Cambridge IGCSE®
Physics

Practical Workbook

Gillian Nightingale

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Contents

Introduction

Investigations in and out of the laboratory have been at the forefront of physics discoveries for most of the last two centuries. The Cavendish Laboratory, at Cambridge University in England, has seen some of the most remarkable and pioneering discoveries since it was established in the 19th century. J.J. Thomson discovered the electron and Ernest Rutherford was able to recreate fission. Their experimental methods and consequent discoveries revolutionised physicists' views on the world. Without the art of experimentation, none of these discoveries would have been possible.

Practical skills form the backbone of any physics course. It is hoped that, by using this book, you will gain confidence in this exciting and essential area of study. This book has been written to prepare Cambridge IGCSE physics students for both the practical paper and the alternative to practical paper. For either paper, you need to be able to demonstrate a wide range of practical skills. Through the various investigations and accompanying questions you can build and refine your abilities so that you gain enthusiasm in tackling laboratory work. Aside from the necessary exam preparation, these interesting and enjoyable investigations are intended to kindle a passion for practical physics. Great care has been taken to ensure that this book contains work that is safe and accessible for you to complete. Before attempting any of these activities, though, make sure that you have read the safety section and are following the safety regulations of the place where you study.

Where practical investigations and or/related questions in this Practical Workbook contain extended syllabus material, this has been identified by a thin vertical bar in the margin next to the relevant material.

Gradient calculations in all topics are extension material and are used in this Workbook to allow students to gain confidence in their graphical skills, and to become comfortable with visualising relationships between variables.

Safety section

Despite the fact that Bunsen burners, electrical circuits and chemicals are used on a regular basis, the science laboratory is one of the safest classrooms in a school. This is due to the emphasis on safety and the adherence to precautions and procedures resulting from regular risk assessment.

It is imperative that you follow the safety rules set out by your teacher. Your teacher will know the names of materials, and the hazards associated with them, as part of their risk assessment for performing the investigations. They will share this information with you as part of their safety brief or demonstration of the investigation.

You should follow the guidance and the safety precautions in each of the investigations in this book. You should aim to use the safety rules as additional direction to help in planning your own investigations.

Here are some precautions that will help to ensure your safety when carrying out most investigations in this workbook.

- Wear safety spectacles to protect your eyes.
- Tie back hair and any loose items of clothing.
- Tidy away personal belongings to avoid tripping over them.
- Wear gloves and protective clothing, as described in the book or by your teacher.
- Turn the Bunsen burner to the cool, yellow flame when it is not in use.
- Keep all electrical circuits away from water.
- Observe hazard symbols and chemical information provided with all substances and solutions.

Many of the investigations require teamwork or group work. It is the responsibility of your group to make sure that you plan how to be safe as diligently as you plan the rest of the investigation.

Skills grid

Assessment objective 3 (AO3) 'Experimental skills and investigations' of the Cambridge International Examinations syllabus is about your ability to work as a scientist. Each aspect of the AO3 has been broken down for you below with a reference to the chapters in this title that cover it. This will enable you to identify where you have practiced each skill and also allow you to revise each one before the exam.
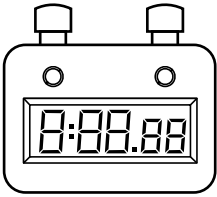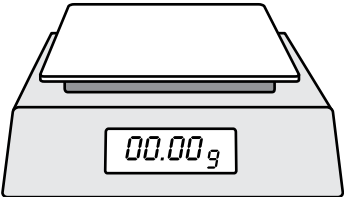
Chapter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A03: Experimental skills and Investigations																							
1.1 demonstrate knowledge of how to safely use techniques	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
1.2 demonstrate knowledge of how to use apparatus and materials	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
1.3 demonstrate knowledge of how to follow a sequence of instructions where appropriate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
2. plan experiments and investigations				X	X		X			X	X				X	X	X	X	X				
3.1 make and record observations	X	X		X		X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
3.2 make and record measurements	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X	X				
3.3 make and record estimates	X								X	X	X					X							X
4.1 interpret experimental observations and data	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
4.2 evaluate experimental observations and data	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X		X	X	X
5.1 evaluate methods	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
5.2 suggest possible improvements to methods	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
Constructing own table				X			X	X		X	X				X		X	X	X				
Drawing/analysing a graph	X	X	X	X	X	X					X							X	X		X		X
Planning safety of an investigation				X	X		X	X	X	X	X						X	X	X				
Mathematical calculations	X	X	X	X	X	X		X		X		X	X					X					

Quick skills section

Apparatus

You will need to be able to identify, use, and draw a variety of scientific apparatus. Complete the table below by adding the diagrams and uses for each piece of apparatus.

Apparatus	Diagram	Uses
timer		
balance/scales		
beaker		
Bunsen burner		
tripod		
test-tube		

Measuring

Being able to take **accurate** measurements is an essential skill for all physics students. As part of the Cambridge IGCSE course, you will be expected to be able to take accurate measurements from a variety of different apparatus. When using measuring cylinders, you will need to look for the **meniscus**, which is the bottom of the curve formed by the liquid.
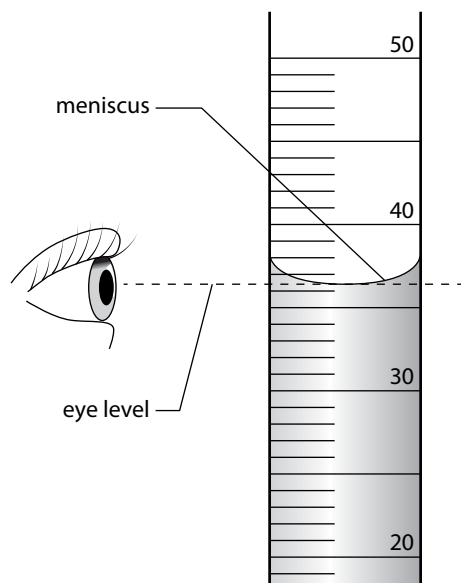
Micrometers: Micrometers are a very common tool for measuring the diameter of small objects in physics experiments. You will need to be able to take reliable readings. Micrometers have two scales: the sleeve scale on the sleeve of the micrometer and the thimble scale on the thimble. You will need to be able to read the measurement given by both scales. To do this, start by reading the highest number visible on the sleeve scale. For example, in the diagram, the number 4 is visible just to the left of the thimble. This represents 4.0 mm. You will notice that between the 4 and the thimble, a smaller line is also visible. This represents an additional 0.5 mm. So far we have a measurement of 4.5 mm from the sleeve scale.

To get a more accurate measurement you will now need to look at the thimble scale. This represents the hundredths of a millimetre that you need to add to the sleeve scale reading, to get your total measurement.

From the example shown in the following figure the number 25 is in line with the central line of the sleeve scale. This represents 0.25 mm.

