STUDENT GUIDE

For the 2016 specifications

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AS/A2 UNIT 3

Physics

Practical techniques and data analysis

Roy White

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Physics

Unit 3 Practical techniques and data analysis

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To do well in AS or A2 physics, you will need to be familiar with the units in which physics measurements are made and how they are combined mathematically. Perhaps more than in any other GCE science, the development of your mathematical skills in physics is vital if you are to achieve the highest grades.

The mathematical material with which you are expected to be familiar is identified in Appendix 1 of the specification. It is worth examining it closely, particularly as you prepare for your AS and A2 examinations. This chapter will help you to focus on how these skills are used in your practical work.

Arithmetic and numerical computation

Throughout your studies you will need to:

- recognise and make use of appropriate units in calculations
- recognise and use expressions in decimal and standard form
- use ratios, fractions and percentages
- estimate results
- use calculators to find and use power functions, exponential and logarithmic functions
- use calculators to handle $\sin x$, $\cos x$ and $\tan x$ when x is expressed in degrees or radians

Physicists use the **SI system** (Système Internationale) of measurement. This system is based on seven fundamental **base units**, of which you are required to know the six shown in Table 1.

SI system The international system of units adopted worldwide by the physics community.

Base units The units on which the SI system is based.

Table 1 SI base units

Measurement	Unit	Abbreviation
Mass	kilogram	kg
Length	metre	m
Time	second	s
Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

All other SI units are combinations of the base units and are called **derived units**. Some of the more common derived units are listed in Table 2.

Derived units Combinations of SI base units.

Table 2 Common derived units in A-level physics

Physical quantity	Common unit	Abbreviation	Derived unit
Area	square metres	m^2	m^2
Volume	cubic metres	m^3	m^3
Density	kilogram per cubic metre	$kg\,m^{-3}$	$kg\,m^{-3}$
Pressure	pascal	Pa	$kg\,m^{-1}\,s^{-2}$
Specific heat capacity	joule per kilogram per kelvin	$J\,kg^{-1}\,K^{-1}$	$m^2\,s^{-2}\,K^{-1}$
Speed	metre per second	$m\,s^{-1}$	$m\,s^{-1}$
Energy	joule	J	$kg\,m^2\,s^{-2}$
Force	newton	N	$kg\,m\,s^{-2}$
Gravitational field strength	newton per kilogram	$N\,kg^{-1}$	$m\,s^{-2}$
Acceleration	metre per squared second	$m\,s^{-2}$	$m\,s^{-2}$
Power	watt	W	$kg\,m^2\,s^{-3}$
Frequency	hertz	Hz	s^{-1}
Electric charge	coulomb	C	A s
Electrical potential difference	volt	V	$kg\,A^{-1}\,m^2\,s^{-3}$
Electrical resistance	ohm	Ω	$kg\,A^{-2}\,m^2\,s^{-3}$
Magnetic flux density	tesla	T	$kg\,A^{-1}\,s^{-2}$

Knowledge check 1

State the derived unit in which you would measure the following physical quantities: (a) resistivity, (b) stress, (c) strain, (d) Young modulus.

Decimal and standard form

Physicists measure quantities as large as the size of the universe and as small as the mass of an electron. Prefixes are used for very small or very large measurements. Table 3 gives some of the common prefixes used in physics.

Standard form A number in the form $a \times 10^n$, where n is a whole number and $1 \leq a < 10$.

Submultiples Fractions of a base unit or a derived unit.

Multiples Large numbers of a base unit or a derived unit.

Table 3 **Submultiple** and **multiple** units in A-level physics

Submultiples		Multiples	
Prefix and symbol	Factor of 10	Prefix and symbol	Factor of 10
centi, c	10^{-2}		
milli, m	10^{-3}	kilo, k	10^3
micro, μ	10^{-6}	mega, M	10^6
nano, n	10^{-9}	giga, G	10^9
pico, p	10^{-12}	tera, T	10^{12}
femto, f	10^{-15}		

It is sometimes necessary to change from one unit to another. For example, the density of ethanol is $790\,kg\,m^{-3}$. What is that in $g\,cm^{-3}$? To answer this question, we must convert kg to g and m^3 to cm^3. Now 1 kg is 1000 g and $1\,m^3$ is (100 cm × 100 cm × 100 cm) or $1\,000\,000\,cm^3$. So $1\,kg\,m^{-3} = 1000\,g/(1\,000\,000)\,cm^3 = 0.001\,g\,cm^{-3}$.

Hence $790\,kg\,m^{-3} = (790 \times 0.001)\,g\,cm^{-3} = 0.79\,g\,cm^{-3}$.

Knowledge check 2

The radius of the hydrogen atom is about 53 pm and the electron orbiting its nucleus does so at a speed of about $22\,Mm\,s^{-1}$. Express these values in m and $m\,s^{-1}$ in **standard form**.

Ratios, fractions and percentages

The use of ratios, fractions and percentages is no more demanding in A-level physics than you experienced in GCSE mathematics. However, it is worth looking at the knowledge checks opposite to confirm your understanding.

Trigonometrical ratios

These are the familiar $\sin x$, $\cos x$ and $\tan x$. At AS, you first come across them in resolving and adding vectors. At A2, you meet them at various parts of the course, but especially when dealing with refraction and diffraction.

A2 students are expected to be familiar with the use of radians as a measure of angles. While it is important to know that the conversion formula from radians to degrees is π radians = 180 degrees, it is essential that you are familiar with the operation of your calculator in both measures. Most scientific calculators allow you to select the unit required using the <Shift> <Mode> buttons.

