedures involved as well as evaluation of the techniques adopted. They may require students to interpret specimen results.
Practical activity	**Practical activity**
1 Determination of *g* by a freefall method. Procedures should include determination of *g* from graph (eg from graph of *s* against t^2).	6 Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, *RC*.
2 Investigation of load-extension graph for a wire and determination of the Young modulus for the material of the wire.	7 Investigation of the efficiency of a transformer.
3 Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of a cell or battery with current.	8 Determination of specific heat capacity by an electrical method.
4 Investigation into simple harmonic systems using a mass-spring system and a simple pendulum.	9 Investigation of Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas.
5 Investigation of interference effects to include the Young's slit experiment and interference by a diffraction grating.	10 Investigation of the inverse square law for light using an LDR and a point source.

TABULATING DATA

It is important to keep a record of data while carrying out practical work. Tables should have clear headings with units indicated using a forward slash before the unit.

pd/V	Current/A
2.0	0.15
4.0	0.31
6.0	0.45

Although using a forward slash (solidus) is the standard format for post-16 studies, other formats are generally acceptable. For example:

Length in m	Time for 10 oscillations in s
0.600	15.52
0.700	16.85
0.800	17.91

Distance (cm)	Count rate (s^{-1})
10.0	53
15.0	25
20.0	12

It is good practice to draw a table before an experiment commences and then enter data straight into the table. This can sometimes lead to data points being in the wrong order. For example, when investigating the electrical characteristics of a component by plotting an I – V curve, a student may initially decide to take current readings at pd values of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 V . On discovering a more significant change in current between 1.5 and 2.0 V, the student might decide to take further readings at 1.6, 1.7, 1.8, 1.9 V to investigate this part of the characteristics in more detail. Whilst this is perfectly acceptable, it is generally a good idea to make a copy of the table in ascending order of pd to enable patterns to be spotted more easily. Reordered tables should follow the original data if using a lab book.

It is also expected that the independent variable is the left hand column in a table, with the following columns showing the dependent variables. These should be headed in similar ways to measured variables. The body of the table should not contain units.

TABULATING LOGARITHMIC VALUES

When the logarithm is taken of a physical quantity, the resulting value has no unit. However, it is important to be clear about which unit the quantity had to start with. The logarithm of a time in seconds will be very different from the logarithm of the same time in minutes.

These should be included in tables in the following way:

Reading number	time/s	log (time/s)
1	2.3	0.36
2	3.5	0.54
3	5.6	0.75

SIGNIFICANT FIGURES

Data should be written in tables to the same number of significant figures. This number should be determined by the resolution of the device being used to measure the data or the uncertainty in measurement. For example, a length of string measured to be 60 cm using a ruler with mm graduations should be recorded as 600 mm, 60.0 cm or 0.600 m, and **not** just 60 cm. Similarly a resistor value quoted by the manufacturer as 56 kΩ, 5% tolerance should **not** be recorded as 56.0 kΩ.

There is sometimes confusion over the number of significant figures when readings cross multiples of 10. Changing the number of decimal places across a power of ten retains the number of significant figures **but changes the precision.** The same number of decimal places should therefore generally be used, as illustrated below.

0.97
0.98
0.99
1.00
1.10

99.7
99.8
99.9
100.0
101.0

It is good practice to write down all digits showing on a digital meter.

Calculated quantities should be shown to the number of significant figures of the data with the least number of significant figures.

Example:

A Young's double-slit experiment is arranged so that the perpendicular distance from the slits to the detector is 0.42 m. The interference fringe spacing is 0.11 m. The wavelength of the microwaves is 3.19×10^{-2} m.

Calculate the slit separation.
Give your answer to an appropriate number of significant figures.

$$s = \frac{\lambda D}{w}$$

$$s = \frac{0.0319 \times 0.42}{0.11}$$

= 0.12 (0.1218 m)

Note that the size of the slit separation can only be quoted to two significant figures, as the *lowest* number of significant figures in the data used with the calculation is two.

UNCERTAINTIES

SOURCES OF UNCERTAINTIES

Students should know that every measurement has some inherent uncertainty.

The important question to ask is whether an experimenter can be confident that the true value lies in the range that is predicted by the uncertainty that is quoted. Good experimental design will attempt to reduce the uncertainty in the outcome of an experiment. The experimenter will design experiments and procedures that produce the least uncertainty and to provide a realistic uncertainty for the outcome.

In assessing uncertainty, there are a number of issues that have to be considered. These include:

- the resolution of the instrument used
- the manufacturer's tolerance on instruments
- the judgments that are made by the experimenter
- the procedures adopted (eg repeated readings)
- the size of increments available (eg the size of drops from a pipette).

Numerical questions will look at a number of these factors. Often, the resolution will be the guiding factor in assessing a numerical uncertainty. There may be further questions that would require candidates to evaluate arrangements and procedures. Students could be asked how particular procedures would affect uncertainties and how they could be reduced by different apparatus design or procedure.

A combination of the above factors means that there can be no hard and fast rules about the actual uncertainty in a measurement. What we can assess from an instrument's resolution is the **minimum** possible uncertainty. Only the experimenter can assess the other factors, based on the arrangement and use of the apparatus. A rigorous experimenter would draw attention to these factors and take them into account.

READINGS AND MEASUREMENTS

It is useful, when discussing uncertainties, to separate measurements into two forms:

- Readings: the values found from a single judgement when using a piece of equipment.
- Measurements: the values taken as the difference between the judgements of two values.

Examples

When using a thermometer, a student only needs to make one judgement (the height of the liquid). This is a reading. It can be assumed that the zero value has been correctly set.

For protractors and rulers, both the starting point and the end point of the measurement must be judged, leading to two uncertainties.

The following list is not exhaustive, and the way that the instrument is used will determine whether the student is taking a reading or a measurement.

Reading (one judgement only)	Measurement (two judgements required)
thermometer	ruler
top pan balance	vernier calliper
measuring cylinder	micrometer
digital voltmeter	protractor
Geiger counter	stopwatch
pressure gauge	analogue meter

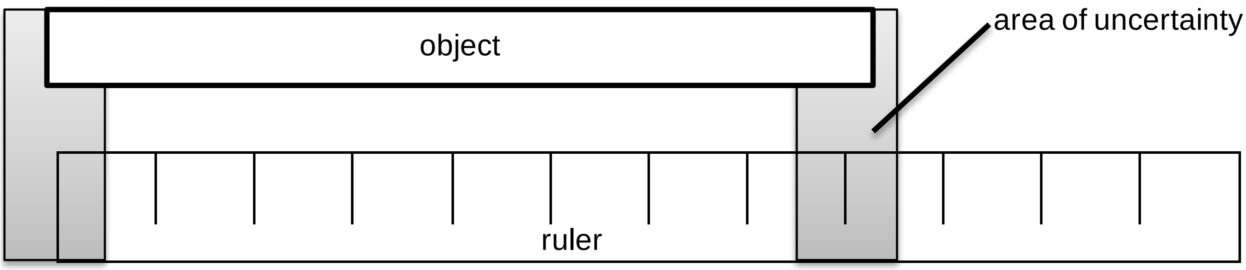
The uncertainty in a **reading** when using a particular instrument is **no smaller** than plus or minus half of the smallest division or greater. For example, a temperature measured with a thermometer is likely to have an uncertainty of ±0.5 °C if the graduations are 1 °C apart.

Students should be aware that readings are often written with the uncertainty. An example of this would be to write a voltage as (2.40 ± 0.01) V. It is usual for the uncertainty quoted to be the same number of decimal places as the value. Unless there are good reasons otherwise (eg an advanced statistical analysis), students at this level should quote the uncertainty in a measurement to the same number of decimal places as the value.

Measurement example: length

When measuring length, **two** uncertainties must be included: the uncertainty of the placement of the zero of the ruler and the uncertainty of the point the measurement is taken from.

As both ends of the ruler have a ±0.5 scale division uncertainty, the measurement will have an uncertainty of ±1 division.



For most rulers, this will mean that the uncertainty in a measurement of length will be ±1 mm.

This "initial value uncertainty" will apply to any instrument where the user can set the zero (incorrectly), but would not apply to equipment such as balances or thermometers where the zero is set at the point of manufacture.

In summary

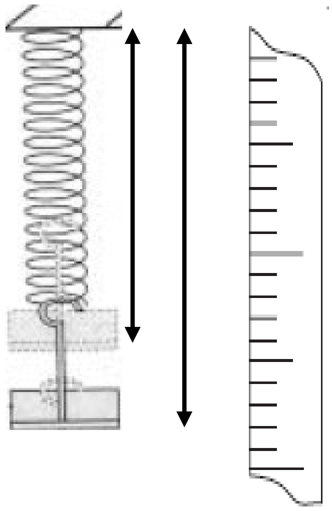
- The uncertainty of a reading (one judgement) is at least ±0.5 of the smallest scale reading.
- The uncertainty of a measurement (two judgements) is at least ±1 of the smallest scale reading.

The way measurements are taken can also affect the uncertainty.

Measurement example: the extension of a spring

Measuring the extension of a spring using a metre ruler can be achieved in two ways

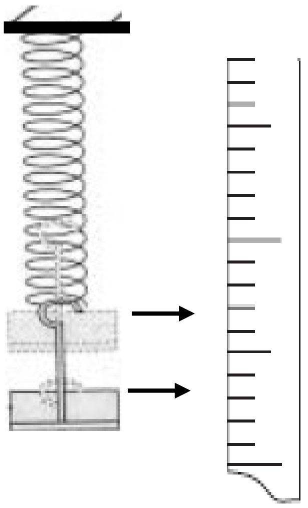
1. Measuring the total length unloaded and then loaded.



Four readings must be taken for this: the start and end point of the unloaded spring's length and the start and end point of the loaded spring's length.

The minimum uncertainty in each measured length is ±1 mm using a meter ruler with 1 mm divisions (the actual uncertainty is likely to be larger due to parallax in this instance). The extension would be the difference between the two readings, so the minimum uncertainty would be ±2 mm.

2. Fixing one end and taking a scale reading of the lower end.



Two readings must be taken for this: the end point of the unloaded spring's length and the end point of the loaded spring's length. The start point is assumed to have zero uncertainty, as it is fixed.

The minimum uncertainty in each reading would be ±0.5 mm, so the minimum extension uncertainty would be ± 1 mm.

Even with other practical uncertainties this second approach would be better.

Realistically, the uncertainty would be larger than this and an uncertainty in each reading of 1 mm or would be more sensible. This depends on factors such as how close the ruler can be mounted to the point as at which the reading is to be taken.

OTHER FACTORS

There are some occasions where the resolution of the instrument is not the limiting factor in the uncertainty in a measurement.

Best practice is to write down the full reading and then to write to fewer significant figures when the uncertainty has been estimated.

Examples:

A stopwatch has a resolution of hundredths of a second, but the uncertainty in the measurement is more likely to be due to the reaction time of the experimenter. Here, the student should write the full reading on the stopwatch (eg 12.20 s), carry the significant figures through for all repeats, and reduce this to a more appropriate number of significant figures after an averaging process later.

If a student measures the length of a piece of wire, it is very difficult to hold the wire completely straight against the ruler. The uncertainty in the measurement is likely to be higher than the ±1 mm uncertainty of the ruler. Depending on the number of "kinks" in the wire, the uncertainty could be reasonably judged to be nearer ± 2 or 3 mm.

The uncertainty of the reading from digital voltmeters and ammeters depends on the electronics and is not strictly the last figure in the readout. Manufacturers usually quote the percentage uncertainties for the different ranges. Unless otherwise stated it may be assumed that ±0.5 in the least significant digit is to be the uncertainty in the measurement. This would generally be rounded up to ±1 of the least significant digit when quoting the value and the uncertainty together. For example (5.21 ±0.01) V. If the reading fluctuates, then it may be necessary to take a number of readings and do a mean and range calculation.

UNCERTAINTIES IN GIVEN VALUES

The value of the charge on an electron is given in the data sheet as 1.60×10^{-19} C.

In all such cases assume the uncertainty to be ±1 in the last significant digit. In this case the uncertainty $\pm 0.01 \times 10^{-19}$ C. The uncertainty may be lower than this but without knowing the details of the experiment and procedure that lead to this value there is no evidence to assume otherwise.

Example:

If the number of lines per m is quoted as 3.5×10^3, it is usual to assume that the uncertainty is ±1 in the last significant figure, $\pm 0.1 \times 10^3$ since there is no indication of the uncertainties in the measurements from which that figure came.

MULTIPLE INSTANCES OF MEASUREMENTS

Some methods of measuring involve the use of multiple instances in order to reduce the uncertainty. For example, measuring the thickness of several sheets of paper together rather than one sheet, or timing several swings of a pendulum. The uncertainty of each measurement will be the uncertainty of the whole measurement divided by the number of sheets or swings. This method works because the absolute uncertainty on the time for a single swing is the same as the absolute uncertainty for the time taken for multiple swings, but there is a lower percentage in the time taken for multiple swings.

Example:

Time taken for a pendulum to swing 10 times: (5.1 ± 0.1) s

Mean time taken for one swing: (0.51 ± 0.01) s

REPEATED MEASUREMENTS

Repeating a measurement is a method for reducing the uncertainty.

With many readings one can also identify those that are exceptional (that are far away from a significant number of other measurements). Sometimes it will be appropriate to remove outliers from measurements before calculating a mean. On other occasions, particularly in Biology, outliers are important to include. For example, it is important to know that a particular drug produces side effects in one person in a thousand.

If measurements are repeated, the uncertainty can be calculated by finding half the range of the measured values.

For example:

Repeat	1	2	3	4
Distance/m	1.23	1.32	1.27	1.22

1.32 – 1.22 = 0.10 therefore

Mean distance: (1.26 ± 0.05) m

PERCENTAGE UNCERTAINTIES

The percentage uncertainty in a measurement can be calculated using:

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

The percentage uncertainty in a repeated measurement can also be calculated using:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{mean value}} \times 100\%$$

Further examples:

Example 1. Some values for diameter of a wire

Repeat	1	2	3	4
Diameter/mm	0.35	0.37	0.36	0.34

The exact values for the mean is 0.36 mm and for the uncertainty is 0.015 mm.

This could be quoted as such or recorded as 0.36 ±0.02 mm given that there is a wide range and only 4 readings. Given the simplistic nature of the analysis then giving the percentage uncertainty as 5% or 6% would be acceptable.

Example 2. Different values for the diameter of a wire

Repeat	1	2	3
Diameter/mm	0.35	0.36	0.35

The mean here is 0.35 mm with uncertainty of 0.005 mm.

The percentage uncertainty is 1.41% so may be quoted as 1% but really it would be better to obtain further data.

UNCERTAINTIES IN EXAMS

Wherever possible, questions in exams will be clear on whether students are being asked to calculate the uncertainty of a reading, a measurement, or given data.

Where there is ambiguity, mark schemes will allow alternative sensible answers and credit clear thinking.

It is important that teachers read the reports on the examination following each series to understand common mistakes to help their students improve in subsequent years.

UNCERTAINTIES IN PRACTICAL WORK

Students are expected to develop an understanding of uncertainties in measurements through their practical work.

ERROR BARS IN PHYSICS

There are a number of ways to draw error bars. Students are not expected to have a formal understanding of confidence limits in Physics (unlike in Biology). The following simple method of plotting error bars would therefore be acceptable:

- plot the data point at the mean value
- calculate the range of the data, ignoring any anomalies
- add error bars with lengths equal to half the range on either side of the data point.

