1.01 Numbers and units

10 m
number   unit   (m is the symbol for metre)
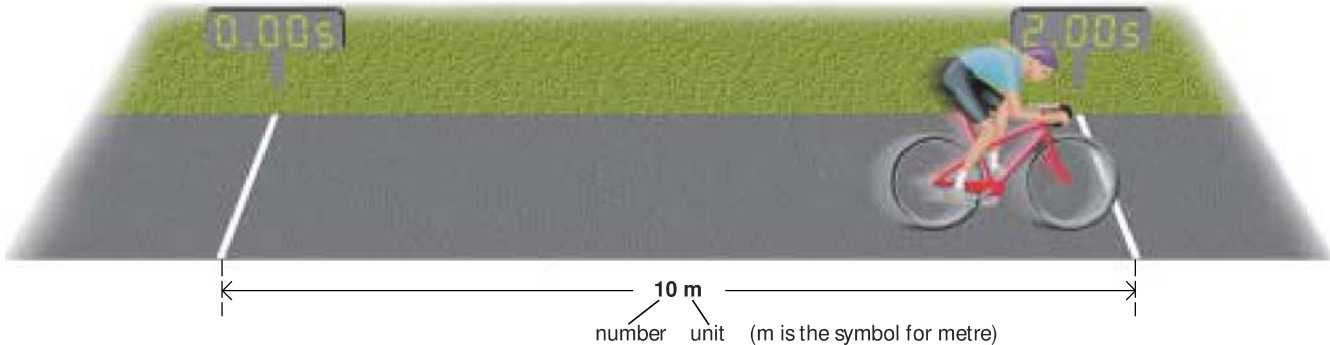
When you make a measurement, you might get a result like the one above: a distance of 10 m. The complete measurement is called a **physical quantity**. It is made up of two parts: a number and a unit.

10 m really means $10 \times m$ (ten times metre), just as in algebra, $10x$ means $10 \times x$ (ten times x). You can treat the m just like a symbol in an algebraic equation. This is important when combining units.

Combining units

In the diagram above, the girl cycles 10 metres in 2 s. So she travels 5 metres every second. Her *speed* is 5 metres per second. To work out the speed, you divide the distance travelled by the time taken, like this:

$$\text{speed} = \frac{10\,\text{m}}{2\,\text{s}} \qquad \text{(s is the symbol for second)}$$

As m and s can be treated as algebraic symbols:

$$\text{speed} = \frac{10}{2} \cdot \frac{\text{m}}{\text{s}} = 5\,\frac{\text{m}}{\text{s}}$$

To save space, $5\,\dfrac{\text{m}}{\text{s}}$ is usually written as 5 m/s.

So m/s is the unit of speed.

Rights and wrongs

This equation is correct: $\text{speed} = \dfrac{10\,\text{m}}{2\,\text{s}} = 5\,\text{m/s}$

This equation is incorrect: $\text{speed} = \dfrac{10}{2} = 5\,\text{m/s}$

It is incorrect because the m and s have been left out. 10 divided by 2 equals 5, and not 5 m/s.

Strictly speaking, units should be included at *all* stages of a calculation, not just at the end. However, in this book, the 'incorrect' type of equation will sometimes be used so that you can follow the arithmetic without units which make the calculation look more complicated.

Advanced units

5 m/s is a space-saving way of writing $5\,\dfrac{\text{m}}{\text{s}}$.

But $5\,\dfrac{\text{m}}{\text{s}}$ equals $5\,\text{m}\,\dfrac{1}{\text{s}}$.

Also, $\dfrac{1}{\text{s}}$ can be written as s^{-1}.

So the speed can be written as $5\,\text{m}\,\text{s}^{-1}$.

This method of showing units is more common in advanced work.

Bigger and smaller

You can make a unit bigger or smaller by putting an extra symbol, called a prefix, in front. (Below, W stands for watt, a unit of power.)

prefix	meaning		example
G (giga)	1 000 000 000	(10^9)	GW (gigawatt)
M (mega)	1 000 000	(10^6)	MW (megawatt)
k (kilo)	1000	(10^3)	km (kilometre)
d (deci)	$\frac{1}{10}$	(10^{-1})	dm (decimetre)
c (centi)	$\frac{1}{100}$	(10^{-2})	cm (centimetre)
m (milli)	$\frac{1}{1000}$	(10^{-3})	mm (millimetre)
μ (micro)	$\frac{1}{1\,000\,000}$	(10^{-6})	μW (microwatt)
n (nano)	$\frac{1}{1\,000\,000\,000}$	(10^{-9})	nm (nanometre)

Powers of 10

$$1000 = 10 \times 10 \times 10 = 10^3$$
$$100 = 10 \times 10 = 10^2$$
$$0.1 = \frac{1}{10} = 10^{-1}$$
$$0.01 = \frac{1}{100} = \frac{1}{10^2} = 10^{-2}$$
$$0.001 = \frac{1}{1000} = \frac{1}{10^3} = 10^{-3}$$

'milli' means 'thousandth', *not* 'millionth'

Scientific notation

An atlas says that the population of Iceland is this:

270 000

There are two problems with giving the number in this form. Writing lots of zeros isn't very convenient. Also, you don't know which zeros are accurate. Most are only there to show you that it is a six-figure number. These problems are avoided if the number is written using powers of ten:

2.7×10^5 ($10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100\,000$)

'2.7×10^5' tells you that the figures 2 and 7 are important. The number is being given to *two significant figures*. If the population were known more accurately, to three significant figures, it might be written like this:

2.70×10^5

Numbers written using powers of ten are in **scientific notation** or **standard form**. The examples on the right are to one significant figure.

decimal	fraction	scientific notation
500		5×10^2
0.5	$\frac{5}{10}$	5×10^{-1}
0.05	$\frac{5}{100}$	5×10^{-2}
0.005	$\frac{5}{1000}$	5×10^{-3}

Q

1 How many grams are there in 1 kilogram?
2 How many millimetres are there in 1 metre?
3 How many microseconds are there in 1 second?
4 This equation is used to work out the area of a rectangle: area = length × width.
   If a rectangle measures 3 m by 2 m, calculate its area, and include the units in your calculation.