Worked example

The angle of refraction in a square block of glass of side 20 cm and refractive index 1.50 is 19°. Calculate **a** the angle of incidence and **b** the length of the path taken by the ray of light in the glass .

Answer

a From Snell's law, $r = \sin^{-1}(n \times \sin r) = \sin^{-1}(1.5 \times \sin 19) = \sin^{-1}(0.488) = 29.2°$

b $D = \dfrac{\text{length of square}}{\cos r} = \dfrac{20}{\cos 19} = 21.2\,\text{cm}$

Exponentials and natural logarithms

AS students do not usually have to use exponentials and natural logarithms. At A2, exponentials and logarithms are mainly found in the topics of capacitance and radioactivity. Exponential growth occurs when the variable you are measuring increases by the same proportion in each equal interval of time. Exponential decay occurs when the measured variable decreases by the same proportion in each equal interval of time.

Worked example

(**A2 only**) The activity of a radioisotope falls from 1200 Bq to 800 Bq in 40 minutes. Find the decay constant and the half-life of the radioisotope.

Answer

From the law of radioactive decay: $A = A_0 e^{-\lambda t}$

Taking natural logs of both sides: $\ln A = \ln A_0 - \lambda t$

Rearranging: $\lambda = \dfrac{\ln A_0 - \ln A}{t}$

Exam tip

Always check whether the values you are given in an exam question have prefixes. Convert these into standard form before you attempt to answer the question.

Knowledge check 3

A metal alloy is made of iron, manganese and chromium in the ratio 7 : 2 : 1.

a What fraction of the alloy is made of chromium?

b What percentage of the alloy is made of non-ferrous metals?

c What is the ratio of iron : other metals?

Knowledge check 4

The refractive index of a material is the ratio of the speed of light in air to the speed of light in that material. If the refractive index of glass is 1.50 and the refractive index of water is 1.33, calculate the ratio speed of light in water : speed of light in glass.

Knowledge check 5

Find the angle for which tan is 1.500, giving your answer in degrees and in radians.

Substituting: $\lambda = \dfrac{\ln 1200 - \ln 800}{40}$

$\lambda = 10.137 \times 10^{-3}\,\text{min}^{-1}$

From half-life equation:

$T_{½} = \dfrac{0.693}{\lambda}$

$T_{½} = \dfrac{0.693}{10.137 \times 10^{-3}}$

$T_{½} = 68.4$ minutes

Exam tip

A-level students have about 2 years to learn their way around a calculator. Get to know it well. Do not buy a calculator with which you are not familiar a few weeks before your exam.

Handling data

Throughout your studies you will need to:

- make order-of-magnitude calculations
- use an appropriate number of significant figures (sf)
- find arithmetic means

Estimation and orders of magnitude

Part of the skill set of an experimental physicist is the ability to make estimates. Physicists sometimes talk about an estimate 'to within an order of magnitude'. The order of magnitude is the **index** when a quantity is expressed in standard form. The charge on an electron is 1.6×10^{-19} C. So, the order of magnitude is 10^{-19}. When physicists refer to 'within an order of magnitude for the electron charge', they mean between 10^{-18} C and 10^{-20} C.

Index The power to which a number or letter is raised. The plural of index is indices.

The key to making estimates is to work to 1 or 2 significant figures only. For example, the volume of a typical school laboratory is about $10\,\text{m} \times 10\,\text{m} \times 3\,\text{m}$ or $300\,\text{m}^3$. It is a good approximation to take π as 3 or 3.1.

Worked example

Estimate the density of steel.

Answer

We already know that the density will be greater than $1\,\text{g}\,\text{cm}^{-3}$ because a steel ball bearing will sink in water.

From experience a small steel ball bearing has a mass of about 5 g (this estimate means its mass lies between 0.5 g and 50 g — correct to within an order of magnitude).

Its radius is certainly less than 1 cm, say 0.5 cm.

So its volume $= \dfrac{4}{3} \times \pi r^3 \sim \dfrac{\pi}{6}$ or $0.5\,\text{cm}^3$.

Its density is therefore about $\dfrac{5\,\text{g}}{0.5\,\text{cm}^3}$, which is around $10\,\text{g}\,\text{cm}^{-3}$.

This compares well with the actual density of steel, which is around $8\,\text{g}\,\text{cm}^{-3}$.

Practical skills

Both the AS 3 and the A2 3 units have two components. AS 3A and A2 3A assess your ability to carry out experimental procedures in a laboratory. During your course you may have carried out practical work in a small group, but in the practical examinations you are working on your own.

While the emphasis is on assessing the transferable, practical skills you have encountered during your course, you may be asked to demonstrate your analytical skills and your ability to evaluate the reliability of data and the conclusions which might be drawn from it. You will also be required to demonstrate your mathematical skills and your ability to refine and develop experimental techniques. Since this is a written assessment, you are expected to be able to communicate observations, measurements, results and conclusions in an appropriate and effective manner.

In AS 3A, you are required to do four short experiments, spending 15 minutes on each. In A2 3A, you will carry out two experiments, spending 30 minutes on each.

