Cambridge IGCSE™ Physics

This print and digital coursebook has been developed from extensive research through lesson observations, interviews and work with our research community (the Cambridge Panel) to meet your specific needs. Activities and questions develop your essential science skills, with a focus on practical work. Exam-style questions give you valuable practice. Projects provide opportunities for assessment for learning, cross-curricular learning and developing skills for life. There are multiple opportunities to engage in active learning, such as scripting a podcast, to discussions and debates. Activities build in complexity to support your learning, and worked examples help you whenever you need to use an equation. The resource is written in accessible language with features to support English as a second language learners.

- Endorsed by Cambridge Assessment International Education for full syllabus coverage
- Develops your scientific enquiry skills, such as making predictions, recording observations, handling data, interpreting data and evaluating methods
- The project feature at the end of each chapter provides opportunities for assessment for learning, cross-curricular learning and skills for life development
- Answers to all questions are accessible to teachers online at www.cambridge.org/go
- For more information on how to access and use your digital resource, please see inside the front cover

This resource is endorsed by Cambridge Assessment International Education

- ✓ Supports the full Cambridge IGCSE and IGCSE (9-1) Physics syllabuses (0625/0972) for examination from 2023
- ✓ Has passed Cambridge International's rigorous quality-assurance process
- ✓ Developed by subject experts
- ✓ For Cambridge schools worldwide

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Cambridge IGCSE™ Physics COURSEBOOK CAMBRIDGE

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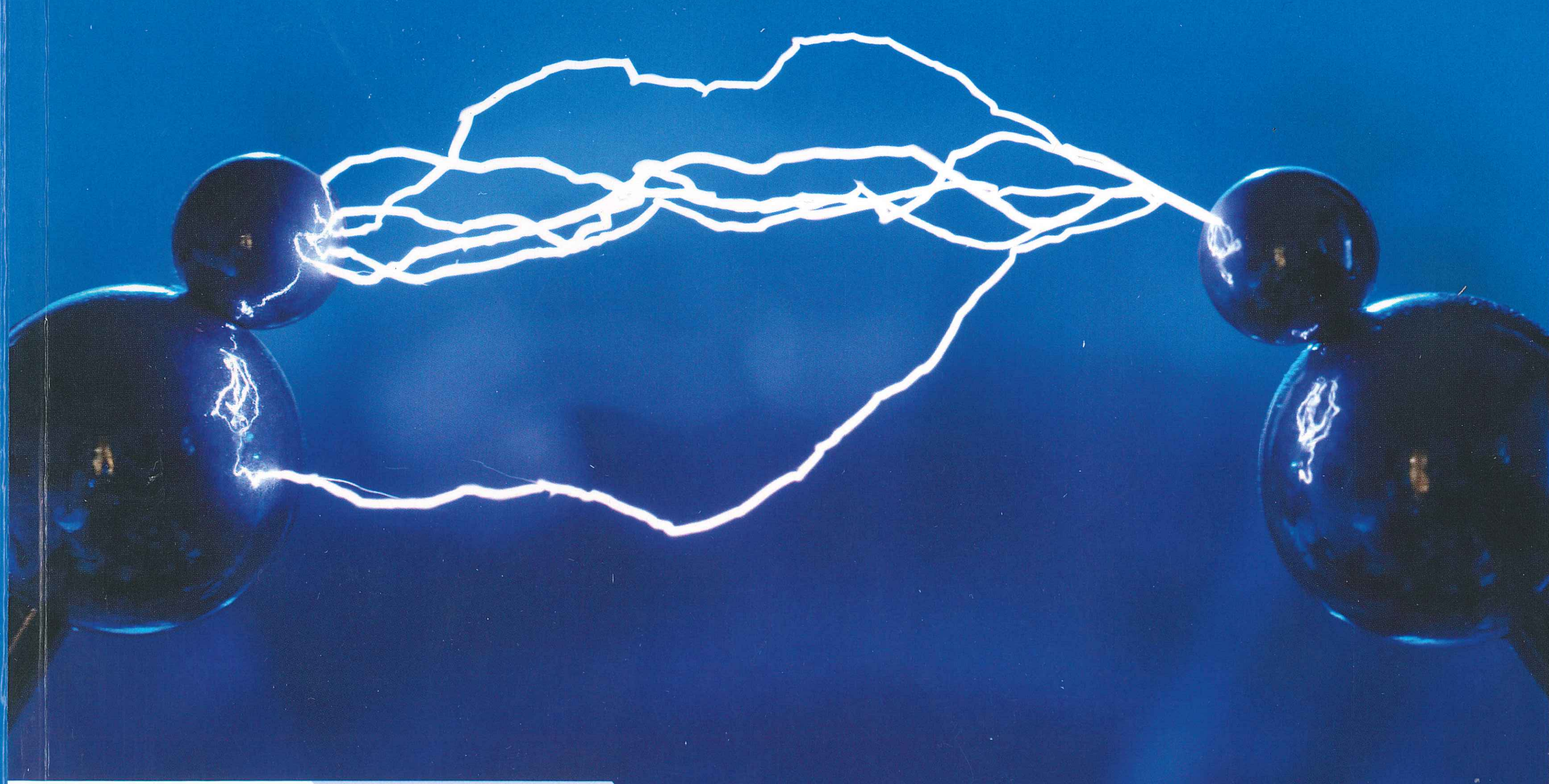
Physics

for Cambridge IGCSE™

COURSEBOOK

David Sang, Mike Follows & Sheila Tarpey



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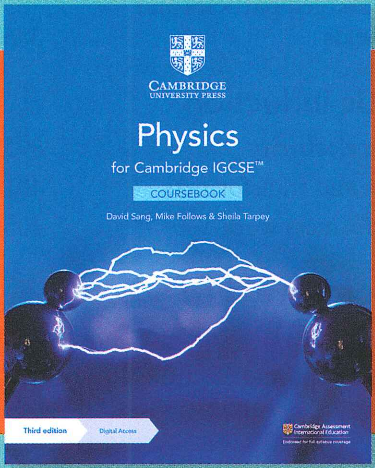
Contents

How to use this series

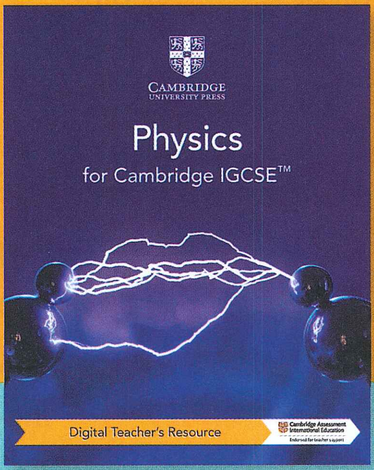
We offer a comprehensive, flexible array of resources for the Cambridge IGCSE™ Physics syllabus. We provide targeted support and practice for the specific challenges we've heard that students face: learning science with English as a second language; learners who find the mathematical content within science difficult; and developing practical skills.

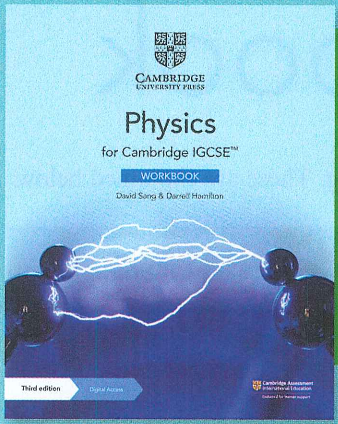


The coursebook provides coverage of the full Cambridge IGCSE Physics syllabus. Each chapter explains facts and concepts, and uses relevant real-world examples of scientific principles to bring the subject to life. Together with a focus on practical work and plenty of active learning opportunities, the coursebook prepares learners for all aspects of their scientific study. At the end of each chapter, examination-style questions offer practice opportunities for learners to apply their learning.

The digital teacher's resource contains detailed guidance for all topics of the syllabus, including common misconceptions identifying areas where learners might need extra support, as well as an engaging bank of lesson ideas for each syllabus topic. Differentiation is emphasised with advice for identification of different learner needs and suggestions of appropriate interventions to support and stretch learners. The teacher's resource also contains support for preparing and carrying out all the investigations in the practical workbook, including a set of sample results for when practicals aren't possible.

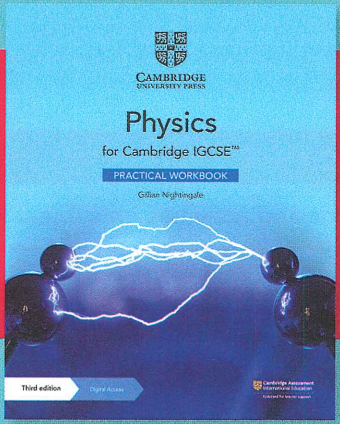
The teacher's resource also contains scaffolded worksheets and unit tests for each chapter. Answers for all components are accessible to teachers for free on the Cambridge GO platform.