5 Write down the following in km:
   2000 m   200 m 2×10^4 m
6 Write down the following in s:
   5000 ms 5×10^7 μs
7 Using scientific notation, write down the following to two significant figures:
   1500 m   1 500 000 m   0.15 m   0.015 m

1.02 A system of units

Mass	Length	Time
lb oz g kg ton cwt	cm yd m mile ft mm km	s hour day month year ms

There are many different units – including those above. But in scientific work, life is much easier if everyone uses a common system of units.

SI units

Most scientists use **SI units** (full name: Le Système International d'Unités). The basic SI units for measuring mass, time, and length are the kilogram, the second, and the metre. From these **base units** come a whole range of units for measuring volume, speed, force, energy, and other quantities.

Other SI base units include the ampere (for measuring electric current) and the kelvin (for measuring temperature).

Mass

Mass is a measure of the amount of substance in an object. It has two effects:
● All objects are attracted to the Earth. The greater the mass of an object, the stronger is the Earth's gravitational pull on it.
● All objects resist attempts to make them go faster, slower, or in a different direction. The greater the mass, the greater is the resistance to change in motion.

The SI base unit of mass is the **kilogram** (symbol **kg**). The standard kilogram is a block of platinum alloy kept at the Office of Weights and Measures in Paris. Other units based on the kilogram are shown below:

The mass of an object can be found using a **balance** like this. The balance really detects the gravitational pull on the object on the pan, but the scale is marked to show the mass.

mass	comparison with base unit	scientific notation	approximate size
1 tonne (t)	1000 kg	10^3 kg	medium-sized car
1 kilogram (kg)	**1 kg**		bag of sugar
1 gram (g)	1 g $\frac{1}{1\,000}$ kg	10^{-3} kg	banknote
1 milligram (mg)	$\frac{1}{1\,000}$ g $\frac{1}{1\,000\,000}$ kg	10^{-6} kg	human hair

Note: the SI base unit of mass is the **kilogram**, not the gram

Time

The SI base unit of time is the **second** (symbol **s**). Here are some shorter units based on the second:

1 millisecond (ms) $= \dfrac{1}{1000}$ s $= 10^{-3}$ s

1 microsecond (µs) $= \dfrac{1}{1\,000\,000}$ s $= 10^{-6}$ s

1 nanosecond (ns) $= \dfrac{1}{1\,000\,000\,000}$ s $= 10^{-9}$ s

To keep time, clocks and watches need something that beats at a steady rate. Some old clocks used the swings of a pendulum. Modern digital watches count the vibrations made by a tiny quartz crystal.
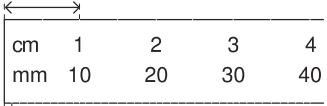
> The second was originally defined as $\dfrac{1}{60 \times 60 \times 24}$ of a day, one day being the time it takes the Earth to rotate once. But the Earth's rotation is not quite constant. So, for accuracy, the second is now defined in terms of something that never changes: the frequency of an oscillation which can occur in the nucleus of a caesium atom.

Length

The SI base unit of length is the **metre** (symbol **m**). At one time, the standard metre was the distance between two marks on a metal bar kept at the Office of Weights and Measures in Paris. A more accurate standard is now used, based on the speed of light, as on the right.

> By definition, one metre is the distance travelled by light in a vacuum in $\dfrac{1}{299\,792\,458}$ of a second.

There are larger and smaller units of length based on the metre:

distance	comparison with base unit	scientific notation	approximate size
1 kilometre (km)	1 000 m	10^3 m	10 football pitches
1 metre (m)	1 m		
1 centimetre (cm)	$\frac{1}{100}$ m	10^{-2} m	cm 1 2 3 4 / mm 10 20 30 40
1 millimetre (mm)	$\frac{1}{1\,000}$ m	10^{-3} m	
1 micrometre (µm)	$\frac{1}{1\,000\,000}$ m	10^{-6} m	bacteria
1 nanometre (nm)	$\frac{1}{1\,000\,000\,000}$ m	10^{-9} m	atoms

Q

1 What is the SI unit of length?
2 What is the SI unit of mass?
3 What is the SI unit of time?
4 What do the following symbols stand for?
   g   mg   t   µm   ms
5 Write down the value of
   a) 1564 mm in m   b) 1750 g in kg
   c) 26 t in kg   d) 62 µs in s
   e) 3.65×10^4 g in kg   f) 6.16×10^{-7} mm in m
6 The 500 pages of a book have a mass of 2.50 kg. What is the mass of each page a) in kg b) in mg?

7 km   µg   µm   t   nm   kg   m
  ms   s   mg   ns   µs   g   mm

Arrange the above units in three columns as below. The units in each column should be in order, with the largest at the top.
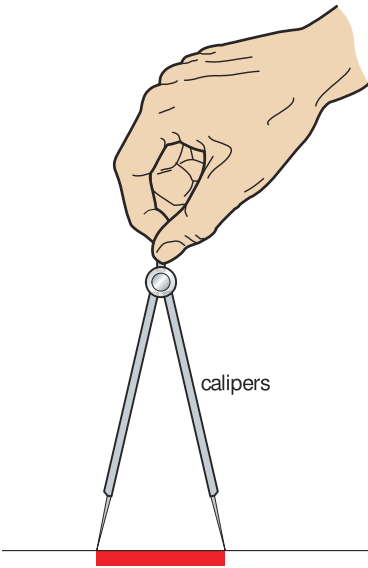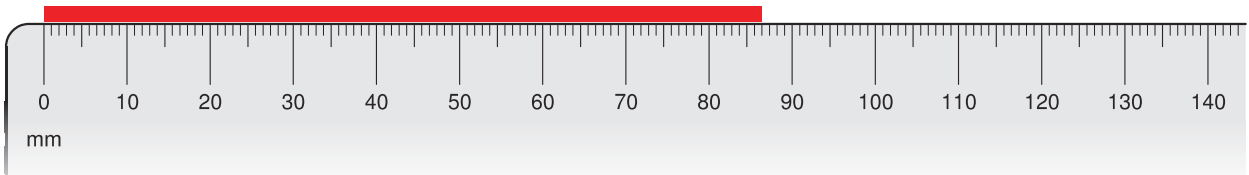
	mass	length	time
largest unit →			

1.03 Measuring length and time

Measuring length

Lengths from a few millmetres up to a metre can be measured using a **rule**, as shown above. When using the rule, the scale should be placed right next to the object being measured. If this is not possible, **calipers** can be used, as shown on the left. The calipers are set so that their points exactly match the ends of the object. Then they are moved across to a rule to make the measurement.