For the final reading, you will now need to add the 4.5 mm and the 0.25 mm to give a final reading of 4.75 mm.
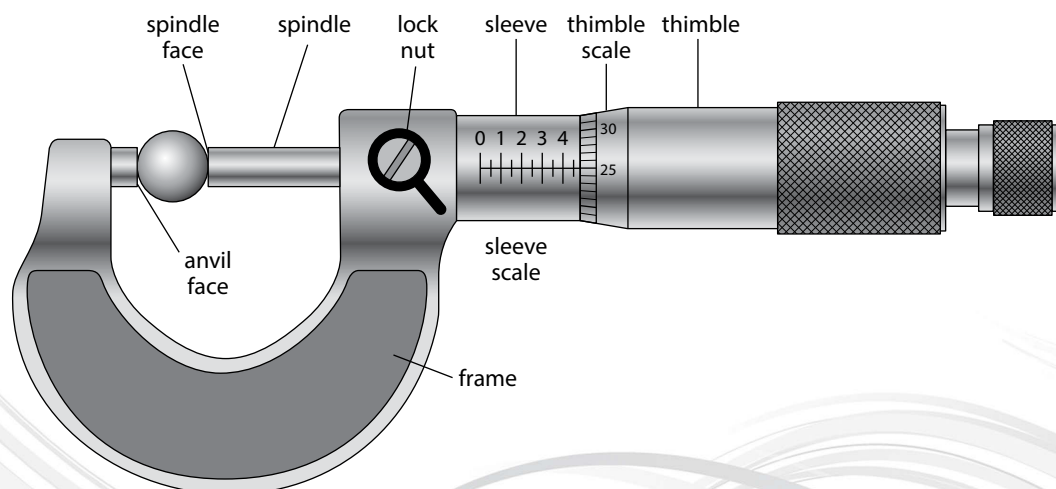
Circuit diagrams

It is important that you can draw the components present in the circuit you are using. You are expected to use internationally recognised circuit symbols to represent the components within your circuit.

Complete the table below by drawing the circuit symbols and stating the use of each of the listed components.

Component	Circuit symbol	Purpose in the circuit
cell		
battery		
switch		
ammeter		
voltmeter		
lamp		
resistor		
variable resistor		
thermistor		
fuse		
light dependent resistor (LDR)		
power supply		

Your circuit diagrams should meet these **expectations**:

- use a sharp pencil
- use a ruler to draw straight lines
- draw circuit symbols clearly, erase any errors and redraw.

Recording

When you are working on investigations, your ability to record data accurately is very important. Sometimes a table will be supplied; however, you need to be able to draw your own table with the correct headings and units.

The first task is to identify the **independent** and **dependent** variables for the investigation you are doing.

The **independent variable** is the one that you are changing, to see if this affects the dependent variable.

The **dependent variable** is the one that you will measure and record in the table.

The variables and their units need to go into the top two boxes in your results table. The independent variable goes in the left-hand column and the dependent variable(s) goes in the right-hand column(s). Separate the name of the variable and its unit by a forward slash (/), for example, Time/seconds. Remember that the column headings need to be physical quantities such as time, mass or temperature.

Next, count how many different values you have for the independent variable. This is the number of data rows you will need to add below the column headings. Finally, add the values for the independent variable into left-hand column. Your table is now ready for you to add the results from your investigation in the right-hand column(s).

Independent variable / units	Dependent variable / units

Graphing

When drawing a graph it is useful to follow a set procedure every time, to ensure that when you are finished the graph is complete.

Axes: You must label the axes with your independent and dependent variables. The independent variable is used to label the horizontal axis and the dependent variable is used to label the vertical axis. Remember to add the units for each of the variables. An easy way to ensure that you get this correct is to copy the column headings from the table of data you are using to draw the graph (see following graphs for reference).
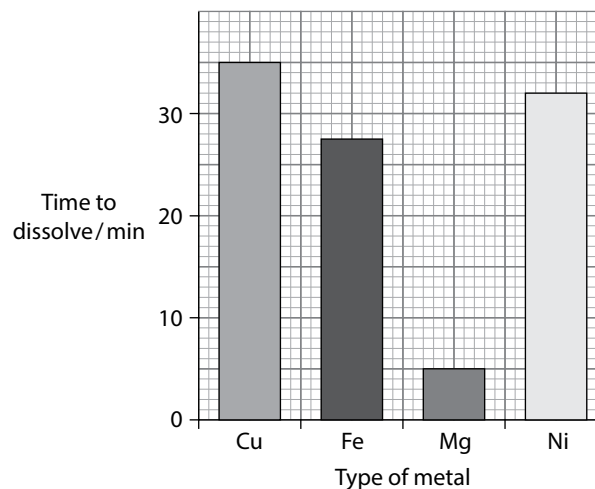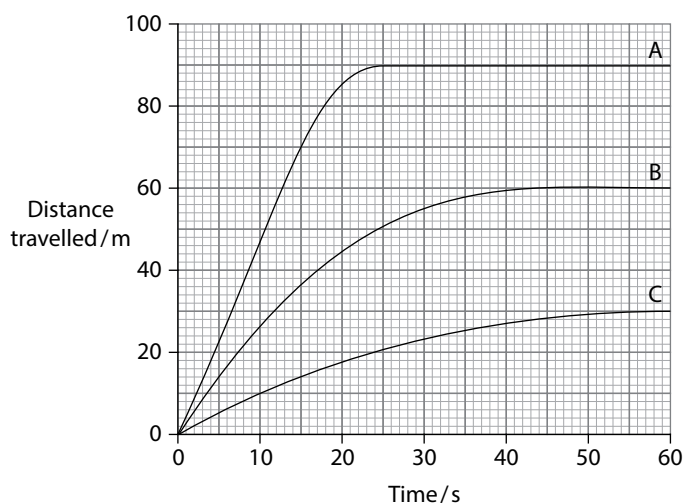
The second stage of drawing a graph is to add a **scale**. You must select a scale that allows you to use more than half of the graph grid in both directions. Choose a sensible ratio to allow you to plot your points easily, for example, each 1 cm on the graph grid represents 1, 2, 5, 10, 50 or 100 units of the variable. If you choose to use other numbers for your scale, it becomes much more difficult to plot your graph. Your skill in this improves the more times you draw a graph. If you plan your graph with light pencil lines, then you can easily make adjustments until you are fully skilled. Now you are ready to plot the **points** of data on the graph grid. You can use either neat crosses ($\times$) or a point enclosed inside a circle ($\odot$) to plot you points but take your time to make sure you plot them accurately. Remember to use a sharp pencil, as large dots make it difficult to see the actual point being plotted and may make it difficult for the accuracy of the plot to be evaluated.