The skills-focused workbook has been carefully constructed to help learners develop the skills that they need as they progress through their Cambridge IGCSE Physics course, providing further practice of all the topics in the coursebook. A three-tier, scaffolded approach to skills development enables learners to gradually progress through 'focus', 'practice' and 'challenge' exercises, ensuring that every learner is supported. The workbook enables independent learning and is ideal for use in class or as homework.

The Cambridge IGCSE practical workbook provides learners with additional opportunities for hands-on practical work, giving them full guidance and support that will help them to develop their investigative skills. These skills include planning investigations, selecting and handling apparatus, creating hypotheses, recording and displaying results, and analysing and evaluating data.



Mathematics is an integral part of scientific study, and one that learners often find a barrier to progression in science. The Maths Skills for Cambridge IGCSE Physics write-in workbook has been written in collaboration with the Association of Science Education, with each chapter focusing on several maths skills that learners need to succeed in their Physics course.

Our research shows that English language skills are the single biggest barrier to learners accessing international science. This write-in workbook contains exercises set within the context of Cambridge IGCSE Physics topics to consolidate understanding and embed practice in aspects of language central to the subject. Activities range from practising using comparative adjectives in the context of measuring density, to writing a set of instructions using the imperative for an experiment investigating frequency and pitch.

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

LEARNING INTENTIONS

These set the scene for each chapter, help with navigation through the coursebook and indicate the important concepts in each topic. These begin with 'In this chapter you will:'.

In the learning intentions table, Supplement content is indicated with a large arrow and a darker background, as in the example here.

GETTING STARTED

This contains questions and activities on subject knowledge you will need before starting the chapter.

SCIENCE IN CONTEXT

This feature presents real-world examples and applications of the content in a chapter, encouraging you to look further into topics that may go beyond the syllabus. There are discussion questions at the end which look at some of the benefits and problems of these applications.

EXPERIMENTAL SKILLS

This feature focuses on developing your practical skills. They include lists of equipment required and any safety issues, step-by-step instructions so you can carry out the experiment, and questions to help you think about what you have learned.

KEY WORDS

Key vocabulary is highlighted in the text when it is first introduced, and definitions are given in boxes near the vocabulary. You will also find definitions of these words in the Glossary at the back of this book.

Supplement content: Where content is intended for learners who are studying the Supplement content of the syllabus as well as the Core, this is indicated in the main text using the arrow and the bar, as on the right here, and the text is in blue. You may also see the blue text with just an arrow (and no bar), in boxed features such as the Key Words or the Getting Started. Symbols in blue are also supplementary content.

Questions

Appearing throughout the text, questions give you a chance to check that you have understood the topic you have just read about. The answers to these questions are accessible to teachers for free on the Cambridge GO site.

ACTIVITY

Activities give you an opportunity to check your understanding throughout the text in a more active way, for example by creating presentations, posters or taking part in role plays. When activities have answers, teachers can find these for free on the Cambridge GO site.

KEY EQUATIONS

Important equations which you will need to learn and remember are given in these boxes.

COMMAND WORDS

Command words that appear in the syllabus and might be used in exams are highlighted in the exam-style questions. In the margin, you will find the Cambridge International definition. You will also find these definitions in the Glossary.

SELF/PEER ASSESSMENT

At the end of some activities and experimental skills boxes, you will find opportunities to help you assess your own work, or that of your classmates, and consider how you can improve the way you learn.

WORKED EXAMPLE

Wherever you need to know how to use an equation to carry out a calculation, there are worked example boxes to show you how to do this.

REFLECTION

These activities ask you to think about the approach that you take to your work, and how you might improve this in the future.

PROJECT

Projects allow you to apply your learning from the whole chapter to group activities such as making posters or presentations, or performing in debates. They may give you the opportunity to extend your learning beyond the syllabus if you want to.

SUMMARY

There is a summary of key points at the end of each chapter.

Supplement content is indicated with a large arrow in the margin and a darker background, as here.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions, some of which may require use of knowledge from previous chapters. The answers to these questions are accessible to teachers for free on the Cambridge GO site.

Supplement content is indicated with a large arrow in the margin and a darker background, as here.

SELF-EVALUATION CHECKLIST

The summary checklists are followed by 'I can' statements which match the Learning intentions at the beginning of the chapter. You might find it helpful to rate how confident you are for each of these statements when you are revising. You should revisit any topics that you rated 'Needs more work' or 'Almost there'.

I can	See Topic...	Needs more work	Almost there	Confident to move on
Core				
Supplement				

Introduction

Studying physics

Why study physics? Some people study physics for the simple reason that they find it interesting. Physicists study matter, energy and their interactions. They might be interested in observing the tiniest sub-atomic particles, or understanding the vastness of the Universe itself.

On a more human scale, physicists study materials to try to predict and control their properties. They study the interactions of radiation with matter, including the biological materials we are made of.

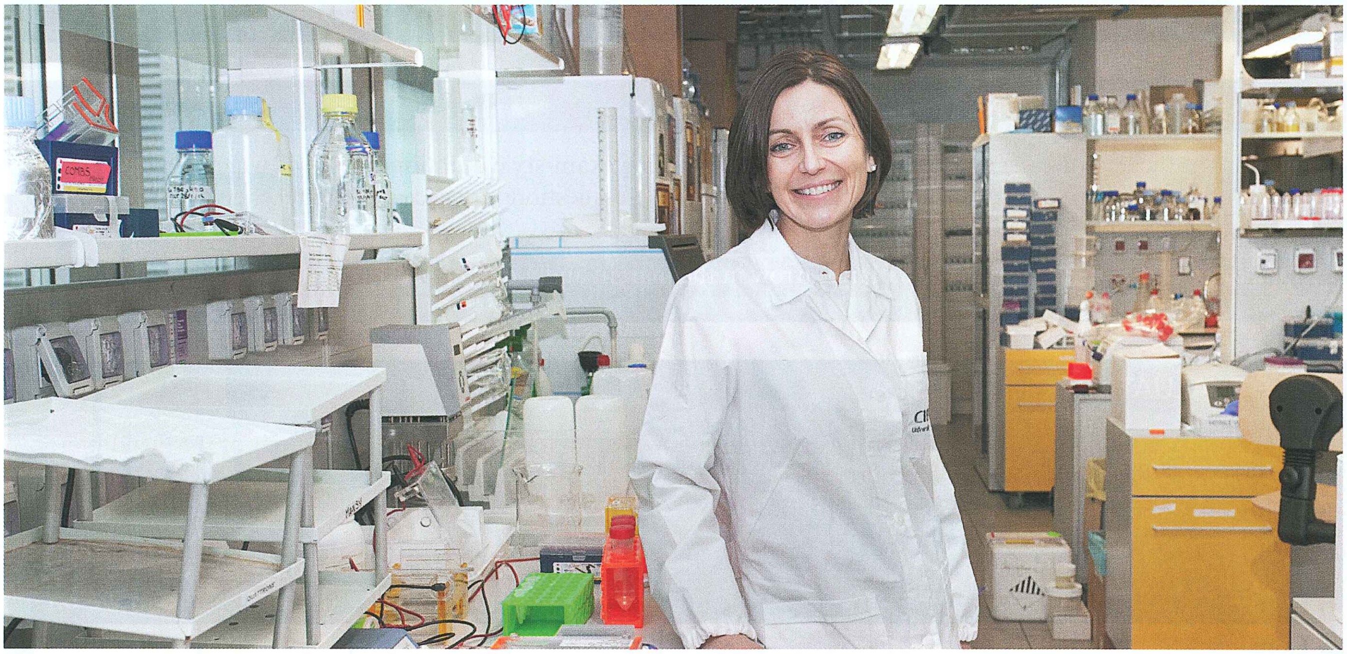
Other people are more interested in the applications of physics. They want to know how it can be used, perhaps in an engineering project, or for medical purposes. Depending on how our knowledge is applied, it can make the world a better place.

Some people study physics as part of their course because they want to become some other type of scientist – perhaps a chemist, biologist or geologist. These branches of science draw a great deal on ideas from physics, and physics may draw on them.

Thinking physics

How do physicists think? One of the characteristics of physicists is that they try to simplify problems – reduce them to their basics – and then solve them by applying some very fundamental ideas. For example, you will be familiar with the idea that matter is made of tiny particles that attract and repel each other and move about. This is a very useful model, which has helped us to understand the behaviour of matter, how sound travels, how electricity flows, and much more.