Lengths of several metres can be measured using a **tape** with a scale on it.
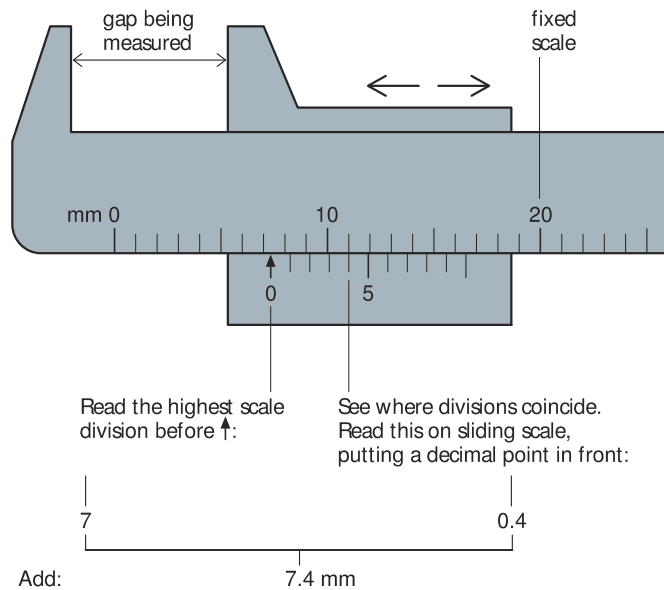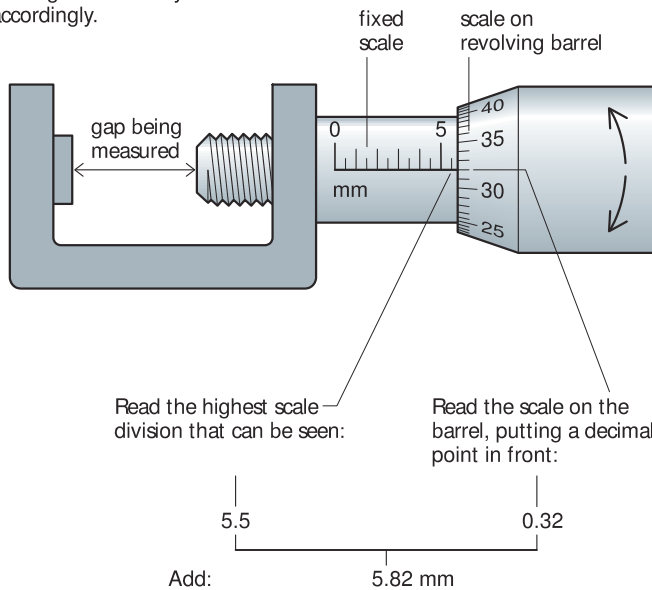
With small objects, more accurate length measurements can be made using the methods shown below:

Micrometer (below left) This has a revolving barrel with an extra scale on it. The barrel is connected to a screw thread and, in the example shown, each turn of the barrel closes (or opens) the gap by one millimetre. First, the gap is opened wide. Then it is closed up until the object being measured *just* fits in it (a 'clicking' sound is heard). The diagram shows you how to take the reading.

Vernier calipers (below right) This is an extra sliding scale fitted to some length-measuring instruments. Its divisions are set slightly closer together than normal so that one of them coincides with a division on the fixed scale. The diagram shows you how to take the reading. (The vernier shown is part of a set of calipers used for making external measurements. A second type of caliper has jaws for making internal measurements.)

calipers

▲ If the rule cannot be placed next to the object being measured, calipers can be used.

Check and record your 'zero-error' reading and amend your answer accordingly.

fixed scale

scale on revolving barrel

gap being measured

gap being measured

fixed scale

Read the highest scale division that can be seen:

5.5

Read the scale on the barrel, putting a decimal point in front:

0.32

Add: 5.82 mm

Read the highest scale division before ↑:

7

See where divisions coincide. Read this on sliding scale, putting a decimal point in front:

0.4

Add: 7.4 mm

▲ Reading a micrometer

▲ Reading a vernier

Measuring time

Time intervals of many seconds or minutes can be measured using a **stopclock** or a **stopwatch**. Some instruments have an **analogue** display, with a needle ('hand') moving round a circular scale. Others have a **digital** display, which shows a number. There are buttons for starting the timing, stopping it, and resetting the instrument to zero.

With a hand-operated stopclock or stopwatch, making accurate measurements of short time intervals (a few seconds or less) can be difficult. This is because of the time it takes you to react when you have to press the button. Fortunately, in some experiments, there is an simple way of overcoming the problem. Here is an example:

rigid support

A pendulum can be set up to investigate the time taken for a single swing.

string — one complete swing

simple pendulum

bob (small mass)
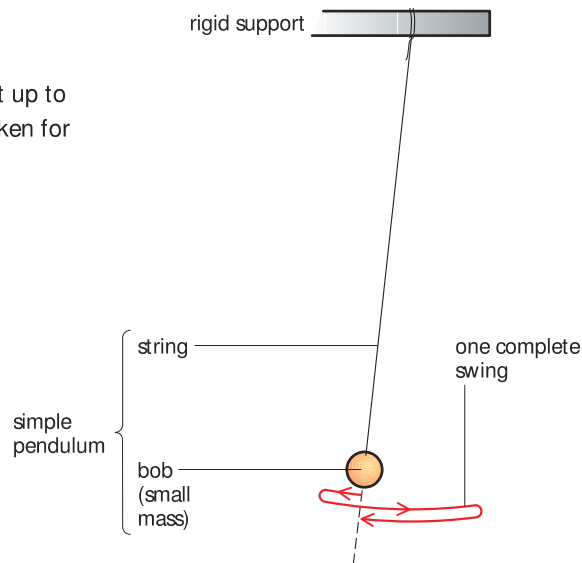
The pendulum above takes about two seconds to make one complete swing. Provided the swings are small, every swing takes the same time. This time is called its **period**. You can find it accurately by measuring the time for 25 swings, and then dividing the result by 25. For example:
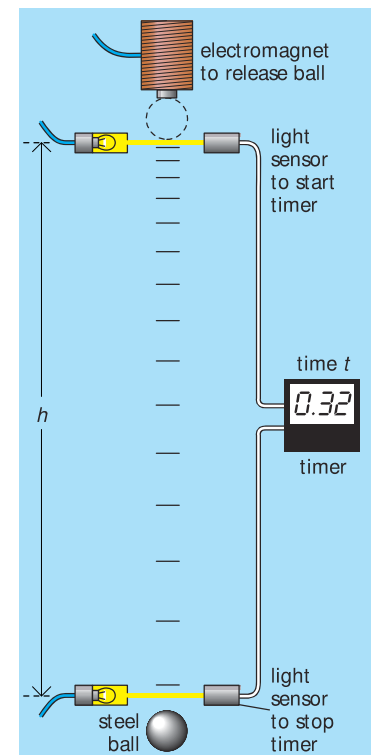
Time for 25 swings = 55 seconds

