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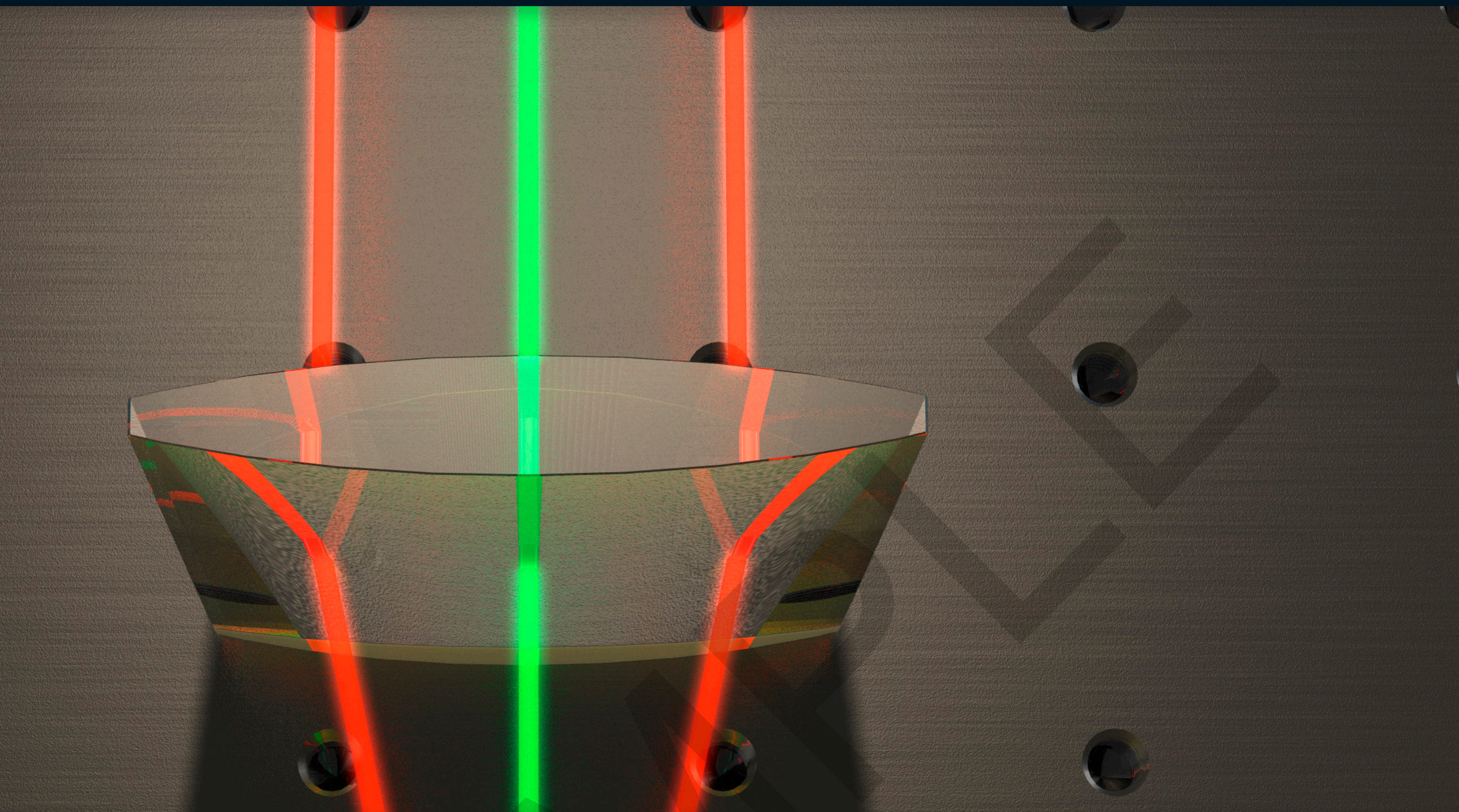

Cambridge International AS & A Level

Physics

Practical Workbook

Graham Jones, Steve Field,
Chris Hewlett and David Styles

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AS & A Level

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Contents

Introduction

Practical work is very important in physics. Many discoveries in the physical world have only been made because practical work has enabled a theory to be proved beyond reasonable doubt, or has shown that current theories or ideas need to be changed. Even today, many of the principles that you will learn as part of your course may only be approximations, and physicists realise that there are still many discoveries yet to be made. Your generation will probably provide insights that will enhance our understanding of the physical world and improve our current theories. But do remember that the work of experimental and theoretical physicists can only be proven to be correct with suitable experimental work. Such experimental work may be on an astronomical scale, for example, to establish what exactly gravity is, or on a microscopic scale, for example, to establish how particles like electrons or atoms can be considered to have wave properties.

It is generally acknowledged that good quality practical work develops a range of skills, knowledge and conceptual understanding. Such skills, involving genuine enquiry, are valuable to the science community as a whole, as well as to physics, and are useful in other areas such as industry and business. By learning how to approach a practical problem, how to plan an investigation, how to take adequate measurements and how to analyse your results, you will be developing skills that you are very likely to make good use of in later life.

You may, initially, be worried because you have done little practical work before you started this course, or perhaps practical work has simply been following instructions to collect specified data using unfamiliar equipment, following stated procedures that perhaps you did not understand. This course is designed to help you improve your practical skills, and also to prepare you for your practical examinations. The skills you will need for these are developed during this course as you progress through the workbook. You will be planning investigations for yourself, taking measurements and analysing your own results. You should take ownership of these results and use your practical time well.

An investigation does not always go well. However, some important advances, such as superconductivity, were made when physicists did not just give up when an experiment did not work, but instead they analysed the unexpected results and then they thought carefully about problems with the apparatus. You can do the same, so that you can learn from investigations that do not work as well as from those that do. This requires thought, but hopefully it will stimulate your interest and determination, as well as developing valuable skills.

You will find guidance on some of the practical skills in Chapters P1 and P2 of the Cambridge International AS & A Level Physics coursebook in this series. You may like to use these chapters as an introduction, or as a reference.

Above all, enjoy your learning and practical work; you may be surprised how enjoyable it can be!

Safety

Working safely in a physics laboratory is an essential aspect of learning which characterises practical work.

Always listen carefully to instructions and carefully follow written instructions and codes of conduct.

If unsure about any aspect of your practical work, ask your teacher. If designing your own investigation, ask your teacher to check your plan before carrying it out.

Many safety issues in a physics laboratory concern the prevention of damage to the equipment.

Working with water	Place all the apparatus in a tray so that any spillage does not affect paperwork. If working with hot or boiling water, use tongs to handle containers such as beakers.
Using a liquid-in-glass thermometer	Place the thermometer securely on the bench when not in use, so that it does not roll off the bench. If a thermometer breaks, inform your teacher immediately. Do not touch either the broken glass or the liquid from inside the thermometer.
Loading thin materials such as wires	Wear safety goggles in case of fracture of the wire. Beware of falling weights if the wire fractures and place a cushion or similar object on the floor.
Connecting electrical components	Do not exceed the recommended voltage for the component: for example, a 6 V lamp.
Toppling retort stands	If a stand is moving or in danger of toppling, secure it to the bench using a G-clamp.
Rolling objects such as cylinders	Place a suitable object such as a box to collect the object so that it does not fall to the floor or affect somebody else's experiment.
Dry cells such as 1.5 V batteries	Do not connect the terminals of the cell to each other with a wire.
Using sharp blades or pins	Tape over sharp edges; keep points of pins downwards, away from eyes.

Table S1

Skills chapter

Collection of data

There are a number of stages needed to collect experimental data. You will need to take accurate measurements from a variety of different apparatus.

You will need to:

- follow instructions both written and in a diagram form
- use practical apparatus correctly
- use practical apparatus safely
- use both analogue and digital measuring instruments
- consider methods to increase the accuracy of measurements, such as timing over a multiple number of oscillations, using a fiducial marker, or using a set square or plumb line
- construct circuits from circuit diagrams ensuring that ammeters and voltmeters are connected correctly, understanding the importance of the polarity of a power supply
- use a signal generator
- use a cathode ray oscilloscope to include the determination of the potential difference from the *y*-axis and the time from the *x*-axis.

In practical activities where a straight-line relationship is expected, the **minimum** number of measurements to be taken should be six. More readings should be taken for a curved trend.

You will need to decide on the range over which you will take readings. The measurements should cover as large a range as possible, with sensible intervals between each reading in the range.

You should also consider repeating readings and determining the mean value.

Presentation of results

Measurements and observations made during an experiment need to be recorded in ways that are easy to follow.

Initially, results should be recorded in a table. The table of results should be planned before the experiment is performed.

The columns of the results table should include space for measurements that are taken and space for values which are going to be calculated from the measurements. Each column heading should include both the quantity and the unit. There should be a distinguishing mark (usually a forward slash '/') to separate the quantity and the unit, for example, length / m, length (cm), *L* / mm etc.

Measurements taken in an experiment should be recorded to the same precision as the measuring instrument. For example, when using a ruler to measure length, measurements are made to the nearest millimetre, so a length of ten centimetres should be recorded as 10.0 cm. In timing experiments using a stopwatch, times can either be recorded to the nearest 0.01 s or rounded to the nearest 0.1 s.

Where calculated values are recorded in your results table, remember to label the column heading with both the quantity and the unit. For example, in an experiment to measure time, t, you may need to calculate time squared, t^2. In this case, the column should be labelled t^2 / s^2.

The calculated values should be recorded to the same number of significant figures as the raw data used to determine the calculated value.

For example, consider the diameter d of a wire. The calculated column may require d^2 to be determined.

d / mm	d^2 / mm^2	d^2 / mm^2 to two significant figures
0.27	0.0729	0.073
0.28	0.0784	0.078
0.29	0.0841	0.084

Table S2

As the values in Table S2 indicate, a change in the second significant figure affects the second significant figure in the calculated value.

Example table of results

In an experiment, the potential difference V across a wire and the current I flowing through the wire are measured for different lengths L of the wire. The resistance of the wire is then calculated as shown in Table S3

Each column heading has a quantity and a unit.

All the length values have been measured to the nearest millimetre.

