

1 Making measurements

This chapter contains investigations on:

- ◆ 1.1 Measuring length and volume
- ◆ 1.4 Density

Throughout this chapter students will be expected to:

- take accurate readings from a range of measuring devices
- take a sufficient range of measurements, repeating where necessary, to obtain an average (mean) value
- present and analyse data graphically.

Practical investigation 1.1 Estimating measurements

Planning the investigation

In this investigation, students will:

- use and describe the use of rules and measuring cylinders to find a length or a volume
- use and describe the use of clocks and devices, both analogue and digital, for measuring an interval of time

This practical can be taught in conjunction with the theory.

Duration: 15–20 minutes

Setting up for the investigation

Student grouping: 2–4 students per group, depending on class size.

Each group will need: metre rule, stopwatch, a micrometer screw gauge, thermometer, top-pan balance, newton scale, micrometer screw gauge, 30 cm rule
 Review how to use a micrometer screw gauge at the beginning of the practical.

Students will require additional support using the micrometer screw gauge

Measuring equipment should be distributed around the classroom to avoid congestion.

Remind students that dropping the balls will distort them.

Safety considerations

- Ensure students keep the floor clear, for example, free from bags, to reduce the risk of tripping.
- Keep the classroom door closed when students measuring its width to prevent fingers being trapped in the hinges.
- Complete a dynamic safety assessment to ensure no risk to students.

Key discussion points for this investigation

- **Precision:** Why use a micrometer screw gauge, rather than a ruler, to measure the diameter of a wire? Why might it be important for an electrician to be more precise with the thickness of cable measurements than an lift engineer, for example?
- **Accuracy:** Why are accurate measurements important? How might an inaccurate measurement affect the outcome of a 100 m race, the value of a diamond, the weight of a gold bar?
- **How can students improve accuracy?** When measuring with a ruler, students should ensure that the ruler is parallel to the object they are measuring, and that their eyes are level with the measurement they are taking, to reduce the effect of a parallax error. When timing events with a short time span, they should record the time for ten events and divide by ten, to find the average time for one.

- **Methods of measurement:** Students should consider alternatives. How many ways could they find the volume of a cube? Which method is more accurate? Why might they choose displacement over length measurement and calculation?

Common errors when conducting this investigation

Set each group a different task, to help avoid congestion around the classroom. They will need to observe the progress of each group to ensure there is no clustering at the more popular tasks.

Supporting your students

Discuss how to use the micrometer screw gauge. Reading the scale might be an issue for some students. Set up the micrometer and invite students to read the scale, to ensure that they understand how to do it. If a student is really struggling, provide digital calipers for them to use as an interim measure.

Challenging your students

In the field of medicine, accurate measurement by doctors helps to ensure that patients are diagnosed correctly and treated effectively. Investigate ways in which doctors use technology to make accurate measurements and how inaccurate measurements can affect patient care. Prepare a two-minute presentation for the class.

Each year billions of goods are sold, based on a measurement of quantity. Why is it important that all traders use accurate equipment to measure their products? How might a business be affected if its measurement system was incorrect by just one per cent? Investigate the impact on the revenue for a business if its fuel pump's measurement system was incorrect by one per cent, based on the pump providing 100 cars with 30 litres of fuel every week for one year.

Answers to workbook questions

- 1 Students record their results in the table.
- 2 Students comment on their estimated and measured results. They make reference to the limits of accuracy of the measuring equipment.
- 3 Students calculate the volume of the glass block, based on their measurements using the micrometer screw gauge.
- 4 Students calculate the volume of the glass block, based on their measurements using rulers.
- 5 A micrometer screw gauge gives a more precise result than a ruler. This increased degree of accuracy is then carried into the calculation.
- 6 Students suggest alternative methods of measurement.
- 7 Micrometer screw gauge precision is correct to 0.01 cm or 0.1 mm; 30 cm ruler precision is correct to 1 mm; metre ruler precision is correct to 1 mm; stopwatch precision is correct to 0.01 s (depending on stopwatch used).

Practical investigation 1.2

Determining π

Planning the investigation

In this investigation students will:

- obtain an average value for a small distance and for a short interval of time (including the period of a pendulum) by measuring multiples
- present data graphically, drawing a line of best fit and calculating a gradient.

This can be taught after basic theory.

Duration: 45–50 minutes, including graph drawing and analysis

Setting up for the investigation

Student grouping: 2–3 depending on class size

Each group will need: 6 modelling clay balls of varying sizes, micrometer screw gauge, string, ruler

The balls of modelling clay should range in size, from a marble up to the maximum size that will fit within the micrometer screw gauge.

Equipment should be laid out on either side of the room. Modelling clay balls should be kept in a box to provide a place where students can collect a ball, returning it when they have used it and collecting the next one.

In this investigation, the students are asked to measure and calculate the diameters and circumferences of six modelling clay balls. Students measure the diameter at three points across the ball and then find an average (mean) value. They use string to measure the circumference of the ball. They then plot a graph of diameter against circumference, draw a line of best fit and calculate its gradient. This should give the value of π (approximately 3.14).