Finally, add a **best-fit line**. This must be a single thin line or smooth curve. It does not need to go through all of the points but it should have roughly the same number of points on either side of the line. Remember to ignore any anomalous data when you draw your line of best fit. Here are some good examples of lines of best fit.
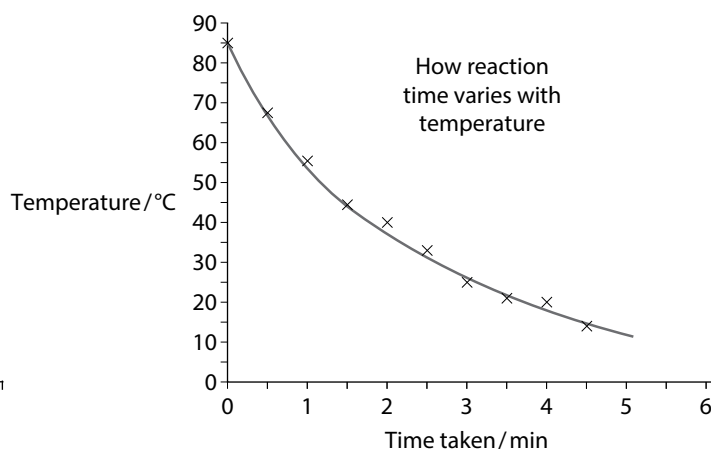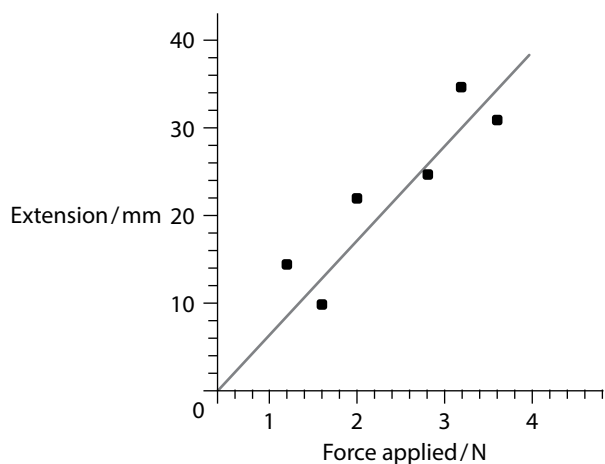
Variables

The independent and dependent variables have already been discussed but there is a third type of variable that you will need to be familiar with – **controlled variables**. These are variables that are kept the same during an investigation to make sure that they do not affect the results. If these variables are not kept the same then you cannot be sure how changing your independent variable affects the results. The more variables that you can control, the more reliable your investigation will be.

Example

A student is investigating the relationship between kinetic energy and the speed of a tennis ball. If he uses a different ball every time he changes the speed of the ball, the mass of the ball may be causing the change in the results, rather than the changing speed. The student should keep the mass of the ball constant, so use the same ball every time.

Reliability, accuracy and precision

A common task in this book will require you to suggest how to change the method used in an investigation to improve its reliability, accuracy and precision. Before discussing how to make these improvements, it is important that you understand what each of these words means.

Reliability is refers to the likelihood of getting the same results if you did the investigation again and being sure that the results are not just down to chance. For this reason, reliability is now often called **repeatability**. If you can repeat an investigation several times and get the same result each time, your investigation is said to be reliable.

You can improve the reliability of your investigation by:
- controlling other variables well so they do not affect the results.
- repeating the experiment until no anomalous results are achieved.

Accuracy is a measure of how close the measured value is to the true value. The accuracy of any results depends on the measuring apparatus used and the skill of the person taking the measurements.

You can improve the accuracy of your results by:
- improving the design of an investigation to reduce errors
- using more precise apparatus
- repeating the measurement and calculating the mean.

Precision relates to how accurately you take your measurements. Precise results have very little deviance from the mean.

You can improve the precision of your investigation by:

• using apparatus that has smaller scale divisions.

 You can observe how these terms are used in the diagram.

Reliability v Precision v Accuracy

A	B
high accuracy high precision high reliability	low accuracy high precision high reliability
C	D
high accuracy low precision low reliability	low accuracy low precision low reliability
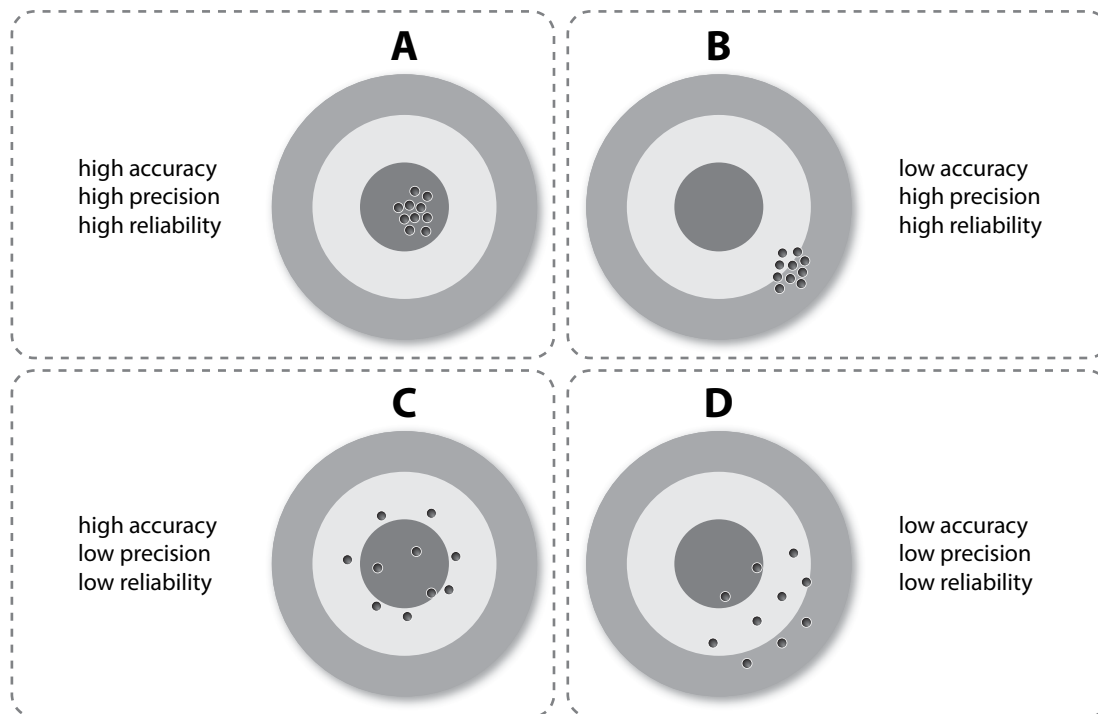
Designing an investigation

When asked to design an investigation you must think carefully about what level of detail to include. The following is an example of how to create a method. Follow these steps to design reliable, accurate investigations.