L / cm	V / V	I / mA	R / Ω
22.2	11.6	73.2	158
30.0	11.6	60.2	193
40.0	12.0	52.8	227
49.7	12.0	45.2	265
59.3	12.2	40.4	302
68.8	12.4	37.6	330

Since both V and I have been recorded to three significant figures, R is also recorded to three significant figures.

All the V values have been measured to the nearest 0.1 V; all the I values have been recorded to the nearest 0.1 mA.

Table S3

At A Level, you will need to understand how to calculate logarithms. For example, consider calculating the logarithm of L for the value of 22.2 cm from Table S3

L / cm	log (*L* / cm)	log (*L* / cm) to three decimal places
22.1	1.344 39	1.344
22.2	1.346 35	1.346
22.3	1.348 30	1.348

Table S4

In Table S4, the number of significant figures (three) in the raw data (*L*) corresponds to the number of decimal places on the calculated logarithmic value. In general, logarithmic values should be given to the same number of decimal places as the **least** number of significant figures in the measured quantities.

Note the number before the decimal place in a logarithmic quantity is a place value. For example, in Table S4 22.2 cm can be written as 222 mm. In this case log (*L*/mm) = 2.346: only the number **before** the decimal place has changed.

Graphs

It is useful to follow a set procedure every time you plot a graph. It is also very useful to draw graphs in pencil so that it is easy to make changes.

Label the axes

The independent variable should be plotted on the *x*-axis and the dependent variable should be plotted on the *y*-axis. Each axis should be labelled in the same way as the column heading in the table, using a quantity and a unit.

Add a scale to each axis

The points should occupy more than half the graph grid in each direction. Scales should be simple so that points can easily be plotted and information from the graph can easily be read from it. Use simple proportions for each 1 cm or 2 cm square, such as 1, 2, 4, 5, 10, 20 or 50. The scales should be labelled at least every two large squares.

Plot the points

All the data values from the table should be plotted on the graph grid (not in the margin area by adding lines to the graph). The plots should be clear and not too thick. It is advisable to check any plots that do not follow a trend are checked.

Draw the best-fit line

Use a transparent 30 cm ruler so that you can easily see the points that you have plotted and that any line that you have drawn is not going to have a join where two rulers have been used. When drawing the best-fit line (or curve) there should be a reasonable balance of points about the line. The line should not be too thick.

At A Level you will also need to add error bars and draw worst acceptable lines.

Figure S1 has been plotted from the data in Table S3

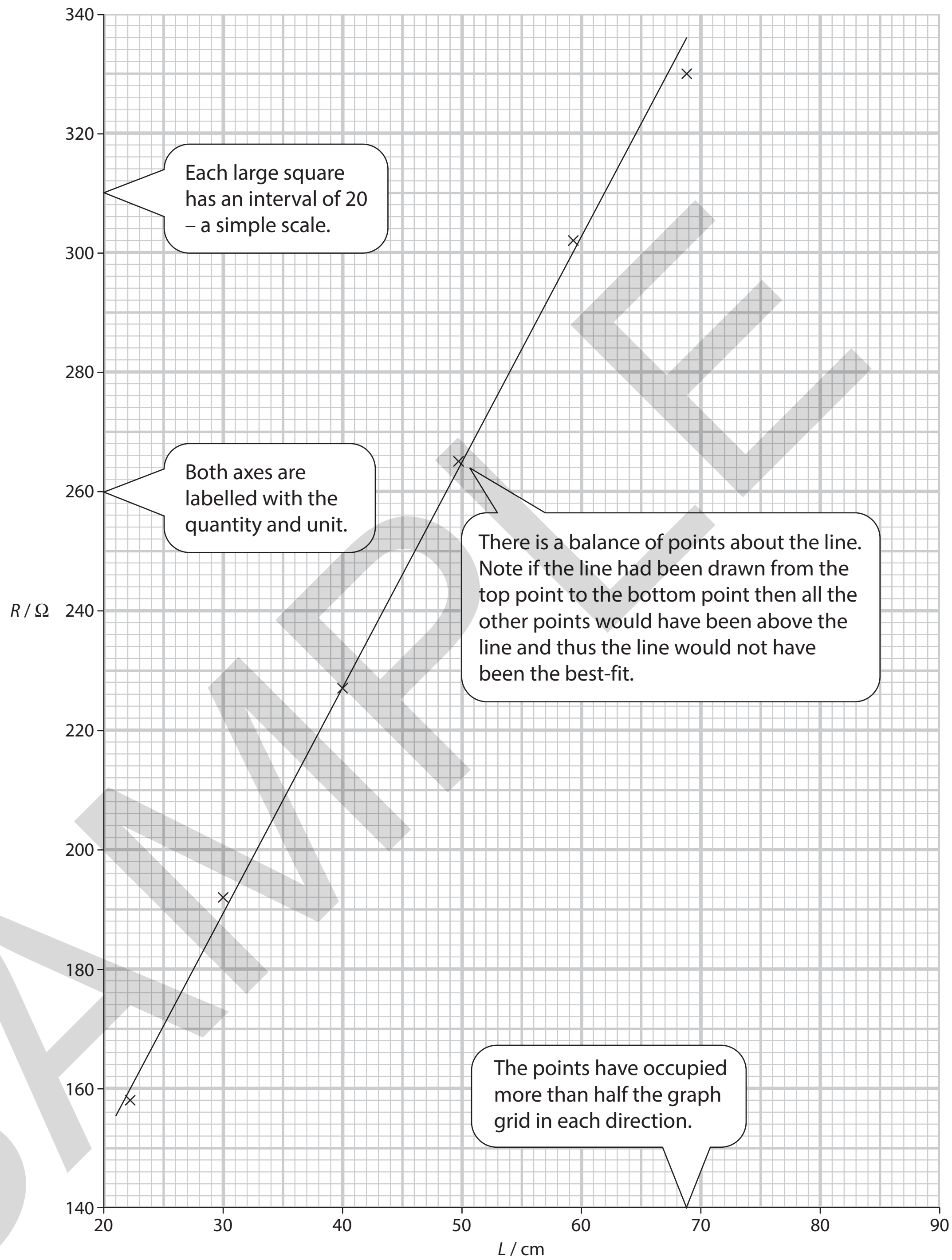

Figure S1

Sometimes you may have a curved trend and you will need to be able to draw a tangent to the curve at a point on the curved trend.

Interpretation of graphs and conclusions

It is expected that you can determine the gradient and *y*-intercept from a graph. All your working should be shown.

To find the gradient, two points (x_1, y_1) and (x_2, y_2) that lie on the best-fit line should be chosen. The two points should be at least half the length of the line apart. It is helpful to try to use points where the best-fit line crosses grid lines. You should only use plots from the table of results if the plots are clearly on the best-fit line. In Figure S1 the plot from Table S2 (22.2, 158) does **not** lie on the best-fit line.

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$$

Using this method, negative gradients are identified.

There are two methods to determine the y-intercept:

a reading the value directly from the y-axis when $x = 0$

b using the calculated gradient and substituting a point from the best-fit line into the equation of a straight line.

The simplest way to do method **b** is to use one of the points from the gradient calculation:

y-intercept $= y_2 -$ gradient $\times x_2$ or y-intercept $= y_1 -$ gradient $\times x_1$

In Figure S1 the x-axis starts at 20 so the substitution method must be used.

The gradient and y-intercept values that you have determined may then be used to determine other values from a given relationship. For Figure S1 and Table S2, the given relationship between R and L may be:

$$R = \frac{4\rho L}{\pi d^2}$$

where ρ is the resistivity of the material and d is the diameter of the wire. You may need to measure the diameter and then determine ρ. It is useful to identify the gradient from the equation:

$$\text{gradient} = \frac{4\rho}{\pi d^2}$$

and then to rearrange the equation with ρ as the subject:

$$\rho = \text{gradient} \times \frac{\pi d^2}{4}$$

Care needs to be taken with powers of ten. In Tables S2 and S3, L/cm could have been written as $L/10^{-2}$ m. The final answer should be given to an appropriate number of significant figures with a correct unit.

Identifying limitations and suggesting improvements

Experimental procedures are not perfect. You should be able to identify limitations in the experimental design and suggest ways in which the procedure might be improved.

Planning

You should develop skills to design appropriate practical activities.

You will need to:

- identify the independent variable (the quantity that will be changed) and the dependent variable (the quantity that will be measured)
- consider how you can make the experiment or investigation a fair test by controlling variables, i.e. identifying the quantities to be kept constant
- select appropriate apparatus
- select appropriate measuring instruments
- describe, in detail, the techniques needed for the proposed experiment including drawing a labelled diagram

- describe any safety precautions explicitly needed for the experiment
- explain how a relationship may be tested; for example, suggest an appropriate graph to plot by identifying quantities to plot on each axis
- explain how the data collected may be analysed.

When testing relationships, it should be remembered that to test if quantity M is directly proportional to quantity L, if the graph is a straight line passing through the origin then the relationship is valid. For a linear relationship that is not directly proportional, you would expect a straight line **not** passing through the origin.

At A Level you are expected to be able to analyse relationships using both logarithms to the base 10 (lg) and natural logarithms (ln).

For example, if the relationship between P and Q is:

$$Q = kP^n$$

where k and n are constants, then the linear form of this equation may be found by taking logs of both sides:

$$\lg Q = n \lg P + \lg k$$

For this relationship to be valid, a graph of $\lg Q$ (y-axis) against $\lg P$ (x-axis) should be plotted.

$$n = \text{gradient and since } y\text{-intercept} = \lg k, \text{ then } k = 10^{y\text{-intercept}}$$

Similarly, if the relationship between S and T is:

$$k = 10^{y\text{-intercept}}$$

where k and w are constants, then the linear form of this equation may be found by taking natural logs of both sides:

$$\ln T = -wS + \ln k$$

For this relationship to be valid, a graph of $\ln T$ (y-axis) against S (x-axis) should be plotted.

$$w = -\text{ gradient and since } y\text{-intercept} = \ln k, \text{ then } k = e^{y\text{-intercept}}$$

Treatment of uncertainties

Measurements should include an estimate of the absolute uncertainty. It is only an estimate of the maximum difference between the actual reading and the true value. For example, in Table S3 V may have been measured to the nearest 0.2 V. The first reading of V could be written as 11.6 ± 0.2 V.