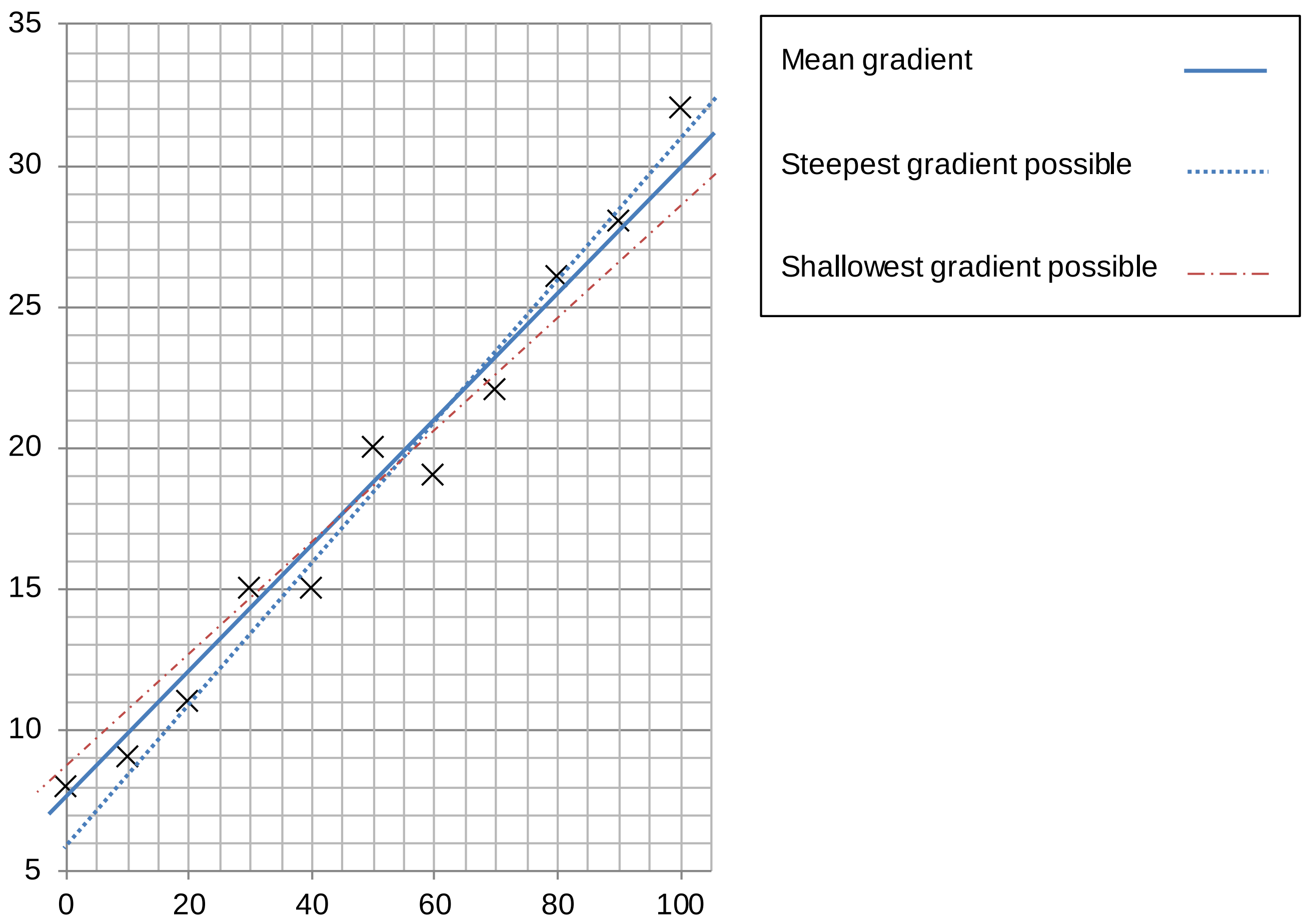
UNCERTAINTIES FROM GRADIENTS

To find the uncertainty in a gradient, two lines should be drawn on the graph. One should be the "best" line of best fit. The second line should be the steepest or shallowest gradient line of best fit possible from the data. The gradient of each line should then be found.

The uncertainty in the gradient is found by:

$$\text{percentage uncertainty} = \frac{1}{2}\left(\frac{\text{steeper gradient - shallowest gradient}}{\text{mean gradient}}\right)$$

Note the modulus bars meaning that this percentage will always be positive.



In the same way, the percentage uncertainty in the y-intercept can be found:

$$\text{percentage uncertainty} = \frac{1}{2}\left(\frac{\text{greatest intercept -smallest intercept}}{\text{mean intercept}}\right)$$

COMBINING UNCERTAINTIES

Percentage uncertainties should be combined using the following rules:

Combination	Operation	Example
Adding or subtracting values $a = b + c$	Add the absolute uncertainties $\Delta a = \Delta b + \Delta c$	Object distance, *u* = (5.0 ± 0.1) cm Image distance, *v* = (7.2 ± 0.1) cm Difference (*v* – *u*) = (2.2 ± 0.2) cm
Multiplying values $a = b \times c$	Add the percentage uncertainties $\varepsilon a = \varepsilon b + \varepsilon c$	Voltage = (15.20 ± 0.1) V Current = (0.51 ± 0.01) A Percentage uncertainty in voltage = 0.7% Percentage uncertainty in current = 1.96% Power = Voltage × current = 7.75 W Percentage uncertainty in power = 2.66% Absolute uncertainty in power = ± 0.21 W
Dividing values $a = \frac{b}{c}$	Add the percentage uncertainties $\varepsilon a = \varepsilon b + \varepsilon c$	Mass of object = (30.2 ± 0.1) g Volume of object = (18.0 ± 0.5) cm^3 Percentage uncertainty in mass of object = 0.3 % Percentage uncertainty in volume = 2.8% Density = $\frac{30.2}{18.0}$ = 1.68 g cm^{-3} Percentage uncertainty in density = 3.1% Absolute uncertainty in density = ± 0.05 g cm^{-3}
Power rules $a = b^c$	Multiply the percentage uncertainty by the power $\varepsilon a = c \times \varepsilon b$	Radius of circle = (6.0 ± 0.1) cm Percentage uncertainty in radius = 1.6% Area of circle = πr^2 = 113.1 cm^2 Percentage uncertainty in area = 3.2% Absolute uncertainty = ± 3.6 cm^2 (Note – the uncertainty in π is taken to be zero)

Note: Absolute uncertainties (denoted by Δ) have the same units as the quantity.

Percentage uncertainties have no units.

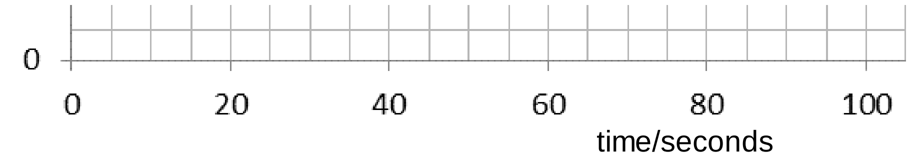
Uncertainties in trigonometric and logarithmic functions will not be tested in A-level exams.

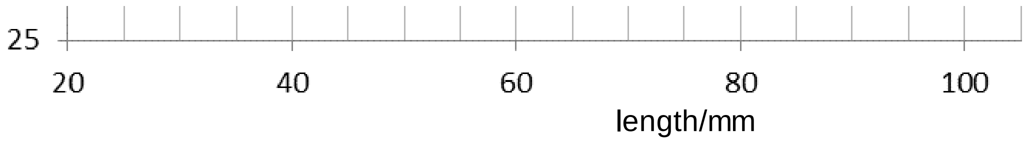
GRAPHING

Graphing skills can be assessed in the written papers for the International AS and A-level grade. Students should recognise that the type of graph that they draw should be based on an understanding of the type of data they are using and the intended analysis of the data. The rules below are guidelines which will vary according to the specific circumstances.

LABELLING AXES

Axes should always be labelled with the variable being measured and the units. These should be separated with a forward slash (solidus):





Axes should not be labelled with the units on each scale marking.

DATA POINTS

Data points should be marked with a cross. Both × and + marks are acceptable, but care should be taken that data points can be seen against the grid.

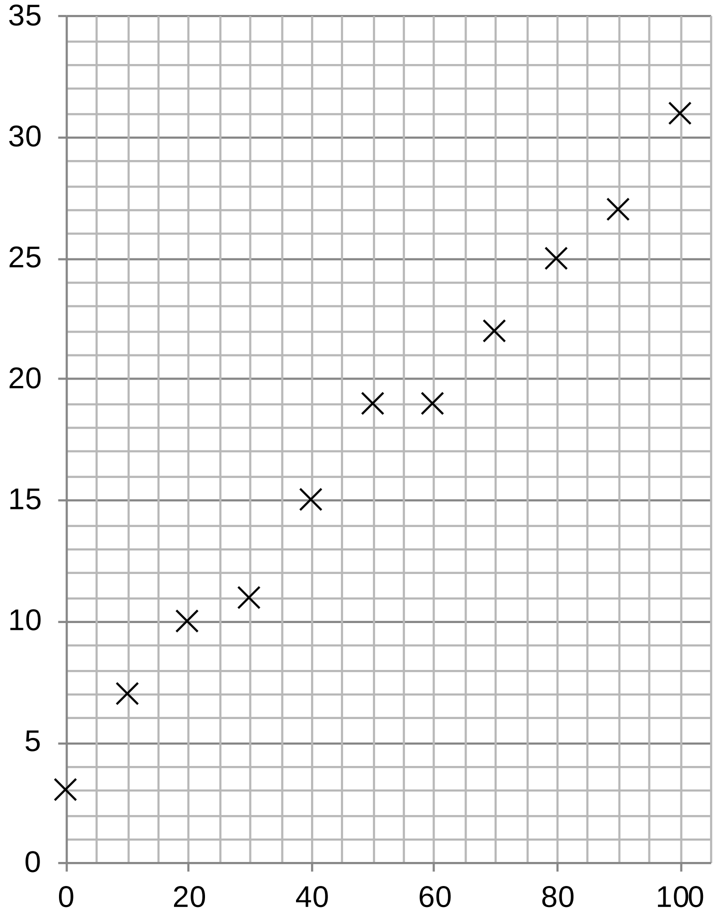
Error bars, standard deviation and ranges can take the place of data points where appropriate.

SCALES AND ORIGINS

Students should attempt to spread the data points on a graph as far as possible without resorting to scales that are difficult to deal with. Students should consider:

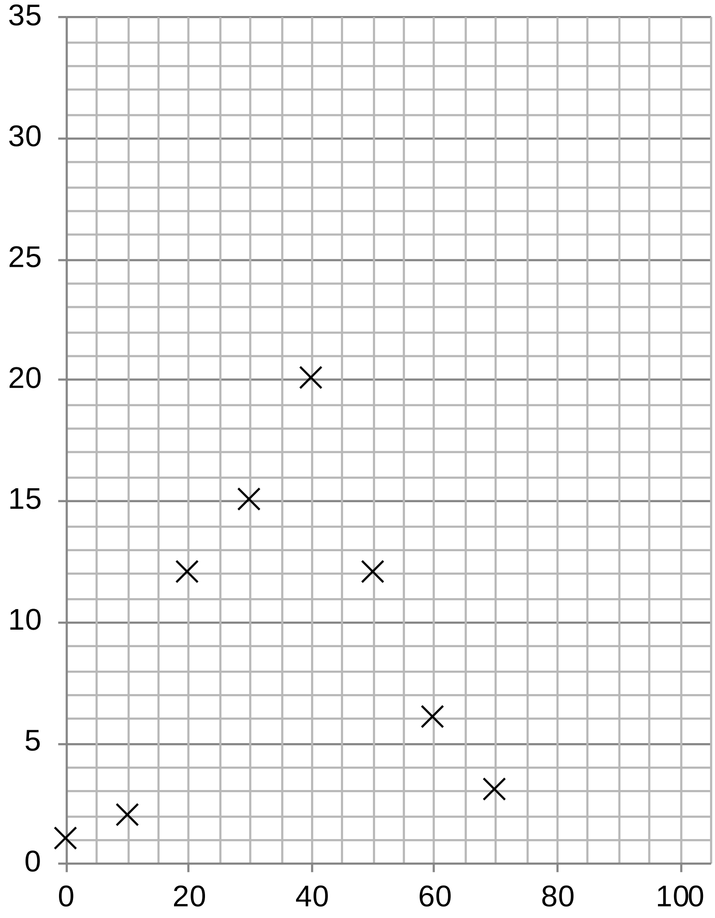
- the maximum and minimum values of each variable
- the size of the graph paper
- whether 0.0 should be included as a data point
- whether they will be attempting to calculate the equation of a line, therefore needing the y intercept (Physics only)
- how to draw the axes without using difficult scale markings (eg multiples of 3, 7, 11 etc)
- in exams, the plots should cover **at least half** of the grid supplied for the graph.

Please note that in the Uncertainties and Graphing sections, many generic graphs are used to illustrate the points made. For example, the following three graphs are intended to illustrate the information above relating to the spread of data points on a graph. **Students producing such graphs on the basis of real practical work or in examination questions would be expected to add in axes labels and units.**

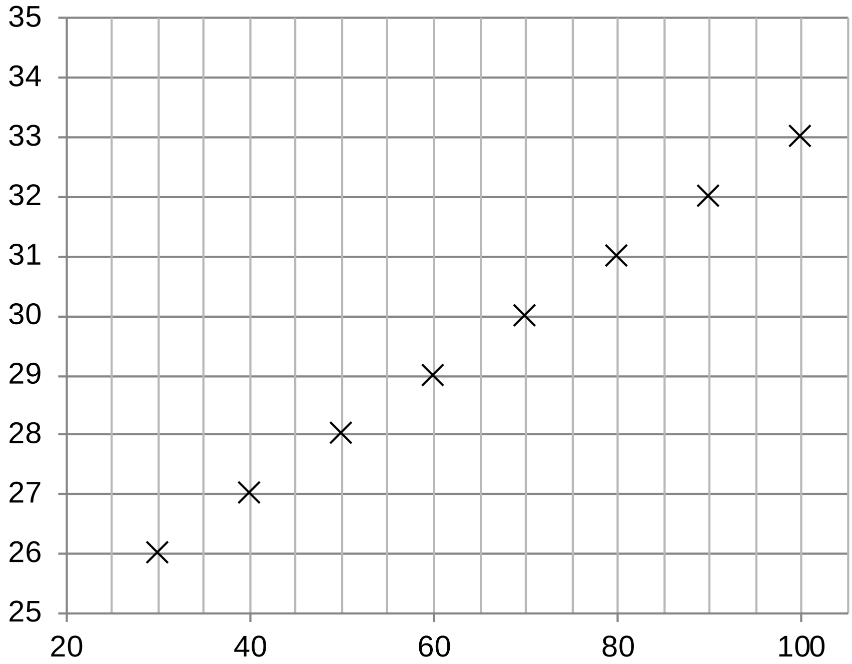


This graph has well-spaced marking points and the data fills the paper.

Each point is marked with a cross (so points can be seen even when a line of best fit is drawn).



This graph is on the limit of acceptability. The points do not quite fill the page, but to spread them further would result in the use of awkward scales.



At first glance, this graph is well drawn and has spread the data out sensibly.

However, if the graph were to later be used to calculate the equation of the line, the lack of a y-intercept could cause problems. Increasing the axes to ensure all points are spread out but the y-intercept is also included is a skill that requires practice and may take a couple of attempts.

LINES OF BEST FIT

Lines of best fit should be drawn when appropriate. Students should consider the following when deciding where to draw a line of best fit:

- Are the data likely to be following an underlying equation (for example, a relationship governed by a physical law)? This will help decide if the line should be straight or curved.
- Are there any anomalous results?
- Are there uncertainties in the measurements? The line of best fit should fall within error bars, if drawn.

There is no definitive way of determining where a line of best fit should be drawn. A good rule of thumb is to make sure that there are as many points on one side of the line as the other. Often the line should pass through, or very close to, the majority of plotted points. Graphing programs can sometimes help, but tend to use algorithms that make assumptions about the data that may not be appropriate.

Lines of best fit should be continuous and drawn as a thin pencil that does not obscure the points below and does not add uncertainty to the measurement of gradient of the line.

Not all lines of best fit go through the origin. Students should ask themselves whether a 0 in the independent variable is likely to produce a 0 in the dependent variable. This can provide an extra and more certain point through which a line must pass. A line of best fit that is expected to pass through (0,0), but does not, would imply some systematic error in the experiment. This would be a good source of discussion in an evaluation.

DEALING WITH ANOMALOUS RESULTS

At International GCSE, students are often taught automatically to ignore anomalous results. At International AS and A-level, students should think carefully about what could have caused the unexpected result and therefore whether it is anomalous. A student might be able to identify a reason for the unexpected result and so validly regard it as an anomaly. For example, an anomalous result might be explained by a different experimenter making the measurement, a different solution or a different measuring device being used. In the case where the reason for an anomalous result occurring can be identified, the result should be recorded and plotted but may then be ignored.

Anomalous results should also be ignored where results are expected to be the same.

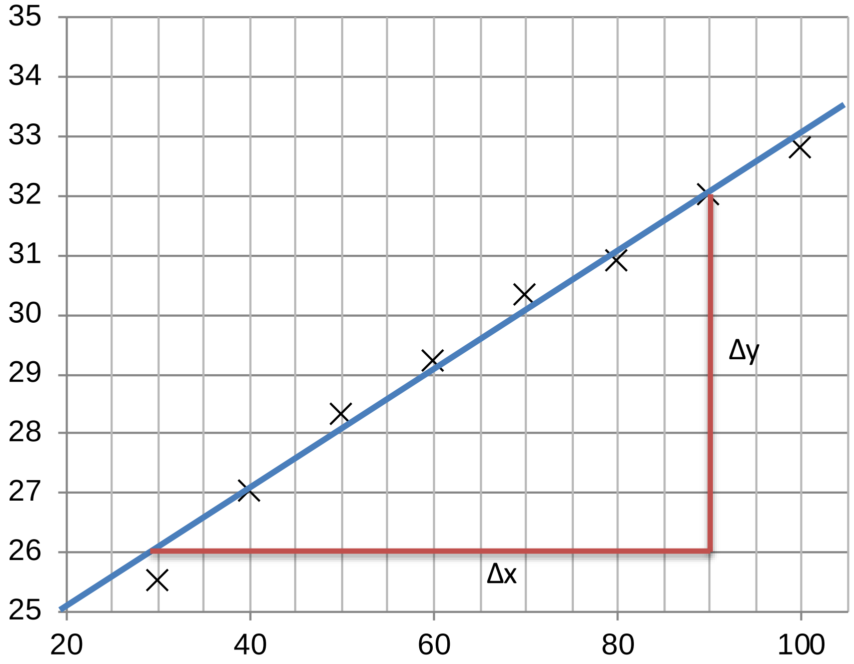
Where there is no obvious error and no expectation that results should be the same, anomalous results should be included. This will reduce the possibility that a key point is being overlooked.