There are no specific experiments that you must learn for these practical assessments. It is certainly expected that during your course you will have done all the experiments set down in the specification. However, many of these experiments require a much longer time than is available in the AS 3 and A2 3 assessments. In addition, many of the experiments carried out during your course must be done in small groups because there is insufficient apparatus to enable every student to do the work individually. This is why the emphasis is on the assessment of your practical *skills*. Each of the experiments from the specification is covered in the Practical activities section of this guide to help you to think through and apply your learning from carrying out each of them in preparation for the assessment.

AS 3B and A2 3B seek to assess your practical knowledge and your skills of data analysis, each in a 1 hour written exam paper. Considerable attention will be paid to the techniques of data analysis later in this book.

Altogether AS 3 is worth 20% of all the marks for the AS qualification and A2 3 accounts for 12% of the A-level qualification.

Physics is a practical subject, and experimental work should form a significant part of your AS or A-level physics course. It is commonly acknowledged that it is easier to learn and remember things if you have actually done them rather than having read about them or been told about them. That is why this section of the book is illustrated throughout by experiments, usually with a set of data for you to work through and questions to answer.

As you complete practical work during your physics course, you will develop skills in the use of a range of apparatus and techniques. Examination questions will test your knowledge and understanding of these techniques.

This section of the practical guide is in five main parts, which reflect an orderly approach to practical work and the approach taken in the subject specification:

- implementing
- analysis
- evaluation
- refinement
- communication

Implementing

You are unlikely to be asked to produce a detailed plan in AS 3, but you may be asked to do so in A2 3. This is simply because you are limited to 15 minutes per experiment in AS 3, but you have 30 minutes per experiment in A2 3.

What is meant by implementing? The CCEA specification makes it clear that you must be able to:

- assemble and use measuring apparatus correctly, skilfully and effectively with full regard for safety, including:
  - spring and top-pan balances (mass)
  - ruler, micrometer and callipers (length)
  - graduated cylinder (liquid volume)
  - clock and stopwatch (time)
  - thermometer and sensor (temperature)
  - ammeter (electric current)
  - voltmeter (potential difference)
  - multimeter (resistance, p.d., current)
  - protractor (angle)
- use and describe how the cathode ray oscilloscope (CRO) can be used to determine the voltage and frequency (**A2 only**)
- make and record sufficient relevant, reliable and valid observations and measurements to the appropriate degree of precision and accuracy, using data loggers where suitable
- show familiarity with both analogue and digital displays

In AS 3A and A2 3A, you are unlikely to be asked which apparatus you should select to do a particular task. However, most certainly you will be required to assemble and use it.

An outline plan

Once the problem has been identified, you may be asked to produce an outline plan. Time constraints in AS 3A and A2 3A mean that a *detailed* description of what you plan to do is seldom required.

In almost all practical activities, the required apparatus is set out for you, often unassembled. The issue will not be what apparatus to use, but *how* to use it and *what* measurements must be made.

Examples of the use of apparatus listed in the specification (see Table 7) will be covered in the Practical activities chapter of this book. It cannot be emphasised enough that the skills to use apparatus effectively can be learnt— but learning skills takes time and practice in experimental activity.

You will also need to be able to consider strategies and techniques to ensure accurate results. For example, in nearly every AS 3A practical there is an experiment involving a stopwatch. If you are measuring the period of a pendulum you need to know how many oscillations to time. You also need to have learned, through practice, the relevant technique. For example, only a poor experimentalist will start the stopwatch at the same time as the bob is released. The examiner will not see you apply these techniques, but they will be critical if you are to obtain satisfactory results.

Table 7 Apparatus used in the practical activities

Apparatus	Practical activities
Spring and top-pan balances (mass)	1, 2, 5, 6, 15, 20, 21
Ruler, micrometer and callipers (length)	1, 3, 4, 5, 6, 12, 13, 14, 15, 16, 17, 18, 19, 21
Graduated cylinder (liquid volume)	1
Clock and stopwatch (time)	3, 20, 21, 22
Thermometer and sensor (temperature)	10
Ammeter (electric current)	7, 8, 9, 11, 20, 22
Voltmeter (potential difference)	7, 8, 9, 11, 20, 22
Multimeter (resistance, p.d., current)	7, 8, 9, 10, 11
Protractor (angle)	12, 13
Cathode ray oscilloscope (voltage and frequency)	23

Where relevant, safety issues will also be examined. Vague statements are unacceptable at this level. Your discussion must be relevant and well argued. You may also be asked what action the experimenter might take to minimise these risks. For example, in some electrical experiments the apparatus might get hot, causing a possible risk of burns to the skin. To reduce the risk, the apparatus might be set on a heat-proof mat and the electrical supply is switched on only when necessary.

Variables

You will be expected to identify the types of variables in *any* experiment you are asked to plan and carry out. You therefore need to be able to identify the **independent**, **dependent** and **control** variables in every experiment you do.

Independent variable The variable for which values are changed by the experimenter.

Dependent variable The variable for which the value is measured in the experiment.

Control variables Variables other than the independent variable, which could affect the outcome of the investigation and therefore have to be kept constant.

Worked example

A student investigates how the frequency of a simple pendulum varies when the length of the string increases. What are the independent, dependent and control variables in this experiment?

Answer

The independent variable is the length of the string.

The dependent variable is the period of the pendulum's oscillation. It is from this that the frequency is calculated.

The control variable is the mass of the pendulum bob.

Accuracy and precision

The accuracy of any experiment you do depends on two factors: the equipment used and your technique. It is important that you can distinguish between accuracy and precision.

The more accurate you are in making a measurement, the closer you are to the true value.