If readings are repeated, then the absolute uncertainty is half the range of the values.

Often it is useful to write uncertainties as fractional uncertainties or percentage uncertainties:

$$\text{fractional uncertainty} = \frac{\text{absolute uncertainty}}{\text{(average) value}} \text{ or}$$

$$\text{percentage uncertainty} = \frac{\text{absolute uncertainty}}{\text{(average) value}} \times 100\%$$

It is often necessary to combine uncertainties. There are some simple rules:

- When adding or subtracting quantities, absolute uncertainties are added.
- When multiplying or dividing quantities, percentage uncertainties are added.
- There is a special case for power terms. For example, if $Q = P^n$
  percentage uncertainty in $Q = n \times$ percentage uncertainty in P.

In a table of results, it may be necessary to indicate the absolute uncertainty in a calculated quantity. For example, in the first row of Table S3, it could be that V was 11.6 ± 0.2 V and I was 73.2 ± 0.2 A. One way of determining the absolute uncertainty in R is to determine the percentage uncertainty in R first and then determine the absolute uncertainty in R.

percentage uncertainty in $R = \left(\frac{0.2}{11.6} + \frac{0.2}{73.2}\right) \times 100 = 2\%$

absolute uncertainty in $R = \frac{2}{100} \times 158 = 3$

There are alternative methods by using maximum and minimum values. Using the data above:

max $R = \frac{11.6 + 0.2\ V}{73.2 - 0.2\ mA} = 161.6\ \Omega$ and

min $R = \frac{11.6 - 0.2\ V}{73.2 + 0.2\ mA} = 155.3\ \Omega$

Each of these values gives an absolute uncertainty of about 3 and half the range is also about 3.

A graph can show the uncertainties of the measurements by drawing error bars. The length of each error bar either side of the plot corresponds to the absolute uncertainty in the quantity.

Having drawn the error bars, a worst acceptable line may be drawn. This is the steepest or shallowest line that, when drawn, passes through all the error bars.

The same methods to determine the gradient and y-intercept of the best-fit line may also be used to find the gradient and y-intercept of the worst acceptable line.

absolute uncertainty in gradient = |gradient of best-fit line − gradient of the worst acceptable line|

absolute uncertainty in y-intercept = |y-intercept of best-fit line − y-intercept of the worst acceptable line|

Using the data from the earlier example and assuming that the uncertainty in V is ± 0.2 V and the uncertainty in I is ± 0.2 mA, the results become those shown in Table S5.

L / cm	**V / V**	**I / mA**	**R / Ω**
22.2	11.6 ± 0.2	73.2 ± 0.2	158 ± 3
30.0	11.6 ± 0.2	60.2 ± 0.2	193 ± 4
40.0	12.0 ± 0.2	52.8 ± 0.2	227 ± 5
49.7	12.0 ± 0.2	45.2 ± 0.2	265 ± 6
59.3	12.2 ± 0.2	40.4 ± 0.2	302 ± 7
68.8	12.4 ± 0.2	37.6 ± 0.2	330 ± 7

Table S5

Plot the graph with error bars for each value of resistance. Draw the best-fit line and then the worst acceptable line. Figure S2 shows the error bars and the (shallowest) worst acceptable line.

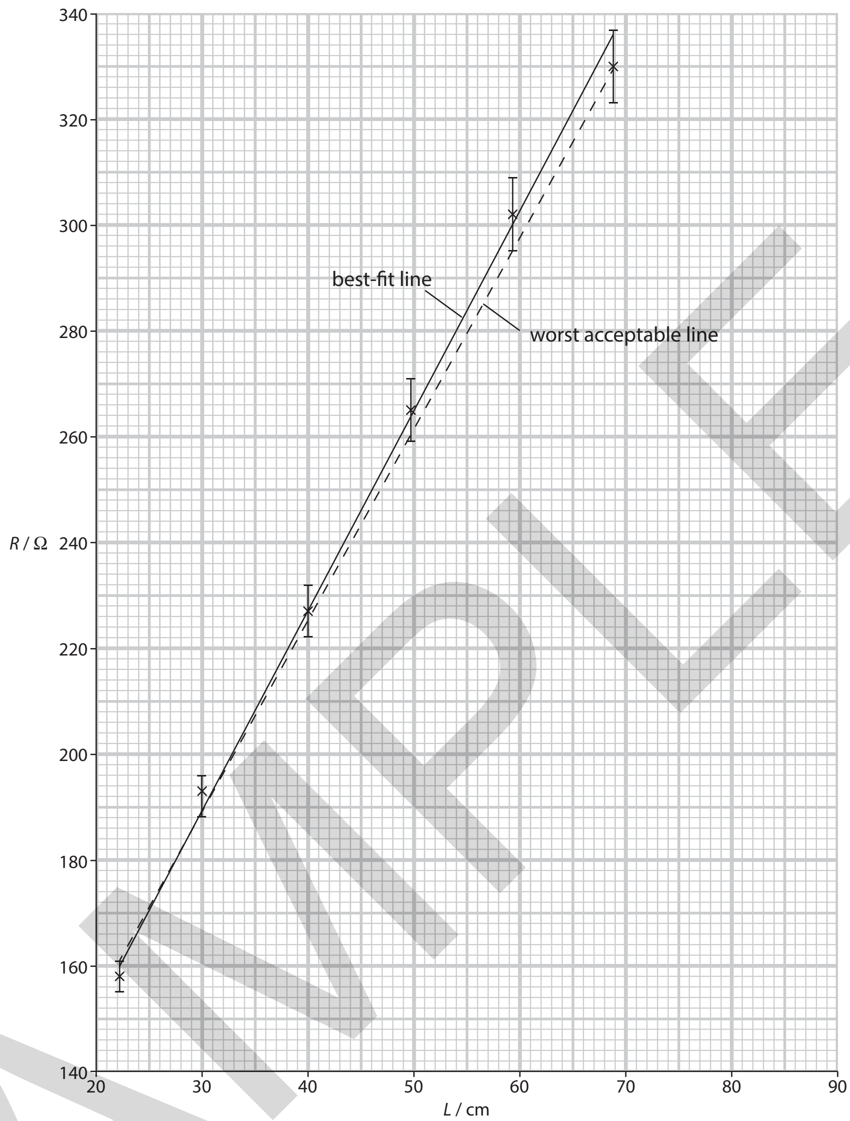

Figure S2

HINT
Use the gradient from the worst acceptable line and a data point from the worst acceptable line

The lines should be labelled and it is usual to show the worst acceptable line as a dashed line. The worst acceptable line should pass through all the error bars unless there is an anomalous plot. The actual worst acceptable line should clearly be seen to pass through each error bar.

The gradient, including the absolute uncertainty, may then be determined:

gradient of best-fit line $= \dfrac{322 - 208}{65 - 35} = \dfrac{114}{30} = 3.80$

gradient of worst acceptable line $= \dfrac{326 - 178}{68 - 27} = \dfrac{148}{41} = 3.61$

Uncertainty in gradient = 3.8 − 3.61 = 0.19

Gradient = 3.80 ± 0.19 ($\Omega\,cm^{-1}$). The units are useful at this stage for any further calculation.

HINT
Uses data points from the worst acceptable line

Since there is a false origin, the ***y***-intercept, including the absolute uncertainty, may be determined from the gradient calculations:

y-intercept of best-fit line = 322 − 3.80 × 65 = 75

y-intercept of worst acceptable line = 326 − 3.61 × 68 = 81

Uncertainty in *y*-intercept = 81 − 75 = 6

y-intercept = 75 ± 6 Ω

Chapter 1:
Using apparatus

Chapter outline

This chapter relates to Chapter 1: Kinematics – describing motion, Chapter 7: Matter and materials and Chapter 9: Electric current, potential difference and resistance, in the coursebook.

In this chapter you will complete investigations on:

- 1.1 Determining the density of water
- 1.2 Determining the spring constant of a spring
- 1.3 Determining the resistance of a metal wire
- 1.4 Determining the average speed of a cylinder rolling down a ramp.

Practical Investigation 1.1:
Determining the density of water

Introduction

Density is defined as mass ÷ volume or, expressed in symbols:

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

The standard unit for density in the SI system of units is $kg\,m^{-3}$. $1000\,kg\,m^{-3} = 1\,g\,cm^{-3}$.

Equipment

You will need:

• metre rule • 30 cm ruler • 250 cm^3 beaker • Vernier or digital callipers.

Access to:

• jug of water • top-pan balance.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Clear any spillages of water.

Part 1: Determining density from single mass and volume measurements

Method

1 Place an empty 250 cm^3 beaker on a top-pan balance. Record the reading on the balance.

Mass of empty beaker …………….. g

2 Pour some water into the beaker until the water level is approximately 180 cm^3.
Estimate the volume of the water.

Estimated volume of water V = …………….. cm^3

3 Record the new reading on the balance.

Mass of beaker and water = …………….. g

Data analysis

a Calculate m using:

$$m = \text{mass of beaker and water} - \text{mass of beaker}$$

m = …………….. g

b Calculate the density ρ of water using your measurements.

ρ = …………….. g cm^{-3}

Part 2: Using a graph to find density

Method

1 Place an empty 250 cm^3 beaker on a balance. Record the reading on the balance in the Results section.

2 Pour some water into the beaker until the water level is approximately 50 cm^3.

3 Record the new balance reading in Table 1.1 in the Results section.

4 The water in the beaker has a diameter d and height h.

i Measure d using the 30 cm rule and record your measurement in the Results section.

ii Measure h using the metre rule and record your measurement in Table 1.1.

5 Change the amount of water in the beaker and take a series of readings of the mass of the beaker and the water and the height h. Record your results in Table 1.1.

Results

Mass of beaker = …………….. g d = …………….. cm

Mass of beaker and water / g	m / g	h / cm

Table 1.1

Data analysis

a Calculate m for each of your readings using

$$m = \text{mass of beaker and water} - \text{mass of beaker}$$

Record your values for m in Table 1.1.

b Plot a graph of m on the y-axis against h on the x-axis using the graph grid.

c Draw the straight line of best fit.

d Determine the gradient of this line.