1   Identify your independent variables and state the range of values that you are planning to use for them.

2   Identify the dependent variable and explain how you are going to measure it. Describe the equipment and apparatus.

3   To ensure that the experiment you are conducting is reliable you will need to identify and control a number of variables that may impact your results. List these and explain how you will keep them constant.

4   Outline the method in a series of numbered steps that is detailed enough for someone else to follow.

5   Remember to include repeat readings to help improve reliability.

6   You must also include any hazards and safety warnings, as well as safety equipment that should be used in the investigation.

1 Making measurements

Overview

Throughout the chapter you will be aiming towards:
- taking accurate readings from a range of measuring devices
- taking a sufficient range of measurements, repeating where necessary, to obtain an average (mean) value
- presenting and analysing data graphically.

Practical investigation 1.1 Estimating measurements

Objective

You probably make estimates of time, distance and space on a daily basis, without realising it. Taking accurate measurements is crucial. A doctor must be accurate in measuring out a volume of medicine to treat a patient correctly. An engineer must measure the forces on a suspension bridge accurately to ensure the bridge will remain firm under a variety of conditions. In these examples, inaccurate measurements could be catastrophic.

In this investigation you will take accurate measurements of mass, weight, temperature, time and distance to compare them with your estimated values.

Equipment

- metre rule
- stopwatch
- thermometer

- top-pan balance
- newton scale
- micrometer screw gauge

- 30 cm rule

Method

1   Look at everything you are going to measure (below). Estimate each value and record your estimates in the table that has been provided.
2   Take measurements of:
    - your partner's height (in cm)
    - how long it takes a student to perform 10 star jumps
    - the length, width and thickness of a glass block (measured with a micrometer screw gauge)
    - the diameter of a piece of wire

- the temperature of a glass of ice water
- the mass of a bag of sugar
- the diameter of a steel ball bearing (using a micrometer screw gauge).

3 Record your accurate measurements in the table.

Safety considerations

Before you start recording the time for star jumps, check that the surrounding area is clear of obstructions. Check the floor for steel ball bearings in case anyone slips on them. Check with your teacher that your footwear is suitable for this task.

Recording data

1 Record your measurements in the table. Remember to include the appropriate units.

Measurement being taken	Estimated value	Measured value

Analysis

2 Are your estimated and measured values very different? Use the data in your table to compare your answers.

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3 Calculate the volume of the glass block, based on the measurements you have taken.

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4 Using a 30 cm rule, re-measure the glass block. Calculate its volume, based on these measurements. Is there a difference between your two values?

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Evaluation

5 Suggest one reason why your volume measurements for the glass block might be different.

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6 Were the measuring instruments that you chose, suitable in each case? If not, suggest what other instrument you could have used.

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7 List three of the instruments you used and give the precision of these instruments. The precision of an instrument is the smallest scale division on the instrument.

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Practical investigation 1.2 Determining π

Objective

There are relationships between many variables in science. One such is the relationship between the circumference and the diameter of a circle. Engineers use this relationship to balance the blades on a helicopter, mechanics use it when fitting tyres and bakers might use it when baking circular pies.

In this investigation you will use two different measuring methods to determine the relationship between the diameter and circumference of a circle. You will use a graph to show the relationship between the two variables. When you have plotted the points on your graph, you will need to draw a **line of best fit**. It should go through as many of the points as possible, with roughly equal numbers of points above and below it. For this investigation, the line of best fit will be a straight line that shows the trend of the plotted points.

Equipment

- 6 modelling clay balls of varying sizes
- micrometer screw gauge
- string
- ruler

Method

1. Select a ball and measure its diameter across its centre, using the micrometer screw gauge. Take care not to squash the ball out of shape. Record your measurement in the table below.
2. Repeat the measurement in two different places across the ball. Record the measurements in the table and find the average (mean) of all three.
3. Loop a piece of string around the ball snugly. Mark the string where it overlaps, passing once around the ball. Remove the string and use the 30 cm ruler to measure the distance between the marks on the string. Record the value in the table provided.
4. Repeat steps 1–3 for five more balls.

Safety considerations

Take care when handling the modelling clay. To prevent slipping, ensure you do not leave any of the balls on the floor.

Recording data

1. Record your measurements in the table.
   NB When recording your data in the table you do not need to include the units next to every reading, **provided that they are included in the table headings**. Make sure you record all values to the same number of decimal places.

Ball	Diameter of ball / cm				Circumference / cm
	1	**2**	**3**	**Average**	
1					
2					
3					
4					
5					
6					

Handling data

2 Plot a graph of your results on the axes below.

   NB You will need to choose a suitable scale, so that your plot is laid out across the grid clearly. As a general rule it is best to use scales that are easy to follow. For example, choose a scale in which each square represents multiples of 2, 5 or 10. Always label the axis beyond your highest values, for example, if the highest value is 38, number the axis to at least 40.

Circumference/cm
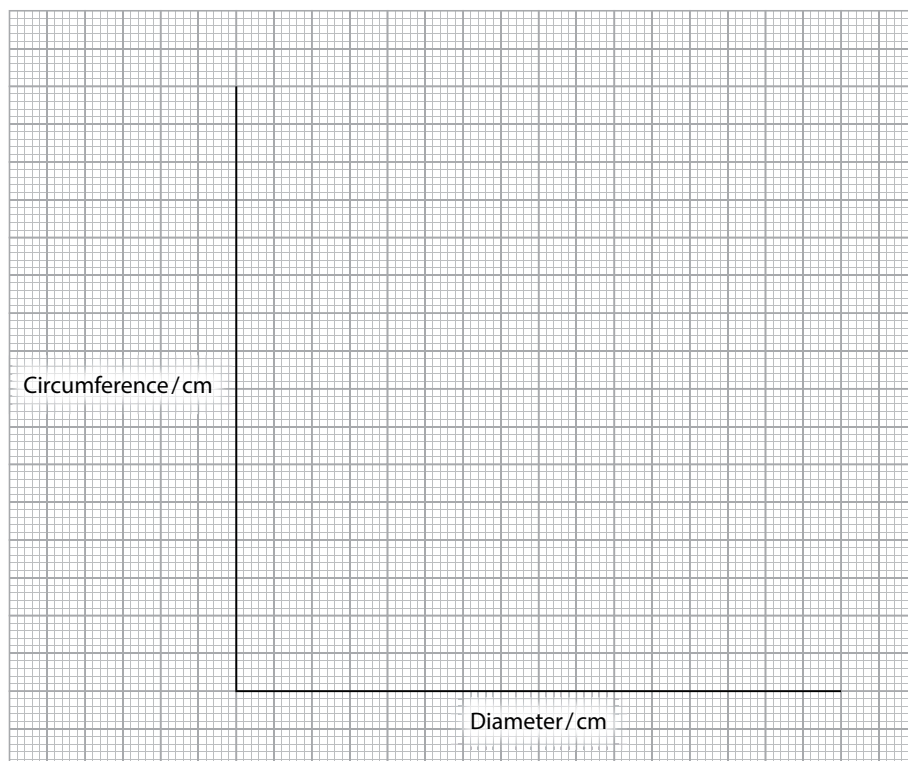
Diameter/cm

3 Draw the line of best fit on your graph.

Analysis

4 Now look at the line of best fit. Describe its appearance and state any key points through which it passes.

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   ....