So: time for 1 swing = 55/25 seconds = 2.2 seconds

Another method of improving accuracy is to use automatic timing, as shown in the example on the right. Here, the time taken for a small object to fall a short distance is being measured. The timer is started automatically when the ball cuts one light beam and stopped when it cuts another.

Zero error

Vernier calipers are said to have a **zero error** if the zero marking on the main scale is not in line with the zero marking on the vernier scale when the jaws are fully closed. For example, on the vernier calipers below, the zero error is +0.02 cm.
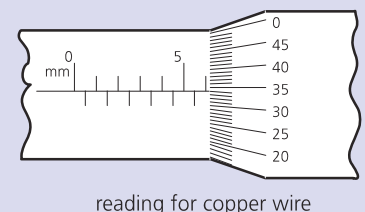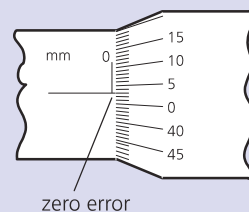
0   1

main scale

vernier scale

5

0   10

If the scale reading = 4.09 cm
Zero error   = 0.02 cm
Then, the corrected reading
= (4.09 − 0.02) = 4.07 cm

---

electromagnet to release ball

light sensor to start timer

time t

0.32

timer

h

steel ball

light sensor to stop timer

Measuring the time t it takes for a steel ball to fall a distance h

---

Q

1 A student measures the time taken for 20 swings of a pendulum. He finds that the time taken is 46 seconds.
 a) What time does the pendulum take for one swing?
 b) How could the student have found the time for one swing more accurately?

2 A student wants to find the thickness of one page of this book. Explain how she might do this accurately.

3 A micrometer is used to measure the diameter of a length of copper wire. The zero error and scale reading are as shown.

mm   0   15
            10
            5
            0
            40
            45

zero error

0   5
mm

0
45
40
35
30
25
20

reading for copper wire

a) What is the zero error of the micrometer?
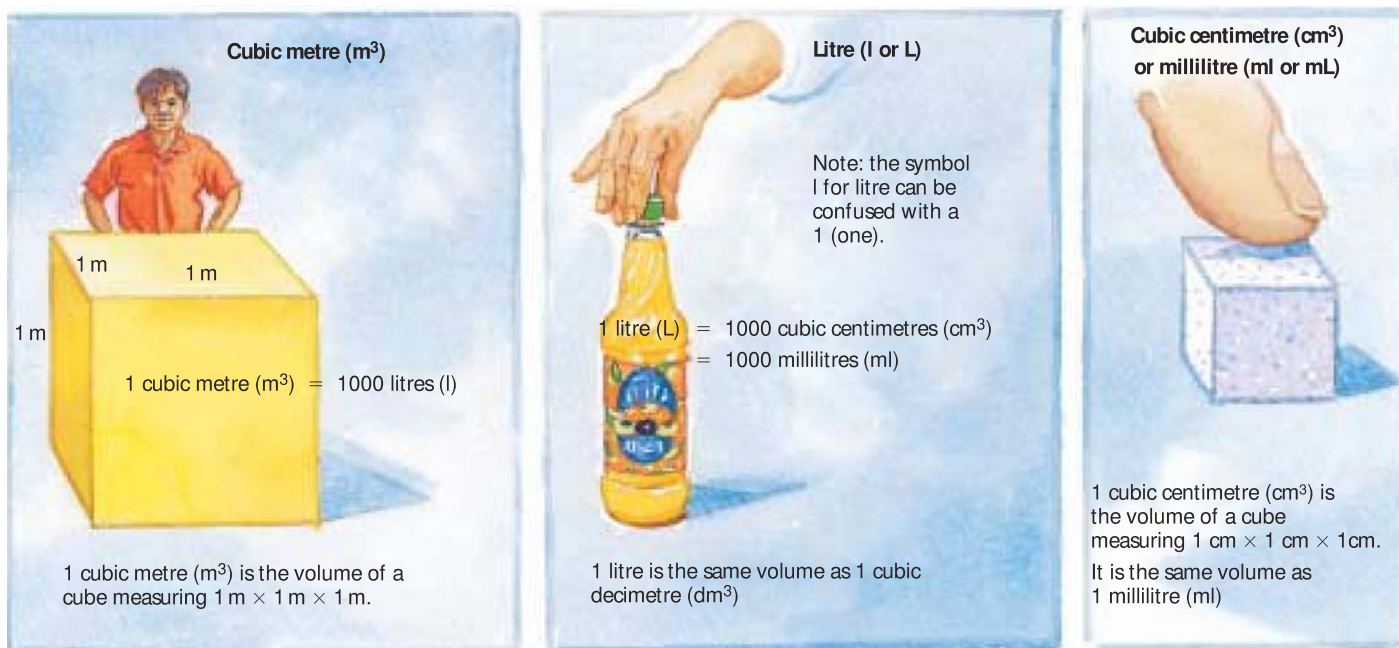b) What is the correct diameter of the wire?

1.04 Volume and density

Volume

The quantity of space an object takes up is called its volume.

The SI unit of volume is the **cubic metre** (m^3). However, this is rather large for everyday work, so other units are often used for convenience, as shown in the diagrams below:

Cubic metre (m^3)

1 m   1 m

1 m

1 cubic metre (m^3) = 1000 litres (l)

1 cubic metre (m^3) is the volume of a cube measuring 1 m × 1 m × 1 m.

Litre (l or L)

Note: the symbol l for litre can be confused with a 1 (one).