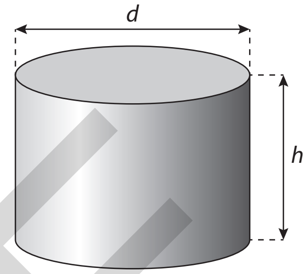

Figure 1.1

Gradient = ……………

e Extension question. The volume V of a circular cylinder with diameter d and height h as shown in Figure 1.1. is given by:

$$V = \frac{\pi d^2 h}{4}$$

Using $\rho = \frac{m}{V}$ and $V = \frac{\pi d^2 h}{4}$, show that $m = \frac{\rho \pi d^2 h}{4}$.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

HINT
π, ρ, d and 4 are all constant.

f Extension question. Show that the gradient of the graph will be $\frac{\rho \pi d^2}{4}$.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

g Determine ρ using:

$$\rho = \frac{4 \times \text{gradient}}{\pi d^2}$$

ρ = …………… g cm^{-3}

Evaluation

h Suggest **two** advantages of using digital callipers instead of a ruler to measure d.

……………………………………………………………………………………………

……………………………………………………………………………………………

Practical Investigation 1.2:

Determining the spring constant of a spring

Introduction

The spring constant is defined as force per unit extension, or expressed in symbols:

$$k = \frac{F}{e}$$

The stiffness of a spring is its resistance to deformation when a load is applied. The stiffer the spring, the greater the value of *k*.

The standard unit for spring constant in the SI system of units is $N\,m^{-1}$.

$$100\,N\,m^{-1} = 1\,N\,cm^{-1}$$

Equipment

You will need:

• expendable steel spring • 100 g mass hanger • 0–10 N newton-meter • 30 cm ruler
• four 100 g slotted masses • 2 × stand • 2 × boss • 2 × clamp • G-clamp.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- If the stand moves or tilts it may be necessary to secure it to the bench using the G-clamp.

Part 1: Determining the spring constant from the measurement of an extension and the calculation of a load

Method

1 Measure the length x_0 of the coiled section of an unextended spring as shown in Figure 1.3 and write your answer in the Results section.

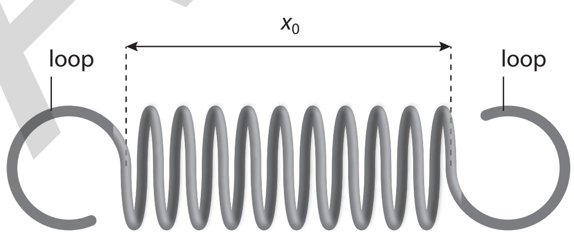

Figure 1.3

2 Suspend the spring from the rod of a clamp.

Attach 500 g from the bottom of the spring as shown in Figure 1.4.

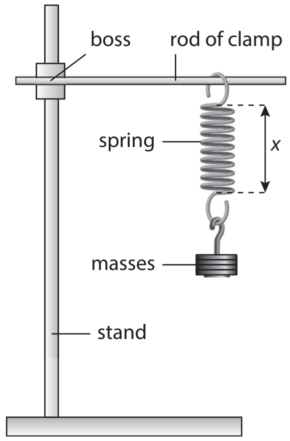

Figure 1.4

3 Measure the length of the coiled section x of the extended spring as shown in Figure 1.4 and write your answer in the Results section.

4 Record the masses of the mass hanger and each of the slotted masses separately to the nearest 0.1 g in Table 1.2 in the Results section.

Results

x_0 = ……………. cm $\qquad$ x = ……………. cm

Mass / g				
mass hanger	**mass 1**	**mass 2**	**mass 3**	**mass 4**

Table 1.2

Data analysis

a Calculate the extension e of the spring using:

$$e = x - x_0$$

Give your answer in metres.

e = ……………. m

b Calculate the total value m of the mass hanger and the 100 g slotted masses

Give your answer in kg.

m = ……………. kg

c $F = m \times g$ where g is acceleration of free fall equal to $9.81\ \text{m s}^{-2}$

Calculate the spring constant k using $k = \frac{F}{e}$

k = ……………. N m^{-1}

Evaluation

d The following will contribute to the uncertainty in *x*:

- both ends of the rule must be viewed at the same time
- the exact positions where the coiled section starts and ends.

List two further sources of uncertainty.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

e Calculate the mean value of a 100 g slotted mass (and hanger) using the values in Table 1.2.

Mean value = …………… g

f Calculate the uncertainty in the value of a 100 g mass from the half range given by:

$$\frac{\text{largest value of mass} - \text{smallest value of mass}}{2}$$

Uncertainty = …………… g

Part 2: Using a newton-meter to measure force

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Take care when moving the bottom clamp because the spring balance and/or the spring could roll off the end of the rod.

Method

HINT
The newton-meter will record a reading of force *F* in newtons.

1 Set up the apparatus as shown in Figure 1.5. Use the same spring as you used in Part 1.

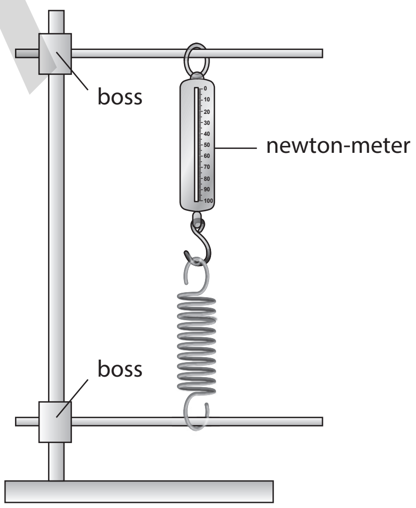

Figure 1.5

2 Move the bottom clamp vertically to different positions. Take a series of readings of *F* and *x*.

Record your data in Table 1.3 in the Results section.

Results

F / N	*x* / m	*e* / m

Table 1.3

Data analysis

a Calculate the extension *e* of the spring and add these values to Table 1.3.

b Plot a graph of *e* on the *y*-axis against *F* on the *x*-axis using the graph grid.

c Draw the straight line of best fit.

d Determine the gradient of this line.

Gradient = ……………

e Extension question. Show that:

$$k = \frac{1}{\text{gradient}}$$

………

………

f Extension question. Determine *k* from your gradient.

k = …………… N m^{-1}

g Measure x_0 again. Has it changed? If so, how does it affect your value of *k*?

………

………

h Suppose you repeated the experiment with a stiffer spring. Draw a dotted line on the graph grid to show the expected result.

Evaluation

i List the advantages and disadvantages of using the newton-meter compared to a number of slotted masses in Table 1.4.

Advantages	Disadvantages

Table 1.4

Practical Investigation 1.3: Determining the resistance of a metal wire

Introduction

The resistance of a resistor is defined by:

$$\frac{\text{potential difference across the resistor}}{\text{current in the resistor}}$$

or, expressed in symbols:

$$R = \frac{V}{I}$$

The standard unit for resistance in the SI system of units is the ohm (Ω).

Equipment

You will need:

• 1.5V cell • connecting leads • crocodile clips • power supply • two digital multimeters • rheostat • metre rule • switch.

Access to:

• reel of wire • scissors • adhesive tape • wire cutters • micrometer.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There are no other specific safety issues with this investigation.

Part 1: Using digital multimeters

Method

1 Switch on one of the multimeters. When the dial is moved from the OFF position there are several possible ranges.

These could include:

- direct voltage
- alternating voltage

- direct current
- resistance.

Some of these ranges are shown in Table 1.5.

	Range from zero to:	**Precision to the nearest:**
direct voltage	600 V	1 V
	200 V	0.1 V
	20 V	0.01 V
	2000 mV (2 V)	1 mV (0.001 V)
	200 mV	0.1 mV
alternating voltage	600 V	1 V
	200 V	0.1 V
direct current	10 A	0.001 A
	200 mA	0.1 mA
	20 mA	0.01 mA
	2000 μA	1 μA
	200 μA	0.1 μA
resistance	2000 kΩ	
	200 kΩ	
	20 kΩ	
	2000 Ω	
	200 Ω	

Table 1.5

Check each range on your multimeter. They should all read zero. The precision can be checked by noting where the decimal point is. If you have different ranges to those shown in Table 1.5, add them in the empty rows in this table.

The resistance ranges will all read '1'. This does **not** mean that there is a reading of 1 Ω. It means that the resistance that is being measured is off the top of the scale. Since no resistor is attached between the terminals of the multimeter, it is measuring a resistance of infinity on all the scales.

2 Connect the voltmeter to the cell. If the reading is negative, reverse the connections to the meter.

i Go through the scales.

ii For each scale, record the reading on the multimeter in Table 1.6.

Scale	Reading
600 V	
200 V	
20 V	
2000 mV	
200 mV	

Table 1.6

3 Choose the most suitable scale and give reasons for your choice.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Part 2: Determining resistance from a single ammeter and voltmeter reading

Method

1 Use the wire cutters to cut a wire of length 110 cm.

2 Use the scissors to cut sufficient tape to attach the wire to the metre rule as shown in Figure 1.6.

Figure 1.6

3 Connect the circuit as shown in Figure 1.7.

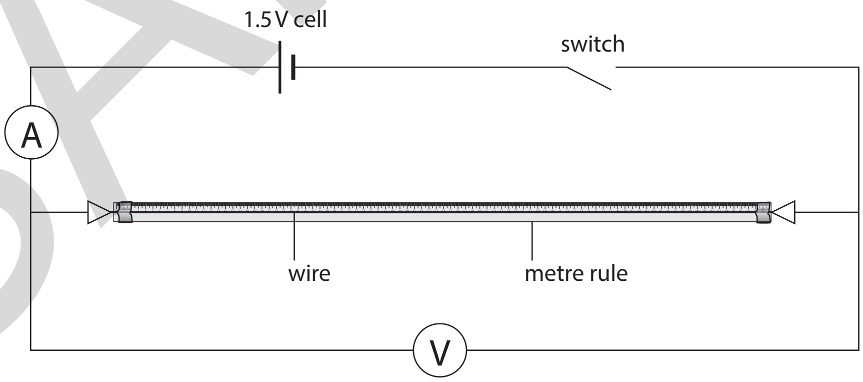

Figure 1.7

i How many connecting leads do you need? ……………

ii How many crocodile clips do you need? ……………

4 Switch both meters to suitable scales and record the readings in Table 1.7 in the Results section.

> **HINT**
> If I mA is 40, then I in Amps is 0.040.