5 The circumference and diameter of a circle are directly proportional. On a graph, this is represented by a straight line through the origin. Does your graph support this relationship? Give reasons for your answer.

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6 Calculate the gradient of your graph.

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7 The equation for the circumference, C, of a circle is:
$C = \pi d$
where π is a constant of approximate value 3.14 and d represents the diameter of the circle.
Do your results agree with this equation?
Use the gradient of your graph to help support your answer.

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Evaluation

8 State another way in which you could have measured the circumference of the ball.

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9 Which of these methods is more accurate? Give reasons for your answer.

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10 Explain why you needed to take three measurements across each ball.

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11 The gradient of your line should be close to 3.14. Suggest one reason why your value might differ from this and from those of other students.

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Practical investigation 1.3 The simple pendulum

Objective

Pendulums are used in everyday life, for example, in clocks and metronomes, to help us keep time, and in construction to protect buildings from damage during earthquakes. A swing in the park is an example of a pendulum. Do you think you would swing more quickly if the swing was shorter in length? In this investigation you will test whether the length of the pendulum affects the time period of oscillation.

Prediction

Physicists often make predictions or hypotheses, based on the information they have. They then use this as a basis for their investigation. An example of a prediction for this experiment could be:

The length of a pendulum has no effect on the time period of a pendulum.'

Write your own prediction for this investigation.

……

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Equipment

- pendulum bob
- string
- 2 small rectangular pieces of wood or corkboard
- clamp stand
- clamp
- boss
- stopwatch
- ruler
- C clamp

Method

1   Hang the pendulum from the clamp stand and wait for it to come to rest.
2   Use the ruler to measure the length of the pendulum from the pendulum's point of suspension to the center of mass of its bob.
3   Keeping the string taut, move the pendulum bob to one side and release it, allowing it to swing at a steady pace. Use the stopwatch to time 10 complete oscillations.
4   Repeat twice more and take an average of the results.
5   Repeat for four different lengths of pendulum.

Safety considerations

Clamp the stand to the bench to ensure it is stable and cannot fall over and cause injury.
Release the pendulum through small angles from the vertical, to prevent injury.

Recording data

1 Record your measurements in the table.

Length of pendulum / cm	Time taken for 10 oscillations / s				Time taken for 1 oscillation / s
	1	**2**	**3**	**Average (mean)**	

Analysis

2 Sketch a graph of length against time period.
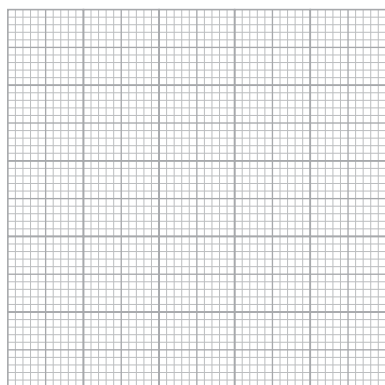
3 Using your results, state and explain whether the length of the pendulum has an effect on the time period of an oscillation.

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....

Evaluation

4 Suggest another variable that might affect the time period of an oscillation.

....

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5 Another student conducts the same investigation but finds it difficult to count the oscillations accurately. How could she improve your method to ensure that she counts the oscillations correctly?

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....

6 She also decided to time ten oscillations. Why is it more accurate to record the time taken for ten oscillations than just for one?

Practical investigation 1.4 Calculating the density of liquids

Objective

Knowing the density of materials can be very useful in engineering, architecture – and even in predicting the weather! Density plays an important role in buoyancy. Substances with a lower density float on substances with a greater density. For example, warmer air floats on top of cooler, more dense air. This drives weather systems. In this investigation you will determine the densities of three common fluids.

Equipment

- 100 ml measuring cylinder
- oil
- salt-water solution
- water
- balance

Method

1 Place the measuring cylinder on the balance and set it to zero.
2 Add 50 ml of water to the measuring cylinder. Record the mass and volume in the table below.
3 Repeat for 10 ml increments of water, up to a maximum of 100 ml. Record the mass and volume of the water in the table below.
4 Empty and dry the measuring cylinder. Now repeat the above procedure for the salt-water solution and the oil.

Safety considerations

Wear goggles to ensure no oil or salt-water solution gets into your eyes. Rinse immediately if this occurs.
Clear any spillages immediately to prevent slipping.

Recording data

1 Record your measurements in the tables.

Water

Mass / g	Volume / cm³

Salt-water solution

Mass / g	Volume / cm³

Oil

Mass / g	Volume / cm³

Handling data

2 Use your results to plot a graph of volume against mass for each of the liquids you have measured. Plot all three graphs on the grid below.

When you draw the graph, label each axis and include the appropriate unit. For this graph, plot the volume along the horizontal axis and the mass up the vertical axis.

Remember to choose an appropriate scale for your each axis.

Mass / g

Volume / cm³
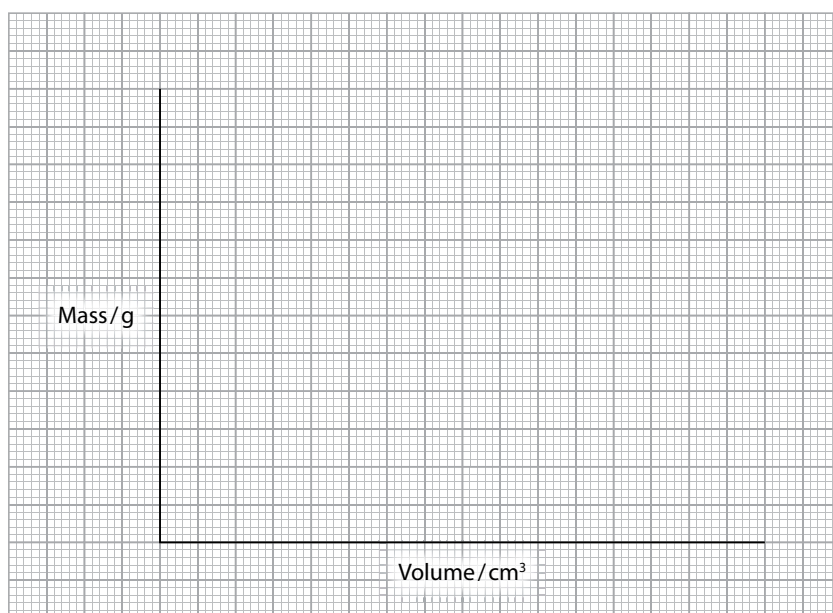
Analysis

3 Draw a line of best fit for each of the liquids you have tested. Label them clearly.

4 The gradient of the line of best fit in each graph is equal to the density of the fluid. By looking at your graph, can you predict which has the highest density? In the space below, explain how you can make this assumption by sight alone.