1 litre (L) = 1000 cubic centimetres (cm^3)
          = 1000 millilitres (ml)

1 litre is the same volume as 1 cubic decimetre (dm^3)

Cubic centimetre (cm^3) or millilitre (ml or mL)

1 cubic centimetre (cm^3) is the volume of a cube measuring 1 cm × 1 cm × 1cm.

It is the same volume as 1 millilitre (ml)

Density

Is lead heavier than water? Not necessarily. It depends on the volumes of lead and water being compared. However, lead is more dense than water: it has more kilograms packed into every cubic metre.

The **density** of a material is calculated like this:

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

In the case of water:
a mass of 1000 kg of water has a volume of $1\,m^3$
a mass of 2000 kg of water has a volume of $2\,m^3$
a mass of 3000 kg of water has a volume of $3\,m^3$, and so on.

Using any of these sets of figures in the above equation, the density of water works out to be $1000\,kg/m^3$.

If masses are measured in grams (g) and volumes in cubic centimetres (cm^3), it is simpler to calculate densities in g/cm^3. Converting to kg/m^3 is easy:

$$1\,g/cm^3 = 1000\,kg/m^3$$

The density of water is $1\,g/cm^3$. This simple value is no accident. The kilogram (1000 g) was originally supposed to be the mass of $1000\,cm^3$ of water (pure, and at $4\,^{\circ}C$). However, a very slight error was made in the early measurement, so this is no longer used as a definition of the kilogram.

The glowing gas in the tail of a comet stretches for millions of kilometres behind the comet's core. The density of the gas is less than a kilogram per cubic *kilo*metre.

substance	density kg/m³	density g/cm³	substance	density kg/m³	density g/cm³
air	1.3	0.0013	granite	2700	2.7
expanded polystyrene	14	0.014	aluminium	2700	2.7
wood (beech)	750	0.75	steel (stainless)	7800	7.8
petrol	800	0.80	copper	8900	8.9
ice (0 °C)	920	0.92	lead	11 400	11.4
polythene	950	0.95	mercury	13 600	13.6
water (4 °C)	1000	1.0	gold	19 300	19.3
concrete	2400	2.4	platinum	21 500	21.5
glass (varies)	2500	2.5	osmium	22 600	22.6

The densities of solids and liquids vary slightly with temperature. Most substances get a little bigger when heated. The increase in volume reduces the density.

The densities of gases can vary enormously depending on how compressed they are.

The rare metal osmium is the densest substance found on Earth. If this book were made of osmium, it would weigh as much as a heavy suitcase.
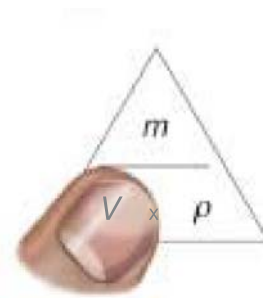
Density calculations

The equation linking density, mass, and volume can be written in symbols:

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

where ρ = density, m = mass, and V = volume

This equation can be rearranged to give: $V = \frac{m}{\rho}$ and $m = V\rho$

These are useful if the density is known, but the volume or mass is to be calculated. On the right is a method of finding all three equations.

Cover V in the triangle and you can see what V is equal to. It works for m and ρ as well.

Example Using density data from the table above, calculate the mass of steel having the same volume as 5400 kg of aluminium.

First, calculate the volume of 5400 kg of aluminium. In this case, ρ is 2700 kg/m³, m is 5400 kg, and V is to be found. So:

$$V = \frac{m}{\rho} = \frac{5400\,\text{kg}}{2700\,\text{kg/m}^3} = 2\,\text{m}^3$$

This is also the volume of the steel. Therefore, for the steel, ρ is 7800 kg/m³, V is 2 m³, and m is to be found. So:

$$m = V\rho = 7800\,\text{kg/m}^3 \times 2\,\text{m}^3 = 15\,600\,\text{kg}$$

So the mass of steel is 15 600 kg.

In the density equation, the symbol ρ is the Greek letter 'rho'.

Q

1 How many cm³ are there in 1 m³?
2 How many cm³ are there in 1 litre?
3 How many ml are there in 1 m³?
4 A tankful of liquid has a volume of 0.2 m³. What is the volume in **a)** litres **b)** cm³ **c)** ml?
5 Aluminium has a density of 2700 kg/m³.
   a) What is the density in g/cm³?
   b) What is the mass of 20 cm³ of aluminium?
   c) What is the volume of 27 g of aluminium?

Use the information in the table of densities at the top of the page to answer the following:

6 What material, of mass 39 g, has a volume of 5 cm³?
7 What is the mass of air in a room measuring 5 m × 2 m × 3 m?
8 What is the volume of a storage tank which will hold 3200 kg of petrol?
9 What mass of lead has the same volume as 1600 kg of petrol?

1.05

Measuring volume and density
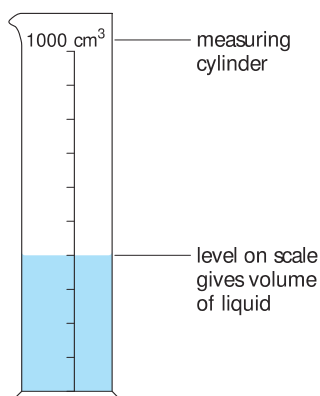
Measuring the volume of a liquid
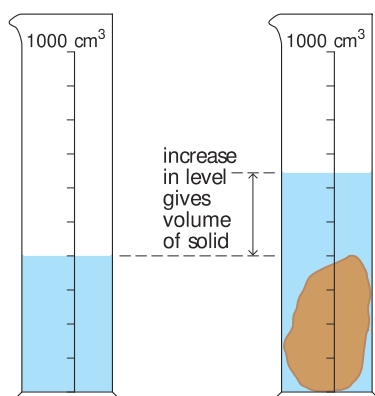
Measuring the volume of a small solid

Using a displacement can. Provided the can is filled to the spout at the start, the volume of water collected in the beaker is equal to the volume of the object lowered into the can.

Measuring volume

Liquid A volume of about a litre or so can be measured using a measuring cylinder. When the liquid is poured into the cylinder, the level on the scale gives the volume.

Most measuring cylinders have scales marked in millilitres (ml), or cubic centimetres (cm^3).