One way to improve **accuracy** is to repeat and then average. For example, suppose five students measure the length of the same metal wire with a metre ruler with a centimetre scale and get the following results: 91 cm, 93 cm, 90 cm, 92 cm, 89 cm. The mean of these results is 91 cm and that is probably the most accurate length possible from these data. Another way to improve accuracy is to use a better

Accuracy Accuracy is how close we get to the true value of any physical measurement.

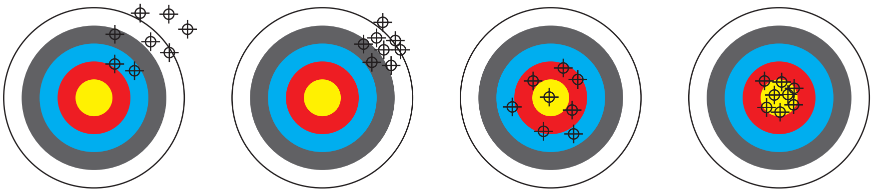


Figure 13 Accuracy and precision

measuring instrument. A digital voltmeter, for example, is likely to be more accurate than an analogue meter.

Precise measurements are those where the range is small. For example, suppose three students measure the mass of a beaker using balance A. They get the results 45.7 g, 45.9 g and 45.8 g. The range of these measurements is 45.9 − 45.7 = 0.2 g. That is the extent of their **precision**.

But you need to be careful. A stopwatch with a sweeping hand might have a **resolution** of 0.1 s while a digital stopwatch might have a resolution of 0.01 s. However, both stopwatches have a similar precision because this factor will be determined by the reaction time of the person using it.

Precision Precision measures the extent to which measurements are the same.

Resolution Resolution is the fineness to which an instrument can be read.

Dataloggers

It is no exaggeration to say that dataloggers have revolutionised the work of the professional physicist. They enable the easy collection and analysis of huge volumes of data over long periods of time with limited involvement of staff. For the A-level physicist, they are increasingly being used in schools and colleges and this is recognised in the CCEA specification.

Where you have experience of using them, use your knowledge in written papers. However, you are unlikely to be asked to use a datalogger in units AS 3A and A2 3A because some schools will not have them and they represent a substantial financial cost.

While you can use a datalogger in most experiments, they are specifically used in Practical activities 4, 5, 6, 8, 25 and 26. Remember that there are always alternatives to the use of dataloggers which will be acceptable to the GCE examiners.

Analysis

The specification states what you are expected to be able to do by way of analysis. Briefly, the expectation is that you can:

- present work appropriately in written, tabular, graphical or other forms
- analyse, interpret and explain your own and others' experimental and investigative activities, using ICT and other methods
- show awareness of the limitations of experimental measurements when commenting on trends and patterns in the data
- draw valid conclusions by applying knowledge and understanding of physics

Practical activities

Practical activity in this book	Practical in CCEA specification Appendix 4	Coverage in CCEA specification
1 Determine the density of a solid or liquid	1	
2 Determine (a) the value of an unknown mass and (b) the mass of a uniform rule using the principle of moments	2, 3	
3 Determine the acceleration of free fall by means of a falling object and light gates	4	
4 Verification of the mathematical form of Newton's second law	5, 6	
5 Verification of the conservation of linear momentum in a collision	7	
6 Investigate the energy exchange between potential and kinetic for a falling body	8	
7 Determine resistance by the ammeter–voltmeter method and using a multimeter or ohmmeter and the I–V characteristics of a metallic conductor at constant temperature and a filament lamp	9, 12, 13	1.10.1 and 1.10.10
8 Verify the relationships for resistors in series and in parallel	10	
9 Determine the resistivity of a material	11	1.10.6
10 Determine the resistance–temperature characteristic of a negative temperature coefficient (ntc) thermistor	14	1.10.13
11 Determine the e.m.f. and internal resistance of a battery	15	1.11.3
12 Verify Snell's law and determine the refractive index of a material	16, 17	2.2.1
13 Determine the critical angle of glass or Perspex using a semicircular block	18	
14 Determine the focal length of a converging lens and verify experimentally the lens equation for real images	19	2.3.3
15 Verify that the magnification of a real image is equal to the ratio of the image distance to the object distance	20	
16 Determine the speed of sound in air using a resonance tube	21	2.4.6
17 Determine the wavelength of light using a double slit	22	
18 Determine the wavelength of light using a grating	22	
19 Determine the Young modulus for the material of a metal wire		4.1.5
20 Perform and demonstrate an electrical method for determining specific heat capacity (of a liquid)		4.2.8
21 Investigate experimentally the motion of the simple pendulum and the loaded spiral spring		4.4.3
22 Describe experiments to demonstrate the discharge and charge of a capacitor and measure the time constant		5.4.6 and 5.4.10
23 Describe how the cathode ray oscilloscope (CRO) can be used to determine the voltage and frequency		6.1.2

Practical activity 1

Determine the density of a solid or liquid

Background information and practical procedure

The density of a material is given by the equation:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Three situations are considered here – a regular solid, an irregular solid and a liquid.

1 A regularly shaped object (such a small solid metal cuboid)

The method involves finding the mass of the solid using a digital top-pan balance and its length, breadth and height using callipers.

The volume of the cylinder is then calculated using the formula:

$$\text{volume} = \text{length} \times \text{breadth} \times \text{height}$$

2 An irregularly shaped object (such as a piece of concrete)

Again, the mass is found using a top-pan balance. The volume is found by the displacement method using a graduated cylinder, as in Figure 17.