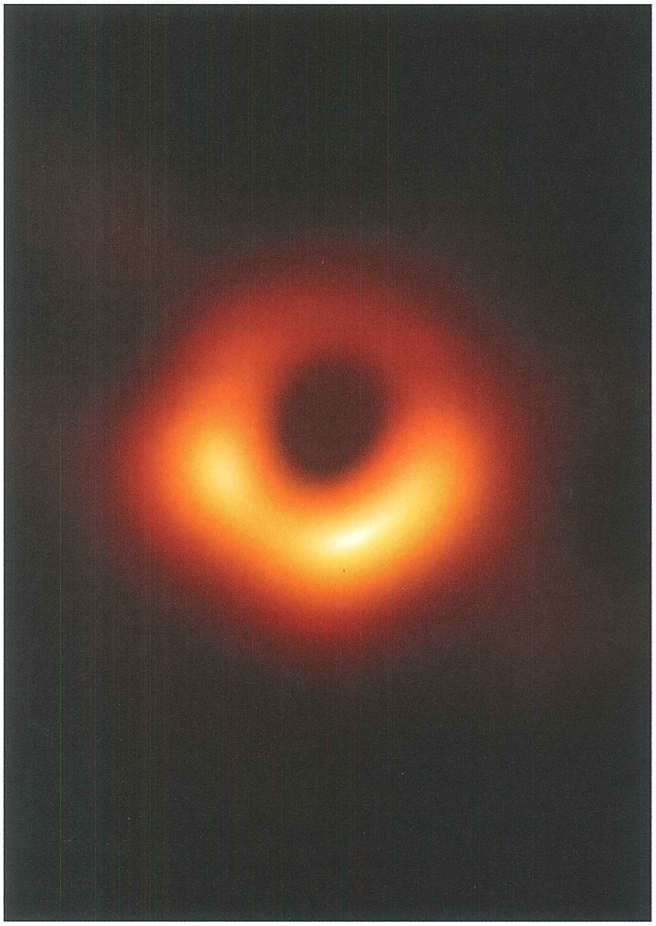
Once a fundamental idea is established, physicists look around for other areas where it might help to solve problems. One of the surprises of 20th century physics was that, once physicists had begun to understand the fundamental particles of which atoms are made, they realised that this helped to explain the earliest moments in the history of the Universe, at the time of the Big Bang.



Medicine is often seen as a biological career but this doctor will use many applications of physics, from X-rays to robotic limbs, in her work.

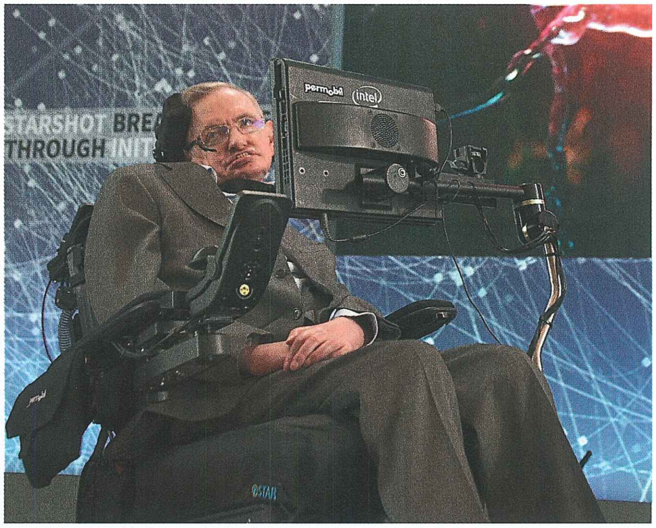
Physics relies on mathematics. Physicists measure quantities and analyse data. They invent mathematical models – equations and so on – to explain their findings. In fact, a great deal of mathematics has been developed by physicists to help them to understand their experimental results. An example of this is the work of Edward Witten, who designed new mathematical tools to unify different versions of superstring theory – a theory which tries to unite all the forces and particles you are learning about.

Computers have made a big difference in physics, allowing physicists to process vast amounts of data rapidly. Computers can process data from telescopes, control distant spacecraft and predict the behaviour of billions of atoms in a solid material.



In April 2019 the first pictures were released of a black hole. The central area is so dense that light cannot escape it. This image was the result of hundreds of scientists using a network of radio telescopes around the world, processing many petabytes of data – 1 petabyte is equal to 1 million gigabytes or 1×10^{15} bytes.

The more you study physics, the more you will come to realise how the ideas join up. Indeed, the ultimate goal for many physicists is to link all ideas into one unifying 'theory of everything'.



Stephen Hawking was a brilliant young student when he was diagnosed with motor neurone disease. He was expected to live only a few years, but at the time of his death at 76 he was still working as a professor at Cambridge University. One of his main aims was to unite relativity (which explains the very large) and quantum physics (which explains the very small).

Hawking came to believe this would not happen, but was glad about this: 'I'm now glad that our search for understanding will never come to an end, and that we will always have the challenge of new discovery. Without it, we would stagnate.'

Using physics

The practical applications of physics are far reaching. Many physicists work in economics and finance, using ideas from physics to predict how markets will change. Others use their understanding of particles in motion to predict how traffic will flow, or how people will move in crowded spaces. This type of modelling can be used to help us understand the spread of pathogens, such as the virus which caused the 2020 Covid-19 pandemic.

Physics is being used to find solutions for the world's major problems. New methods of generating electricity without adding to greenhouse gas emissions are helping to reduce our dependence on fossil fuels. Developments in battery technology allow us to store electrical energy, making electric vehicles a reality.

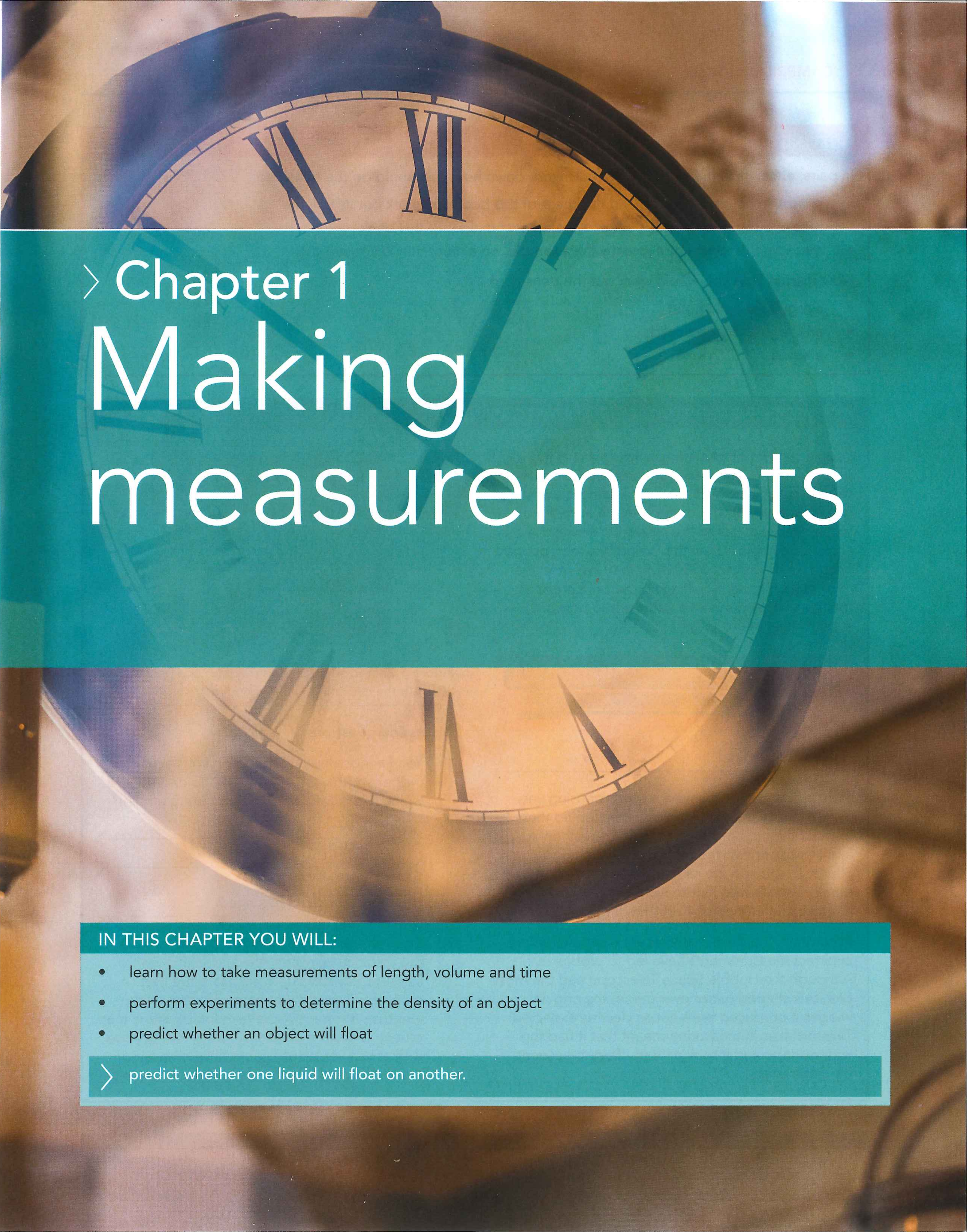
If this child drives it will probably be in an electric vehicle like this one. Many countries aim to phase out polluting, fossil fuel powered vehicles by the middle of the 21st century. Physicists are improving car design and battery life to make this feasible.