Regular solid If an object has a simple shape, its volume can be calculated. For example:

$$\text{volume of a rectangular block} = \text{length} \times \text{width} \times \text{height}$$

$$\text{volume of a cylinder} = \pi \times \text{radius}^2 \times \text{height}$$

Irregular solid If the shape is too awkward for the volume to be calculated, the solid can be lowered into a partly filled measuring cylinder as shown on the left. The *rise* in level on the volume scale gives the volume of the solid.

If the solid floats, it can be weighed down with a lump of metal. The total volume is found. The volume of the metal is measured in a separate experiment and then subtracted from this total.

Using a displacement can If the solid is too big for a measuring cylinder, its volume can be found using a displacement can, shown below left. First, the can is filled up to the level of the spout (this is done by overfilling it, and then waiting for the surplus water to run out). Then the solid is slowly lowered into the water. The solid is now taking up space once occupied by the water – in other words, it has displaced its own volume of water. The displaced water is collected in a beaker and emptied into a measuring cylinder.

The displacement method, so the story goes, was discovered by accident, by Archimedes. You can find out how on the opposite page.

Measuring density

The density of a material can be found by calculation, once the volume and mass have been measured. The mass of a small solid or of a liquid can be measured using a balance. However, in the case of a liquid, you must remember to allow for the mass of its container.

Here are some readings from an experiment to find the density of a liquid:

volume of liquid in measuring cylinder	= 400 cm³	(A)
mass of measuring cylinder	= 140 g	(B)
mass of measuring cylinder with liquid in	= 560 g	(C)

Therefore: mass of liquid = 560 g – 240 g = 320 g   (C – B)

$$\text{Therefore density of liquid} = \frac{\text{mass}}{\text{volume}} = \frac{320 \text{ g}}{400 \text{ cm}^3} = 0.8 \text{ g/cm}^3$$

Relative density*

The relative density of a substance tells you how the density compares with that of water. It is calculated like this:

$$\text{relative density} = \frac{\text{density of substance}}{\text{density of water}}$$

For example, lead has a density of $11\,300\,\text{kg/m}^3$ ($11.3\,\text{g/cm}^3$) and water has a density of $1000\,\text{kg/m}^3$ ($1\,\text{g/cm}^3$). So:

$$\text{relative density of lead} = \frac{11\,300\,\text{kg/m}^3}{1000\,\text{kg/m}^3} = \frac{11.3\,\text{g/cm}^3}{1\,\text{g/cm}^3} = 11.3$$

Relative density has no units. It is a number whose value is the same as that of the density in g/cm^3. It used to be known as 'specific gravity'.

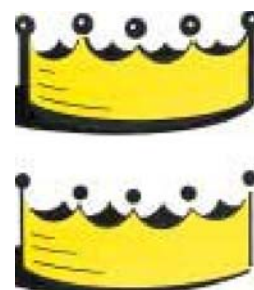| substance	density	relative density
water	$1.0\,\text{g/cm}^3$	1.0
aluminium	$2.7\,\text{g/cm}^3$	2.7
copper	$8.9\,\text{g/cm}^3$	8.9
lead	$11.4\,\text{g/cm}^3$	11.4
mercury	$13.6\,\text{g/cm}^3$	13.6
gold	$19.3\,\text{g/cm}^3$	19.3
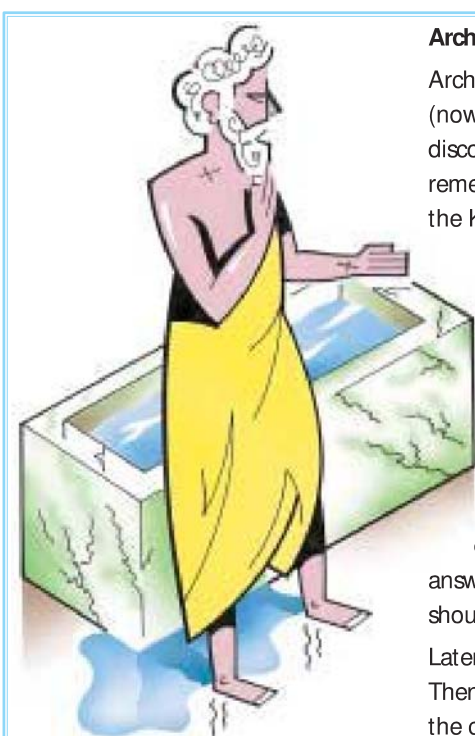
Archimedes and the crown

Archimedes, a Greek mathematician, lived in Syracuse (now in Sicily) around 250 BC. He made important discoveries about levers and liquids, but is probably best remembered for his clever solution to a problem set him by the King of Syracuse.

The King had given his goldsmith some gold to make a crown. But when the crown was delivered, the King was suspicious. Perhaps the goldsmith had stolen some of the gold and mixed in cheaper silver instead. The King asked Archimedes to test the crown.

Archimedes knew that the crown was the correct mass. He also knew that silver was less dense than gold. So a crown with silver in it would have a greater volume than it should have. But how could he measure the volume? Stepping into his bath one day, so the story goes, Archimedes noticed the rise in water level. Here was the answer! He was so excited that he lept from his bath and ran naked through the streets, shouting "Eureka!", which means "I have found it!".

Later, Archimedes put the crown in a container of water and measured the rise in level. Then he did the same with an equal mass of pure gold. The rise in level was different. So the crown could not have been pure gold.
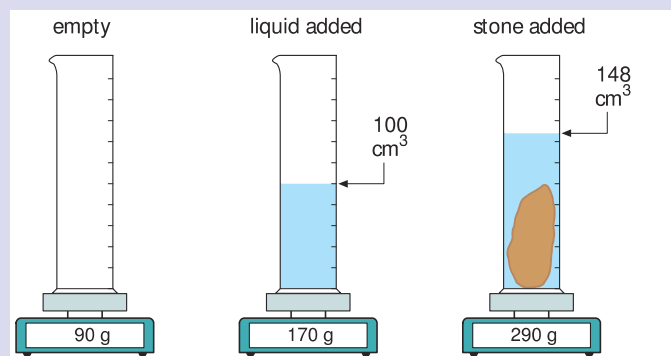

Q

	crown A	crown B	crown C
mass/ g	3750	3750	3750
volume/ cm³	357	194	315

density: gold $19.3\,\text{g/cm}^3$; silver $10.5\,\text{g/cm}^3$

empty — liquid added ($100\,\text{cm}^3$, 170 g) — stone added ($148\,\text{cm}^3$, 290 g); empty 90 g