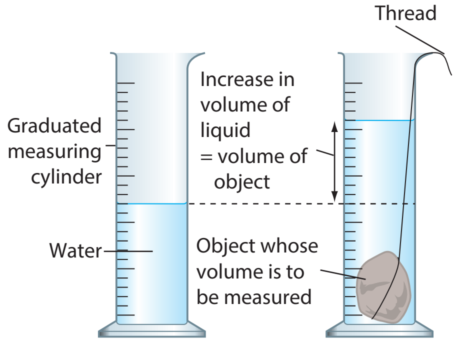


Figure 17 Finding the volume of a lump of concrete

3 A liquid

The mass is found with a top-pan balance and a measuring cylinder. The volume is found from the graduations on the measuring cylinder, as in Figure 18.

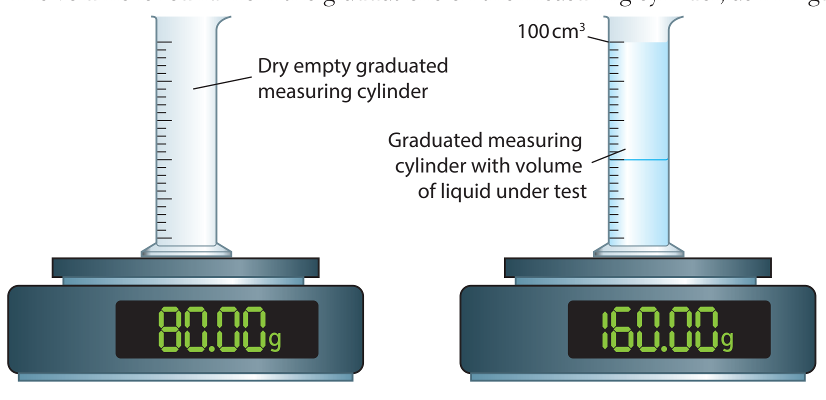


Figure 18 Finding the mass of a known volume of liquid

Safety

Density experiments frequently use glassware. It is important that every precaution is taken to prevent beakers and measuring cylinders rolling off the bench and smashing into small, dangerous pieces. If this happens, the laboratory supervisor should be informed, the experiment suspended and steps taken to clean up the area in the vicinity of the accident.

Worked example 1

A regular solid

The mass of a regular solid in the form of a cuboid is found to be 75.62 ± 0.01 g. Its dimensions are measured using callipers and found to be:

length: 31.2 ± 0.1 mm   breadth: 24.5 ± 0.1 mm   height 15.5 ± 0.1 mm

a Calculate the density of the solid.

b Calculate the uncertainty in the density.

Answer

a $\text{density} = \dfrac{\text{mass}}{\text{volume}} = \dfrac{75.62}{3.12 \times 2.45 \times 1.55} = 6.38\,\text{g}\,\text{cm}^{-3}$

b $\%\text{ uncertainty in length} = \dfrac{0.1}{31.2} \times 100\% = \pm 0.32\%$

$\%\text{ uncertainty in breadth} = \dfrac{0.1}{24.5} \times 100\% = \pm 0.41\%$

$\%\text{ uncertainty in height} = \dfrac{0.1}{15.5} \times 100\% = \pm 0.65\%$

$\%\text{ uncertainty in volume} = 0.32\% + 0.41\% + 0.65\% = \pm 1.38\%$

$\%\text{ uncertainty in mass} = \dfrac{0.01}{75.62} \times 100\% = \pm 0.01\%$

% uncertainty in density = % uncertainty in mass + % uncertainty in volume = ± 1.39%

Worked example 2

A liquid

Various volumes of liquid are poured into a measuring cylinder and, in each case, the total mass of the measuring cylinder and its contents are recorded, as in Table 8.

Table 8 Experimental data

Mass of liquid + container/g	76.0	92.0	108.0	124.0	140.0
Volume of liquid/cm^3	20.0	40.0	60.0	80.0	100.0

Plot the graph of mass of measuring cylinder and contents against volume and use the graph to find the density of the liquid and the mass of the measuring cylinder.

Answer

Mass of liquid plus container = (density of liquid × volume of liquid) + mass of container

or

$$M = d \times V + m$$

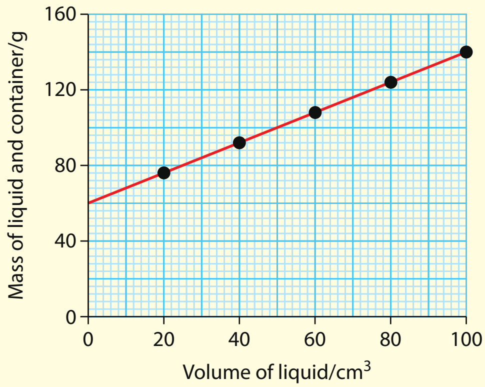


Figure 19 Graph to find the mass of a cylinder and liquid density

Map this equation against that of a straight line:

$$y = mx + c$$

M is equivalent to *y*, *d* is equivalent to gradient *m*, *V* is equivalent to *x* and *m* is equivalent to intercept *c*.