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5 Now calculate the gradient of each of the lines of best fit. Do your values support your answer to question **4**?

<u>Water</u>

....

....

<u>Oil</u>

....

....

<u>Salt-water solution</u>

....

....

6 Fluids that are less dense float on top of more dense substances. In the measuring beaker in Figure 1.1, draw in the order in which the fluids would settle, labelling each one clearly.
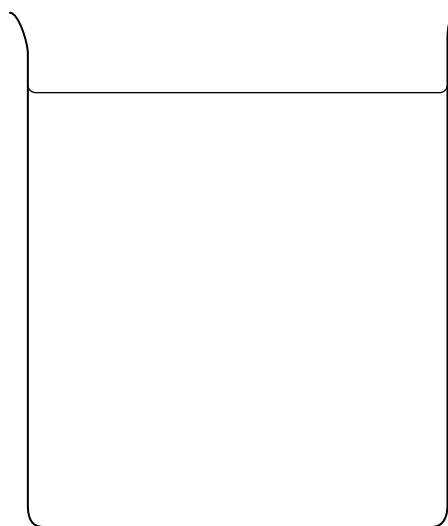
Figure 1.1

Evaluation

7 Your teacher will give you the actual values of density for the fluids you have tested. How do your results compare? Suggest two reasons why your results may be different.

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8 An oil spill occurs out at sea. A student suggests that a clean-up operation would be impossible because the two substances would mix. Do you think the student is correct? Comment on the student's statement, relating it to the experiment you have conducted here.

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Exam-style questions

A student has been asked to determine the material from which a key is made (Figure 1.2).
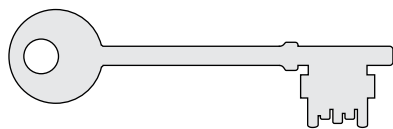
Figure 1.2

The student has been given the table below, which lists the densities of a variety of common metals based on measurements taken from $1\,cm^3$ metal blocks found in the laboratory.

Type of metal	Density / g/cm³
aluminium	2.7
iron	7.9
lead	11.4
steel	8.4

The student fills a measuring cylinder with water and carefully adds the key, using another measuring cylinder to collect the water that is displaced. The displaced water collected in the measuring cylinder is displayed in Figure 1.3.
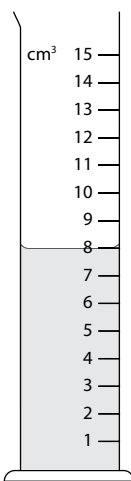
Figure 1.3

1 Show clearly on the diagram the line of sight you would use to obtain an accurate reading. [2]

2 State the volume of the key. [1]

………

3 The student then takes the key, dries it and uses a balance to measure its mass. The mass of the key is 65.01 g. Calculate the density of the material from which the key is made. [3]

………

………

4 Refer to the table above to determine the metal from which the key is most likely to be made. [1]

………

………

2 Describing motion

> ## In this chapter, you will complete investigations on:
>
> ◆ **1.2** Motion

Overview

Throughout this chapter you will be aiming towards:
- manipulating apparatus to obtain measurements
- recording observations in a table, using appropriate units and to a consistent and appropriate degree of precision
- presenting and analysing data graphically, including the use of best-fit lines where appropriate and calculating the gradient of a line

Practical investigation 2.1 Average speed

Objective

Suppose a train takes four hours to travel from London to Edinburgh, which is a distance of approximately 300 miles. Its average speed is calculated as $\frac{\text{total distance travelled}}{\text{total time taken}}$, which is 75 miles per hour. The average speed of an object gives an indication of the speed of an object over a period of time. Average speed doesn't show when the object is speeding up or slowing down.

To measure what happens within the journey you need to calculate the instantaneous speed at certain points. In this investigation you are going to travel a distance of 100 metres determining your average speed over 20 metre sections. You will also calculate your instantaneous speed.

Equipment

- chalk or cones
- measuring tape
- stopwatches

Method

1 Use the chalk to mark a starting point.
2 Use the measuring tape and chalk to measure and mark a distance of 20 metres from this point. Repeat every 20 metres until you reach 100 metres from the starting point.
3 Choose a member of the group to run the 100 m. The other members act as timers, each taking a stopwatch and standing at a different 20 m interval (20 m, 40 m, 60 m, 80 m, 100 m).
4 The timers start their stopwatches when runner starts to run and stop them when the runner passes their marker.

Safety considerations

Check the area is clear of trip hazards. Make sure that your runner is well warmed up and that sensible shoes for running are worn.

Recording data

1 Use the table below to record the times taken to run 20 m, 40 m, 60 m, …

Distance / m	Time / s

Handling data

2 Use the data from your table to plot a distance–time graph of your results on the grid below. Plot distance on the vertical (distance) axis and time along the horizontal axis. Remember to label your axes and include the relevant units.
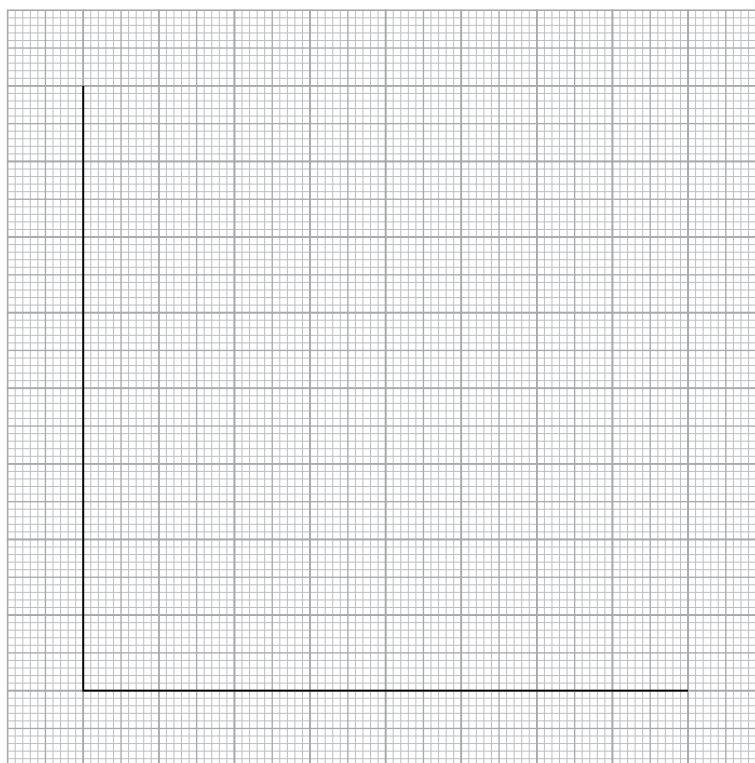
Analysis

3 Without doing any calculation, state which section of the run was the fastest. Give reasons for your answer.

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4 Calculate the speed during the slowest and fastest sections of the run.