Results

Voltmeter reading V / V	Ammeter reading I / mA	I / A

Table 1.7

Data analysis

a Calculate *R*.

R = …………… Ω

Part 3: Using a rheostat

Method

The rheostat has three terminals, A, B and C, as shown in Figure 1.8.

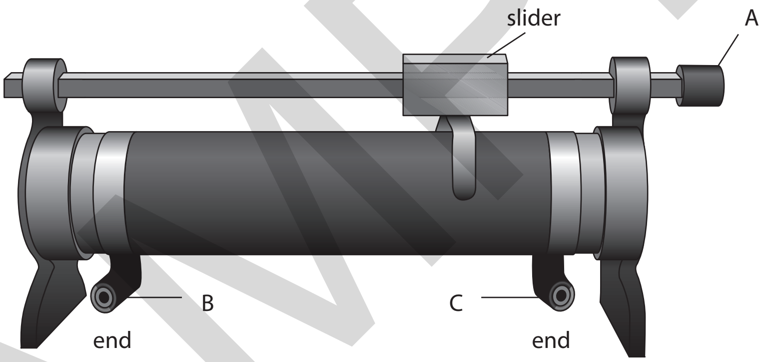

Figure 1.8

1 Switch the multimeter to the 200 Ω range.

Connect the rheostat to the multimeter and complete Table 1.8.

Connections	Does the resistance reading change when the slider is moved?
A and B	yes / no
B and C	yes / no
A and C	yes / no

Table 1.8

Part 4: Determining resistance using a graph

Method

1 Connect the rheostat into the circuit as shown in Figure 1.9.

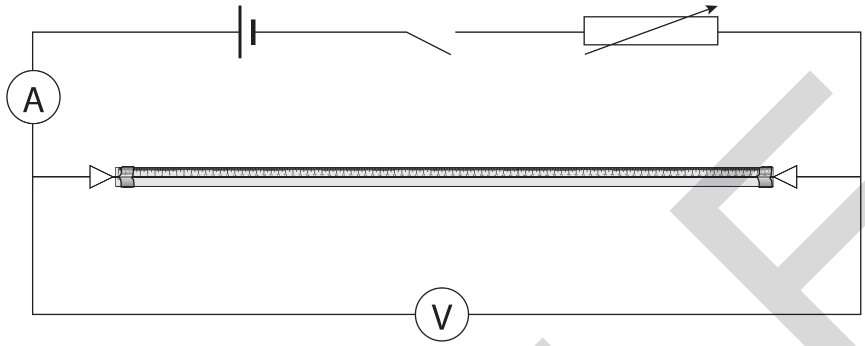

Figure 1.9

2 Move the slider on the rheostat and take a series of readings of V and I.

Record these readings in Table 1.9 in the Results section.

3 Open the switch between readings to prevent discharging the battery.

Results

V / V	I / A

Table 1.9

Data analysis

a Plot a graph of I on the y-axis against V on the x-axis using the graph grid.

b Draw the straight line of best fit.

c Determine the gradient of this line.

Gradient = ……………

d Determine R using $R = \frac{1}{\text{gradient}}$.

R = …………… Ω

Evaluation

e How could you use the rheostat to take a wide range of equally spaced readings?

……

……

Part 5: Using a micrometer

Resistance per unit length (resistance of 100 cm length of wire) depends on the diameter of the wire. Table 1.10 shows the properties of some wires A, B, C, D. E.

Wire	Diameter / mm	Resistance per unit length / $\Omega\,m^{-1}$
A	0.38	4.4
B	0.27	8.3
C	0.19	16.8
D	0.15	27.0
E	0.10	60.0

Table 1.10

Method

1 Use the micrometer to measure the diameter of your wire.

Diameter = …………… mm

Data analysis

a Use the data in Table 1.10 and your value of *R* to identify your wire.

……

b Give a reason(s) for your choice

……

……

c Theory suggests that the graph line in Part 4 should go through the point (0, 0).

Suppose you repeated the experiment with a wire of smaller diameter. Draw a dotted line on the graph grid in Part 4 to show the expected result.

Practical Investigation 1.4:
Determining the average speed of a cylinder rolling down a ramp

Introduction

The average speed of an object is defined by:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

or, expressed in symbols:

$$v = \frac{d}{t}$$

The standard unit for speed in the SI system of units is $m\,s^{-1}$.

> ### Equipment
> **You will need:**
> • cylinder • wooden board • stand • boss • clamp • metre rule • protractor • stopwatch
> • book or pencil case to act as a barrier at the bottom of the ramp.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Use a book or a pencil case to stop the cylinder after it has reached the bottom of the wooden board.

Part 1: Investigating reaction time

Method

1 Set your stopwatch to zero.

2 Switch the stopwatch on and off as quickly as you can and record the reading.

3 Repeat this reading and record the three values in Table 1.11 in the Results section.

Results

t_1 / s	t_2 / s	t_3 / s

Table 1.11

Data analysis

a Calculate the mean value of *t*.

t = ……………. s

Evaluation

b Figure 1.10 shows a reading of 1.44 seconds on a stopwatch.

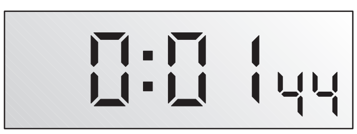

Figure 1.10

Use your result in Table 1.11 to calculate the percentage uncertainty in the reading in Figure 1.10.

Percentage uncertainty = ……………

Part 2: Determining average speed

Method

1 Set up the apparatus as shown in Figure 1.11.

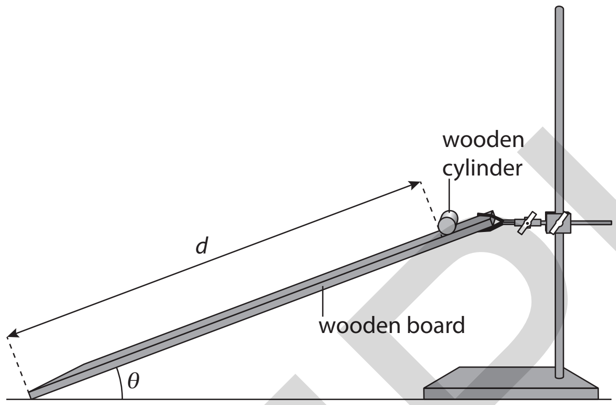

Figure 1.11

2 Place the cylinder near the top of the wooden board.

Measure the distance *d* that the cylinder will travel down the wooden board when it is released. Write this value in the Results section.

3 Release the cylinder and measure the time t_1 for the cylinder to travel the distance *d* down the slope.

4 Repeat this reading and record the three values in Table 1.12 in the Results section.

Results

d = …………… cm

t_1 / s	t_2 / s	t_3 / s

Table 1.12

Data analysis

a Calculate the mean value of *t* from your results in Table 1.12.

Mean value of *t* = …………… s

b Calculate the average speed *v*.

v = …………… cm s^{-1}

Part 3: Investigating how the average speed depends on the angle of the plane

Method

1 Use the protractor to measure the angle θ between the plane and the bench as shown in Figure 1.11.

2 Take a series of readings of θ and t.

Record your data in Table 1.13 in the Results section.

Results

	t / s			
θ/°	**1st value**	**2nd value**	**3rd value**	**mean**

Table 1.13

Data analysis

a Use Table 1.14 to record calculated values of sin θ, t sin θ and v.

sin θ	**t sin θ / s**	**v / cm s^{-1}**

Table 1.14

b Plot a graph of v on the y-axis against t sin θ on the x-axis using the graph grid.

c Draw the straight line of best fit.

d Determine the gradient of this line.

Gradient = ……………

e The relationship between v, t and θ is:

$$\left(\frac{gt}{3}\right)\sin\theta$$

where g is the acceleration of free fall.

Use your gradient to determine a value for g.

g = …………… m s^{-2}

Evaluation

f The accepted value for *g* is 9.81 m s^{-2} (or 981 cm s^{-2}) and the theory predicts that the *y*-intercept is zero.

Does your value for *g* differ from the accepted value?

....

....

g Does your straight line of best fit go through (0, 0)?

....

....

h Are there any anomalous point(s) that you did not include in your straight line of best fit?

....

....

Chapter 2:
Limitations and improvements

Chapter outline

This chapter relates to Chapter 4: Forces – vectors and moments and Chapter 7: Matter and materials, in the coursebook.

In this chapter you will complete investigations on:

- 2.1 Thermal energy loss from water in a polystyrene cup
- 2.2 Loaded rubber band
- 2.3 Balanced metre rule.

Practical Investigation 2.1:
Thermal energy loss from water in a polystyrene cup

Introduction

The thermal energy loss from hot water contained in a polystyrene cup depends on several factors.

One of these factors is the mass of water in the cup. You are going to measure the time taken for the temperature of different masses of water to drop between two fixed temperatures.

Equipment

You will need:

• long-stem thermometer: −10 °C to 110 °C × 1 °C • 200 cm^3 polystyrene cup • stopwatch • stirrer • paper towel.

Access to:

• electric kettle or other means to heat water to boiling safely • top-pan balance • jug of cold water • waterproof pen.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Take care when pouring hot water into the cup or emptying the hot water from the cup into a sink or container.
- When the thermometer is not in use, place it on the paper towel so that it does not fall onto the floor.