Joining in

So, when you study physics, you are doing two things.

i You are joining in with a big human project – learning more about the world around us and applying that knowledge.

ii At the same time, you are learning to think like a physicist – how to apply some basic ideas, how to look critically at data, and how to recognise underlying patterns. Whatever path you take, these skills will remain with you and help you make sense of the rapidly changing world in which we live.



Chapter 1
Making measurements

IN THIS CHAPTER YOU WILL:

- learn how to take measurements of length, volume and time
- perform experiments to determine the density of an object
- predict whether an object will float

- predict whether one liquid will float on another.

GETTING STARTED

In pairs, either take the measurements or write down how you would do the following:

- measure the length, width and thickness of this book and work out its volume
- measure the thickness of a sheet of paper that makes up this book
- measure the length of a journey (for example, on a map) that is not straight.

Now discuss how you would work out the density of:

- a regular-shaped solid
- an irregular-shaped solid
- a liquid.

ARE WE CLEVERER THAN OUR ANCESTORS WERE?

People tend to dismiss people who lived in the past as less intelligent than we are. After all, they used parts of their bodies for measuring distances. A cubit was the length of the forearm from the tip of the middle finger to the elbow. However, the ancient Egyptians knew this varied between people. Therefore, in around 3000 BCE, they invented the royal cubit (Figure 1.1), marked out on a piece of granite and used this as a **standard** to produce cubit rods of equal length.

Figure 1.1: Cubit rod.

The Ancient Egyptians were experts at using very simple tools like the cubit rod. This enabled them to build their pyramids accurately. Eratosthenes, a brilliant scientist who lived in Egypt in about 300 BCE, showed the same care and attention to detail. This allowed him to work out that the Earth has a circumference of 40 000 km (Figure 1.2).

In contrast, there are many recent examples where incorrect measurements have led to problems. Although the Hubble Space Telescope had the most precisely shaped mirror ever made, the original images it produced were not as clear as expected. Tiny mistakes in measuring meant that it had the wrong shape and it took a lot of effort to account for these errors.

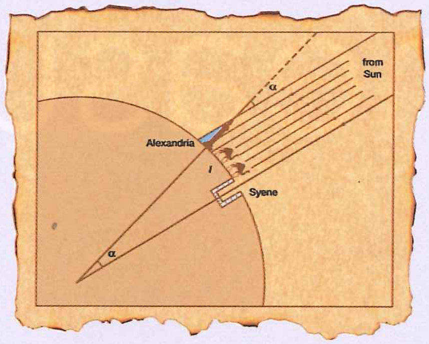


Figure 1.2: Eratosthenes used shadows and geometry to work out the circumference of the Earth.

Discussion questions

1 You cannot always depend on your eyes to judge lengths. Look at Figure 1.3 and decide which line is longer? Check by using a ruler.

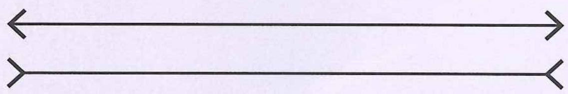


Figure 1.3: Which line is longer?

2 Eratosthenes may have hired a man to pace the distance between Alexandria and Syene (present-day Aswan) to calculate the Earth's circumference. People have different stride lengths so some people take longer steps than others. Discuss the possible ways that anyone with any stride length could have measured the distance between these towns accurately.

1.1 Measuring length and volume

In physics, we make measurements of many different lengths, for example, the length of a piece of wire, the height of liquid in a tube, the distance moved by an object, the diameter of a planet or the radius of its orbit. In the laboratory, lengths are often measured using a ruler (such as a metre ruler).

Measuring lengths with a ruler is a familiar task. But when you use a ruler, it is worth thinking about the task and just how reliable your measurements may be. Consider measuring the length of a piece of wire (Figure 1.4).

- The wire must be straight, and laid closely alongside the ruler. (This may be tricky with a bent piece of wire.)
- Look at the ends of the wire. Are they cut neatly, or are they ragged? Is it difficult to judge where the wire begins and ends?
- Look at the markings on the ruler. They are probably 1 mm apart, but they may be quite wide. Line one end of the wire up against the zero on the scale. Because of the width of the mark, this may be awkward to judge.
- Look at the other end of the wire and read the scale. Again, this may be tricky to judge.

Now you have a measurement, with an idea of how **precise** it is. You can probably determine the length of the wire to within a millimetre. But there is something else to think about – the ruler itself. How sure can you be that it is correctly **calibrated**? Are the marks at the ends of a metre ruler separated by exactly one metre? Any error in this will lead to an inaccuracy (probably small) in your result.

The point here is to recognise that it is always important to think critically about the measurements you make, however straightforward they may seem. You have to consider the method you use, as well as the instrument (in this case, the ruler).

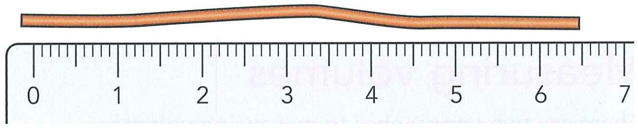


Figure 1.4: Simple measurements still require careful technique, for example, finding the length of a wire.

KEY WORDS

standard: is an absolute or primary reference or measurement

precise: when several readings are close together when measuring the same value

calibrated: should agree closely with a standard or agrees when a correction has been applied

More measurement techniques

If you have to measure a small length, such as the thickness of a wire, it may be better to measure several thicknesses and then calculate the average. You can use the same approach when measuring something very thin, such as a sheet of paper. Take a stack of 500 sheets and measure its thickness with a ruler (Figure 1.5). Then divide by 500 to find the thickness of one sheet.

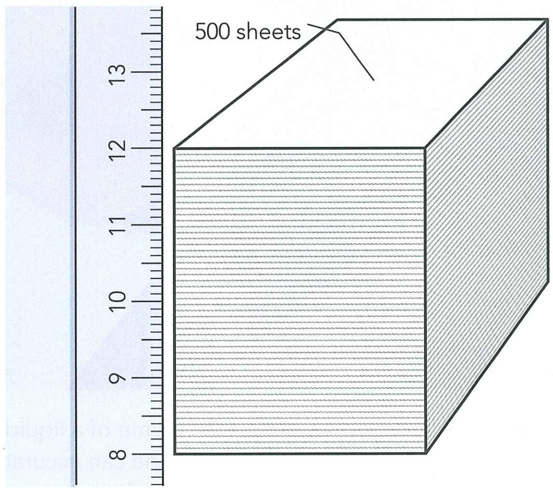


Figure 1.5: Making multiple measurements.

For some measurements of length, such as curved lines, it can help to lay a thread along the line. Mark the thread at either end of the line and then lay it along a ruler to find the length. This technique can also be used for measuring the circumference of a cylindrical object such as a wooden rod or a measuring cylinder.

Measuring volumes

There are two approaches to measuring volumes, depending on whether or not the shape is regular.

For a cube or cuboid, such as a rectangular block, measure the length, width and height of the object and multiply the measurements together. For objects of other regular shapes, such as spheres or cylinders, you may have to make one or two measurements and then look up the equation for the **volume**.

For liquids, measuring cylinders can be used as shown in Figure 1.6. (Recall that these are designed so that you look at the scale horizontally, not at an oblique angle, and read the level of the bottom of the **meniscus**.) The meniscus is the curved upper surface of a liquid, caused by surface tension. It can curve up or down but the surface of water in a measuring cylinder curves downwards. Think carefully about the choice of cylinder. A 1 litre (or a 1 dm^3) cylinder is unlikely to be suitable for measuring a small volume such as 5 cm^3. You will get a more accurate answer using a 10 cm^3 cylinder.

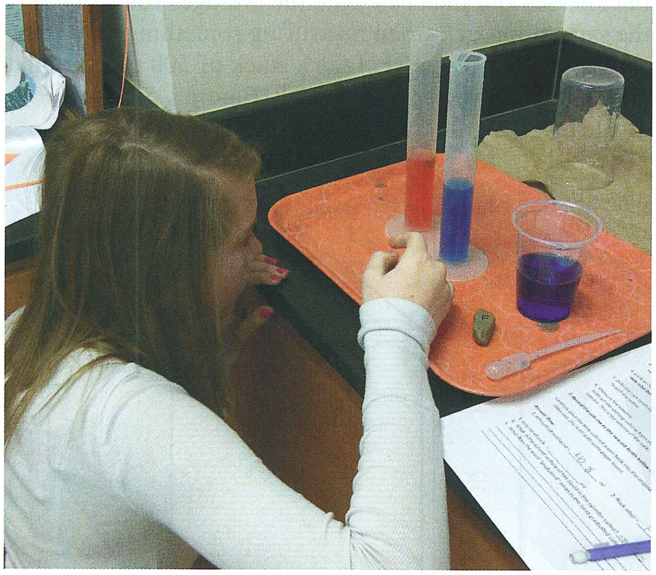


Figure 1.6: A student measuring the volume of a liquid. Her eyes are level with the scale so that she can accurately measure where the meniscus meets the scale.