Please note: when recording results it is important that all data are included. Anomalous results should only be ignored at the data analysis stage.

It is best practice whenever an anomalous result is identified for the experiment to be repeated. This highlights the need to tabulate and even graph results as an experiment is carried out.

MEASURING GRADIENTS

When finding the gradient of a line of best fit, students should show their working by drawing a triangle on the line. The hypotenuse of the triangle should be at least half as big as the line of best fit.



The line of best fit here has an equal number of points on both sides. It is not too wide so points can be seen under it.

The gradient triangle has been drawn so the hypotenuse includes more than half of the line.

In addition, it starts and ends on points where the line of best fit crosses grid lines so the points can be read easily (this is not always possible).

$$\boldsymbol{gradient} = \frac{\Delta \boldsymbol{y}}{\Delta \boldsymbol{x}}$$

When finding the gradient of a curve, eg the rate of reaction at a time that was not sampled, students should draw a tangent to the curve at the relevant value of the independent variable (x-axis).

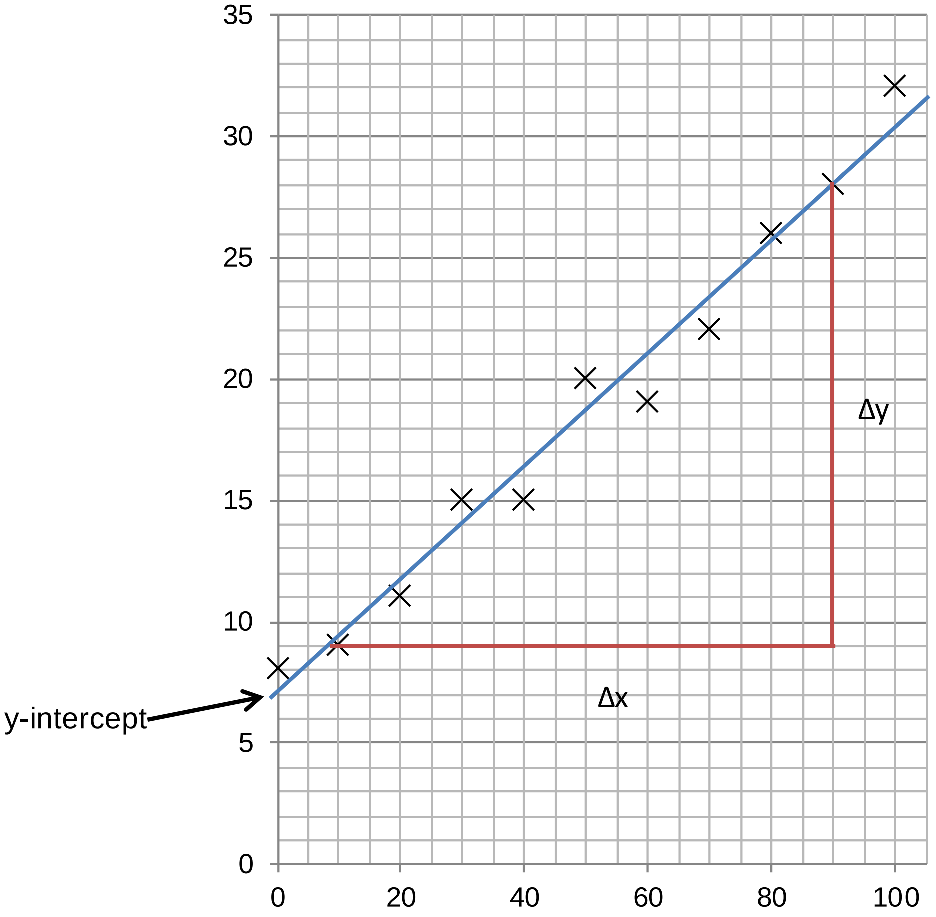
Use of a set square to draw a triangle over this point on the curve can be helpful in drawing an appropriate tangent.

THE EQUATION OF A STRAIGHT LINE

Students should be able to translate graphical data into the equation of a straight line.

$$y = mx + c$$

Where y is the dependent variable, m is the gradient, x is the independent variable and c is the y-intercept.



Δy = 28 – 9 = 19

Δx = 90 – 10 = 80

gradient = 19 / 80 = 0.24 (2 sf)

y-intercept = 7.0

equation of line:

y = 0.24x + 7.0

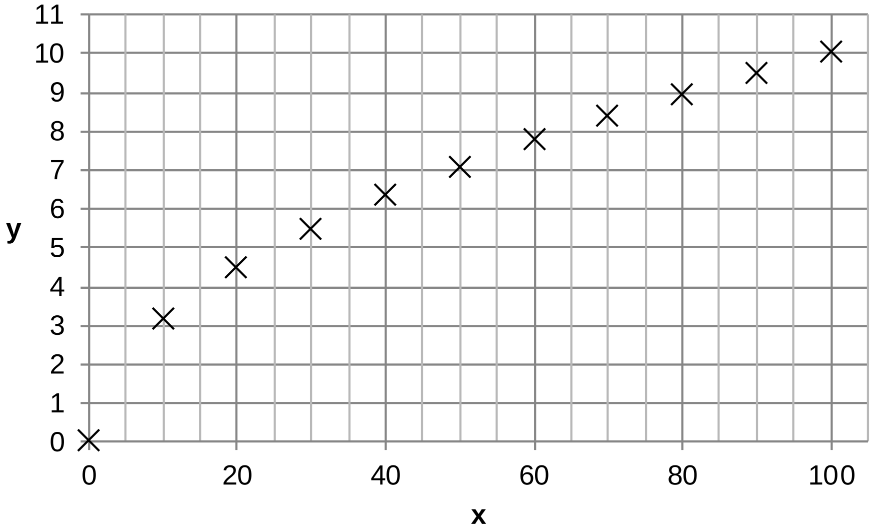
TESTING RELATIONSHIPS

Sometimes it is not clear what the relationship between two variables is. A quick way to find a possible relationship is to manipulate the data to form a straight line graph from the data by changing the variable plotted on each axis.

For example:

Raw data and graph

x	y
0	0.00
10	3.16
20	4.47
30	5.48
40	6.32
50	7.07
60	7.75
70	8.37
80	8.94
90	9.49
100	10.00

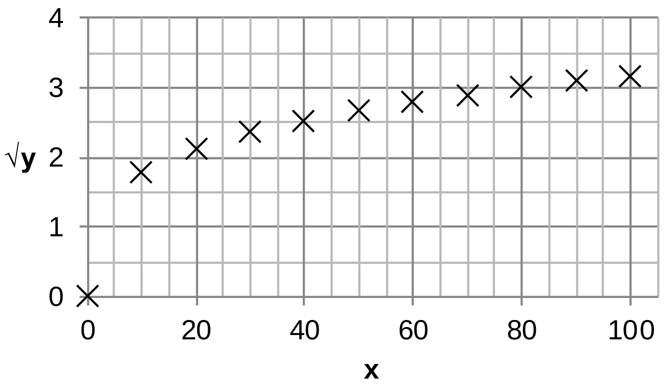


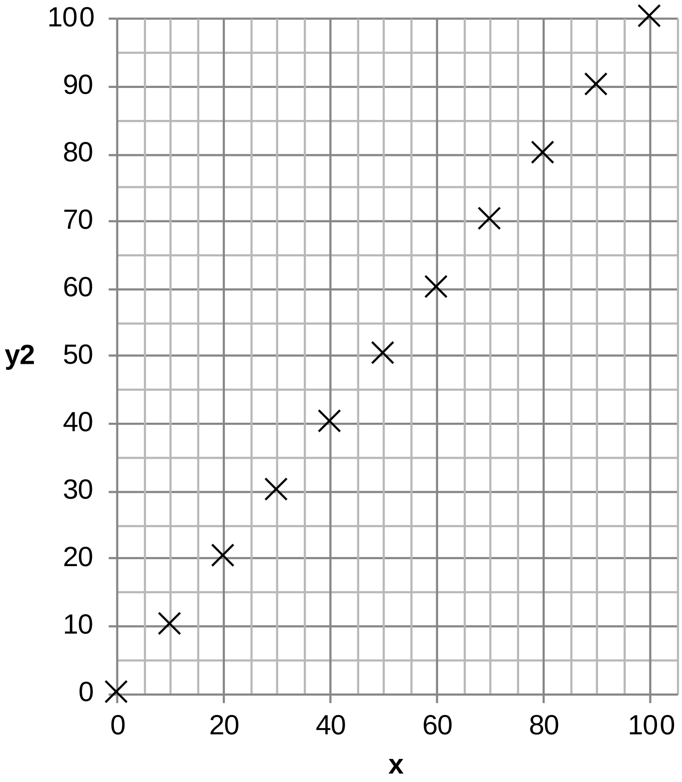
This is clearly not a straight line graph. The relationship between x and y is not clear.

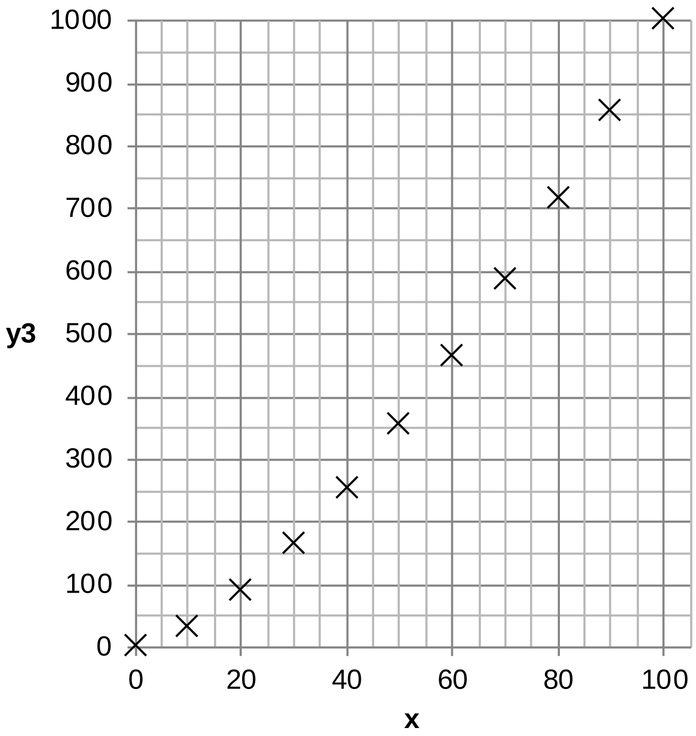
MANIPULATED DATA AND GRAPHS

A series of different graphs can be drawn from these data. The one that is closest to a straight line is a good candidate for the relationship between x and y.

x	y	$\sqrt{y}$	y^2	y^3
0	0.00	0.00	0.00	0.00
10	3.16	1.78	10.00	32
20	4.47	2.11	20.00	89
30	5.48	2.34	30.00	160
40	6.32	2.51	40.00	250
50	7.07	2.66	50.00	350
60	7.75	2.78	60.00	470
70	8.37	2.89	70.00	590
80	8.94	2.99	80.00	720
90	9.49	3.08	90.00	850
100	10.00	3.16	100.00	1000







This is an idealised set of data to illustrate the point.

The straightest graph is y^2 against x, suggesting that the relationship between x and y is

$$y^2 \propto x$$

MORE COMPLEX RELATIONSHIPS

Graphs can be used to analyse more complex relationships by rearranging the equation into a form similar to y=mx+c.

Example one

When water is displaced by an amount l in a U tube, the time period, T, varies with the following relationship:

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

This could be used to find g, the acceleration due to gravity.

- Take measurements of T and l.
- Rearrange the equation to become linear:

$$T^2 = 4\pi^2\frac{l}{2g}$$

- Calculate T^2 fr each value of l.
- By re-writing the equation as:

$$T^2 = \frac{4\pi^2}{2g}\mathrm{l}$$

It becomes clear that a graph of T^2 against l will be linear with a gradient of $\frac{4\pi^2}{2g}$.

- Calculate the gradient (m) by drawing a triangle on the graph.
- Find g by rearranging the equation $m = \frac{4\pi^2}{2g}$ into $g = \frac{4\pi^2}{2m} = \frac{2\pi^2}{m}$

Example two: testing power laws

A relationship is known to be of the form $y=Ax^n$, but n is unknown.

Measurements of y and x are taken.

A graph is plotted with log(y) plotted against log(x).

The gradient of this graph will be n, with the y intercept log(A), as log(y) = n(log(x)) + log(A)

Example three

The equation that relates the pd, *V*, across a capacitor, *C*, as it discharges through a resistor, *R*, over a period of time, *t*.

$$V = V_0 e^{-\frac{t}{RC}}$$

Where V_o = pd across capacitor at *t* = 0

This can be rearranged into

$$\ln V = -\frac{t}{RC} + lnV_o$$

So a graph of lnV against t should be a straight line, with a gradient of $-\frac{1}{RC}$ and a y-intercept of lnV_o

USE OF MIRRORS

It is possible to use mirrors in class to draw lines of best fit. However, mirrors are **not** allowed to be used in exams.

SUBJECT SPECIFIC VOCABULARY

THE LANGUAGE OF MEASUREMENT

The following subject specific vocabulary provides definitions of key terms used in our International AS and A-level science specifications.

ACCURACY

A measurement result is considered accurate if it is judged to be close to the true value.

CALIBRATION

Marking a scale on a measuring instrument.
This involves establishing the relationship between indications of a measuring instrument and standard or reference quantity values, which must be applied.
For example, placing a thermometer in melting ice to see whether it reads 0 °C, in order to check if it has been calibrated correctly.

DATA

Information, either qualitative or quantitative, that has been collected.

ERRORS

See also uncertainties.

Measurement error
The difference between a measured value and the true value.

Anomalies
These are values in a set of results which are judged not to be part of the variation caused by random uncertainty.

Random error
These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next.

Random errors are present when any measurement is made, and cannot be corrected. The effect of random errors can be reduced by making more measurements and calculating a new mean.

Systematic error
These cause readings to differ from the true value by a consistent amount each time a measurement is made.
Sources of systematic error can include the environment, methods of observation or instruments used.

Systematic errors cannot be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

Zero error

Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero, eg the needle on an ammeter failing to return to zero when no current flows. A zero error may result in a systematic uncertainty.

EVIDENCE

Data which has been shown to be valid.

FAIR TEST

A fair test is one in which only the independent variable has been allowed to affect the dependent variable.

HYPOTHESIS

A proposal intended to explain certain facts or observations.

INTERVAL

The quantity between readings, eg a set of 11 readings equally spaced over a distance of 1 metre would give an interval of 10 centimetres.

PRECISION

Precise measurements are ones in which there is very little spread about the mean value.

Precision depends only on the extent of random errors – it gives no indication of how close results are to the true value.

PREDICTION

A prediction is a statement suggesting what will happen in the future, based on observation, experience or a hypothesis.

RANGE

The maximum and minimum values of the independent or dependent variables; important in ensuring that any pattern is detected.
For example a range of distances may be quoted as either:

'from 10 cm to 50 cm' or 'from 50 cm to 10 cm'

REPEATABLE

A measurement is repeatable if the original experimenter repeats the investigation using same method and equipment and obtains the same results.

REPRODUCIBLE

A measurement is reproducible if the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained.

RESOLUTION

This is the smallest change in the quantity being measured (input) of a measuring instrument that gives a perceptible change in the reading.

SKETCH GRAPH

A line graph, not necessarily on a grid, that shows the general shape of the relationship between two variables. It will not have any points plotted and although the axes should be labelled they may not be scaled.

TRUE VALUE

This is the value that would be obtained in an ideal measurement.

UNCERTAINTY

The interval within which the true value can be expected to lie, with a given level of confidence or probability, eg “the temperature is 20 °C ± 2 °C, at a level of confidence of 95%.

VALIDITY

Suitability of the investigative procedure to answer the question being asked. For example, an investigation to find out if the rate of a chemical reaction depended upon the concentration of one of the reactants would not be a valid procedure if the temperature of the reactants was not controlled.