Method

1 Determine the mass of the cup using the top-pan balance. Record this value in the Results section.

2 Make three marks on the **inside** of the polystyrene cup at the positions shown in Figure 2.1.

Figure 2.1

3 Pour cold water into the cup until it reaches the bottom line.

4 Determine the mass of the cup and water. Record this value in Table 2.1 in the Results section.

5 Repeat steps **3** and **4** for the middle line and the top line.

6 Empty the water from the cup.

7 Pour boiling water into the cup until it reaches the bottom line.

8 Place the thermometer and stirrer in the cup.

9 Start the stopwatch when the temperature of the water in the cup is 85 °C.

10 Stop the stopwatch when the temperature of the water in the cup is 80 °C.

11 Record the time *t* in Table 2.1.

12 Repeat steps **6**, **7**, **8**, **9**, **10** and **11** for the middle line and the top line.

Results

Mass of cup = …………………… g

Mark on cup	Mass of cup and water / g	*m* / g	*t* / s	
bottom				
middle				
top				

Table 2.1

Data analysis

a Calculate the mass of water *m* using:

m = mass of cup and water − mass of cup

and record these values in Table 2.1

b How does *t* vary with *m*?

……

……

Evaluation

c Why was the same starting temperature (85 °C) and temperature change (5 °C) used in each experiment?

……

……

d There is a spare column in Table 2.1.

Write in the spare column estimated times if a starting temperature of 80 °C had been used for the same temperature change (5 °C).

Suggest a reason for your estimated times.

....

....

....

e In Table 2.2 there are some suggested limitations and improvements.

A and **B** require additional apparatus so it is appropriate to suggest the improvements.

It is appropriate to suggest that **C** and **D** are limitations. However, the improvements could have been achieved with the existing apparatus.

Suggest one more valid limitation and improvement and add these to row **E** in Table 2.2.

	Limitation	Improvement
A	The rate of thermal energy loss depends on the area of the water surface exposed to the air. In each experiment the area was different.	Use a cup that has straight vertical sides.
B	It was difficult to read the thermometer, stir the water and hold the stopwatch at the same time.	Use a stand and clamp to hold the thermometer.
C	After the first experiment the cup was warmed up so this may have affected the remaining results.	Rinse the cup with cold water after each experiment.
D	If room temperature had changed during the experiment it would have affected the results.	Check room temperature before and after each experiment.
E	....	....

Table 2.2

Practical Investigation 2.2: Loaded rubber band

Introduction

When a material is subject to a force it undergoes tensile deformation. You are going to investigate the relationship between the force exerted on a rubber band and its extension.

Equipment

You will need:

• two stands • two bosses • two clamps • G-clamp • 100 g mass hanger • four 100 g slotted masses • protractor • metre rule • rubber band with approximate cross-section 2 mm × 1 mm and approximate circumference 20 cm.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Take care when moving the stand. It may topple when the rubber band is stretched.
- Do not try to extend the rubber band as much as possible. This could break the rubber band causing the masses to fall to the bench or the floor.

Part 1: Suspending the rubber band from two rods

Method

1 Set up the apparatus as shown in Figure 2.2. The distance *x* between the rods of the clamps should be approximately 10 cm.

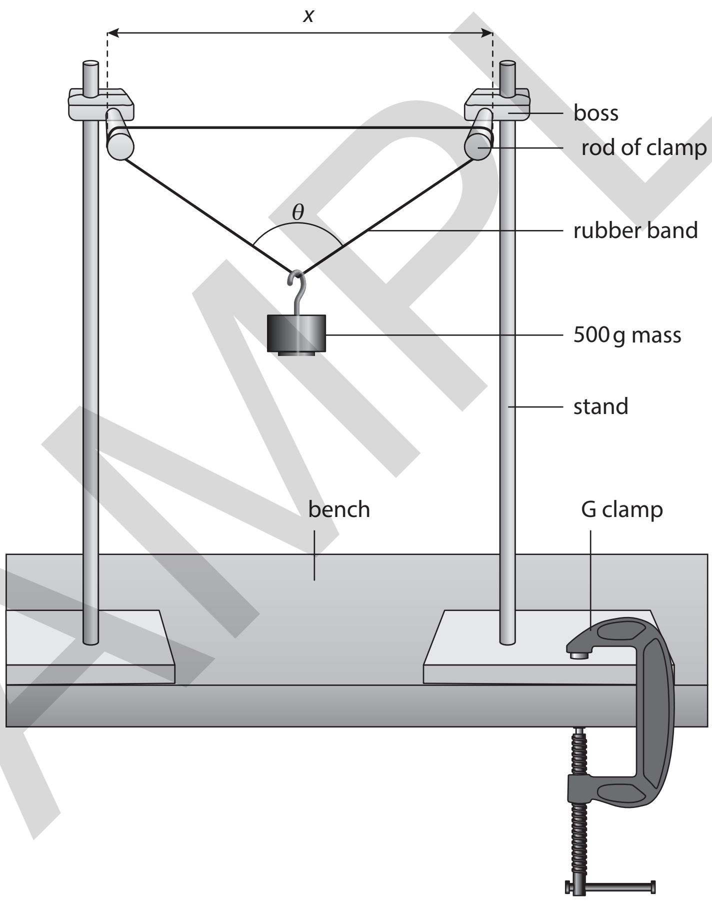

Figure 2.2

2 Record your value of *x* in Table 2.3 in the Results section.

3 Measure the angle θ and record this value in Table 2.3.

4 Move the left-hand stand to the left and take a series of readings of *x* and θ.

Record your data in Table 2.3.

5 After you have taken all your readings, remove the rubber band from the clamps.

Measure its total length (circumference) C.

Record this value under Table 2.3.

Results

x / cm	θ / °	$\sin\left(\frac{\theta}{2}\right)$	L / cm	e / cm

Table 2.3

C = …………………… cm

Data analysis

a The total length L of the extended rubber band is given by:

$$L = x + \frac{x}{\sin\left(\frac{\theta}{2}\right)}$$

Calculate values of $\sin\left(\frac{\theta}{2}\right)$ and L and record your values in Table 2.3.

b How does L vary with x?

………

………

c Calculate the extension e of the rubber band using:

$$e = L - C$$

Record your values of e in Table 2.3.

Part 2: Suspending the rubber band from one rod

Method

1 Set up the apparatus as shown in Figure 2.3. The distance between the top of the rod of the clamp and the hook of the mass hanger is R.

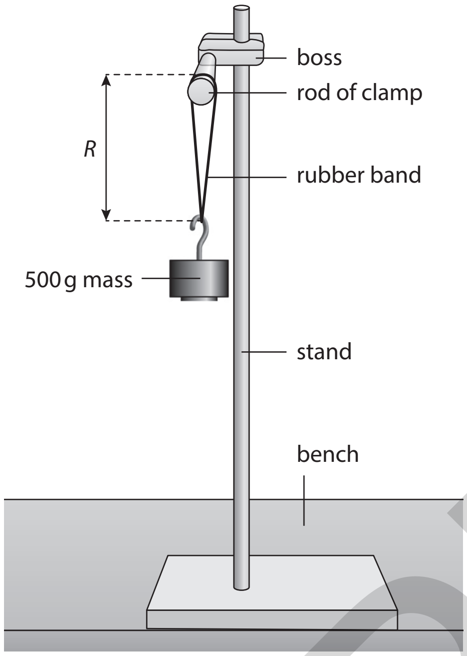

Figure 2.3

2 Measure and record R.

R = …………………… cm

Data analysis

a Calculate the extension e of the rubber band using:

$$e = 2R - C$$

Extension = …………………… cm

b Look at the data in Table 2.3 and estimate the value of x that would result in the same extension that you determined in part **1**.

Estimated value of x = …………………… cm

Evaluation

c In Table 2.4 there are three suggested limitations and improvements, but only **two** of them are acceptable.

In **A** and **B** either a different technique or using extra apparatus is suggested.

In **C** the suggestion could have been performed using the existing apparatus, so this is **not** a good suggestion.

Write two more limitations and improvements in rows **D** and **E** in Table 2.4.

HINT
Give a **reason** why it was difficult to measure θ.

	Limitation	Improvement
A	It was difficult to measure θ because the hook of the mass hanger was in the way.	Set up a card behind the rubber band. Draw lines on the card which are parallel to the rubber band. Measure θ on the card.
B	It was difficult to measure θ because the hook of the mass hanger was in the way.	Tie a thin string loop around the rubber band from which to suspend the mass.

	Limitation	Improvement
C	It was difficult to measure θ because the hook of the mass hanger was in the way.	Determine $\frac{\theta}{2}$ by measuring lengths and using trigonometry.
D	…………………………………………… …………………………………………… …………………………………………… ……………………………………………	…………………………………………… …………………………………………… …………………………………………… ……………………………………………
E	…………………………………………… …………………………………………… …………………………………………… ……………………………………………	…………………………………………… …………………………………………… …………………………………………… ……………………………………………

Table 2.4

Practical Investigation 2.3:
Balanced metre rule

Introduction

When a system is in equilibrium there is no resultant force and no resultant torque. You are going to use a balanced metre rule to determine an unknown mass.

Equipment

You will need:

• stand • boss • clamp • metre rule • loop of thick string of circumference 20 cm • 50 g slotted mass • three 10 g slotted masses • mass *M* of modelling clay • small triangular pivot.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- If the masses move off the rule when it slides through the string loop, move the boss closer to the bench.

Method

1 Set up the apparatus as shown in Figure 2.4. The metre rule should be balanced with the centres of mass *M* and the 50 g mass each positioned 2 cm from each end of the rule. The distance between the centre of the 50 g mass and the string is *y*.