Measuring volume by displacement

Most objects do not have a regular shape, so we cannot find their volumes simply by measuring the lengths of their sides. Here is how to find the volume of an irregularly shaped object. This technique is known as measuring volume by **displacement**.

- Select a measuring cylinder that is about three or four times larger than the object. Partially fill it with water (Figure 1.7), enough to cover the object. Note the volume of the water.
- **Immerse** the object in the water. The level of water in the cylinder will increase, because the object pushes the water out of the way and the only way it can move is upwards. The increase in its volume is equal to the volume of the object.

Units of length and volume

In physics, we generally use SI units (this is short for Le Système International d'Unités or The International System of Units). The SI unit of length is the metre (m). Table 1.1 shows some alternative units of length, together with some units of volume. Note that the litre and millilitre are not official SI units of volume, and so are not used in this book. One litre (1 l) is the same as 1 dm^3, and one millilitre (1 ml) is the same as 1 cm^3.

KEY WORDS

volume: the space occupied by an object

meniscus: curved upper surface of a liquid

displace: moving something to another place so water is moved out of the way (upwards) when an object is lowered into it

immerse: to cover something in a fluid (usually water) so that the object is submerged

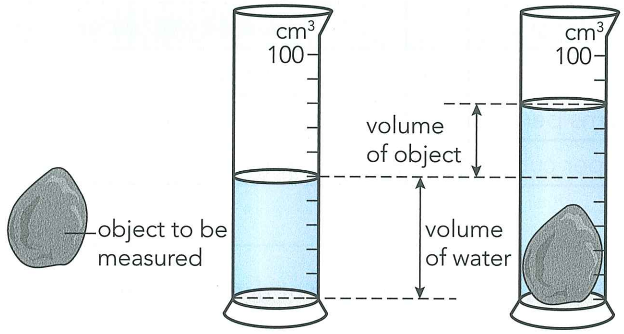


Figure 1.7: Measuring volume by displacement.

Quantity	Units
length	metre (m) 1 decimetre (dm) = 0.1 m 1 centimetre (cm) = 0.01 m 1 millimetre (mm) = 0.001 m 1 micrometre (μm) = 0.000 001 m 1 kilometre (km) = 1000 m
volume	cubic metre (m^3) 1 cubic centimetre (cm^3) = 0.000 001 m^3 1 cubic decimetre (dm^3) = 0.001 m^3

Table 1.1: Some units of length and volume in the SI system.

Questions

1 The volume of a piece of wood which floats in water can be measured as shown in Figure 1.8.

 a Write a paragraph to describe the procedure.

 b State the volume of the wood.

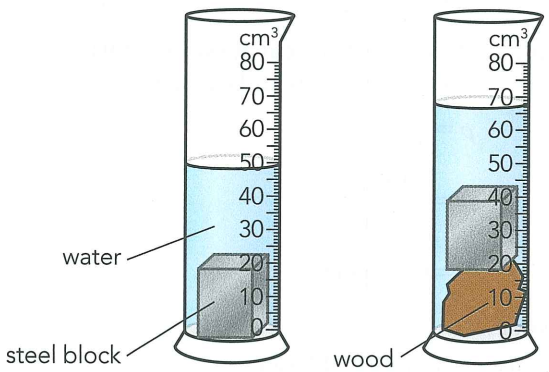


Figure 1.8: Measuring the volume of an object that floats.

2 A stack of paper contains 500 sheets of paper. The stack has dimensions of 0.297 m × 21.0 cm × 50.0 mm.

 a What is the thickness of one sheet of paper?

 b What is the volume of the stack of paper in cm^3?

1.2 Density

Our eyes can deceive us. When we look at an object, we can judge its volume. However, we can only guess its **mass**. We may guess incorrectly, because we misjudge the density. You may offer to carry someone's bag, only to discover that it contains heavy books. A large box of chocolates may have a mass of only 200 g.

The mass of an object is the quantity (amount) of matter it is made of. Mass is measured in kilograms. But **density** is a property of a material. It tells us how concentrated its mass is. You will learn more about the meaning of mass and how it differs from **weight** in Chapter 3.

In everyday speech, we might say that lead is heavier than wood. We mean that, given equal volumes of lead and wood, the lead is heavier. In scientific terms, the density of lead is greater than the density of wood. So we define density as shown, in words and as an equation.

Density is the mass per unit volume for a substance.

KEY EQUATION

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

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

KEY WORDS

mass: the quantity of matter a body is composed of; mass causes the object to resist changes in its motion and causes it to have a gravitational attraction for other objects

density: the ratio of mass to volume for a substance

weight: the downward force of gravity that acts on an object because of its mass

The symbol for density is ρ, the Greek letter rho. The SI unit of density is kg/m^3 (kilograms per cubic metre). You may come across other units, as shown in Table 1.2.

Unit of mass	Unit of volume	Unit of density	Density of water
kilogram, kg	cubic metre, m^3	kilograms per cubic metre	1000 kg/m^3
kilogram, kg	cubic decimetre, dm^3	kilograms per cubic decimetre	1.0 kg/dm^3
gram, g	cubic centimetre, cm^3	grams per cubic centimetre	1.0 g/cm^3

Table 1.2: Units of density.

Values of density

Some values of density are shown in Table 1.3. Gases have much lower densities than solids or liquids.

An object that is less dense than water will float. Ice is less dense than water which explains why icebergs float in the sea, rather than sinking to the bottom. Only about one tenth of an iceberg is above the water surface. If any part of an object is above the water surface, then it is less dense than water.

	Material	Density / kg/m^3
Gases	air	1.29
	hydrogen	0.09
	helium	0.18
	carbon dioxide	1.98
Liquids	water	1000
	alcohol (ethanol)	790
	mercury	13 600
Solids	ice	920
	wood	400–1200
	polyethene	910–970
	glass	2500–4200
	steel	7500–8100
	lead	11 340
	silver	10 500
	gold	19 300

Table 1.3: Densities of some substances. For gases, these are given at a temperature of 0 °C and a pressure of 1.0×10^5 Pa.

Many materials have a range of densities. Some types of wood, for example, are less dense than water and will float. Other types of wood (such as mahogany) are more dense and will sink. The density depends on the nature of the wood (its composition).

Gold is denser than silver. Pure gold is a soft metal, so jewellers add silver to make it harder. The amount of silver added can be judged by measuring the density.

It is useful to remember that the density of water is 1000 kg/m^3, 1.0 kg/dm^3 or 1.0 g/cm^3.

Calculating density

To calculate the density of a material, we need to know the mass and volume of a sample of the material.

WORKED EXAMPLE 1.1

A sample of ethanol has a volume of 240 cm^3. Its mass is found to be 190.0 g. What is the density of ethanol?

Step 1: Write down what you know and what you want to know.

mass $m = 190.0$ g

volume $V = 240\ cm^3$

density $\rho = ?$

Step 2: Write down the equation for density, substitute values and calculate ρ.

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

$$= \frac{190\ g}{240\ cm^3}$$

$$= 0.79\ g/cm^3$$

Answer

Density of ethanol = 0.79 g/cm^3

Measuring density

The easiest way to determine the density of a substance is to find the mass and volume of a sample of the substance.

For a solid with a regular shape, find its volume by measurement (see Section 1.1). Find its mass using a balance. Then calculate the density.

Questions

3 A brick is shown in Figure 1.9. It has a mass of 2.8 kg.

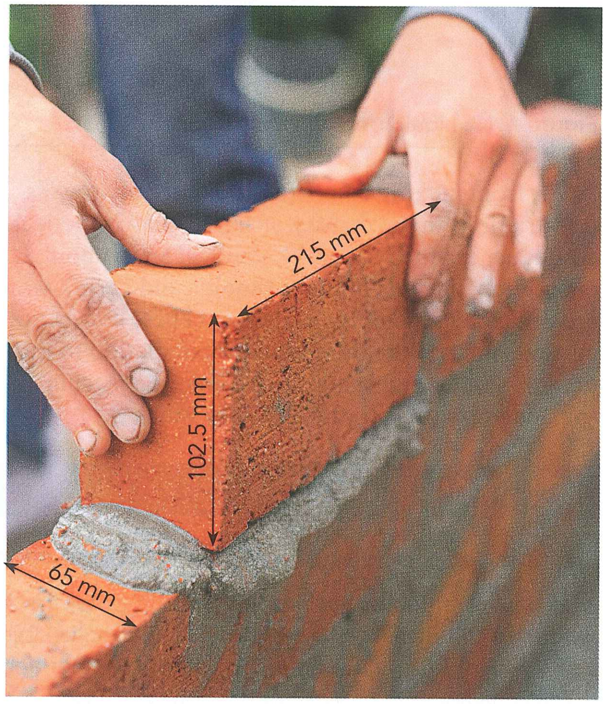


Figure 1.9: A brick labelled with its dimensions.

a Give the dimensions of the brick in metres.

b Calculate the volume of the brick.

c Calculate the density of the brick.