They will need to take measurements of the balls before the lesson so that they have a set of results from which to work.

Safety considerations

- Remind students not to throw the modelling clay balls, to prevent injury to other students.
- Advise students how to use a micrometer screw gauge correctly, to prevent injury to themselves and other students.

Suggested discussion points for this practical

- **Rationale for multiple measurements of diameter across the ball:** For example, to ensure an average diameter of each ball, as the diameter may not be uniform, or to reduce errors in measurement for the smaller balls.
- **Scaling for the plotting of graphs:** Acceptable scales are based on a multiple of 2, 5 or 10 and should allow the plot to take up $\frac{3}{4}$ of the graph grid.
- **Lines of best fit:** Discuss how to draw one, why they are used, use of a pencil and ruler, and so on.
- **Gradient calculation:** Remind the students how to calculate a gradient, the relevance of the gradient in this practical (represents π).
- **Directly proportional:** What does this mean? How would this be represented on a graph?

Supporting your students

Students often struggle to read micrometer screw gauge. Prepare paper printouts showing a micrometer screw gauge and provide examples for the class to read, using the paper versions as a starter for the session. These can then also be used for one-to-one support during the practical.

Scaling of the graph and calculation of the gradient might present problems. Starter exercises could focus on a ‘What scale would you choose?’ activity, where example results are given and students have to choose the appropriate scale. They could also be given sample gradient calculations.

Challenging your students

Students can be introduced to the general equation $y = mx + c$ as a means of checking their results.

Investigate how racing-car team engineers use this relationship to increase the performance of their cars. Produce an A4 leaflet explaining the principle and how it is applied in Formula 1.

Answers to workbook questions

- 1 Students record their results in the table.
- 2 Students plot their graphs.
- 3 Students draw a line of best fit.
- 4 Straight-line graph through the origin.
- 5 Yes. This is because the line of best fit is a straight line through the origin.
- 6 Students calculate $\frac{\text{change in circumference values}}{\text{change in diameter values}}$ or use the triangle method, the gradient should be approximately 3.14.
- 7 Yes, because the gradient of the graph is equal to π .
- 8 Mark a line on the ball, start to roll the ball in a line along a ruler and measure one complete rotation.
- 9 The marking the ball method. String might not be tight round the ball, or might not lie exactly around the widest part, so might give an incorrect measurement of diameter.
- 10 The balls might not be uniformly spherical.
- 11 Errors in measurement might affect the result.

Practical investigation 1.3 The simple pendulum

Planning the investigation

In this investigation students will:

- obtain an average value for a small distance and for a short interval of time (including the period of a pendulum) by measuring multiples.

This can be taught after theory.

Duration: 20 minutes

Setting up for the investigation

Each group will need: pendulum bob, string, 2 small rectangular pieces of wood or corkboard, clamp stand, clamp, boss, stopwatch, ruler

During the experiment, students should fix the string of the pendulum between the jaws of the clamp.

Use a secondary C-clamp to fix the clamp stand to the bench for safety to prevent toppling.

This investigation considers the relationship between the length of a pendulum and its time period of oscillation. Students are asked to vary the length of the pendulum string and record the time period of oscillation each time. Students will be expected to measure the time taken for ten swings. They will repeat this three times for each length and take an average. Dividing this average by ten will give the time taken for one oscillation.

Safety considerations

- Show students the correct way to swing the pendulum. Demonstrate pulling the pendulum so the string makes a small angle from the vertical and releasing gently, to prevent students releasing the pendulum aggressively. If you have a particularly lively class, suggest goggles should be worn for the practical investigation.
- Fix the clamp stand to the desk or bench with the C-shaped clamp, to prevent it toppling and causing injury.

Key discussion points for this investigation

- **How to measure the time period of one oscillation when the practical equipment is set up:** Discuss why multiple measurements will reduce error in reading.

- **How accuracy in measurements can be improved:**
 For example, by counting as the bob passes a fixed point or fiducial marker, or passes through its lowest point.
- **The variable that affects the time period:** Graphical representation of these relationships (time period and length) can be presented to the students to discuss the idea of direct proportion when considering $\frac{T^2}{l}$ or what a curve represents if T^2 is plotted against l .

Common errors when conducting the investigation

The pendulum should be released through small amplitudes. If it is released through a large amplitude the swing will not be periodic and will give incorrect readings, which will affect the results. Discuss this with students before starting the investigation. Students might struggle to remain focused when recording the number of oscillations. A prior discussion about fiducial markers is recommended. Students might count the beginning of the oscillation as 'one', when they need to wait for a complete oscillation, with the pendulum returning to its initial position, before counting. This might cause their results to be smaller than the actual time period.

Supporting your students

Some students might struggle to understand why counting more oscillations reduces error in the final measurements. Use analogies to help the students understand that the error due to human reaction time will remain constant. However, if they count more oscillations, that percentage error will represent a smaller proportion of time than when just recording one oscillation.