1 Use the information above to decide which crown is gold, which is silver, and which is a mixture.
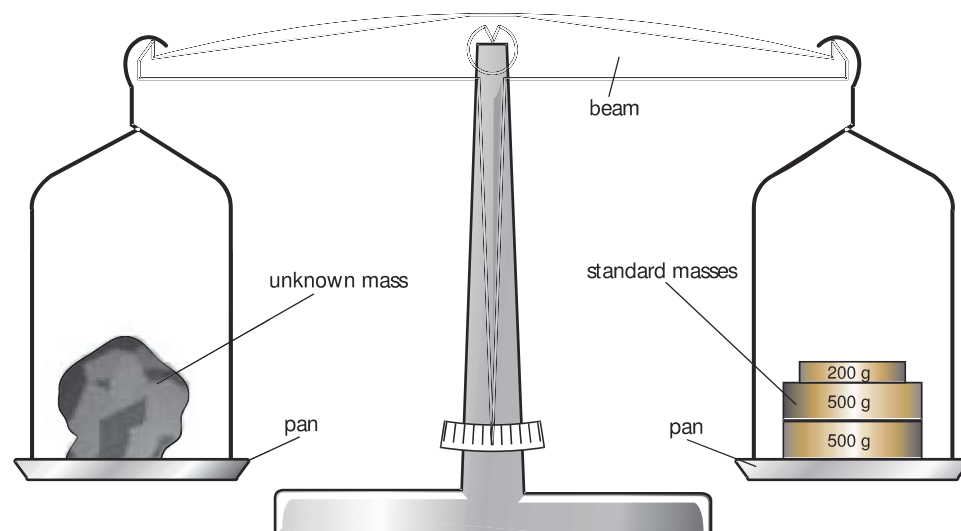
2 Use the information above to calculate:
  a) the mass, volume, and density of the liquid,
  b) the mass, volume, and density of the stone.

1.06 More about mass and density

Density essentials

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

Comparing masses

beam

unknown mass

standard masses

200 g
500 g
500 g

pan

pan

▶ A simple beam balance

The device above is called a **beam balance**. It is the simplest, and probably the oldest, way of finding the mass of something. You put the object in one pan, then add standard masses to the other pan until the beam balances in a level position. If you have to add 1.2 kg of standard masses, as in the diagram, then you know that the object also has a mass of 1.2 kg.

The balance is really comparing weights rather than masses. Weight is the downward pull of gravity. The beam balances when the downward pull on one pan is equal to the downward pull on the other. However, masses can be compared because of the way gravity acts on them. If the objects in the two pans have the same weight, they must also have the same mass.

When using a balance like the one above, you might say that you were 'weighing' something. However, 1.2 kg is the mass of the object, not its weight. Weight is a force, measured in force units called **newtons**. For more on this, and the difference between mass and weight, see spreads 2.07 and 2.09.

A more modern type of balance is shown on the left.

A more modern type of balance. It detects the gravitational pull on the object on the pan, but gives its reading in units of mass.

Q

1 On the Moon, the force of gravity on an object is only about one sixth of its value on Earth. Decide whether each of the following would give an accurate measurement of mass if used on the Moon.
a) A beam balance like the one in the diagram at the top of the page.
b) A balance like the one in the photograph above.

2 A balloon like the one on the opposite page contains 2000 m^3 of air. When the air is cold, its density is 1.3 kg/m^3. When heated, the air expands so that some is pushed out of the hole at the bottom, and the density falls to 1.1 kg/m^3. Calculate the following.
a) The mass of air in the balloon when cold.
b) The mass of air in the balloon when hot.
c) The mass of air lost from the balloon during heating.

Planet density

The density of a planet increases towards the centre. However, the average density can be found by dividing the total mass by the total volume. The mass of a planet affects its gravitational pull and, therefore, the orbit of any moon circling it. The mass can be calculated from this. The volume can be calculated once the diameter is known.

The average density gives clues about a planet's structure:

Earth

Average density 5520 kg/m^3

This is about double the density of the rocks near the surface, so the Earth must have a high density core – probably mainly iron.

Jupiter

Average density 1330 kg/m^3

The low average density is one reason why scientists think that Jupiter is a sphere mostly of hydrogen and helium gas, with a small, rocky core.

not to scale

Float or sink?

You can tell whether a material will float or sink by comparing its density with that of the surrounding liquid (or gas). If it is less dense, it will float; if it is more dense, it will sink. For example, wood is less dense than water, so it floats; steel is more dense, so it sinks.

Density differences are not the *cause* of floating or sinking, just a useful guide for predicting which will occur. Floating is made possible by an upward force produced whenever an object is immersed in a liquid (or gas). To experience this force, try pushing an empty bottle down into water.

Ice is less dense than water in its liquid form, so icebergs float.

Hot air is less dense than cold air, so a hot-air balloon will rise upwards – provided the fabric, gas cylinders, basket, and passengers do not increase the average density by too much.

1 Copy and complete the table shown below:

measurement	unit	symbol
length	?	?
?	kilogram	?
?	?	s

[6]

2 Write down the number of

A mg in 1 g
B g in 1 kg
C mg in 1 kg
D mm in 4 km
E cm in 5 km　　　　　　　　　　　[5]

3 Write down the values of

a) 300 cm, in m
b) 500 g, in kg
c) 1500 m, in km
d) 250 ms, in s
e) 0.5 s, in ms
f) 0.75 km, in m
g) 2.5 kg, in g
h) 0.8 m, in mm　　　　　　　　　[8]

4 The volume of a rectangular block can be calculated using this equation:

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

Using this information, copy and complete the table below. 　　　　　　　　　　　　[4]

length	width	height	volume of rectangular block
2 cm	3 cm	4 cm	?
5 cm	5 cm	?	100 cm^3
6 cm	?	5 cm	300 cm^3
?	10 cm	10 cm	50 cm^3

5 In each of the following pairs, which quantity is the larger?

a) 2 km or 2500 m?
b) 2 m or 1500 mm?
c) 2 tonnes or 3000 kg?
d) 2 litres or 300 cm^3?　　　　　　[4]

6 Which of the following statements is/are correct?

A One milligram equals one million grams.
B One thousand milligrams equals one gram.
C One million milligrams equals one gram.
D One million milligrams equals one kilogram.　　　　　　　　　　　　　　[2]