4 A box full of 35 matches has a mass of 6.77 g. The box itself has a mass of 3.37 g.

a What is the mass of one match in grams?

b What is the volume (in cm^3) of each match. A match has dimensions of 42 mm × 2.3 mm × 2.3 mm?

c What is the density of the matches?

d How do you know if these matches will float?

5 The Earth has a mass of 6×10^{24} kg and a radius of about 6400 km. What is the density of the Earth (in kg/m^3)? The volume of a sphere is given by the equation $V = \frac{4}{3}\pi r^3$, where r is the radius.

6 40 drawing pins (thumb tacks) like those shown in Figure 1.10 have a mass of 17.55 g. What is the volume (in mm^3) of one pin when they are made of metal with a density of $8.7\ g/cm^3$?

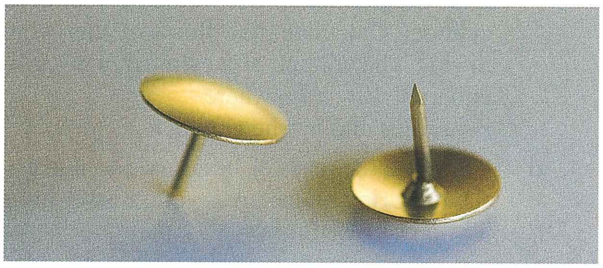


Figure 1.10: A pair of drawing pins (thumb tacks).

7 A young girl from the Kayan people in northern Thailand wears a neck ring made of brass (Figure 1.11). It looks as if there are 21 individual rings but the ring is actually one continuous length of brass fashioned (bent) into a coil. The height of the brass coil is 12 cm and its average circumference is 40 cm. Neck rings are usually only removed to be replaced with a bigger one as the girl grows. However, we can estimate the mass of this neck ring without removing it.

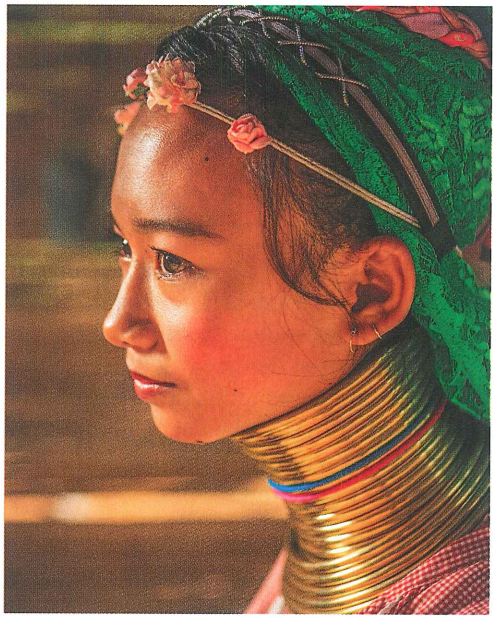


Figure 1.11: A Kayan girl wearing a neck ring.

a What looks like 21 individual rings around the girl's neck is actually 21 turns of a coil of brass. Each turn has a circumference of 40 cm. Calculate (in cm) the total length of brass used to make the girl's neck ring.

b The coil has a height of 12 cm and the coil has 21 turns. Calculate the radius of the brass in cm.

c If the brass coil is unwound from the girl's neck and straightened out, it would be a long, thin, cylinder. Calculate the volume of this cylinder in cm^3. The volume of a cylinder is given by the equation $V = \pi r^2 h$, where r = radius and h = height.

d Calculate the mass of brass used to make the neck ring and express your answer in kg. The density of brass = 8.73 g/cm^3.

Finding the density of a liquid

Figure 1.12 shows one way to find the density of a liquid. Place a measuring cylinder on a balance. Set the balance to zero. Now pour liquid into the cylinder. Read the volume from the scale on the cylinder. The balance shows the mass.

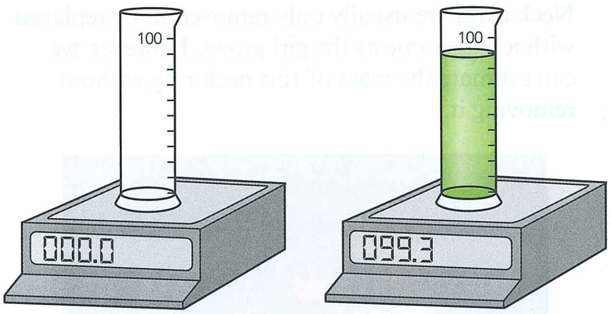


Figure 1.12: Measuring the mass of a liquid.

When liquids with different densities are poured into the same container, they will arrange themselves so that the liquid with the lowest density will be at the top and the ones with the highest density will be at the bottom. This is because the denser liquids displace the less dense liquids. This is easier to see when each liquid is given a different colour. In Figure 1.13, the green liquid is less dense than the red liquid and so on.

When a distinct layer forms in a mixed solution, the liquids are said to be immiscible, which means they do not mix. This is why oil floats on water. However, not all liquids stay separated so you would be disappointed if you tried this at home with squash and water, for example.

When liquids mix, it is usually because one liquid dissolves in the other. For example, orange squash is a concentrated syrup that is diluted by dissolving it in water.

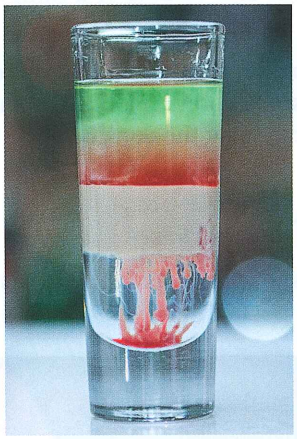


Figure 1.13: Liquid density towers.

Apart from making colourful liquid density towers, do variations in the density of liquids have practical consequence? In Chapter 11, you will learn about convection currents in fluids (liquids and gases), which are driven by differences in density. These convection currents include the thermohaline circulation in the oceans. Colder and saltier water sinks, displacing (pushing up) warmer and less salty water.

ACTIVITY 1.1

Finding the density of a regularly shaped solid

In pairs, create a worksheet on the computer for finding the density of a regularly shaped solid object (for example, a rectangular block) using a ruler and a mass balance. Your worksheet should include:

- a method for measuring the mass and working out the volume
- the equation for calculating density
- a table to record the data.

You could include an optional task to work out the density of a liquid.

After your allotted time, another pair is going to test a copy of your worksheet (perhaps by doing the experiment). They are going to add any steps that are missing or make suggestions to make your worksheet clearer. When you get your worksheet returned, edit and save a new version of it.

CONTINUED

Finding the density of an irregularly shaped solid

Before you start, make a copy of your previous worksheet and save it under a new name. Some of what you included in the previous worksheet can be kept and some will need to be edited.

In pairs, create a worksheet for finding the density of an irregularly shaped solid object using a mass balance, a measuring cylinder, some thread, a pair of scissors and a eureka can (if you have access to one). Your method explaining how to measure the mass and how to calculate the density should be the same. However, you should:

- explain how to measure volume by displacement
- say something about choosing a suitably sized measuring cylinder
- change your previous table

You could include an optional task to work out the density of an irregularly shaped solid object that is less dense than water. Finding its mass and calculating the density is straightforward. The challenging part is explaining how to work out the volume of an object that floats.

Design a flowchart or decision-tree (optional)

Design a flowchart or decision-tree for use by anyone who wants to work out the density of any liquid or any solid object. Ensure that your flowchart includes enough information so that someone could take the measurements. Ask your partner or someone else who has completed the first two parts to check and correct your flowchart.

REFLECTION

Write down one thing that you did really well in this activity.

Write down one thing that you will try to do better next time. How will you do this?

1.3 Measuring time

The athletics coach in Figure 1.14 is using his stopwatch to time a sprinter. For a sprinter, a fraction of a second (perhaps just 0.01 s) can make all the difference between winning and coming second or third. It is different in a marathon, where the race lasts for more than two hours and the runners are timed to the nearest second.

Figure 1.14: An athletics coach uses a stopwatch to time a hurdler, who can then learn whether she has improved.

ACTIVITY 1.2

How dense can you be?

In groups of three, write a method showing how you could work out your own density, or that of a friend or of a younger sibling. Alternatively, plan out your strategy and be prepared to share it with the class. There are at least two methods: a dry method and a wet method. Discuss one or both of them.