VALID CONCLUSION

A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning.

VARIABLES

These are physical, chemical or biological quantities or characteristics.

Categoric variables
Categoric variables have values that are labels, eg names of plants or types of material.

Continuous variables
Continuous variables can have values (called a quantity) that can be given a magnitude either by counting (as in the case of the number of shrimp) or by measurement (eg light intensity, flow rate etc).

Control variables
A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation and therefore has to be kept constant or at least monitored.

Dependent variables
The dependent variable is the variable of which the value is measured for each and every change in the independent variable.

Independent variables
The independent variable is the variable for which values are changed or selected by the investigator.

Nominal variables
A nominal variable is a type of categoric variable where there is no ordering of categories (eg red flowers, pink flowers, blue flowers)

REQUIRED PRACTICAL ACTIVITIES: EXEMPLAR EXPERIMENTS

During the development of our International AS and A-levels in Biology, Chemistry and Physics, we have spoken to hundreds of teachers. Teachers helped us to develop every part of the specification, including its contents and layout, what is examined in which paper and the question types we include. Teachers also helped us to decide which practical activities to include in our required practicals for each subject.

Teachers asked us for full, comprehensive instructions on how to carry out each of the 10 required practicals. In response, we have included a **sample** method for each practical in this section. These have been prepared so that a reasonably equipped school can cover the required activity with their students. It gives **one possible version** of the experiment that teachers could use. They will help inform planning the laboratory time required and help schools ensure they have the right equipment. Many are based on existing tasks as we know that they work well and schools have been using them for a number of years in the current AQA UK specifications.

This document should only be seen as a starting point. We do not intend to stifle innovation and would encourage teachers to try different methods. Students will not be examined on the specific practical work exemplified within this section but on the skills and understanding they build up through their practical work. Teachers can vary all experiments to suit their and their students' needs.

SAFETY

At all times, the teacher is responsible for safety in the classroom. Teachers should intervene whenever they see unsafe working. Risk assessments should be carried out before working, and advice from CLEAPSS and other organisations should be followed.

It is appropriate to give students at International AS and A-level more independence when making decisions about safety. They should be taught how to assess risks and how to write risk assessments when appropriate. They should also understand the appropriate use of safety equipment and how to put measures in place to reduce risks.

To support teachers further, Mary Philpott, Biology Adviser, previously from CLEAPSS, outlines the difference between identification of major hazards, associated risk and control measures and a full risk assessment:

The risk assessment should always be complete, as it is this that prevents injury or ill-health.

The risk assessment is fundamentally the **thinking** that has taken place before and during an activity, so that any foreseeable risk is reduced to a minimum. A written record is necessary only to show that the thinking has taken place.

We tend to get caught up in the paperwork that provides evidence for the risk assessment, but the guidance from the Health and Safety Executive is that the written record should be on a **point-of-use document** and there is no particular form etc that needs to be filled in.

The tables/forms etc that many schools use are simply planning documents that the teachers use to provide the point of use risk assessment for each of their lessons. Incidentally, CLEAPSS members must refer to our current advice when preparing their point-of-use documents.

The student is not responsible for their risk assessment. In a large part, therefore, the student's risk assessment will be that they carry through the safety measures that the teacher has put in place. It is therefore fine if the student makes a note on their point-of use document that shows they have thought about how to behave safely, and carried it through. The teacher will also be able to record what they have seen in a practical that shows that the student's risk assessment is effective. For example, the student's written risk assessment could be as simple as making notes on a method sheet about where they will put on eye protection or how they will arrange any heating equipment so that there is a minimum risk of scalding or burning themselves or the person next to them.

The teacher's observation notes will refer to whether they have carried out their written plans.

It might help the students to think safely if the teacher gives them a little time at the start of each practical to highlight or make notes about the safety aspects, and a class discussion about safety could show up any safety aspects that perhaps the teacher had not considered.

The students may also note where they have reminded other students about any safety issues.

If the students are planning their own practical activities, they could use the safety advice given in the CLEAPSS Student Safety Sheets.

In this case, they could identify hazards, risks and control measures.

In this case, they would make their own point of use document, with the control measures clearly identified.

The teacher would need to check that the risk assessment is adequate before they let the students proceed with the activity.

These are examples of 10 experiments that can be done as part of the International AS/A-level Physics course. The methods are written using commonly used reagents and techniques, although teachers can modify the methods and reagents as desired.

TRIALLING

All practicals should be trialled before use with students.

RISK ASSESSMENT AND RISK MANAGEMENT

Risk assessment and risk management are the responsibility of the centre.

Safety is the responsibility of the teacher and the centre. It is important that students are taught to act safely in the laboratory at all times, including the wearing of goggles at all times and the use of additional safety equipment where appropriate.

NOTES FROM CLEAPSS

Technicians/teachers should follow CLEAPSS guidance, particularly that found on Hazcards and recipe sheets. The worldwide regulations covering the labelling of reagents by suppliers are currently being changed. Details about these changes can be found in leaflet GL101, which is available on the CLEAPSS website. You will need to have a CLEAPSS login.

INTERNATIONAL AS AND A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 1

Determination of *g* by a freefall method. Procedures should include determination of *g* from graph (eg from graph of *s* against t^2).

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

MATERIALS AND EQUIPMENT

- stand and clamp
- electromagnet
- low voltage variable DC supply (to power the electromagnet)
- $2\ \mathrm{kg}$ mass
- steel ballbearing
- two light gates with bosses to attach them to the stand
- an electronic clock or data logger with precision $1\ \mathrm{ms}$ or better.
- a pad (eg of felt) to protect the bench when the ballbearing lands.
- metre ruler.

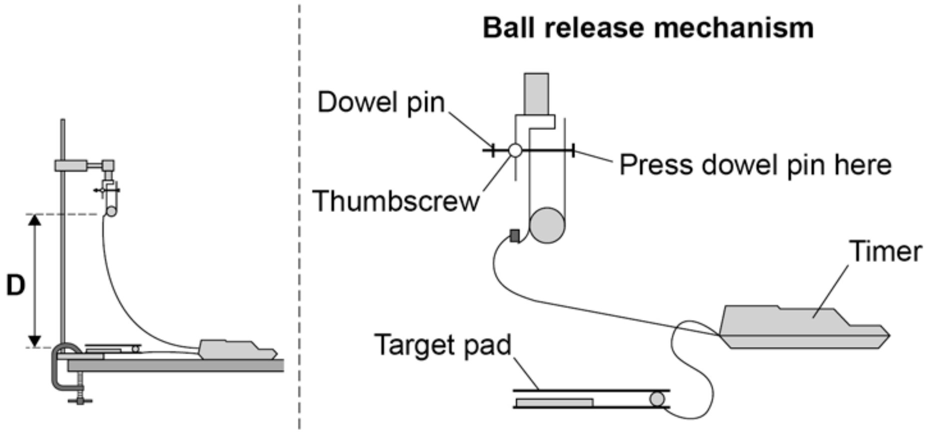
TECHNICAL INFORMATION

- The electromagnet is a convenient way of releasing the ballbearing.
- The low voltage supply should be set at the voltage specified by the manufacturer for the electromagnet.
- The supply is switched on and the ballbearing hung from the electromagnet. It will then be released when the supply is switched off.
- Several trials and adjustments will be required to ensure the ballbearing falls directly through the light gates. A plumb line can be used to make sure that the ball bearing will fall through both light gates and hit the pad.
- A mechanical release mechanism could be used (eg holding the ballbearing in the clamp which is opened to release the ball bearing, but this is not as quick to reset, and won't give as clean a release).
- The upper light gate should be connected to the clock or data logger to start the timing.

  The lower gate should be connected to stop the timing.
- The $2\ \mathrm{kg}$ mass is used as a counterweight to ensure the stand does not topple over (an alternative would be to clamp the stand to the bench using a G-clamp).

ADDITIONAL NOTE

If students have no access to light gates, they can use the same method but with a slightly different arrangement of apparatus:



Once the ball bearing is released, the stopclock starts measuring the time. When the ball bearing hits the pad, it triggers the micro switch and stops the stopclock.

SAMPLE RESULTS

The table below shows sample readings for 'g' by free fall:

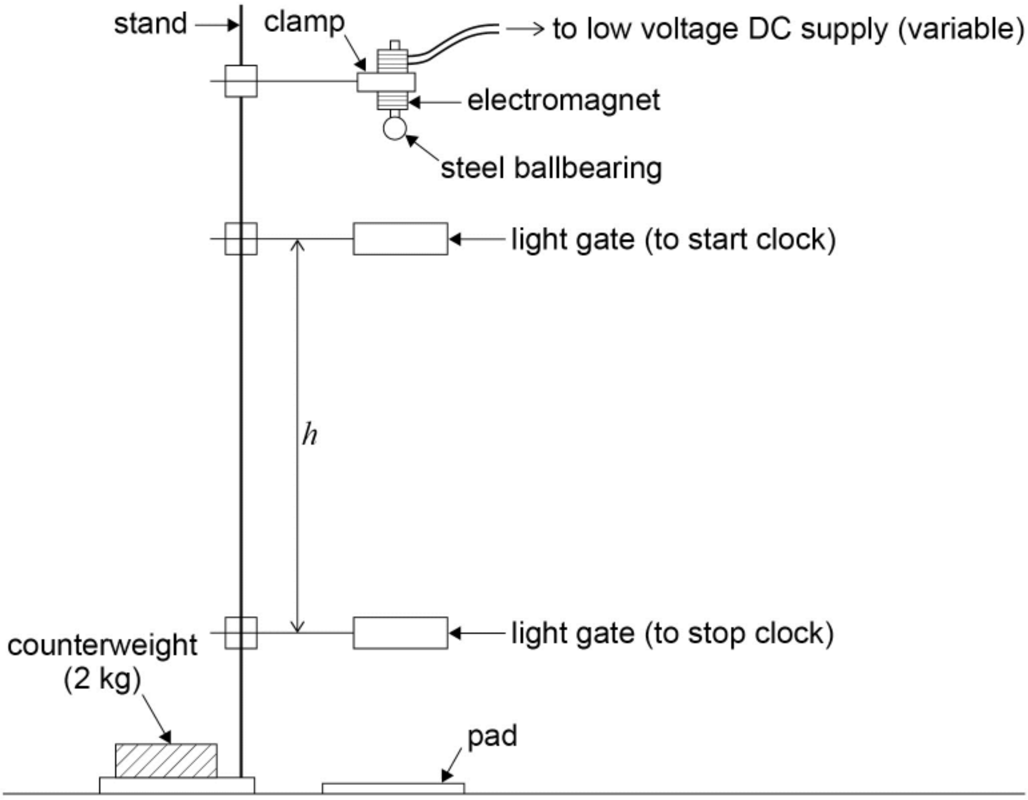
h / m	t / s	g / m s^{-2}
1.35	0.50	10.80
1.10	0.45	10.90
0.85	0.40	10.60
0.65	0.35	10.60

Determination of *g* by a freefall method. Procedures should include determination of *g* from graph (eg from graph of *s* against t^2).

STUDENT SHEET

Method

- Set up the apparatus as shown in the diagram.



- The height between the starting position of the ballbearing and the upper light gate should be kept constant, so that the velocity, *u*, with which the ballbearing reaches this light gate is also constant.
- Adjust the position of the lower light gate so that *h* is 0.500 m measured using the metre ruler (If a taller stand is available, *h* could be set at a higher starting value).
- Switch on the supply to the electromagnet, and hang the ballbearing from it (or fit the ballbearing into the clamp if a mechanical release mechanism is being used).
- Reset the clock or data logger to zero and switch off the electromagnet (or open the clamp).
- Read the time on the clock or data logger once the ballbearing has passed through the light gates.
- Take repeat readings to find the mean time, *t*.
- Reduce *h* by 0.050 m and repeat the procedure down to a value of 0.250 m (lower values than this make it difficult to obtain accurate timings).

- Plot a graph of $2h/t$ against t.
- Draw the best straight line of fit though the points and find the gradient (the graph should be a straight line with intercept $2u$).

$h = ut + gt^2/2$

Re-arranging

$2h/t = gt + 2u$

Hence the gradient of the graph gives g in $\mathrm{m s^{-2}}$

The intercept will be $2u$.

INTERNATIONAL AS AND A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 2

Investigation of load-extension graph for a wire and determination of the Young modulus for the material of the wire.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

MATERIALS AND EQUIPMENT

- ceiling beam or suitably strong fixing to attach loaded wires
- 2 × 1.5 m lengths of steel wire (eg 0.45 mm diameter mild steel wire)
- scale and vernier arrangement with integral clamps for the wires
- micrometer screw gauge
- metre ruler
- 2 × slotted kg mass holders
- selection of 0.5 kg and 1 kg slotted masses
- safety goggles (in case wire breaks)
- sand tray (to catch masses if wire breaks).

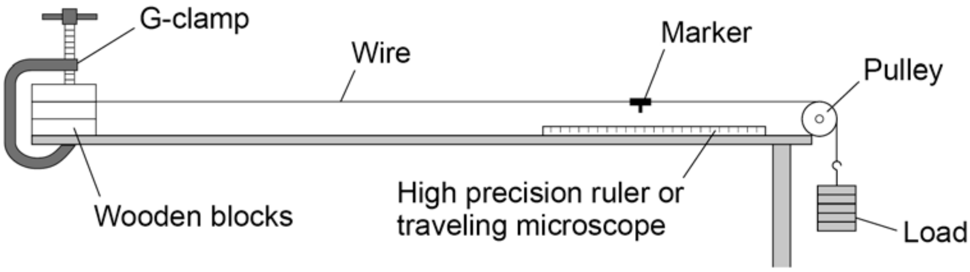
TECHNICAL INFORMATION

- It is important that the steel wire used is completely free from kinks – otherwise any measured ‘extension’ will partly be due to the straightening out of the kinks. Scientific equipment suppliers produce suitable wires for this experiment. They also supply suitable clamps to attach the wires to the ceiling beam, vernier-scale arrangement and mass holder.
- A 1 kg mass will produce an extension of 0.47 mm for a 1.5 m steel wire of diameter 0.45 mm. Consequently an accurate measurement of extension requires specialised apparatus. The mm scale and vernier arrangement is one designed specifically for this experiment – the vernier is attached to, and slides alongside the main scale. The main mm scale is usually clamped to the comparison wire and the vernier section clamped to the test wire.
- The main safety consideration is the possibility of the wire breaking. Goggles should be worn and a sand tray placed underneath the arrangement to catch the falling masses.
- The comparison wire compensates for sagging of the beam and thermal expansion effects, and provides a reference point against which to measure the extension of the loaded test wire.

ADDITIONAL NOTES

- When stretching a wire horizontally, Tippex or a small dressmaker pin could be used as a marker.
- For the horizontal version of the experiment, use 2 m of 32SWG copper wire (400 g mass should produce an extension of about 1 mm).

Searle's apparatus is very precise, but sometimes there is not enough room in the classroom to install a full class set. Similar results could be achieved using a horizontal version and traveling microscope, as shown below. If traveling microscopes are not available, high precision rulers could be used (0.5 mm precision).



SAMPLE RESULTS

The table below sample readings for a wire stretched horizontally across a bench using a traveling microscope.

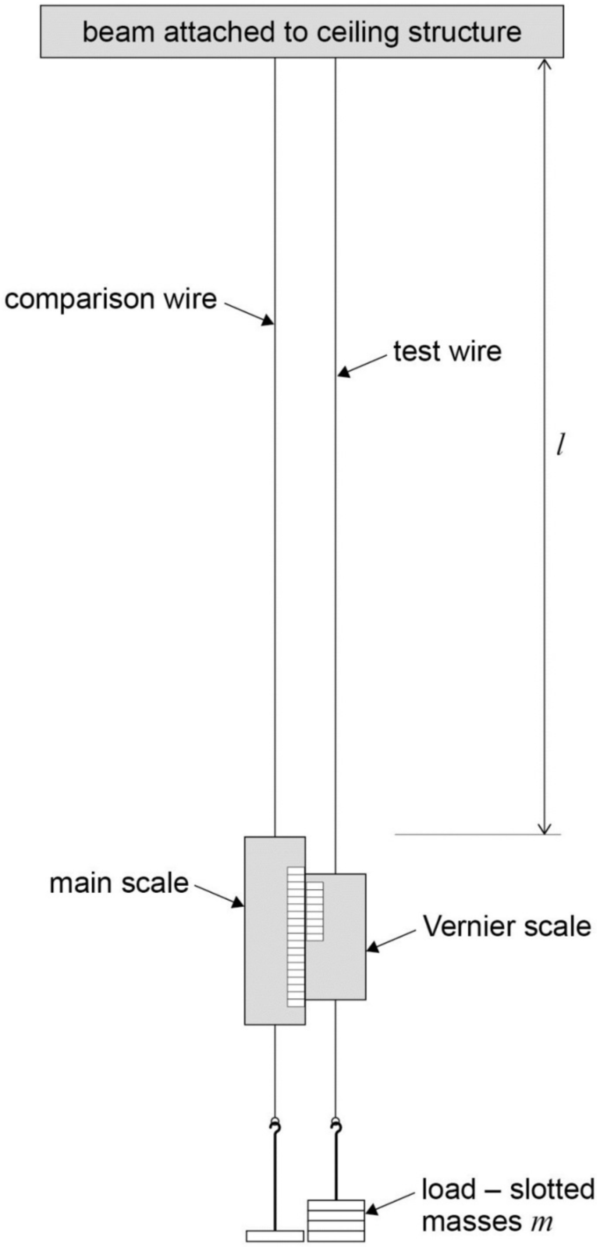
	L **= 2.4 m**		**d = 0.274 mm**					
m **/ kg**	0.200	0.400	0.600	0.800	1.000	1.200	1.400	1.600
ΔL / mm	0.5	1.0	1.6	2.1	2.7	3.5	4.0	5.0
E / GPa	133.2	133.2	124.8	126.8	123.3	114.1	116.5	106.5

Investigation of load-extension graph for a wire and determination of the Young modulus for the material of the wire.