Challenging your students

Ask students to investigate the effect of changing the mass of the bob rather than the length of the string. Ask them to consider the potential variables they will need to keep the same. Students should create a short presentation of their results for the class. Foucault's pendulum is probably the most famous pendulum in science. Investigate the significance of Foucault's pendulum and the impact it has had on our knowledge of the Earth.

Answers to workbook questions

- 1 Students record their results in the table.
- 2 Students sketch their graphs, with length on the horizontal axis and time period on the vertical axis, to produce a roughly horizontal line.
- 3 Results should show that mass has a negligible effect on the time period of the pendulum.
- 4 Students may suggest that the length of the string and the angle from which it is released affect the time period.
- 5 Add in a fiducial marker and count as it passes this point.
- 6 It reduces the significance of any errors in measurement on time if the number of oscillations recorded increases.

Practical investigation 1.4

Calculating the density of liquids

Planning the investigation

In this investigation students will:

- recall and use the equation $\rho = \frac{m}{V}$
- describe an experiment to determine the density of a liquid and of a regular 3d solid and make the necessary calculations
- predict whether an object will float, based on density data.

This practical can be conducted in conjunction with teaching the theory.

Duration: 45–60 minutes including graphical analysis

Setting up for the investigation

Grouping: 2–4 depending on class size

Each group will need: 100 ml measuring cylinder, oil, salt-water solution, water, balance

250 ml measuring cylinders can be used, in place of the 100 ml ones.

Any oil that is readily available such as baby oil, cooking oil, rapeseed oil may be used.

Any salt-water solution will have a different density to water, heavily salted water could be used containing food colouring to distinguish it from unsalted water, allow 100 ml per pair.

Equipment should be set out around the classroom, evenly distributed so it is easily accessible and prevents crowding. Dispense the oil and salt-water solution into labelled beakers to prevent students needing to queue for the bottle.

In this investigation the students are asked to record the mass of a fluid for increasing volumes. They will do this for oil, water and a salt-water solution. Students will then be expected to plot their results as a graph of mass against volume. The gradients of the graphs represent the densities of the fluids. From this, students will be asked to determine which solution will float on top of which.

Safety considerations

HH

- Students should wear goggles to ensure no oil or salt-water solution gets into eyes. Rinse immediately if this occurs.

- Clear any spillages immediately to prevent slipping.
- Ask your students if any of them have allergies to rapeseed oil and warn them how important it is that the oil doesn't touch their mouths.

Suggested discussion points for this investigation

- **Taking readings from the bottom of meniscus:** Explain what the meniscus is.
- **Graph skills:** Discuss choosing a scale, drawing the line of best fit, calculating gradient.
- **Discussion:** If students had the same volume of each of the fluids, how could they determine the densities? Why is it important to measure equal volumes?
- **Discussion:** How might temperature affect density? Why would an increase in temperature cause a decrease in density? How is this related to convection?

Common errors when conducting the investigation

Advise students to measure the mass of the water first, then the salt-water solution, then the oil. This is primarily because the water is the easiest to remove from the cylinder, so there will be no residue to affect the mass measurement.

The balance should be tared (zeroised) at the beginning of the experiment to take account of the mass of the measuring cylinder. It should be done again when students start with the next fluid. Students often forget to tare, or continually zero throughout the experiment, which will give them incorrect results.

Students should plot all three graphs on the one grid and should label each line of best fit as they go along so they are clear which line is which.

Supporting your students

Students will generally struggle with drawing lines of best fit and calculating gradients. Discuss how to calculate a gradient at the beginning of the session and leave a worked example on the board throughout, as a point of reference.

One-to-one help might be required when discussing lines of best fit. It is beneficial to have worksheets with sample plots for students to practise drawing lines of best fit, as an aid.

Challenging your students

Give students some additional items, such as a small piece of crayon, a piece of dried pasta, a paperclip and a small piece of wood. Students should layer the fluids they have used, based on their densities, and place the objects in the mix. The objects should settle in different layers. Students should explain, in terms of density, why this has happened and what this implies about the density of the items in comparison to the fluids in which they are suspended.

Students can use the internet or books to research the Galilean thermometer. They can then design a practical that investigates the effect of temperature on the density of fluids.

Answers to workbook questions

- 1 Students record their results in the table.
- 2 Students sketch their graphs of volume against mass for each of the liquids.
- 3 Students draw and label the line of best fit on each graph.
- 4 The graph that has the steepest gradient will have the highest density. The gradient of the salt-water solution is the steepest showing that salt water has the highest density of all the solutions.
- 5 Water 1 g/cm^3 , oil 0.92 g/cm^3 , salt water 1.03 g/cm^3
- 6 Salt-water solution, water, oil
- 7 Students suggest reasons: errors in measurement, errors in calculations.
- 8 The student is incorrect. Results from this investigation show that oil is less dense than salt water so would float on the surface of the sea water. This would make it possible to separate the two.

Answers to exam-style questions

- 1 eye level with 8 cm^3 line [2]
- 2 8 cm^3 [1]
- 3 $\rho = \frac{m}{V}, \frac{65.01}{8}$ [1], 8.13 [1] g/cm^3 (1)
- 4 steel [1]

Total marks [7]