You will need to include:

- a method that is detailed enough for someone to follow (this should include advice about how a measurement should be taken)
- any calculations
- possible sources of uncertainty in the measurements
- what you expect your answer to be.

If you actually carried out the experiment, comment on how close your measurement was to what you expected.

In the laboratory, you might need to record the temperature of a container of water every minute, or find out how long an electric current is flowing. For measurements like these, stopclocks and stopwatches can be used. You may come across two types of timing device.

An **analogue** clock (Figure 1.15) is like a traditional clock whose hands move round the clock's face. You find the time by looking at where the hands are pointing on the scale. It can be used to measure time intervals to no better than the nearest second.

Figure 1.15: An analogue clock.

A **digital** clock (Figure 1.16) or stopwatch is one that gives a direct reading of the time in numerals. For example, a digital clock might show a time of 9.58 s. A digital clock records time to a precision of at least one hundredth of a second. You would never see an analogue watch recording times in the Olympic Games.

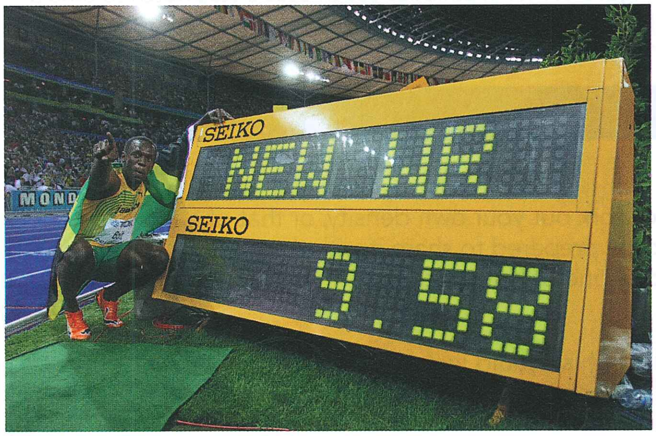


Figure 1.16: A digital clock started when the gun fired and stopped 9.58 s later when Usain Bolt crossed the finishing line to win the 100 m at the 2009 World Championships in world record time.

> **KEY WORDS**
>
> **analogue:** display has hands (or a needle) and is often not very precise
>
> **digital:** display shows numbers and is often precise

When studying motion, you may need to measure the time taken for a rapidly moving object to move between two points. In this case, you might use a device called a light gate connected to an electronic timer. This is similar to the way in which runners are timed in major athletics events. An electronic timer starts when the marshal's gun is fired, and stops as the runner crosses the finishing line.

You will learn more about how to use electronic timing instruments in Chapter 2.

Measuring short intervals of time

Figure 1.17 shows a typical lab pendulum. A mass, called a **plumb bob**, hangs on the end of a string. The string is clamped tightly at the top between two wooden jaws. If you pull the bob gently to one side and release it, the pendulum will swing from side to side.

The time for one **oscillation** of a pendulum (when it swings from left to right and back again) is called its **period**. A single period is usually too short a time to measure accurately. However, because a pendulum swings at a steady rate, you can use a stopwatch to measure the time for a large number of oscillations (perhaps 20 or 50), and calculate the average time per oscillation. Any inaccuracy in the time at which the stopwatch is started and stopped will be much less significant if you measure the total time for a large number of oscillations.

> **KEY WORDS**
>
> **plumb bob:** a mass (usually lead) hanging from a string to define a vertical line
>
> **oscillation:** a repetitive motion or vibration
>
> **period:** the time for one complete oscillation or wave; the time it takes an object to return to its original position

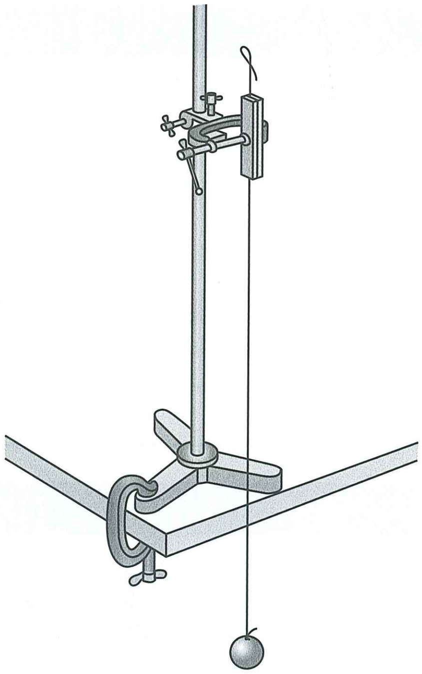


Figure 1.17: A simple pendulum.

Questions

8 High-speed video can record sporting events at a frame rate of 60 frames per second (frame/s).

a What is the time interval between one frame and the next?

b If we can see 24 frame/s as continuous motion, by what factor can the action recorded at 60 frame/s be slowed down and still look continuous?

9 A student was investigating how the period of a pendulum varied with the length of the string and obtained the results in Table 1.4.

Length of string / m	Time for 20 oscillations / s	Time for 1 oscillation / s
0.00	0.0	
0.20	18.1	
0.40	25.1	
0.60	28.3	
0.80	39.4	
1.00	40.5	
1.20	44.4	
1.40	47.9	

Table 1.4

a Why did the student record the time for 20 swings?

b Make a copy of Table 1.4 and, for each length of the pendulum, calculate the time for one oscillation and record the value in the third column of the table.

c Plot a graph of the period of the pendulum against its length (that is, plot the length of the pendulum on the x-axis).

d Use the graph to work out the length of the pendulum when the period is 2 seconds. This is the length of pendulum used in a grandfather clock.

ACTIVITY 1.3

Using a pendulum as a clock

In 1656 the Dutch scientist Christiaan Huygens invented a clock based on a swinging pendulum. Clocks like these were the most precise in the world until the 1930s. One oscillation of a pendulum is defined as the time it takes for a plumb bob at the bottom of the string to return to its original position (Figure 1.18).

You need to develop a worksheet so that students can plot a graph of how the period of oscillation of a pendulum varies with the length of the string. They then need to use the graph to find the length the pendulum needs to be to give a period of one second (useful for a clock). Your worksheet needs to:

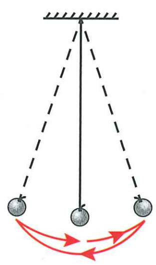


Figure 1.18: One oscillation is when the plumb bob swings one way and then the other and returns back to its original position.

CONTINUED

- define what an oscillation means (so that a student knows when to start and stop the stopwatch)
- explain why we take the time for 10 or 20 oscillations when we only need the time for one oscillation
- provide a labelled diagram of the assembled apparatus (not just a list of equipment) so that students know how to put the equipment together
- a method (step-by-step instructions).

Swap copies of your worksheet with a classmate. Write down suggestions for any improvements on the worksheet you receive before returning it to its owner. Note down any improvements if you have a class discussion.

PROJECT

In groups of three or four, produce a podcast (no more than five minutes long) on one of the following options.

Option 1: Can we build on what we have learned about density?

This is opportunity to revise what you have learned about density and then consolidate that knowledge and understanding by applying it to one of the two examples below.

- You must explain how density is calculated, including the equation.
- You should describe how to measure the mass and volume of both regular and irregular shaped objects.
- You could describe how to work out the density of an object that can float.

1 RSS Titanic

It was claimed that the RSS Titanic was unsinkable. However the ship sank in 1912 on its first voyage.

- You must explain why a ship can float despite being made of material that is denser than water.
- You should explain why a ship can sink, in terms of changes in density.
- Do some research to find out about bulkheads in ships: what are they and what are they for? Why did the RSS Titanic sink despite being fitted with bulkheads?

2 Submarines and scuba divers

You could describe one phenomenon that depends on changes or differences in density. You could think of your own or select one of these:

- Explain how a submarine or scuba diver moves up and down in the water column (or perhaps explain how a Cartesian diver demonstration works).
- Explain how differences in fluid density can lead to convection (something you will meet in Chapter 11). You might want to go on to discuss how this relates to ocean currents or wind.

Option 2: What was the solution to the longitude problem?

A clock based on a pendulum is impractical on the moving deck of a (sailing) ship but knowing the time is important for navigation as this provides your longitude on a spinning Earth. Lines of longitude are the vertical lines on a map. When you move east or west you are changing your longitude; move far enough and you change time zone.

- You must start with a short description of the longitude problem.
- You could describe the various suggested solutions to the longitude problem.
- You could describe the final solution to the longitude problem. For this, you would need to look up John Harrison and his marine chronometer.

Option 3: How did the Ancient Egyptians build their pyramids so accurately?

The pyramids are an incredible feat of engineering, even by today's standards. Using very basic tools, the Egyptians' pyramids are perfectly symmetrical.

- You could start by introducing the dimensions of the Giza pyramid and the number of blocks required to build it.

CONTINUED

- You could explain how the Egyptians managed to get the sides of their pyramids lined up with true north (without a compass) and how they got the base of them absolutely level (flat) without a (spirit) level.