STUDENT SHEET

METHOD

- Set up the apparatus as shown in the diagram. Ensure all the wire clamps are fully tightened. Details of wire clamps are **not** shown on this diagram

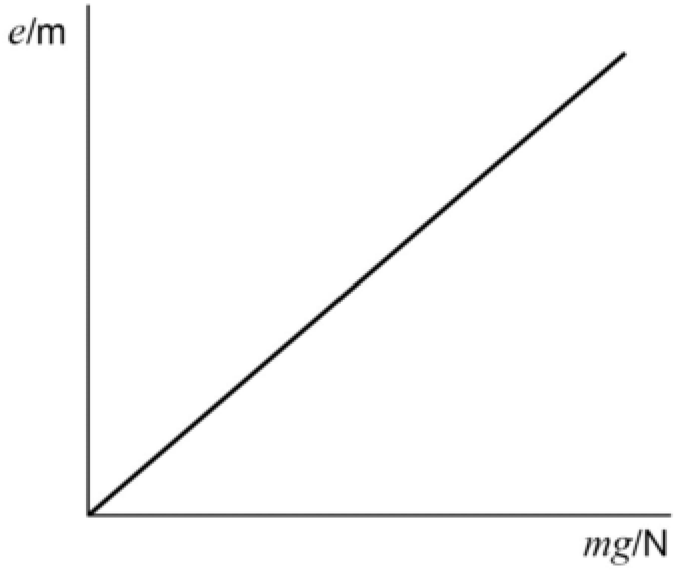


- Measure the initial length of the test wire, *l*, with the metre ruler.
- A 1 kg mass hanger is initially attached to each wire, to ensure both wires are initially stretched taught.
- Take the initial scale reading, using the vernier scale to read to 0.1 mm.
- Add an additional 1 kg (or 0.5 kg) mass to the test wire and take the new scale reading using the vernier. The extension of the wire can be calculated by subtracting the two scale readings.
- Repeat the process, adding an extra 1 kg mass (or 0.5 kg) mass each time, take the new scale reading and calculate the corresponding extension. A total mass of up to 8 kg should be adequate.
- With the wire full loaded remove a 1 kg mass and take the scale reading.
- Continue to unload the wire, 1 kg at a time, taking the scale reading each time.
- The extension of the wire for each mass during the unloading process can then be calculated. If the extension during unloading is greater than during loading, the elastic limit for the wire might have been exceeded. If the extension values are similar a mean extension for loading /unloading can be calculated for each mass.
- Measure the diameter of the wire at several places using a micrometer screw gauge.
- Plot a graph of mean extension, e, on the y-axis against load, mg. (where g = 9.81 N/kg)
- The Young Modulus for the material of the wire (steel) can be calculated using the gradient of the graph.
- Estimate the uncertainty in your values of *l, A, e* and *m*. Use the values to estimate the overall uncertainty in the value obtained for Youngs Modulus.

$$\text{Young modulus } E = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{mg/A}{e/L} = \frac{mgL}{Ae} = \frac{L}{A \times \text{gradient}}$$

***A* = cross sectional area of wire**

***L* = initial length of wire**



INTERNATIONAL AS AND A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 3

Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of a cell or battery with current.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

MATERIALS AND EQUIPMENT

- cell or battery whose internal emf and internal resistance is being investigated. Avoid using rechargeable cells or batteries as these have a very low internal resistance, making it difficult to measure and they can deliver high currents or short circuit
- Cell holder (or suitable connectors for cell/battery used)
- variable resistor (eg a large wire wound rheostat is suitable)
- digital voltmeter (eg 0–10 V)
- digital ammeter (eg 0–1 A)
- switch
- connecting leads.

TECHNICAL INFORMATION

- Ideally the cells and/or batteries used should be fairly new. The emf and internal resistance of older, 'run down', cells will vary during the experiment. It is advisable to switch off the circuit between readings to avoid the cells/batteries running down.
- Ensure that the power rating of the variable resistor is adequate for the maximum current used.

Photographs of an exemplar set-up of this practical can be found in our set-up guide, which is available on our A-level Practicals page.

SAMPLE RESULTS

The table below shows sample readings for a 1.5 V D-cell with rheostat set to minimum and maximum resistance.

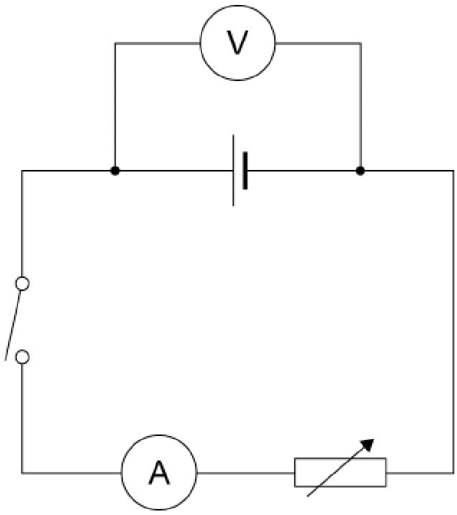
V / V	*I* / mA
1.58	70.00
1.52	180.00

So EMF = 1.62 V and r = 0.54 **Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of a cell or battery with current.**

STUDENT SHEET

METHOD

- Set up the circuit as shown in the diagram. Set the variable resistor at its maximum value.



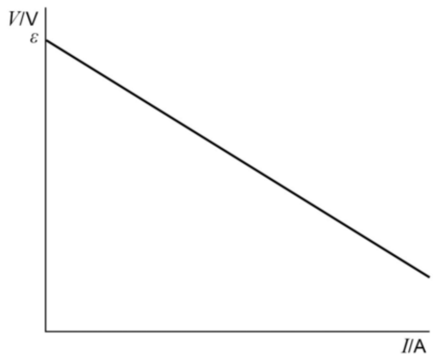
- With the switch open record the reading, V, on the voltmeter.
- Close the switch and take the readings of pd, V, on the voltmeter and current, I, on the ammeter.
- Adjust the variable resistor to obtain pairs of readings of V and I, over the widest possible range.
- Open the switch after each pair of readings. Only close it for sufficient time to take each pair of readings.
- Plot a graph of V on the y-axis against I.

Using $\varepsilon = I\,(R+r)$ and $V = I\,R$

Gives $\varepsilon = V + I\,r$

Rearranging $V = \varepsilon - I\,r$

A graph of V against I will have a gradient = - r and an intercept ε on the y-axis.



EXEMPLAR FOR REQUIRED PRACTICAL 4

Investigation into simple harmonic systems using a mass-spring system and a simple pendulum.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

Simple pendulum to investigate how the time period varies with length and to measure *g*

MATERIALS AND EQUIPMENT

- pendulum bob
- approximately 1.5 m string or thread
- two small wooden blocks to clamp the string
- stand, boss and clamp
- pin and Blu-Tack to use as fiducial mark
- metre ruler
- stopclock (reading to 0,01 s)

TECHNICAL INFORMATION

This is a standard laboratory experiment which can be used to give an accurate value for the acceleration due to gravity. For accurate results it is important the pendulum oscillates with small amplitude and in a straight line.

SAMPLE RESULTS

The table below shows sample readings for the pendulum and the mass-spring:

Pendulum	Spring
$L = 1.3\ \mathrm{m}$	$m = 400\ \mathrm{g}$
$T_{10} = 23.4\ \mathrm{s}$	$T_{10} = 7.8\ \mathrm{s}$
$g = 10.1\ \mathrm{m\ s^{-2}}$	$k = 27.3\ \mathrm{N\ m^{-1}}$

Mass-spring system

TEACHER AND TECHNICIAN SHEET

MATERIALS AND EQUIPMENT

- helical spring
- 100 g slotted mass hanger
- 100 g slotted masses
- stand, boss and clamp
- pin and Blu-Tack to use as fiducial mark
- metre ruler
- stopclock (reading to 0,01 s)

TECHNICAL INFORMATION

Expendable springs (with k approximately $25\ \mathrm{Nm^{-1}}$) are suitable for this experiment, together with a range of slotted masses from 0–800 g.

SAMPLE RESULTS

The table below shows sample readings for the pendulum and the mass-spring.

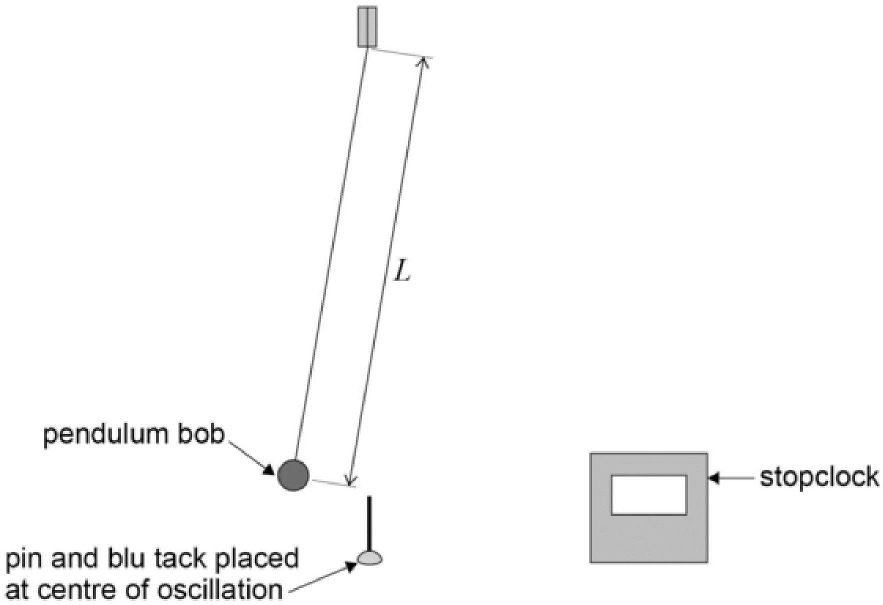
Pendulum	Spring
$L = 1.3\ \mathrm{m}$	$m = 400\ \mathrm{g}$
$T_{10} = 23.4\ \mathrm{s}$	$T_{10} = 7.8\ \mathrm{s}$
$g = 10.1\ \mathrm{m\ s^{-2}}$	$k = 27.3\ \mathrm{N\ m^{-1}}$

Investigation into simple harmonic systems using a simple pendulum.

STUDENT SHEET

METHOD

- Attach the pendulum bob to the string and clamp it between two small wooden blocks.

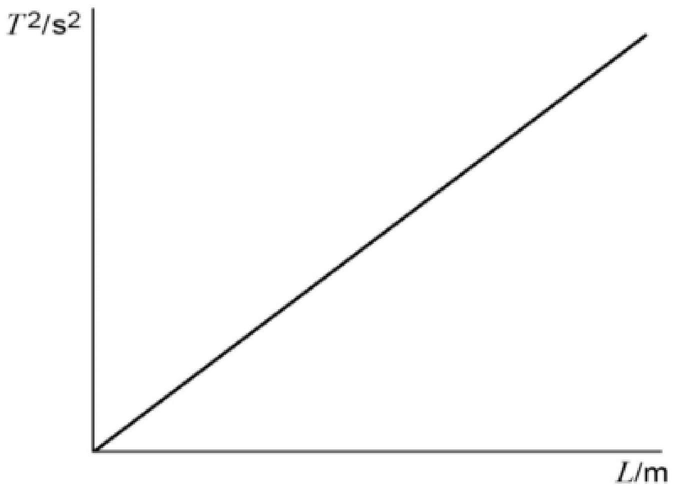


- Measure the length, L, of the pendulum from the point of suspension to the centre of mass of the pendulum bob. (It might be easier to measure to the top of the pendulum bob and then add on the radius of the bob to give L.)
- The pendulum should be suspended from the stand as shown, with a pin and Blu-Tack acting as a fiducial marker, placed immediately below the pendulum bob. This will be at the centre of the oscillation when the pendulum oscillates.
- Carefully pull the pendulum bob to the side and release it. The pendulum should oscillate with **small amplitude and in a straight line**. Check that it continues in a straight line by viewing the oscillation from the side – if not stop it and start the oscillation again.
- Determine the time period of the simple pendulum by timing 10 complete oscillations.
- Take repeat readings of the time for 10 oscillations, T_{10}.
- Change the length of the pendulum and repeat the process to determine the time period.
- Determine the time period of the pendulum for at least seven different lengths, L.
- Tabulate your data, including columns for L, T_{10}, repeat values of T_{10}, mean value of T_{10}, time period for one oscillation T, and an additional column for T^2.
- Plot a graph of T^2 on the *y*-axis against L. A straight line through the origin verifies that T^2 is proportional to L.
- Measure the gradient of the graph and use it to determine a value for the acceleration due to gravity, g.
- Estimate the uncertainty in your values of L and T. Hence estimate the uncertainty in the value of g.

SIMPLE PENDULUM

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

gives $T^2 = \frac{4\pi^2 L}{g}$ hence $g = \frac{4\pi^2}{\text{gradient}}$

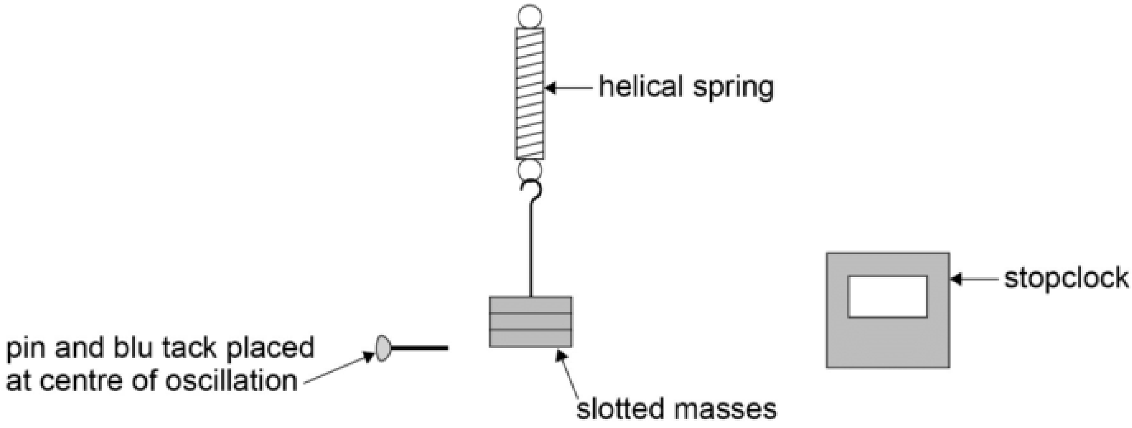


Investigation into simple harmonic systems using a mass-spring system.

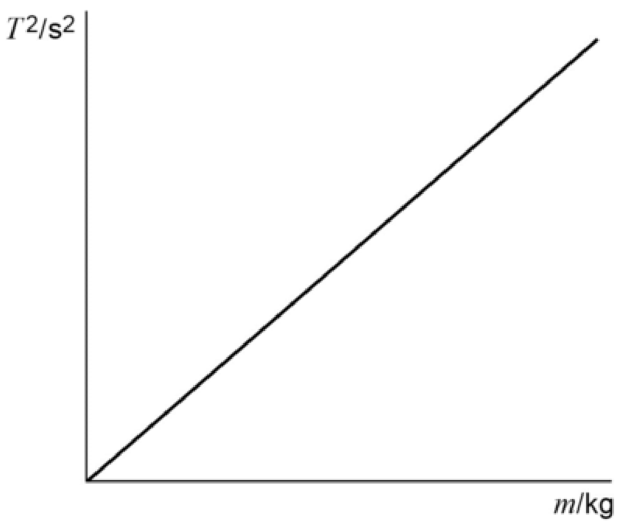
STUDENT SHEET

METHOD

- Hang the spring from a clamp and attach the 100 g mass hanger. Ensure the spring is securely attached from its support.