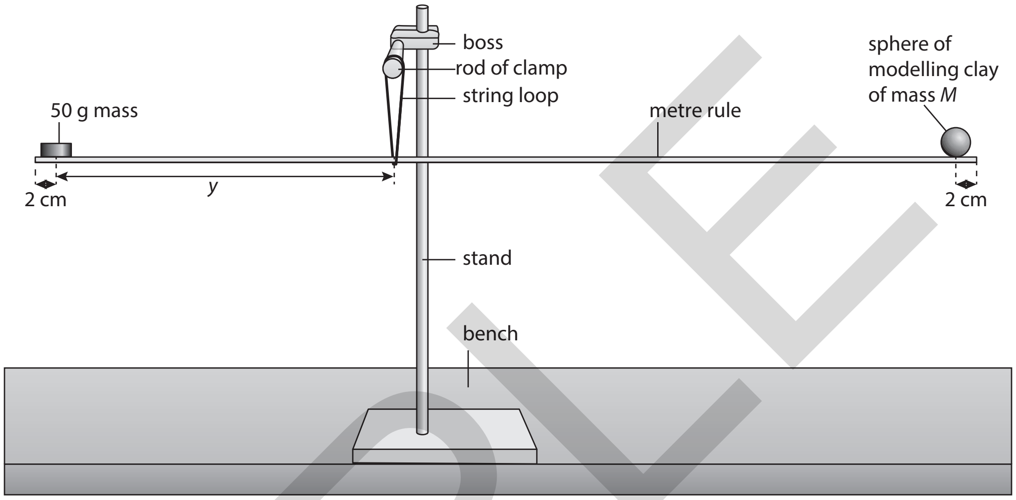

Figure 2.4

Record this value of mass *m* (50 g) and the value of *y* in Table 2.5.

2 Change the mass *m* and slide the metre rule through the string loop until it is balanced again. Record the new values of *m* and *y* in Table 2.5.

3 Repeat step **2** with different values of *m* and record your data in Table 2.5.

HINT
The masses provided allow you to have seven different values of *m*.

Results

m / g	*y* / cm

Table 2.5

Data analysis

a How does *y* vary with *m*?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

b Plot a graph of *y* on the *y*-axis against *m* on the *x*-axis using the graph grid.

c Draw the curve of best fit through your points.

d When *m* and *M* are the same, the metre rule should be balanced when the string is at the mid-point (i.e. $y = 48\,\text{cm}$) of the metre rule. Use your graph to determine *M*.

Evaluation

e In Table 2.6 there is one suggested limitation and improvement in row **A**. Write two more limitations and improvements in rows **B** and **C** in this table.

HINT
Try using the small triangular pivot: is it an improvement? If not, why not?

	Limitation	Improvement
A	It was difficult to read the scale on the metre rule because the string was too thick.	Use thinner string.
B	....	....
C	....	....

Table 2.6

Chapter 3:
Kinematics and dynamics

Chapter outline

This chapter relates to Chapter 1: Kinematics, Chapter 2: Motion, and Chapter 3: Dynamics, in the coursebook.

In this chapter you will complete investigations on:

- 3.1 Acceleration of connected masses
- 3.2 Energy and amplitude of a pendulum
- 3.3 Range of a projectile
- 3.4 Terminal velocity of a ball falling through water in a tube.

Practical Investigation 3.1:
Acceleration of connected masses

Introduction

If a string over a pulley has a mass attached to each end, any difference in the masses causes the system to accelerate. In this investigation, part of one mass is transferred to the other so that the mass difference is changed but the total mass is constant.

Equipment

You will need:

• pulley wheel to clamp to edge of bench • thin string • two mass hangers, each with a total mass of 500 g • two paper clips • 20 steel washers (steel rings) • stopwatch • metre rule • thick cardboard mat.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- One of the masses will hit the cardboard mat on the floor. You must keep your feet away from this area.

Method

1 Set up the apparatus as shown in Figure 3.1.

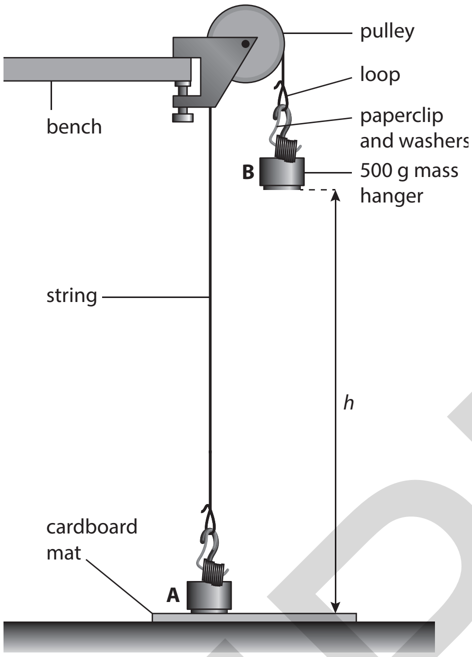

Figure 3.1

2 There is a loop tied at each end of the string.

3 Each paper clip is opened out into a hook and 10 washers are threaded onto it.

4 A 500 g mass and a paper clip are hooked onto each loop.

5 Pull mass hanger A down until it is touching the cardboard mat and measure the height *h* of mass hanger B above the mat. Record *h* in the Results section.

6 Move washers, one at a time, from A to B until B starts to move down steadily to the mat.

7 Record the difference *n* between the numbers of washers on A and the numbers of washers on B in Table 3.1 in the Results section.

8 Lift B up until A is just touching the mat, then release it and measure the time *t* for it to reach the mat. Record the value in Table 3.1.

9 Move more washers from A to B and repeat steps **7** and **8**. Repeat until you have six sets of values for *n* and *t* in Table 3.1.

> **HINT**
> Measure *t* several times for each *n* and record all the values.

HINT
Remember to record metre rule measurements to the nearest mm.

Results

h = …………………….. cm

n	t / s				a / cm s^{-2}
	first	second	third	mean	

Table 3.1

Data analysis

a For each row in Table 3.1 calculate the mean value of t.

b For each row in Table 3.1 calculate the acceleration a using:

$a = \frac{2h}{t^2}$.

c Use the grid to plot a graph of a (on vertical axis) against n (on horizontal axis).

HINT
Refer to the Skills chapter for advice on best-fit lines.

d Draw the straight line of best fit through the points.

e Determine the gradient and intercept of the line.

Gradient = …………………… Intercept = ……………………

Evaluation

f The theory for this experiment is based on:

mass × acceleration = force

and since the total mass is constant this gives:

a is proportional to *n*

In practice, the graph does **not** pass through the origin. Explain why the first transfers of washers do **not** produce an acceleration.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Practical Investigation 3.2:
Energy and amplitude of a pendulum

Introduction

The arrangement of apparatus enables the bob of a pendulum to be given the same amount of energy each time in repeated tests. The investigation looks at how the pendulum amplitude varies with its length.

Equipment

You will need:

• table tennis ball with length of thread attached • stand, boss and clamp • glass marble in small tray • inclined pipe held in stand • rectangular block • metre rule.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There are no special safety issues with this experiment.

Method

1 Set up the apparatus as shown in Figure 3.2. The angle and height of the pipe has been set for you. Do **not** adjust it.

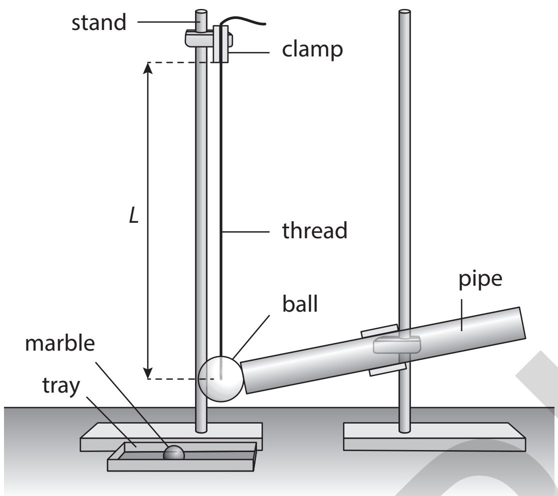

Figure 3.2

2 Adjust the thread in the clamp and the clamp height until the length *L* to the centre of the ball is approximately 50 cm and the ball is just touching the end of the pipe.

3 Measure *L* and record the value in Table 3.2.

4 Place the marble in the top of the pipe so that it rolls down and hits the ball. The ball will swing out a horizontal distance *d*, as shown in Figure 3.3. Repeat this several times, moving the rectangular block closer until the ball just reaches it as it swings.

HINT
This uses a 'trial and error' method to find **d**.

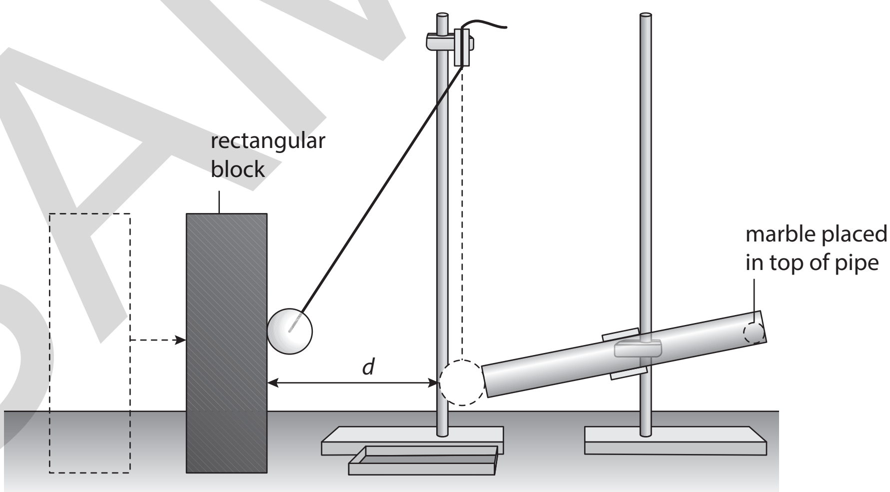

Figure 3.3

HINT
For step 5, you may feel that there is some uncertainty in *d*, but as you are measuring with a metre rule you should record your value to the nearest mm.

5 Measure the amplitude *d* and record the value in Table 3.2.

6 Reduce *L* by about 5 cm by moving the thread in its clamp.

7 Lower the clamp holding the thread so that the ball is just touching the end of the pipe again, then repeat steps **3**, **4** and **5**. **Do not adjust the pipe**.

8 Repeat steps **6** and **7** until you have six sets of values of *L* and *d* in Table 3.2.

Results

l / cm	d / cm	d^2 / cm^2

Table 3.2

Data analysis

a Calculate the values of d^2 and add them to Table 3.2.

b Use the grid to plot a graph of d^2 (on the vertical axis) against L (on the horizontal axis).

HINT
Choose scales so that the points use most of the grid (refer to the Skills chapter).

c Draw the line of best fit through the points.

d Determine the gradient and intercept of the line.