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5 The overall gradient of this distance–time graph represents the average speed for the whole journey. How could you measure the speed at the 50 m point?

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6 The gradient of a distance -time graph represents the speed of the travelling object. Use your graph to calculate the average speed across the whole 100 metres. Show how you have done this, clearly, on the graph.

....

....

Evaluation

7 State the precision of the measuring instruments you used and suggest one way in which you could improve the precision of your measurements.

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8 When conducting this investigation, how did you ensure that all timers started their stopwatches at the same time?

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9 How would the distance–time graph have differed if the runner accelerated gradually through the run?

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Practical investigation 2.2 Velocity–time graphs using ticker tape

Objective

Speed and velocity are different measures in physics, although they are closely related. The velocity of an object is its speed in a given direction. For objects travelling in a straight line at a constant speed their velocity does not change. However, if the object changes direction, speeds up or slows down, its velocity does change. You can track the changing velocity of an object by plotting a graph of its motion. For example, imagine a Formula-1 (F1) car on the starting straight, as far as the beginning of the first bend. It takes 3 seconds for the car to reach a speed of 100 mph and then it brakes sharply, reducing its speed to 40 mph in 2 seconds to enter the corner. From a velocity–time graph of the car's motion you can calculate its acceleration, deceleration and the distance it travels during this time. It is important for the race team to be able to see how the car is performing, so tracking its changing velocity is crucial, as this can help inform changes to the car to improve its performance in the next race.

In this investigation you will use a ticker timer to track the velocity of a trolley down a ramp.

Equipment

- trolley
- ticker timer
- ticker tape
- power pack
- ramp
- plain coloured paper
- scissors
- glue
- sticky tape

Method

1 Set up the apparatus as shown in Figure 2.1, ensuring the ticker tape goes underneath the carbon paper disc in the ticker timer.
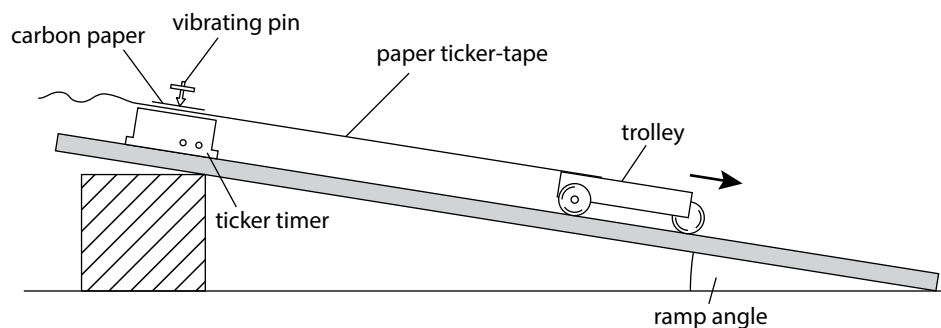
Figure 2.1

2 Fasten the ticker tape securely to the trolley. Keep the trolley stationary and turn on the ticker timer.
3 Release the trolley down the ramp and catch it at the bottom. Cut the ticker tape at the timer.
4 Find the start on the ticker tape. From the first dot, count ten gaps. Cut the tape on the 11th dot.
5 Repeat until all of the tape is cut into sections of 10.
  Label the sections of tape in the order in which you cut them.

Safety considerations

- The ramps are long and heavy so work in pairs, to carry them, to avoid injury.
- Place a buffer at the end of the ramp to catch the trolley, to prevent injury to feet or damage to the trolley or floor.

Recording and handling data

1 Cut the ticker tape at every tenth dot. Each section of ticker tape represents 0.2 seconds in time. The length of the tape is how far the trolley travelled in that time. This means that each piece of ticker tape represents the velocity of the trolley in that time.

2 Draw the velocity–time axes on a piece of plain paper. Velocity is on the vertical axis, with a scale of 1 cm to represent a velocity of 5 cm/s. Label the horizontal axis as time, in seconds, with 0.2 seconds divisions.

3 Glue the pieces of ticker tape vertically onto the graph, side by side, in the order that you cut them, with section 1 first, and with the long edges touching.

Analysis

4 From your graph, read the greatest velocity of the trolley on its journey. Write it down.

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5 Describe the shape of your graph. What does this tell you about the velocity of the trolley during its journey?

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6 Draw in a line of best fit. This should be a straight line that goes through the middle of the top dot on as many ticker tape pieces as possible.

7 Calculate the gradient of this line. What does this line represent?

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8 The area under a velocity-time graph is representative of the distance travelled. Calculate the distance travelled by the trolley from your graph.

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Evaluation

9 It can sometimes be difficult to count the gaps in the ticker tape. State one way you overcame this difficulty.

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10 Another student completes the same investigation but their graph of results gives ticker tape strips of similar lengths. Suggest why this might have happened and one way in which you could prevent this from happening.

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Exam-style questions

A student is asked to use a light gate and interrupt card to investigate the velocity of a trolley down a ramp, as shown in Figure 2.2. The student measures the velocity of the trolley at different points along its journey down the path by moving the light gate to the positions marked on the diagram. The computer records the velocity, v, and the time, t, taken.
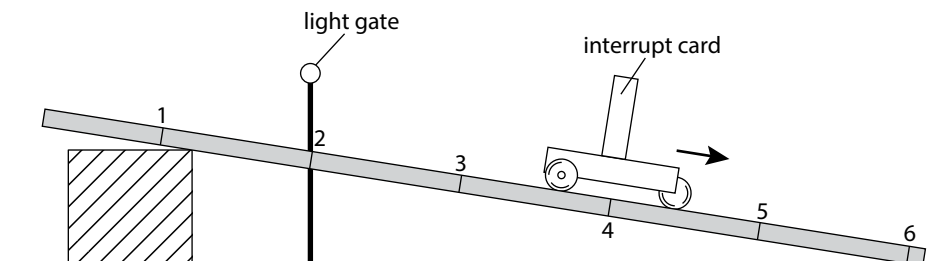
Figure 2.2

The student's results were as follows.