- Position the Blu-Tack and pin, acting as a fiducial marker, at the bottom of the mass as a reference point. This will represent the centre of the subsequent oscillations.
- Pull the mass hanger vertically downwards a few centimetres and release. The spring should oscillate vertically up and down.
- Determine the time period of the mass-spring system by timing 10 complete oscillations.
- Take repeat readings of the time for 10 oscillations, T_{10}. Use the values of T_{10} to find the time period for one oscillation, T.
- Add a 100 g mass to the mass hanger and repeat the timing process to enable the time period of the oscillations to be found.
- Repeat the experiment with a range of different masses, m, and for each mass determine the corresponding time period, T.
- Plot a graph of T^2 on the y-axis against m.



- A straight line through the origin will confirm the relationship between T and m predicted by SHM theory ie $T^2 = \frac{4\pi^2 m}{k}$ where k is the spring constant or stiffness of the spring.
- The gradient of the graph can be used to determine k

$$T^2 = \frac{4\pi^2 m}{k} \qquad \text{hence} \qquad k = \frac{4\pi^2}{gradient}$$

- Estimate the uncertainty in T and m. Hence find the uncertainty in k.

INTERNATIONAL AS AND A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 5

Investigation of interference effects to include Young's slit experiment and interference by a diffraction grating.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

Young's slit experiment

MATERIALS AND EQUIPMENT

- laser – class II optical laser with output 1 mW or less
- darkened slide with double slit 'rulings' (usually 1 mm slit separation)
- vernier callipers to measure slit separation
- adjustable single slit (might be unnecessary with the laser)
- white screen (wall covered with white paper may be suitable but paper must be matt finish or non-reflective to reduce chances of reflected beams)
- metre ruler.

TECHNICAL INFORMATION

Using a laser for this experiment makes it possible to produce visible interference fringes in a partially darkened laboratory. Ensure lasers are used safely and set up so they are not pointed directly into anyone's eyes.

SAMPLE RESULTS

The table below shows sample readings for the Young double slit experiment:

s = 0.1 mm		
***D* / m**	***w* / mm**	***λ* / nm**
1.50	9.42	628.00
1.30	8.21	631.50
1.00	6.27	627.00
0.90	5.66	628.90
0.70	4.44	634.30
0.50	3.11	622.00

Diffraction with a plane transmission diffraction grating at normal incidence.

TEACHER AND TECHNICIAN SHEET

MATERIALS AND EQUIPMENT

- laser – class II optical laser with output 1 mW or less
- plane transmission diffraction grating
- white screen (wall covered with white paper may be suitable but paper must be matt finish or non-reflective to reduce chances of reflected beams)
- metre ruler.

SAMPLE RESULTS

The table below shows sample readings for the diffraction grating experiment:

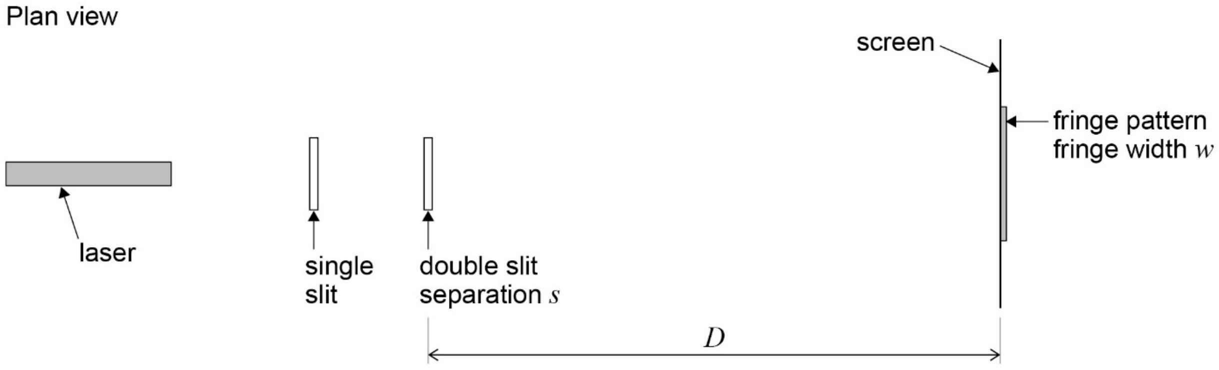
D **= 1.09 m**			
n	***h*** **/ mm**	**tan** θ	λ **/ nm**
1	68.20	0.06	624.50
2	138.40	0.13	629.80
3	208.60	0.19	626.60
4	282.40	0.26	627.00

Investigation of interference effects to include Young's slit experiment and interference by a diffraction grating.

STUDENT SHEET

METHOD

- A partially darkened laboratory is required ensuring lasers are used safely.
- Set up the apparatus as shown in the diagram, with the laser illuminating the double slit and the screen a distance *D* of initially about 1 metre. (With the laser the single slit might not be required, provided the laser beam is wide enough to illuminate across the double slit).



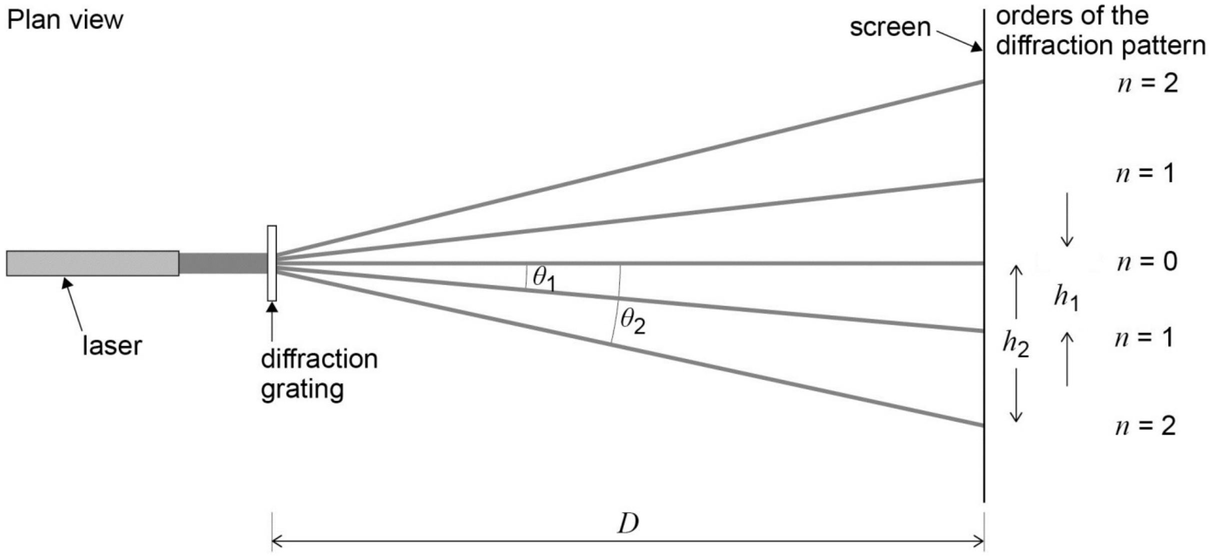
- Carefully adjust the position of the laser until the light spreads evenly over the two slits. An interference pattern should be visible on the screen.
- The fringe width (or fringe spacing), *w*, can be measured by measuring across a large number of visible fringes. (Take care when counting – counting from the first bright fringe to the tenth bright fringe would represent nine fringe widths!).
- Use the metre ruler to measure D.
- A measurement of the slit separation, *s*, is required. The value could be measured with vernier callipers or travelling microscope. If a travelling microscope is used it must only be used to measure slit separation and **not the fringe width**. Alternatively the manufacturer may quote the value on the slide.
- Use the equation $\lambda = \frac{w\,s}{D}$
- Alternatively, the value of *D* could be changed from approximately $0.5\ \mathrm{m}$ to $1.5\ \mathrm{m}$ and the fringe width, *w*, measured for each value of *D*.
- A graph of *w* on the *y*-axis against *D* should be a straight line through the origin, with gradient $= \lambda / s$.

Investigation of interference effects to include Young's slit experiment and interference by a diffraction grating.

STUDENT SHEET

METHOD

- A partially darkened laboratory is required. Please ensure lasers are used safely.
- Set up the apparatus as shown in the diagram, with the laser illuminating the diffraction grating and the screen a distance *D* of initially about 1 metre.



- Carefully adjust the position of the diffraction grating so that the diffraction grating is perpendicular to the beam of light from the laser. (A large set square might be useful).
- The diffraction pattern should be visible on the screen. The number of orders shown will depend on the line spacing of the diffraction grating.
- The angles θ_1 and θ_2 can be determined by measuring the distances h_1 , h_2 and *D*. (This gives the tangent of the angles, and hence the angles can be calculated).
- The formula $n\lambda = d \sin\theta$ can be used to determine the wavelength of the laser light.
  n is the order of the diffraction pattern
  d is the grating spacing = 1/number of lines per metre
  λ is the wavelength of light
- The values of θ for each order, both above and below the zero order, should be measured. A mean value for λ can be calculated from the data.

SINGLE SLIT DIFFRACTION

This arrangement can also be used to illustrate diffraction at a single slit. The diffraction grating is replaced by an adjustable single slit. The effect of 'slit width' can easily be observed.

INTERNATIONAL A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 6

Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, *RC*.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

MATERIALS AND EQUIPMENT

- stopclock
- electrolytic capacitors (suitable values: 1000 μF, 2200 μF, 4700 μF)
- resistors (0.25 W carbon film, values in the range 10 kΩ to 100 kΩ)
- battery 3 V, 6 V or 9 V
- digital voltmeter, range 0–10 V
- SPDT (single pole double throw) switch
- connecting leads.

TECHNICAL INFORMATION

- It is essential that the electrolytic capacitors are connected into the circuit with **correct polarity,** as indicated on the capacitor body. The voltage rating of the capacitor should also be greater than the dc supply used.
- Resistor and capacitor values, indicated above, have been chosen to give a time constant *RC* in the range 10 s to 500 s.

SAMPLE RESULTS

The table below shows sample readings for a 2200 μF capacitor and a 22 kΩ resistor:

Discharge	
***t* / s**	***V* / V**
0.00	9.30
10.00	7.61
20.00	6.13
30.00	4.90
40.00	4.12
60.00	2.98

Charge	
***t* / s**	***V* / V**
3.00	1.00
10.00	3.00
20.00	5.00
58.00	6.00
120.00	6.50

TEACHER AND TECHNICIAN SHEET

MATERIALS AND EQUIPMENT

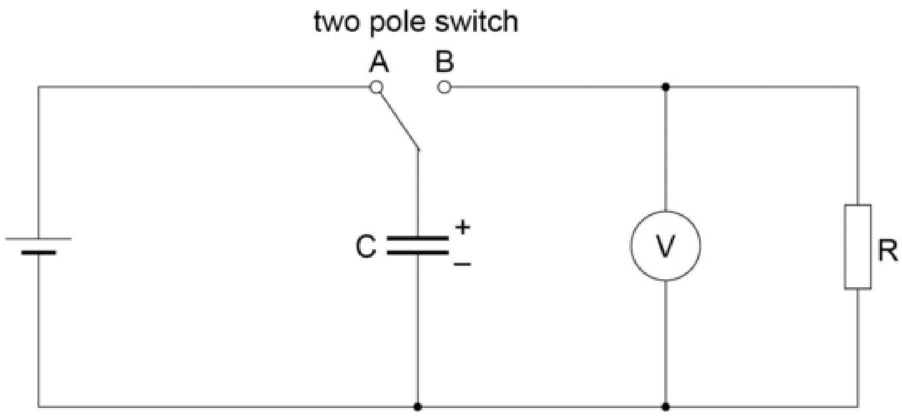
- stopclock
- electrolytic capacitors (suitable values: 1000 µF, 2200 µF, 4700 µF)
- resistors (0.25 W carbon film, values in the range 10 kΩ to 100 kΩ)
- battery 3 V, 6 V or 9 V
- digital voltmeter, range 0–10 V
- SPST (single pole single throw) switch
- connecting leads.

Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant, *RC*.

STUDENT SHEET

METHOD

- Set up the circuit as shown in the diagram (taking care to ensure the polarity of the capacitor is correct).



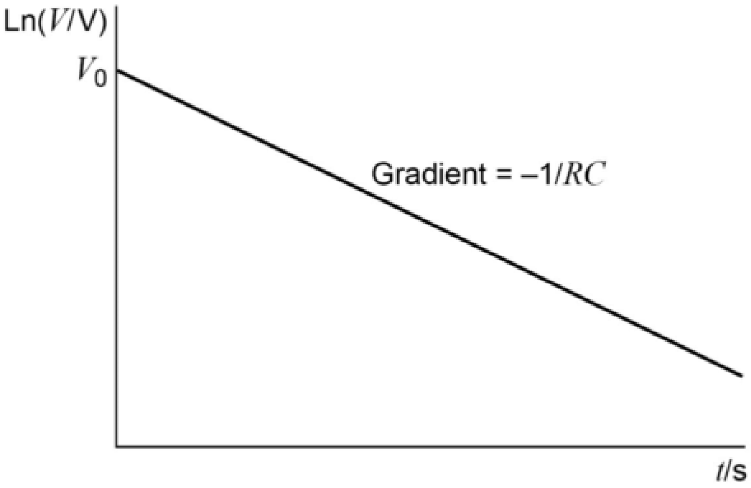
- With the two pole switch in position A the capacitor will charge. The internal resistance of the battery is usually enough to limit the charging current to a safe value, but allowing the capacitor to charge up almost instantly.
- The switch should now be moved to position B so that the capacitor, C, will discharge through the resistor, R. (It is well worth doing a 'trial discharge' at this point, to see how quick the discharge is so that a suitable time interval can be decided when taking voltage readings during the discharge process).
- After the 'trial discharge' move the switch to position A to charge up the capacitor.
- Switch to position B, start the stopclock, and observe and record the voltage reading at time t = 0. Continue to take voltage readings at 5 s intervals as the capacitor discharges. (For a slower discharge, voltage readings at 10 s intervals will be sufficient).
- Repeat the process with the same capacitor and different resistors.
- The process can also be repeated with different capacitors.
- Plot a graph of pd across the capacitor, *V*, on the *y*-axis against time, *t*. This should give an exponential decay curve, as given by the equation $V = V_0 e^{-t/RC}$
- To confirm that this is an exponential, plot a graph of Ln(*V*/V) on the *y*-axis against *t*.

This will give a straight line graph with a negative gradient according to the ‘log form’ of the equation

$$\ln(V) = \ln(V_0) - t/RC$$

This graph will have a gradient of $\frac{-1}{RC}$

Hence, the time constant *RC* can be determined from the gradient of the graph. If *R* is known, the value of *C* can also be found.

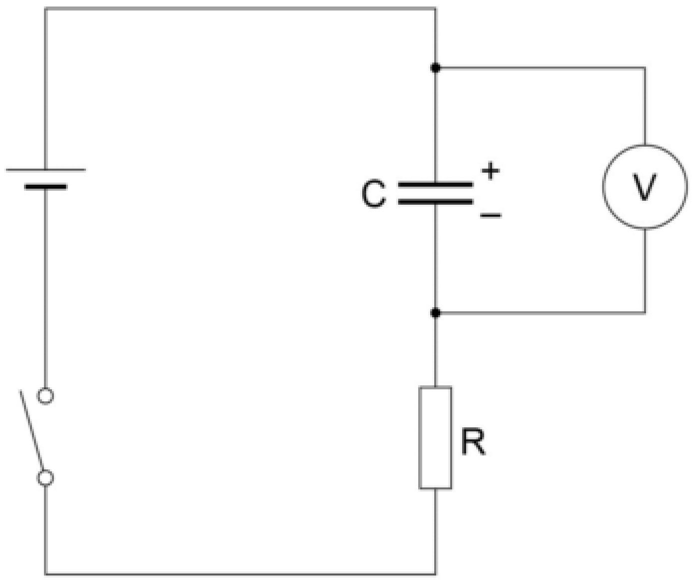


Charging a capacitor through a resistor.