Gradient of graph = density $d = \frac{140 - 60}{100 - 0} = 0.8\,\text{g cm}^{-3}$

Mass of measuring cylinder *m* = intercept on vertical axis = 60 g

Practical activity 2

Determine (a) the value of an unknown mass and (b) the mass of a uniform ruler using the principle of moments

Background information

Here are three important definitions exemplified in this practical activity:

1. The centre of gravity (CoG) of an object is the point through which the entire weight of that object can be thought to act.
2. The moment of a force about a point is equal to the product of the force and the perpendicular distance from the point to the line-of-action of the force.
3. The principle of moments (PoM) states that for an object in equilibrium, the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point.

If a metre stick is suspended at its CoG, it may come to rest as a horizontal lever. An object of known mass at one side of the CoG may be balanced with another of unknown mass on the other. Applying the PoM then allows us to calculate the unknown force and hence the unknown weight.

If the metre stick is suspended at some point other than its CoM, then its own weight will cause it to tilt because of the unbalanced moment. If now we attach a known weight to restore equilibrium, we can use the PoM to determine the weight and hence the mass of the metre ruler itself.

Questions & Answers

About this section

The AS 3B and A2 3B examination papers are designed to test your knowledge and understanding of physics practical techniques and procedures. They are both of 1-hour duration and both carry 50 marks. That means that you should spend not much more than 1 minute per mark in each question. In general, there are slightly more questions on the AS paper (usually 6) than there are in the A2 paper (usually 4). So the questions on the A2 3B paper are generally a little longer and are somewhat harder. They have what examiners call an element of 'stretch-and-challenge'.

The questions are all structured. That means each question is set around a theme, but there are many parts. In general, your answers will be quite short. They must be direct, relevant and focused on the material being assessed. While there are no QWC questions, it is important that your answers are coherent, written in good English and show an understanding of scientific vocabulary.

Both papers are synoptic. That means the AS paper contains material drawn from units AS 1 and AS 2. The A2 paper can contain material drawn from the AS course as well as the A2 course. In both papers, you are likely to see material which you have never encountered before. That should not be surprising. These are designed to be *skills-based* papers, so there is likely to be less material which is pure recall, that is, material which you just have to remember to get the right answer.

Question structure

The words of our physics teachers 'Read the question!' always ring in our ears. But you should do more than that. Many GCE questions have a set structure: a preamble, a command line and an advice line. It is helpful to recognise this structure when you are planning your response.

Consider the following question:

> A student is planning to investigate what property of light determines the width of the fringes produced by a given Young's double slit on a screen.
>
> Outline how you would carry out this investigation.
>
> You are not required to draw a diagram of the apparatus.

The first paragraph is the preamble – it sets the scene.

The second is called the command line – note carefully the command word 'Outline' which tells you the type of response the examiner requires.

The third line is the advice line – it gives you information about what the examiner expects.

Clearly, it is essential that you understand the meanings of the command words used in examination papers. In this case, it is essential that you know what is meant by the word 'outline'.

Command words

Calculate: Use a formula and carry out a calculation (usually with your calculator).

Choose: Select information from material that the question supplies.

Complete: Finish something that has already been started in the question, such as a table or a diagram.

Define: State formally the scientific meaning of a particular word or phrase.

Describe: Give a detailed account, in words, of relevant facts and features relating to the topic being examined.

Design: Use your knowledge and experience and be creative in solving an experimental task.

Determine: Use given data in a question to solve a problem.

Draw: Produce or add to some kind of illustration. This command requires you to take a little more time than that required to produce a 'sketch'.

Estimate: Use the numbers given in the question to produce an approximate answer to a problem.

Evaluate: Use the information supplied in the question, as well as any relevant outside knowledge, to consider evidence for and against an argument.

Explain: The answer must contain some element of reasoning or justification.

Give: Provide some new information.

Identify: Select key information from a source provided for you.

Justify: Use the evidence supplied to support and take one argument forward.

Label: Add text to a diagram, illustration or graph to indicate what particular items are.

Measure: Find a figure of data for a given quantity. You may also be asked to use an instrument to determine a particular property.

Name: Identify an object, an item, a process, a procedure or a theory.

Outline: This command word means 'summarise', but it is often used to ask students to set out how something should be done (such as 'Outline a plan', 'Outline an experiment' and so on).

Plan: Give detailed information about how a procedure or task might be carried out.

Plot: Draw and label axes on a grid and mark the points provided. If there is a correlation, you may also be asked to draw the line(s) of best fit. Remember that the line of best fit may be a curve.

Predict: Write down what you think will happen if a particular condition is met.

Show: Demonstrate with clear evidence that the statement given is true. You will often be expected to use the information provided.

State: This command word means the same as 'Write'.

Sketch: Produce some kind of illustration, which may be produced quickly.

Suggest: Use your knowledge and understanding to provide a solution to a problem you are unfamiliar with, or to explain an aspect of physics you may not have studied.

Use: Extract appropriate information from diagrams, tables or graphs etc. Remember that, if you do not show how you obtained this information, you will lose marks.

Write: Use written English in your answer. Unlike command words such as 'Design', 'Explain' or 'Describe', 'Write' usually only requires a short response.

AS 3B paper-style questions

Question 1

Figure 1 shows the readings on an ammeter and a voltmeter when used to find the resistance of a length of constantan wire.

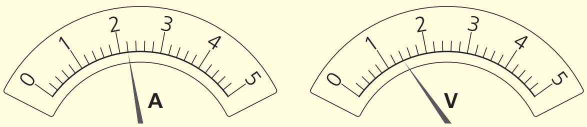


Figure 1

a State the reading on the ammeter shown in Figure 1. — 1 mark

> The first few questions of your examination paper are likely to be equally straightforward. But beware – there is no partial credit for a 1 mark question. You get full marks or you get zero marks.

b State the reading on the voltmeter shown in Figure 1. — 1 mark

c Calculate the percentage uncertainty in the ammeter reading. — 2 marks

> Always show your full working for all calculations. By doing so you may pick up marks for a correct method even if your final answer is incorrect.