Light gate position	v/m/s	t/s
1	0.79	0.60
2	1.12	0.90
3	1.38	1.09
4	1.58	1.12
5	1.78	1.40
6	1.95	1.55

1 Plot a graph of velocity v/m/s (vertical axis) against time t/s (horizontal axis).   [5]
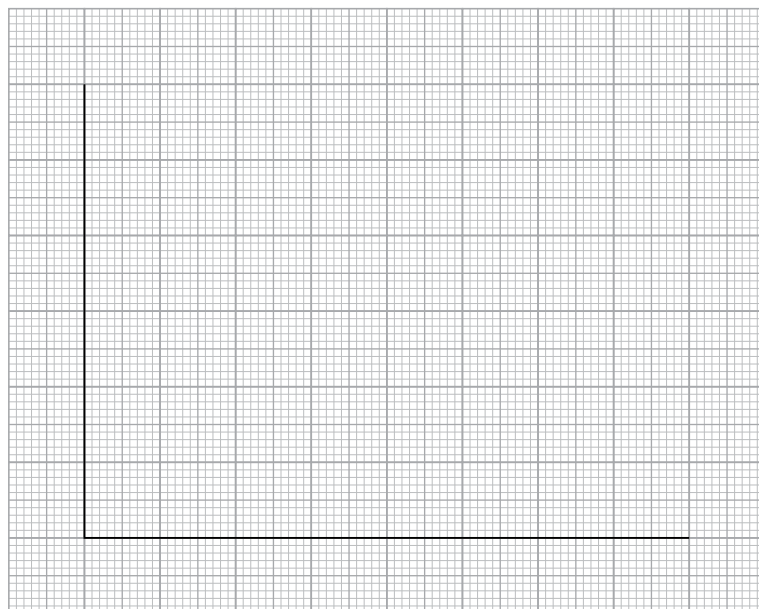
2 The gradient of the line represents the acceleration of the trolley. Calculate the acceleration of the trolley and state its units. [3]

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Units ....

3 Light gate position 6 was at the end of the ramp. Calculate the length of the ramp. [3]

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....

4 The student suggests that the acceleration is not uniform. State whether or not this is correct. Give a reason to support your answer. [2]

Correct ....

Reason ....

....

3 Forces and motion

In this chapter, you will complete investigations on:

◆ **1.3**   Mass and weight

◆ **1.5.1**   Effects of forces

◆ **1.5.5**   Scalars and vectors

◆ **1.6**   Momentum

Overview

Throughout this chapter you will be aiming towards:

- drawing an appropriate conclusion, justifying it by reference to the data and using an appropriate explanation
- commenting critically on a procedure and suggesting an appropriate improvement
- evaluating the quality of data, identifying and dealing appropriately with any anomalous results
- identifying possible causes of uncertainty, in data or in a conclusion.

Practical investigation 3.1 Estimating acceleration of free fall

Objective

When an object is dropped it falls downwards, because the force of gravity is pulling it towards the ground. With this force comes an acceleration, which gives the object its weight. On Earth, gravity can vary, depending on how far from the centre of the Earth you are. One way of seeing how the effect of gravity changes as your distance from the surface of the Earth changes is to consider air pressure. The higher up a mountain you travel, the less dense the air becomes. This is because the force of gravity acting on the air is reduced, so the distance between the gas particles in the air increases, causing the air pressure to drop. This is why aeroplane cabins have to be pressurised and fighter pilots have to wear oxygen masks whilst flying.

At sea level, the accepted value for gravity is $9.81 \, \text{m/s}^2$, which is often rounded to $10 \, \text{m/s}^2$ to make calculations easier. In this practical you will estimate the acceleration of free fall for your classroom.

Equipment

- metre rule
- balls
- stopwatch

Safety considerations

- Wear shoes with closed toes or toe caps, to protect your feet from the falling ball.
- Make sure nobody is in the drop zone before releasing the ball.

Method

1 Measure a height of 0.5 m from the floor. Hold the ball at this height.
2 Release the ball and time how long it takes to reach the floor.
3 Record your results.
4 Repeat for different release heights for the ball.

The time periods for this investigation are very short, so practise how you will start and stop the stopwatch before you conduct the investigation.

Recording data

1 Complete the column in your table headed t^2 / s^2.

Distance/m	Time/s				t^2/s^2
	1	2	3	Average	
0.5					

Handling data

2 Plot a graph of s (vertical axis) against t^2 (horizontal axis).

You can use the equation for constant acceleration to do this.

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

where s represents the distance travelled by the ball

u represents the initial velocity

a represents the acceleration

t represents the time taken.

In this investigation the ball started from rest so the first part of the equation, ut, is always equal to zero. If you plot a graph with t^2 on the horizontal axis and s on the vertical axis, you can use the gradient of the graph to calculate a.

3 Plot a graph of *s* (vertical axis) against t^2 (horizontal axis).
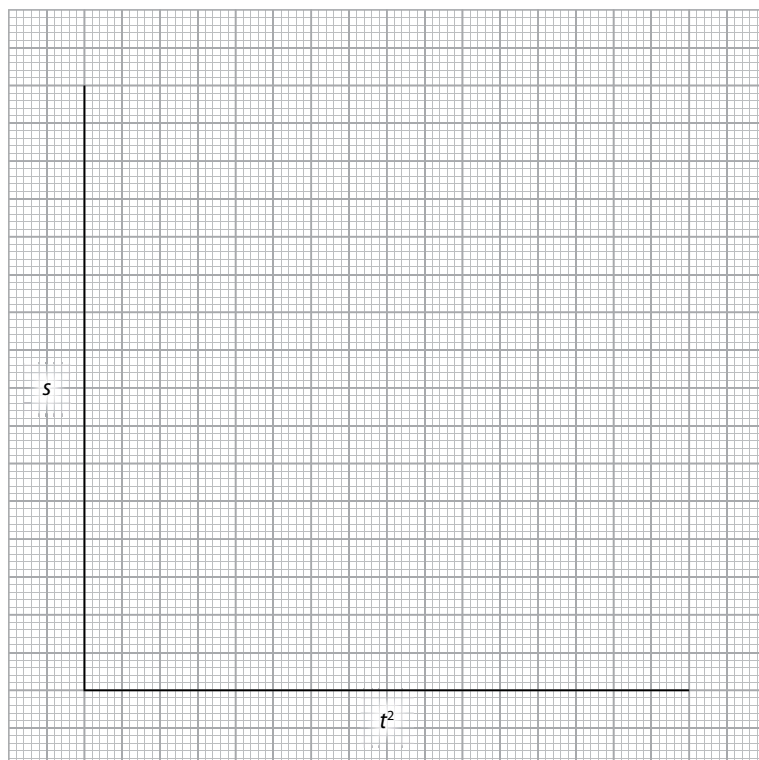
Analysis

4 Draw in a line of best fit for your points.

5 Calculate the gradient of your line.

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6 Rearrange and use the equation below to calculate the acceleration of free fall for your experiment.

$$\text{gradient} = \frac{1}{2} \times \text{acceleration}$$

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7 The accepted value for the acceleration of free fall is in the region of $10\,\text{m/s}^2$. How does your result compare with this? Give justification for why you think it might differ.

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8 'The acceleration of free fall near the surface of the Earth is constant.' Do you agree with this statement? Use your graph to support your answer.

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Evaluation

9 The experimental method you have used is not very accurate. Suggest two ways in which you could have improved the method to increase the accuracy of your results.

……

……