STUDENT SHEET

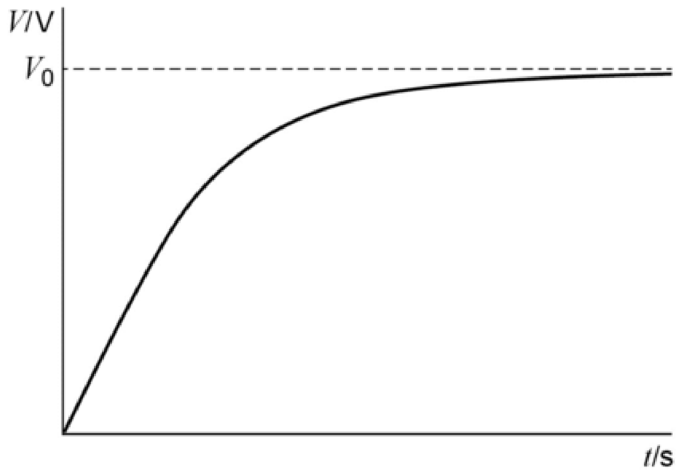
METHOD

- Set up the circuit as shown in the diagram. (Ensure the capacitor is connected with correct polarity). With the switch open and the capacitor initially uncharged, the voltmeter should read zero.



- Close the switch to start the charging process and observe and record the voltage across the capacitor at 5 s intervals (or longer time intervals if the charging process is 'slow').
- Repeat with different combinations of C and R. Ensure the capacitor is completely discharged before starting each new charging process
- Plot graphs of pd, *V*, on the *y*-axis against time, *t.* The graph will show an 'exponential growth' of pd across the capacitor as it charges as given by the equation

$$V = V_0(1\text{-}e^{-t/RC})$$



INTERNATIONAL A-LEVEL PHYSICS
EXEMPLAR FOR REQUIRED PRACTICAL 7

Investigation of the efficiency of a transformer. Investigation of the variation of the efficiency of a simple transformer as the secondary current is altered.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

Investigation of transformer efficiency

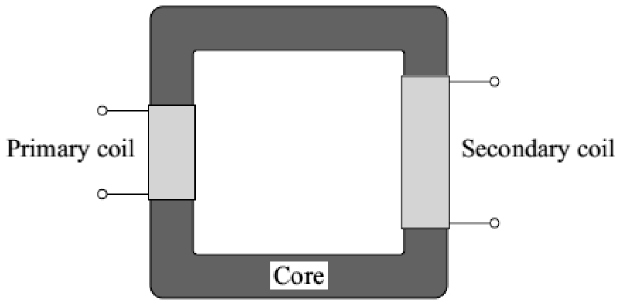
MATERIALS AND EQUIPMENT

- 2 V ac power supply
- double C-core and clip
- 120 + 120 turn coil (2)
- Multimeter to read ac voltage 20 V fsd (2)
- Multimeter to read ac current 5 A fsd (2)
- 16Ω 5 A rheostat
- Leads

TECHNICAL INFORMATION

The transformer is constructed from two 120 + 120 turn coils linked with the double C-core and clip. The coils can be used to form a step-up transformer (120 to 240 turns) or a step-down transformer (240 to 120 turns) and this investigation can be undertaken with either configuration. When the rheostat resistance is set to zero the resistance of the secondary coil will limit the secondary current but students should be instructed not to allow the coils of the transformer to overheat

If the a.c. power supply has internal resistance the primary voltage will decrease as it supplies a larger current.



Investigation of the efficiency of a transformer. Investigation of the variation of the efficiency of a simple transformer as the secondary current is altered.

STUDENT SHEET

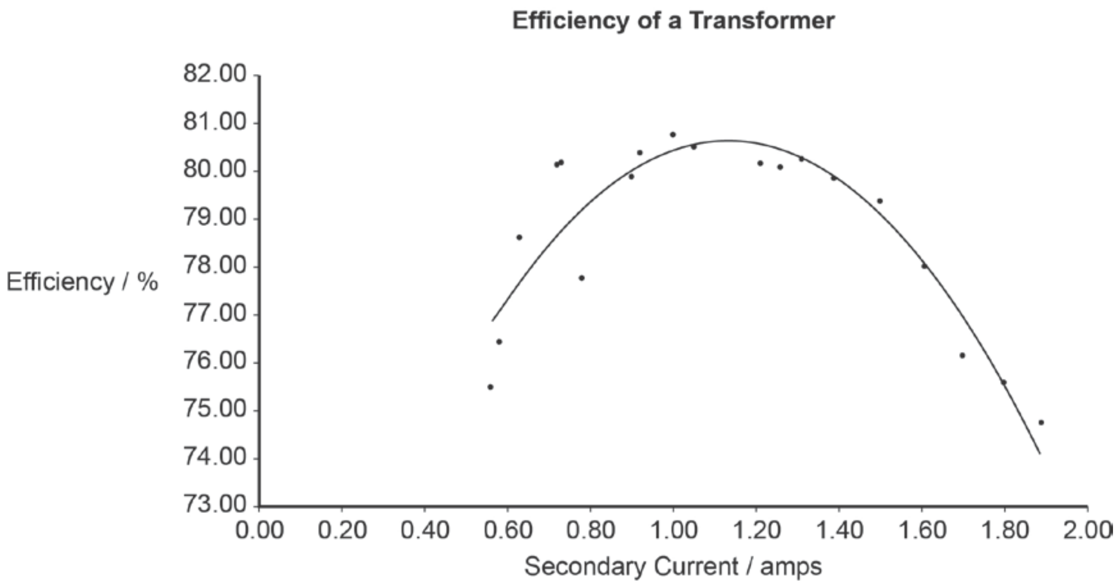
METHOD

- Set the rheostat to maximum resistance
- Set the input to the primary coil to approximately 6 volts if the transformer is being used as a step up transformer and to approximately 12 volts if it is being used as a step down transformer
- Record the primary voltage, V_p, the primary current, I_p, the secondary voltage, V_s, and the secondary current, I_s.
- Adjust the rheostat to reduce its resistance and increase I_s.
- Record the new primary voltage, V_p, primary current, I_p, secondary voltage, V_s, and secondary current, I_s.
- Continue to adjust the rheostat until its resistance is zero and obtain the voltage and current readings.
- Use the meter readings to calculate power delivered to the primary coil, V_p x I_p, and the power delivered to the load, V_s x I_s for each adjustment of the rheostat
- Calculate the efficiency of the transformer.

Efficiency = (power delivered to the transformer/ power supplied to the primary coils) × 100%

- Plot a graph of efficiency (y-axis) against I_s (x-axis)
- List the possible causes of inefficiency in a transformer – iron and copper losses.
- Which of these is more pronounced at high transformer currents and low transformer currents?

V(p)	I(p)	P(in)	V(s)	I(s)	P(out)	Efficiency
volts	amps	watts	Volts	amps	watts	%
12.1	1.79	21.66	21.6	0.78	16.85	77.79
12.0	1.98	23.76	21.1	0.90	18.99	79.92
12.0	1.36	16.32	22.0	0.56	12.32	75.49
11.9	2.01	23.92	20.9	0.92	19.23	80.39
11.9	1.39	16.54	21.8	0.58	12.64	76.44
11.8	2.14	25.25	20.4	1.00	20.40	80.79
11.8	1.46	17.23	21.5	0.63	13.55	78.62
11.7	2.24	26.21	20.1	1.05	21.11	80.53
11.7	1.62	18.95	21.1	0.72	15.19	80.15
11.6	2.55	29.58	19.6	1.21	23.72	80.18
11.6	1.64	19.02	20.9	0.73	15.26	80.20
11.5	2.64	30.36	19.3	1.26	24.32	80.10
11.4	2.72	31.01	19.0	1.31	24.89	80.27
11.3	2.88	32.54	18.7	1.39	25.99	79.87
11.2	3.07	34.38	18.2	1.50	27.30	79.40
11.1	3.29	36.52	17.7	1.61	28.50	78.03
11.0	3.47	38.17	17.1	1.70	29.07	76.16
10.9	3.67	40.00	16.8	1.80	30.24	75.59
10.8	3.84	41.47	16.4	1.89	31.00	74.74



INTERNATIONAL A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 8

Determination of specific heat capacity by an electrical method.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

Measuring specific heat capacity.

MATERIALS AND EQUIPMENT

For metal:

- 12 V immersion heater (typically 60 W)
- 1 kg aluminium or copper or brass blocks
- thermometer, 0 – 100 °C
- power supply, 0 – 12 V rated to supply 6 A
- 4 mm leads
- two digital multimeters
- stop clock

For water:

- 12 V immersion heater (typically 60 W)
- Copper calorimeter with stirrer and insulation
- thermometer, 0 – 100 °C
- power supply, 0 – 12 V rated to supply 6 A
- 4 mm leads
- two digital multimeters
- stop clock
- top pan balance

TECHNICAL INFORMATION

A number of methods may be used depending on the abilities of the students. Certainly you should not feel constrained to use the traditional method with blocks and immersion heaters if other equipment is already available. It might be possible with an able group to introduce a method of mixtures as a final piece of extension material but this would need careful treatment with a simpler method first.

Energy losses are a problem in this experiment. The electrical energy measured going into the heater will be greater than the thermal energy delivered to the block itself (some raises the temperature of the immersion heater and the surroundings) and so the temperature will increase less than expected. The effect this has on their experimental value for the specific heat capacity can be discussed when their result is compared with the data book value.

Impress on students the need to avoid running the immersion heaters outside the blocks, and not to cool them in water.

If you can provide a selection of different metals, it might be interesting to ask groups of students to use different blocks in order to compare values.

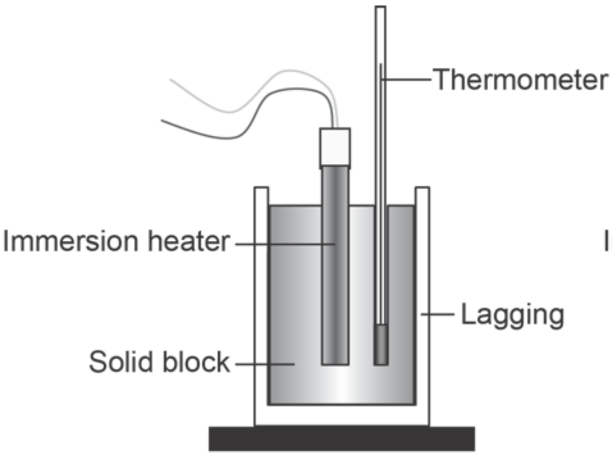


Figure 1(a)

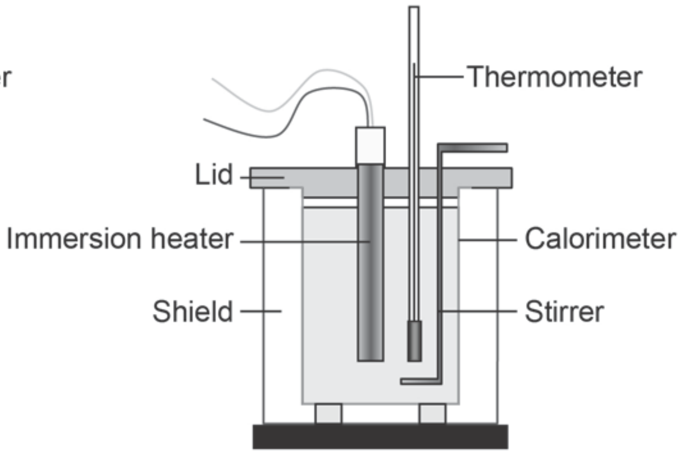


Figure 1(b)

Determination of specific heat capacity by an electrical method.

STUDENT SHEET

METHOD

- Insert a thermometer and the immersion heater into their respective holes in the block. Putting a small amount of oil into the thermometer hole will improve the thermal contact between thermometer and block.
- Allow the thermometer to reach thermal equilibrium with the block and then write down the initial temperature.
- Set up a suitable circuit that will enable you to measure the energy input to the heater.
- The immersion heater is connected in series with a low voltage d.c. power supply and a d.c ammeter. A voltmeter is also connected in parallel with the power supply
- Turn on the current and the stop clock simultaneously.
- Record the voltmeter and ammeter readings as the energy is supplied.
- They may change slightly as components in the circuit warm up so record their values 3 times during the course of the experiment and find their average value.
- Allow the block to heat up by about 10 °C, then turn off the current and stop the stop clock.
- The temperature of the block will continue to rise as heat is conducted through the block. Once the temperature remains constant record this final value
- Calculate the energy supplied to the block using:
  Energy = ΔE= current × potential difference × time.
- Use $\Delta E = mc\,\Delta\theta$ to calculate the specific thermal capacity, c, of your block. The mass of your block will be 1 kg.
- Compare your answer with a data book value.

- The method for water is almost identical but:
  - Measure the mass of water needed to cover the immersion heater
  - Continually stir the water during the experiment to ensure all the water is at the same temperature

- Was your calculated value of specific thermal capacity too high or too low compared with the data book value? Which of the measurements you made is likely to be the one most in error? In which direction is it in error, and why might this be?
- Compare values of the specific heat capacities of different metals and water.
- How could energy losses in this experiment be reduced further?

INTERNATIONAL A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 9

Investigation of Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiments, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

BOYLE'S LAW

MATERIALS AND EQUIPMENT

- stand and clamp
- $10\ \mathrm{ml}$ syringe with $0.5\ \mathrm{ml}$ divisions
- $5\ \mathrm{cm}$ length of thin-walled rubber or silicone tubing to fit nozzle of syringe
- pinch clip
- $2\ \mathrm{kg}$ mass
- loop of string
- $9 \times 100\ \mathrm{g}$ masses on a $100\ \mathrm{g}$ mass holder
- micrometer.

TECHNICAL INFORMATION

- The syringe should be the type with a rubber seal on the plunger which is less likely to stick. The type with an O ring seal on the end of the plunger are better, and tend to stick less than the type where the end of the piston is made of solid rubber.
- The rubber tubing should fit tightly onto the nozzle of the syringe. It can then be folded over and clamped with the pinch clip to produce an airtight seal.
- The clip should be as close as possible to the nozzle. There will be a little air in the nozzle, but this has negligible volume compared to the volume of air in the barrel of the syringe.
- A loop of string should be tied to the end of the plunger so that the mass holder can be hung on it.
- The $2\ \mathrm{kg}$ mass is used as a counterweight to ensure the stand does not topple over (an alternative would be to clamp the stand to the bench using a G-clamp).

SAMPLE RESULTS

The table below shows sample readings for a 20 ml syringe:

***d* = 20 mm**		
***m* / kg**	***V* / ml**	***P* / kPa**
0.4	4.0	88.5
0.9	5.0	72.9
1.3	6.0	60.4
1.6	7.0	51.0

CHARLES'S LAW

TEACHER AND TECHNICIAN SHEET

MATERIALS AND EQUIPMENT

- 25 cm length of glass capillary tubing (eg outer diameter 5 mm and bore 1 mm – whilst other sizes will work the bore should not exceed 1 mm)
- 5 cm length of thin-walled rubber tubing to fit over the end of the capillary tubing
- contact adhesive
- concentrated sulfuric acid
- 30 cm ruler
- 2 elastic bands
- thermometer (eg –10 to 110 °C)
- 2 litre beaker
- 250 ml glass beaker
- paper towels
- kettle.

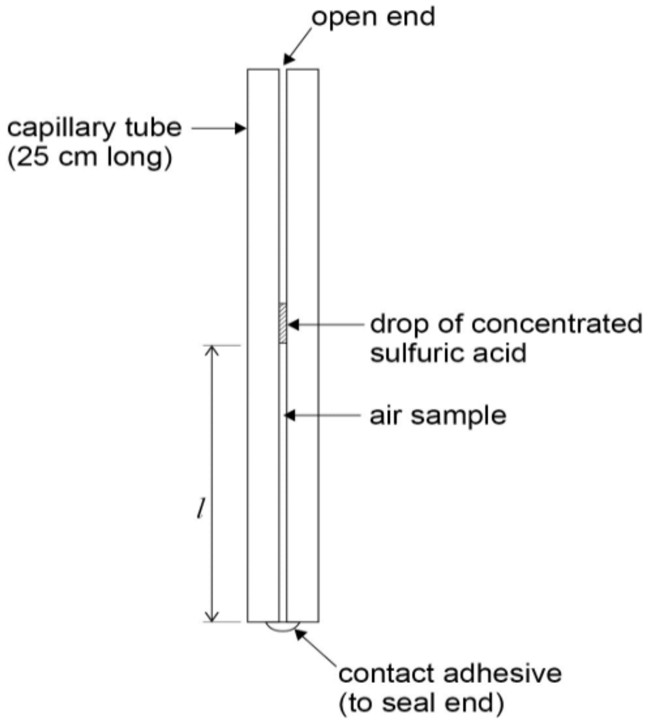
TECHNICAL INFORMATION

As concentrated sulfuric acid is being used, safety spectacles or goggles must be worn. Lab coats and gloves could also be worn. The technician should prepare the capillary tubing with a small drop of concentrated sulfuric acid about half way down its length, with the lower end sealed using contact adhesive. This can be achieved as follows:

- Pour a little concentrated sulfuric acid into a 250 ml glass beaker.
- Attach the length of rubber tubing to one end of the capillary tubing.
- Place the other end into the acid.
- Pinch the rubber tubing, then place a finger over the end and release the tubing to draw a drop of acid into the capillary tube.
- Remove the capillary tube from the acid, and use the same pinch and release technique to move the drop of acid to about half way along the tube.
- Holding the capillary tube horizontally, remove the rubber tubing from the end, and apply a small amount of adhesive to this end of the capillary tubing (see diagram on the following page).
- Using a paper towel, wipe off any surplus acid from the other end of the capillary tubing.
- Leave the tube for the contact adhesive to dry.
- Attach the capillary tubing to a 30 cm ruler using the elastic bands, with the end sealed with contact adhesive at the zero mark.
- The drop of concentrated sulfuric acid will dry the air as well as trap the sample of air in the capillary tubing.