The percentage uncertainty in the voltmeter reading is 7.1%.

d Calculate the absolute uncertainty in the resistance of the wire, giving your answer to 1 significant figure. — 4 marks

Student answer

a Ammeter reading = 2.2 A ✓

b Voltmeter reading = 1.4 V ✓

c Percentage uncertainty in the ammeter reading $= \frac{0.1}{2.2} \times 100\%$ ✓

$= 4.5\%$ ✓

d Resistance $= \frac{V}{I} = \frac{1.4\,\text{V}}{2.2\,\text{A}} = 0.64\,\Omega$ ✓

% uncertainty in resistance = % uncertainty in voltage + % uncertainty in current

= 7.1% + 4.5% = 11.6% ✓

Absolute uncertainty in resistance = 11.6% of 0.64 Ω ✓ = 0.074 Ω ✘

> In part d the student has not stated absolute uncertainty to 1 sf as required. The correct answer is 0.07 Ω (to 1 sf). Nonetheless, the first 3 marks are awarded because all the steps taken in the calculation are correct.
> **3/4 marks awarded**

Question 2

The resistance of a metal wire changes with temperature according to the equation:

$$R = R_0(1 + \alpha T)$$

where R_0 is the resistance at 0 °C, T is the temperature in °C and α is a constant called the temperature coefficient of resistance.

The graphs in Figure 2 show the results of an experiment to investigate this relationship.