Gradient = ……………………. Intercept = …………………….

e It is suggested that L and d are related by the equation $d^2 = AL + B$ where A and B are constants. Use your answers from part **d** to determine the values of A and B. Give suitable units.

A = ……………………. B = …………………….

Evaluation

f This experiment relies on the marble hitting the ball at the same speed each time: this impact speed is a controlled variable. Given that the length and slope of the tube are constant, how could this impact speed vary from one test to the next?

………

………

Practical Investigation 3.3: Range of a projectile

Introduction

In this practical investigation you will investigate how far a ball travels when it is launched horizontally at different heights above a tray of sand. The data is used to calculate the horizontal launch velocity.

Equipment

You will need:

• curved tube fixed to a cardboard rectangle • steel ball (ball bearing) in a small container • tray of sand • pencil • stand, boss and clamp • set square • 30 cm ruler • metre rule.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There are no special safety issues with this experiment.

Method

1 Set up the apparatus as shown in Figure 3.4.

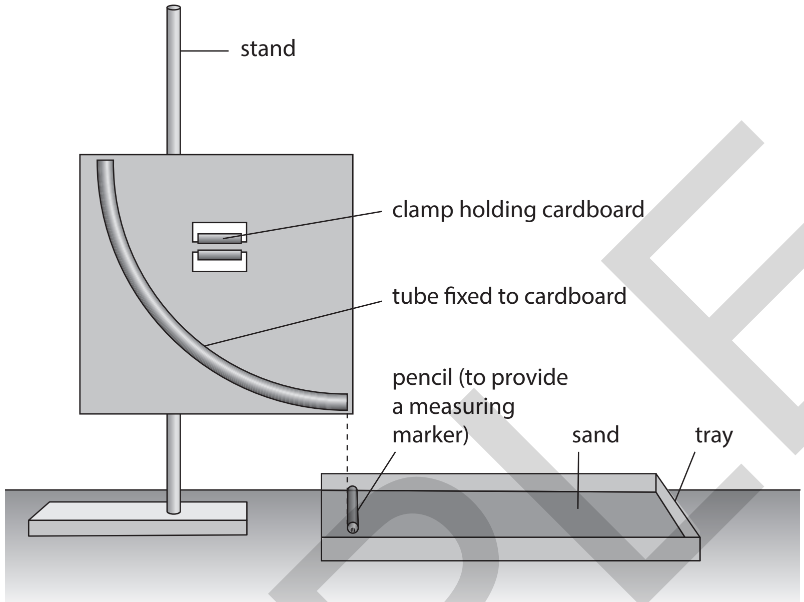

Figure 3.4

The bottom edge of the cardboard should be parallel to the bench.

The horizontal pencil should be pushed into the sand so that it is vertically below the end of the tube and parallel to the end of the tray, as shown on the diagram.

2 Measure the height *h* of the tube above the sand, as shown in Figure 3.5, and record it in Table 3.3 in the Results section.

> **HINT**
> In two places, measure the height of the cardboard above the bench. The measurements should be the same.

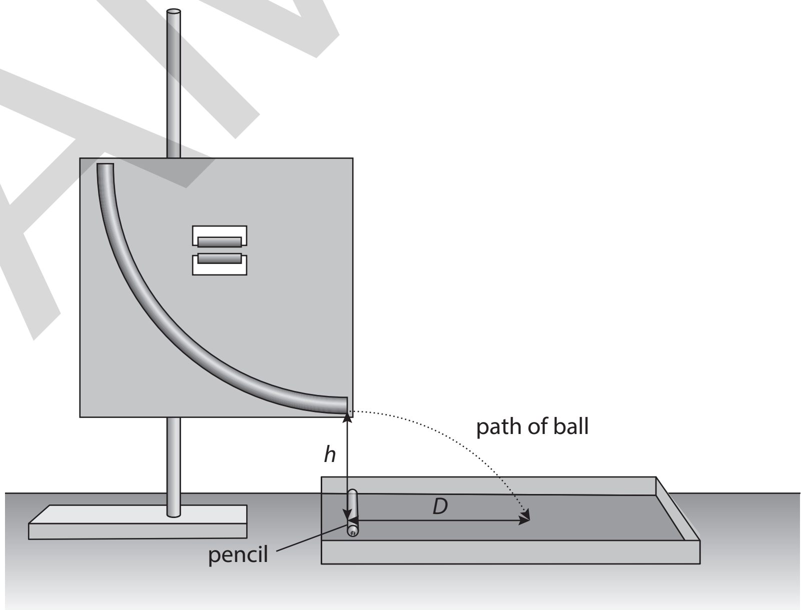

Figure 3.5

3 Put the steel ball into the top of the tube so that it rolls out and falls onto the sand.

4 Measure the distance *D* from the ball landing position to the pencil, as shown in Figure 3.5, and record it in Table 3.3.

5 Pick up the ball and smooth the sand with the set square.

6 Repeat steps **3** and **4** several times, recording the results in Table 3.3 and calculating the mean value of *D*.

7 Change *h* and repeat steps **2**, **3**, **4**, **5** and **6** until you have six sets of values of *h* and mean *D* in Table 3.3.

HINT
After each change of *h* check that the end of the tube is horizontal and is vertically above the pencil.

Results

h / cm	*D* / cm					D^2 / cm^2
	1	2	3	4	mean	

Table 3.3

Data analysis

a Calculate the values for D^2 and enter them in Table 3.3.

b Use the graph grid to plot a graph of D^2 (on vertical axis) against *h* (on horizontal axis).

c Draw the line of best fit through the points.

d Determine the gradient and intercept of the line.

Gradient = ……………………. Intercept = …………………….

Evaluation

e The theory for the motion of a horizontal projectile suggests that the gradient of the graph is equal to $\frac{2v^2}{g}$ where v is the horizontal velocity and $g = 9.81\ \text{m s}^{-2}$.

Use your value for the gradient to calculate v. Include the unit.

HINT

Convert g to cm s^{-2} before calculating v.

v = ……………………..

Practical Investigation 3.4:
Terminal velocity of a ball falling through water in a tube

Introduction

Figure 3.6 shows part of a tube filled with water. As a ball falls through the tube, water has to move from below the ball to above it, flowing through the gap between ball and tube.

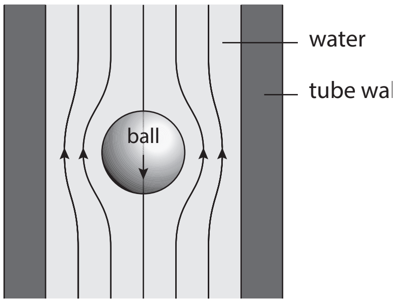

Figure 3.6

In this investigation you will test how the friction force varies with the size of the gap between the ball and the tube.

Equipment

You will need:

- tall U-shaped plastic tube filled with water
- short sample of the same plastic tube
- two sizes of steel ball (five of each size) in a small tray
- digital calipers
- stopwatch
- magnet
- metre rule.

Safety considerations

- Make sure you have read the Safety advice at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There are no special safety issues in this investigation.

Method

HINT
Make sure your value for *L* matches the unit on the answer line.

1 The tall plastic U-tube has been set up for you as shown in Figure 3.7. One leg of the U-tube has two marks on it. Measure the distance *L* between the upper mark and the lower mark. Record the value of *L* in the Results section.

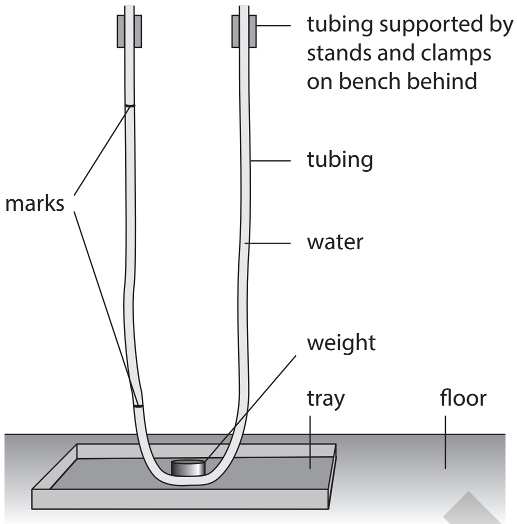

Figure 3.7

2 Measure the inside diameter *D* of the short sample of plastic tube and record the value in the Results section.

3 Measure the diameter *d* of one of the smaller steel balls and record the value in Table 3.4 in the Results section.

4 Drop one of the smaller steel balls into the tube and measure the time *T* it takes to fall from the upper mark to the lower mark. Record the value in Table 3.4.

5 Repeat step **4** for the rest of the smaller balls. If necessary, the balls can be lifted out of the tube using the magnet.

6 Repeat steps **4** and **5** using the larger balls.

HINT
Look at the advice on timing experiments in the Skills chapter.

Results

L = …………………… m   *D* = …………………… mm

	***d* / mm**	**Values of *T* / s**				
Smaller balls						
Larger balls						

Table 3.4

Data analysis

a For each row in Table 3.4, calculate the mean value for *T* and record it in Table 3.5.

	***T* / s**			***k***
Smaller balls				
Larger balls				

Table 3.5

b For each row in Table 3.4, calculate the ball velocity v using:

$v = \frac{L}{T}$. Record the values in Table 3.5.

c For each row in Table 3.4, calculate the area A of the gap between the ball and the walls of the tube using:

$A = \frac{\pi(D^2 - d^2)}{4}$. Record the values in Table 3.5.

d Add the units for v and A in the headings in Table 3.5.

e It is suggested that v and A are related by:

$$v = kA$$

where k is a constant.

For each row in Table 3.4, calculate the value of k and enter it in Table 3.5.

f Calculate the percentage difference between the two values of k.

Percentage difference = ……………………

g Estimate the percentage uncertainty in your values of T.

Percentage uncertainty = ……………………

HINT
When calculating the percentage, do **not** use the smallest division on the stopwatch; use an estimate of the uncertainty due to human reaction time (e.g. 0.2 s).

Evaluation

h Explain whether your answers in steps **e** and **f** support the relationship suggested in step **d**.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………