The method suggests adding hot water to the beaker and allowing it to cool to produce the required variation in temperature. This is safer than heating a large beaker of water using a Bunsen and tripod. If a plastic 30 cm ruler is used, the boiled water should be allowed to cool a little before pouring it into the beaker in order to avoid the plastic softening. Students must be told that the apparatus contains concentrated sulfuric acid, and to treat it with care. If dropped or broken, it should be reported immediately and cleared up by someone wearing safety goggles.

SEALING THE CAPILLARY TUBING



ADDITIONAL NOTES

Capillary tubing with a 1 mm diameter bore as a maximum is recommended.

The bore of the tube needs to be 'clinically clean' ie no slight traces of oil, grease or other chemicals. This is often the reason why the thread of concentrated sulfuric acid splits.

There is a limit to how long they can be stored for. Some teachers have fed back that they have used them in successive years, but most tend to set new tubes up for each new year group.

SAMPLE RESULTS

The table below shows sample readings for a 1 mm bore capillary tube:

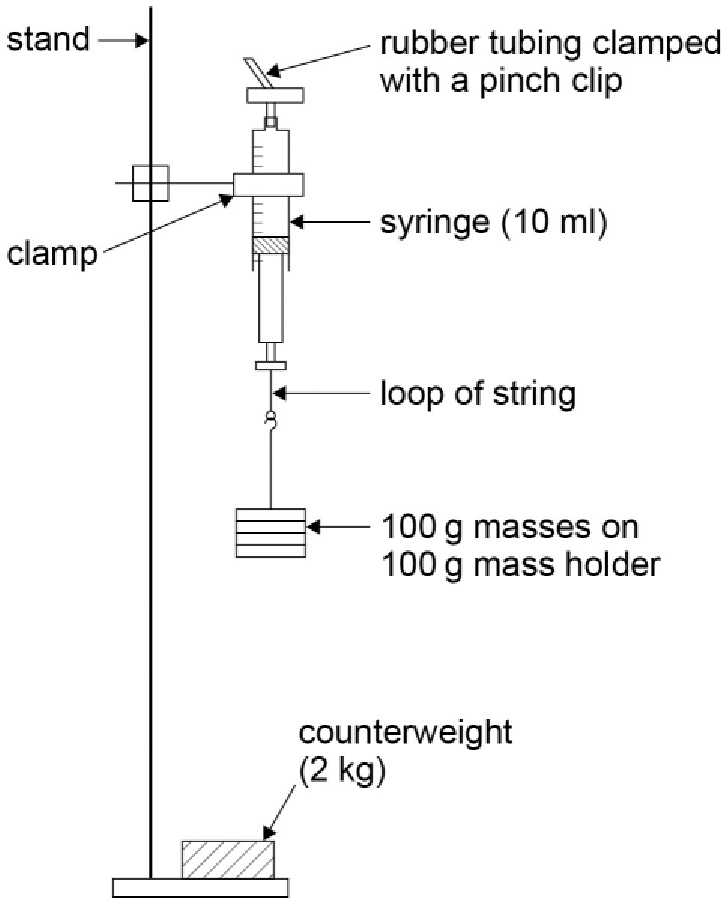
θ / °C	l / cm
92.0	26.7
77.0	26.1
65.0	25.6
51.0	25.3
38.0	24.9
23.0	24.5

BOYLE'S LAW

STUDENT SHEET

METHOD

- Remove the plunger from the syringe and measure the diameter of the rubber seal, d, using the micrometer. Convert this into metres.
- Calculate the cross-sectional area of the seal $A = \pi d^2/4$ in m^2.
- Replace the plunger and draw in $4.0\ \mathrm{ml}$ of air.
- Fit the rubber tubing over the nozzle, fold the tubing over and clamp it with the pinch clip as close to the nozzle as possible.



- Set up the apparatus as shown in the diagram initially with the $100\ \mathrm{g}$ mass holder carrying one $100\ \mathrm{g}$ mass. Ensure that the string is securely attached to the plunger handle. The clamp should be above the plunger so that the scale can be read. Clamping the syringe barrel can distort it, making it more difficult for the plunger to move freely. Consequently ensure the clamp is high enough on the barrel above the position where the plunger moves. There should be sufficient room below the masses so that the plunger can move down as masses are added.

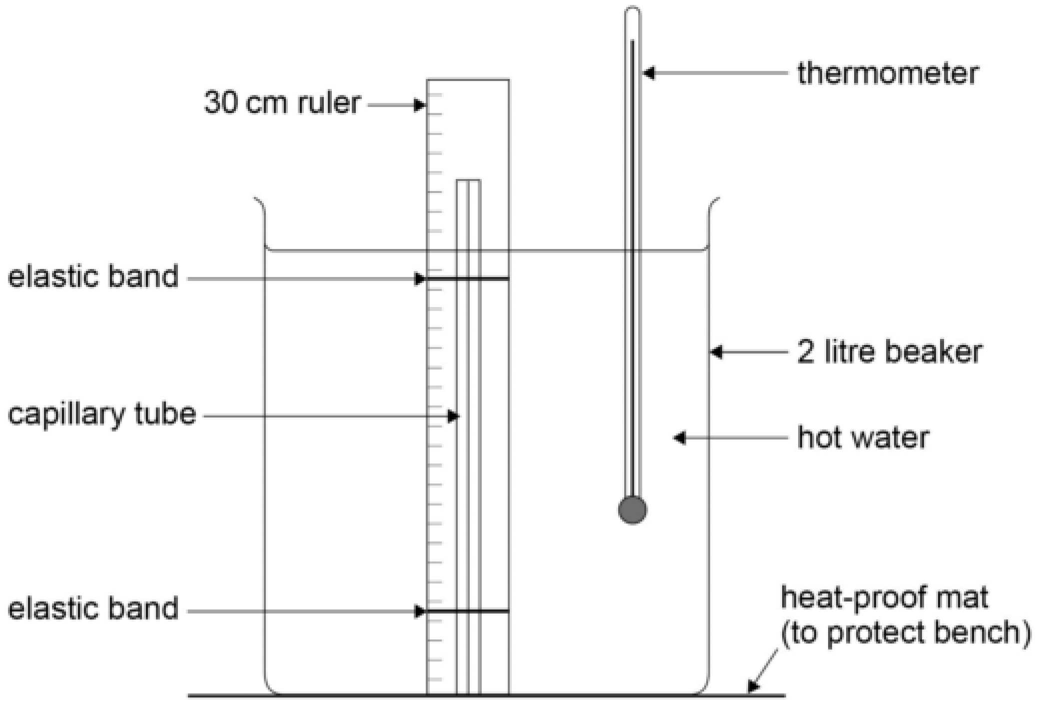
- Gently move the plunger up and down a few millimetres to ensure it is not sticking.
- Read the new volume on the syringe scale (fractions of a division should be estimated).
- Repeat the procedure with an extra two $100\ \mathrm{g}$ masses added to the holder each time, up to a total mass of $1000\ \mathrm{g}$.
- The whole experiment should then be repeated to obtain a second set of results, and the mean volumes found.
- The force exerted by the masses can be calculated using $F = mg$ where m is the mass in kg and g, the gravitational field strength, is $9.81\ \mathrm{Nkg^{-1}}$.
- The pressure exerted by this force on the air sample is then F/A in Pascals (Pa). Convert this into kPa.
- This should be subtracted from standard atmospheric pressure, $101\ \mathrm{kPa}$, to obtain the pressure of the air sample, P. (Note: the initial volume of the air with no masses hung on the loop will be at standard atmospheric pressure).
- A graph of $1/V$ against P should then be plotted (where V is the mean volume of the air sample for each value of P).
- Provided care has been taken to ensure the plunger does not stick, a reasonable straight line through the origin should be obtained. (Any slight sticking could result in a graph which curves slightly and/or does not pass through the origin).

CHARLES'S LAW

STUDENT SHEET

METHOD

- Set up the apparatus as shown in the diagram with the open end of the capillary tube at the top. Allow the boiled water from the kettle to cool a little before pouring it into the beaker. The hot water should cover the air sample.



- Stir the water well using the thermometer, read the value of its temperature, θ, and the length of the air sample, l, on the 30 cm ruler (see diagram above).
- Allow the water to cool by 5 °C and repeat the procedure until room temperature has been reached. (The cooling process can be speeded up by pouring a little water out of the beaker and topping it up with cold water.)
- Plot a graph of l against θ. Start the axes at a convenient value, and use a scale which will give a spread of points over at least half the graph paper in both directions.
- Draw the best straight line of fit though the points and find the gradient, m.
- The form of the graph is $l = m\theta + c$, where c is the value of l when $\theta = 0$ °C.
- The value of c can be found by reading a pair of values for length and temperature for a point on the straight line (l_1 and θ_1, say). Then $c = l_1 - m\theta_1$.
- An estimate of the value of absolute zero, θ_0, can then be found by substituting $l = 0$ into the equation for the form of the graph: $0 = m\theta_0 + c$ so $\theta_0 = -c/m$.

INTERNATIONAL A-LEVEL PHYSICS EXEMPLAR FOR REQUIRED PRACTICAL 10

Investigation of the inverse-square law for gamma radiation.

TEACHER AND TECHNICIAN SHEET

This worksheet gives full details of the experiment, primarily for use by teachers and technicians who may be unfamiliar with the experiment. The worksheet would normally be adapted for student use to provide opportunity for students to make procedural decisions.

It is important that any 'student version' of this worksheet takes due account of any relevant safety issues. **It is the responsibility of the centre to ensure that the apparatus they provide is used safely.**

MATERIALS AND EQUIPMENT

- 100 W filament lamp in a suitable holder
- LED
- method of holding the LED in place aligned with the centre of the filament lamp and pointing towards it
- multimeter set to a mV scale
- suitable electrical connections between the LED and the multimeter
- metre ruler
- using an optical bench would be a convenient way of ensuring that the lamp and the LED were always aligned and at the same height. It is possible to do the experiment without an optical bench.

TECHNICAL INFORMATION

- Any ordinary LED is suitable for this experiment. When illuminated, the LED produces an emf. The magnitude of the emf is directly proportional to the intensity of the illumination. The magnitude of the emf produced also depends on the colour of the LED. The data below were produced using a red LED.
- The 100 W filament lamp will be hot when in operation and care should be taken when measuring the distance to the edge of the lamp. In the absence of an optical bench, it would be good practice to fix the metre rule to the work bench with the zero mark vertically below the edge of the lamp. Measurements may then be taken from the metre rule without touching the hot lamp.

SAMPLE RESULTS

The table below shows sample readings for a red LED and a 100 W filament lamp:

d / cm	$\overline{E}$ / mV
20	252
40	131
60	80
80	58
100	40
120	32
140	25
160	20
180	17
200	14

Investigation of the inverse-square law for gamma radiation.

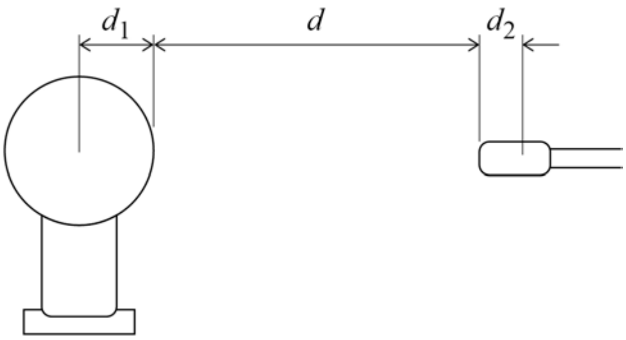
STUDENT SHEET

The inverse square law suggests that the intensity, I, of light from a point source is inversely proportional to the square of the separation, r, between the source and the detector.

$$I = \frac{k}{r^2}$$

In this experiment you will use an LED as the light detector. When illuminated with light, an LED will produce an emf, E. The magnitude of E is directly proportional to the intensity of the light.

You will measure the distance d between a filament lamp and the front edge of your LED. However, the light is produced a distance d_1 inside the lamp and is detected a distance d_2 inside the LED.

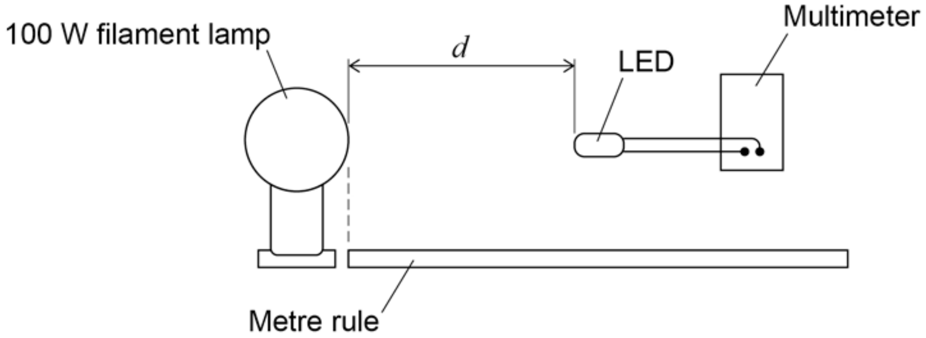


Thus, in this experiment, the inverse square law equation becomes:

$$E = \frac{C}{(d_1 + d_2 + d)^2} \quad \text{where C is a constant}$$

METHOD

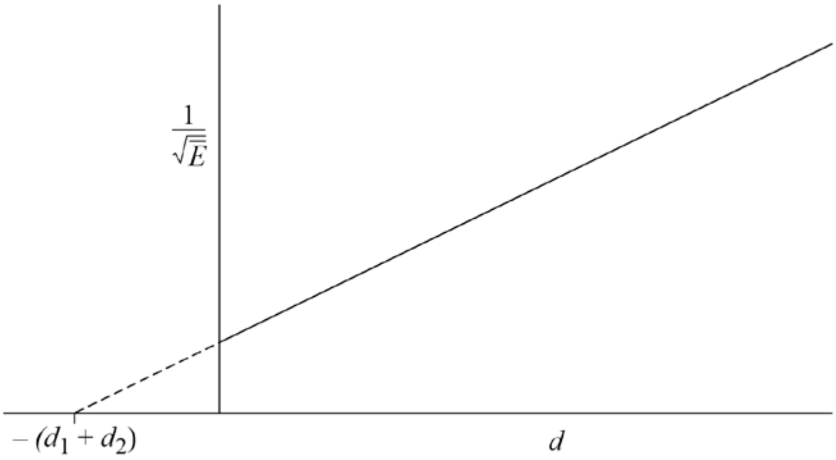
- Connect the LED to the multimeter and select an appropriate scale. The longer leg of the LED is positive but connecting it the wrong way round will only result in the multimeter reading being negative: the magnitude of the emf will be unaffected.
- Arrange the LED so that it is at the same height as the centre of the lamp and ensure that the LED is pointing at the lamp.
- Make measurements of d and E. The range of distances that you use will depend on the type of LED that you are using. Make sure that you have at least 8 sets of results.
- Repeating each set of results several times would allow you to estimate the uncertainties involved in you measurements and to draw your graph with error bars.



Clamps and holders are **not** shown

- If the experiment is conducted in a dim room, there is no need to make allowances for the ambient illumination. If it is not possible to use a dim room, adopt the following procedure:
  - Make your measurements of E and d (for example $E = 34$ mV when $d = 120$ mm).
  - Insert an opaque card between the lamp and the LED.
  - The multimeter reading will now be the emf appropriate to the level of ambient illumination in the room. Take this reading. (for example, new multimeter reading = 2 mV).
  - Subtract the new multimeter reading from your original reading to give the emf that is appropriate to the illumination directly from the filament lamp. (for example, emf = 34 – 2 = 32 mV).
- Record r, E and $\overline{E}$, the mean value of E in a suitable table. Add a final column for $\frac{1}{\sqrt{\overline{E}}}$
- Plot a graph with $\frac{1}{\sqrt{\overline{E}}}$ on the *y*-axis and *r* on the *x*-axis.

A straight line graph would verify the inverse square law relationship for light. The data is plotted this way around (rather that plotting E against $1/d^2$), to eliminate the systematic error in distance measurement. The intercept on the distance axis of the graph is $-(d_1 + d_2)$.



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