Option 4: How did Eratosthenes work out the circumference of the Earth?

Eratosthenes was a brilliant scientist. He was told that, at the same time every year (12 noon on 21 June), vertical columns in Syene (present day Aswan) cast no shadows while columns where he lived in Alexandria cast shadows. He used this to work out that the Earth is round. Eratosthenes may have hired a man to measure out the distance between Alexandria and Syene.

- You could start with a short biography of Eratosthenes.
- You should explain why the observation with the shadows shows that the Earth is a sphere. You might want to include a diagram like Figure 1.2.
- You should try and show how the man hired by Eratosthenes could have worked out his stride-length (the distance of each step) and kept count of his strides (steps). Think about his possible journey: did he follow a straight line; were there any hills in the way? Could this have introduced errors in measuring the distance between Alexandria and Syene?
- Finally, you could show how Eratosthenes did the calculation.

Option 5: How did Archimedes really work out that the goldsmith had replaced some of the gold in Hiero's crown with silver?

Archimedes was probably the most brilliant scientist of his era. He is supposed to have solved the problem of how to work out the density of the crown while having a bath. Legend has it that he then ran into the streets shouting 'eureka' (I've solved it).

- You could start with a short biography of Archimedes.
- You could then describe the usual explanation of how he worked out that some gold had been stolen. Silver is less dense than gold so the same mass of silver has a bigger volume and will displace a bigger volume of water. However, it would be difficult to measure the difference in volume, especially since bubbles of air could cling to the submerged crown and there could be other sources of error.
- You could describe a better method, which uses a mass balance. You would need to explain why, when the masses are equal, the balance tips towards the denser mass when lowered into water.
- Gold needs some silver impurity or it would be too soft and would be easy to bend out of shape. Perhaps the goldsmith was falsely accused? Perhaps this idea could form part of a piece of creative writing (some prose or a play) but be sure to include the physics.

REFLECTION

- For your project, write down some thoughts about what you feel went well and areas where you could improve.
- Give yourself a score out of ten for how much you know and understand the physics you included. If you scored ten, write down how you could have produced a more ambitious project. If you scored less, do you need to thoroughly review the material or are you making careless errors? Write down what concrete steps you need to take to improve for next time.
- Give yourself a score out of ten for the quality of your presentation. Write down what you thought was good about the other presentations or any effective presentation ideas that you might use next time you present.

SUMMARY

Length can be measured using a ruler.
The period of one oscillation can be measured by measuring the time for 20 oscillations and then dividing the time by 20.
The volume of a cube or cuboid can be found by measuring the length of the three sides and multiplying the measurements together.
The volume of a liquid can be measured using a measuring cylinder where the bottom of the meniscus appears on the scale when looked at horizontally.
All objects that sink in water displace their own volume of water.
The volume of an irregularly shaped object can be found from the change in the height of liquid in a measuring cylinder when it is immersed in the liquid.
Density is the ratio of mass to volume for a substance: $\rho = \frac{m}{V}$.
The density of water is 1000 kg/m^3 or 1.0 g/cm^3.
Anything less dense than water will float in water and anything denser than water will sink in water.
Ice floats because it is less dense than water.
One liquid will float on top of another liquid if it is less dense.
Time can be measured using a clock or watch.
An analogue clock has hands and can only measure time to the nearest second.
A digital clock displays numbers and records time to a precision of at least one hundredth of a second.

EXAM-STYLE QUESTIONS

Use this table to answer questions 1 and 2.

Metal	Density / g/cm^3
gold	19.30
silver	10.49
lead	11.34

1 Three metal cubes have the same volume but are made of different metals. Each one is lowered into a beaker of water. Use the data in the table to decide which one will cause the biggest rise in water level. **[1]**

A gold
B silver
C lead
D all will cause the same rise in water level

CONTINUED

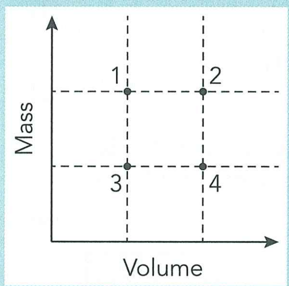
2 Three metal cubes have the same mass but are made of different metals. Each one is lowered into a beaker of water. Use the data in the table to decide which one will cause the biggest rise in water level. **[1]**

A gold
B silver
C lead
D all will cause the same rise in water level

3 Astronauts land on another planet and measure the density of the atmosphere on the planet surface. They measure the mass of a 500 cm³ conical flask plus stopper as 457.23 g. After removing the air, the mass is 456.43 g (1 m³ = 1000 litres). What is the best estimate of the density of the air? **[1]**

A 0.000 001 6 kg/m³
B 0.0016 kg/m³
C 0.16 kg/m³
D 1.6 kg/m³

4 The graph shows the mass and volume of several different objects.

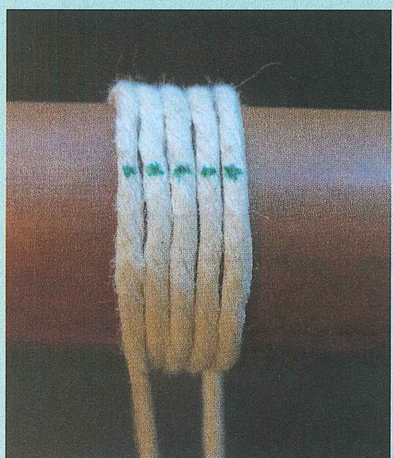


Which two objects have the same density? **[1]**

A 2 and 3 **B** 1 and 4 **C** 2 and 4 **D** 3 and 4

5 A student measures the circumference of a circular copper pipe.

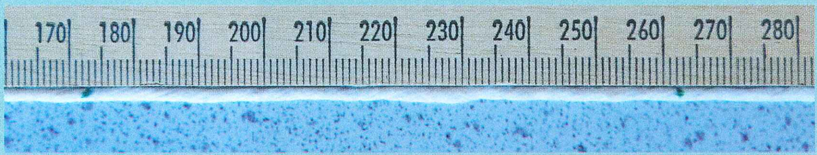
He wraps a length of string four times around the pipe and marks it with ink, as shown in the photograph.



CONTINUED

a The student unwraps the string and holds it against a ruler with a centimetre scale.

The photograph shows the first two ink marks on the string.



i Use the photograph to estimate the circumference of the pipe. **[1]**

ii The student finds that the total length of string for 4 turns is 354 mm. **Calculate** the average (mean) circumference of the pipe using this value. **[1]**

[Total: 2]

6 **Suggest** how you would work out the thickness of a single sheet of paper if the only measuring device available was a ruler and its smallest division was 1 mm. **[1]**

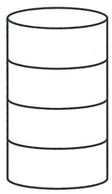
7 What is the mass of a microscope slide that has dimensions of 75 mm × 26 mm × 1 mm and has a density of 2.24 g/cm^3? **[2]**

8 Four different liquids are poured into a 100 cm^3 measuring cylinder that is 10 cm tall. Each liquid has a different density and each has a different colour.

a Calculate the missing values in the table. **[4]**

	Liquid	Mass / g	Volume / cm^3	Density / g/cm^3
clear	ethanol	i	20.00	0.79
red	glycerin	20.00	ii	1.26
green	olive oil	25.90	28.80	iii
blue	turpentine	30.00	35.30	iv

b Copy the diagram below. Using the data from the table above, write down the colour of the liquid you would expect to find in each layer and how thick the layer would be. **[2]**



Colour of layer	Thickness of layer / cm

9 Metals are denser than water. **Explain** why a metal ship can float. **[1]**

10 Suggest how you could work out the density of a drawing pin. **[3]**

COMMAND WORDS

calculate: work out from given facts, figures or information

suggest: apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals/ put forward considerations

explain: set out purposes or reasons; make the relationships between things evident; provide why and/or how and support with relevant evidence

SELF-EVALUATION CHECKLIST

After studying this chapter, think about how confident you are with the different topics. This will help you to see any gaps in your knowledge and help you to learn more effectively.

I can	See Topic...	Needs more work	Almost there	Confident to move on
Measure length, volume and time.	1.1, 1.3			
Calculate the volume of a cube or cuboid from measurements using a ruler.	1.1			
Determine the volume of an irregularly shaped object.	1.1			
Measure the size of tiny objects (for example, the thickness of a sheet of paper, the volume of a drawing pin).	1.1			
Calculate density.	1.2			
Predict whether an object will float or sink in water based on its density.	1.2			
Describe an experiment to find the density of a liquid.	1.2			
Predict whether a liquid will float on top of another liquid if their densities are known and they cannot mix.	1.2			
Describe an experiment to find the density of a cube or cuboid.	1.2			
Describe an experiment to find the density of an irregularly shaped object.	1.2			
Describe the differences between analogue and digital watches or clocks.	1.3			