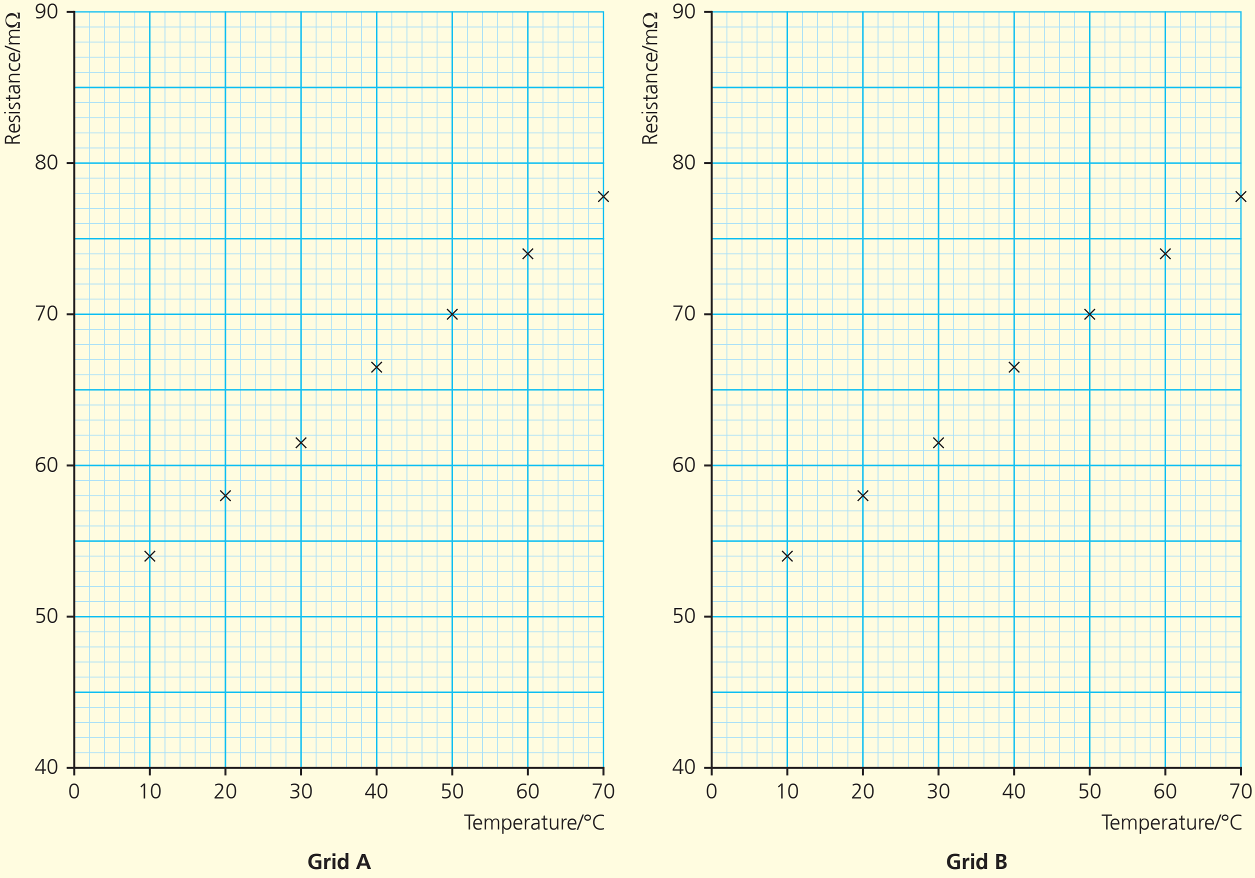


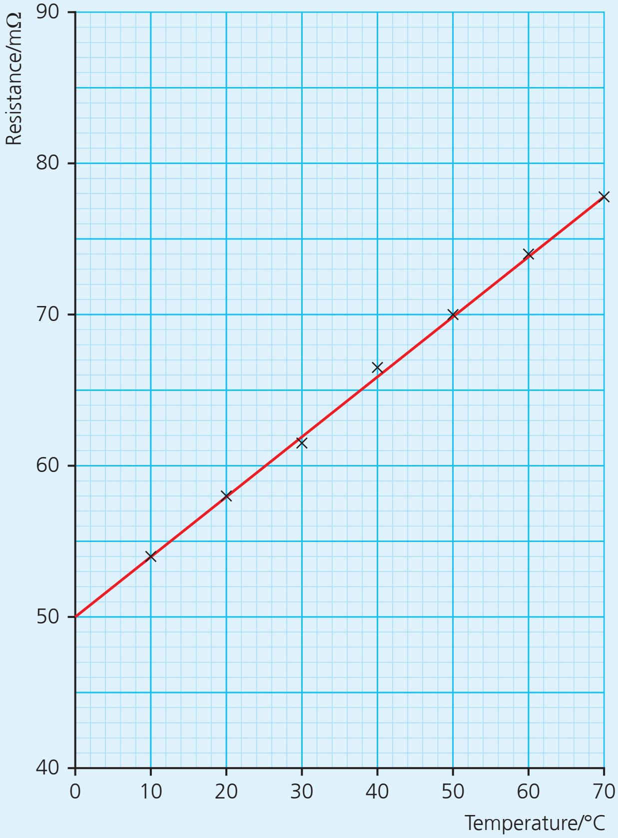
Figure 2

a On grid A, draw the line of best fit on the graph and use it to find the values of R_0 and α. State the units of α. 5 marks

b Estimate the % uncertainty in R_0 by drawing a line of extreme fit on grid B. 4 marks

Student answer

a



Grid A

Line of best fit ✓

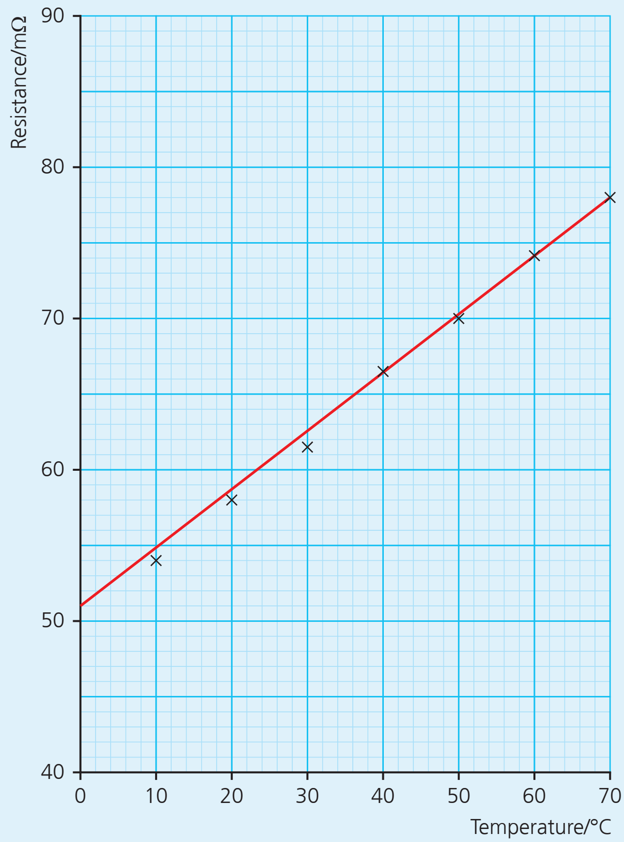
Line of best fit shows R_0 as the intercept at 50 milliohms. ✓

Gradient $= R_0\alpha = \dfrac{28\,\text{m}\Omega}{70\,°\text{C}} = 0.4\,\text{m}\Omega\,°\text{C}^{-1}$, ✓

so $\alpha = \dfrac{0.4\,\text{m}\Omega\,°\text{C}^{-1}}{50\,\text{m}\Omega} = 0.008\,°\text{C}^{-1}$ ✓ ✓ (number and unit)

The student has shown as many points as possible on the line of best fit, with the same number of points just above and just below the line.
5/5 marks awarded

b



Grid B

Line of extreme fit ✓

Gives R_0 as 52 mΩ ✘

Absolute uncertainty is 2 mΩ ✓

So % uncertainty = (2/50) × 100% = 4% ✓

The line of fit crosses the vertical axis one small square above 50 milliohms — but this corresponds to 51 mΩ, not 52 mΩ. The student would be penalised only once for this error. Note that an answer of 4% without showing the calculation would probably score only 1 mark – for the line of extreme fit. This example illustrates the necessity of showing the examiner exactly how you arrive at your answers.

3/4 marks awarded

Question 3

The internal and external diameters of a glass tube were measured using callipers and found to be 8.3 ± 0.1 mm and 11.3 ± 0.1 mm.

a From these measurements, calculate the thickness of the tube, stating the absolute uncertainty in your answer. 2 marks

b Calculate the % uncertainty in the thickness of the glass tube. 2 marks

c Explain why the % uncertainty in the thickness of the glass is much bigger than that of the external diameter. 2 marks

d Suggest, briefly, an alternative method to measure the thickness of the glass. 1 mark