7

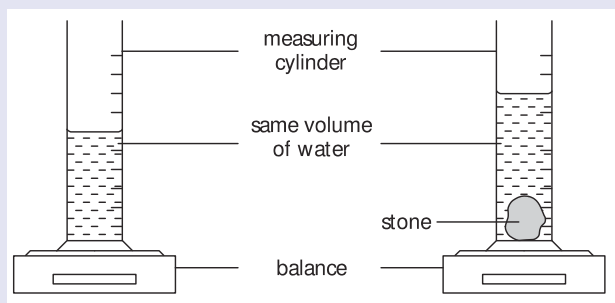| m	g/cm^3	m^3	km	cm^3
kg	ms	ml	kg/m^3	s

Which of the above are
a) units of mass?
b) units of length?
c) units of volume?
d) units of time?
e) units of density?　　　　　　　[11]

8 Which block is made of the densest material?

block	mass/g	length/cm	breadth/cm	height/cm
A	480	5	4	4
B	360	10	4	3
C	800	10	5	2
D	600	5	4	3

9 The mass of a measuring cylinder and its contents are measured before and after putting a stone in it.

Which of the following could you calculate using measurements taken from the apparatus above?

A the density of the liquid only
B the density of the stone only
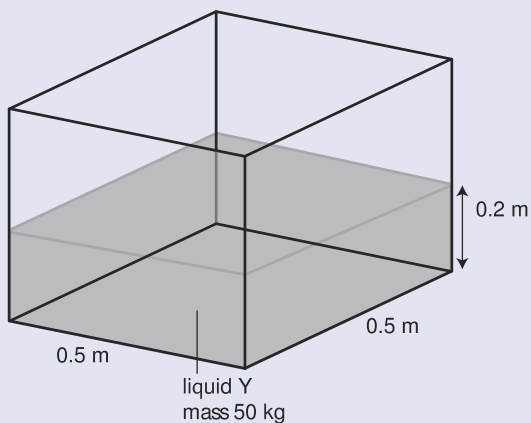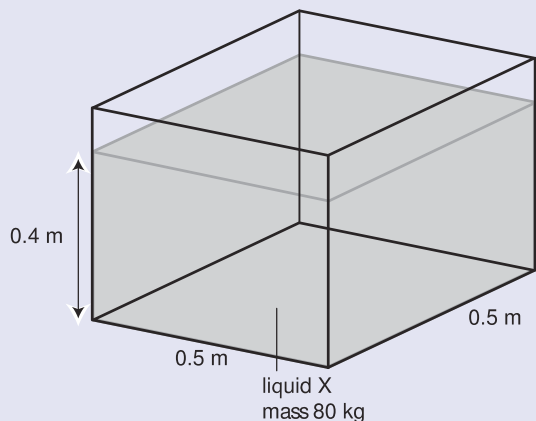**C** the densities of the liquid and the stone　　[2]

10 A plastic bag filled with air has a volume of 0.008 m^3. When air in the bag is squeezed into a rigid container, the mass of the container (with air) increases from 0.02 kg to 0.03 kg. Use the formula

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

to calculate the density of the air in the bag.　　[2]

11

0.4 m

0.5 m

0.5 m

liquid X
mass 80 kg

0.2 m

0.5 m

0.5 m

liquid Y
mass 50 kg

In the diagram above, the tanks contain two different liquids, X and Y.
a) What is the volume of each liquid in m³? [2]
b) If you had 1 m³ of the liquid X, what would its mass be? [2]
c) What is the density of liquid X? [2]
d) What is the density of liquid Y? [2]

12 The table shows the density of various substances.

substance	density/ g/cm³
copper	8.9
iron	7.9
kerosene	0.87
mercury	13.6
water	1.0

Consider the following statements:
A 1 cm³ of mercury has a greater mass than 1 cm³ of any other substance in this table – true or false?
B 1 cm³ of water has a smaller mass than 1 cm³ of any other substance in this table – true or false?
C 1 g of iron has a smaller volume than 1 g of copper – true or false?
D 1 g of mercury has a greater mass than 1 g of copper – true or false? [2]

13 A student decides to measure the period of a pendulum (the period is the time taken for one complete swing). Using a stopwatch, he finds that 8 complete swings take 7.4 seconds. With his calculator, he then uses this data to work out the time for one swing. The number shown on his calculator is 0.925.

a) Is it acceptable for the student to claim that the period of the pendulum is 0.925 seconds? Explain your answer. [2]
b) How could the student measure the period more accurately? [2]
c) Later, another student finds that 100 complete swings take 92.8 seconds. From these measurements, what is the period of the pendulum? [2]

Photocopy the list of topics below and tick the boxes of the ones that are included in your examination syllabus. (Your teacher should be able to tell you which they are.) Use your list when you revise. The spread number in brackets tells you where to find more information.

❏ **1** How to use units. (1.01)

❏ **2** Making bigger or smaller units using prefixes. (1.01)

❏ **3** Writing numbers in scientific notation. (1.01)

❏ **4** Significant figures. (1.01)

❏ **5** SI units, including the metre, kilogram, and second. (1.02)

❏ **6** What calipers are used for. (1.03)

❏ **7** How to read a micrometer. (1.03)

❏ **8** How to read a vernier scale. (1.03)

❏ **9** How to measure short intervals of time. (1.03)

❏ **10** How to find the period of a simple pendulum. (1.03)

❏ **11** The meaning of zero error. (1.03)

❏ **12** Units for measuring volume. (1.04)

❏ **13** How density is defined. (1.04)

❏ **14** Using the equation linking mass, volume, and density. (1.04)

❏ **15** Methods of measuring the volume of

– a liquid

– a regular solid

– an irregular solid. (1.05)

❏ **16** How to use a displacement can. (1.05)

❏ **17** The meaning of relative density. (1.05)

❏ **18** How to compare masses with a beam balance. (1.06)

2

Forces and Motion

A bungee jumper leaps more than 180 metres from the top of the Sky Tower in Auckland, New Zealand. With nothing to oppose his fall, he would hit the ground at a speed of 60 metres per second. However, his fall is slowed by the resistance of the air rushing past him, and eventually stopped by the pull of the bungee rope. Side ropes are also being used to stop him crashing into the tower.