1.4 Density

FOCUS POINTS

- ★ Define density and calculate the density of a liquid and both regular- and irregular-shaped solid objects.
- ★ Use density data to determine whether an object will float or sink.
- ★ Use density data to determine whether one liquid will float on another liquid.

A pebble thrown into a pond will sink to the bottom of the pond, but a wooden object will float. Objects of the same shape and size but made from different materials have different masses. In this topic you will see how you can quantify such differences with the idea of density. Density specifies the amount of mass in a unit volume. To measure the density of a material you will need to know both its mass and its volume. The mass can be found using a balance, and the volume by measurement. If the density of an object is greater than that of a liquid it will sink, but if the density of the object is less than that of the liquid it will float.

In everyday language, lead is said to be heavier than wood. By this it is meant that a certain volume of lead is heavier than the same volume of wood. In science such comparisons are made by using the term **density**. This is the *mass per unit volume* of a substance and is calculated from

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

For a mass m of volume V, the density $\rho = m/V$.

Key definition

Density mass per unit volume

The density of lead is 11 grams per cubic **centimetre** (11 g/cm^3) and this means that a piece of lead of volume 1 cm^3 has mass 11 g. A volume of 5 cm^3 of lead would have mass 55 g. If the density of a substance is known, the mass of *any* volume of it can be calculated. This enables engineers to work out the weight of a structure if they know from the plans the volumes of the materials to be used and their densities. Strong enough foundations can then be made.

The SI unit of density is the kilogram per cubic metre. To convert a density from g/cm^3, normally the most suitable unit for the size of sample we use, to kg/m^3, we multiply by 10^3. For example, the density of water is 1.0 g/cm^3 or 1.0×10^3 kg/m^3.

The approximate densities of some common substances are given in Table 1.4.1.

▼ **Table 1.4.1** Densities of some common substances

Solids	Density/g/cm^3	Liquids	Density/g/cm^3
aluminium	2.7	paraffin	0.80
copper	8.9	petrol	0.80
iron	7.9	pure water	1.0
gold	19.3	mercury	13.6
glass	2.5	**Gases**	**Density/kg/m^3**
wood (teak)	0.80	air	1.3
ice	0.92	hydrogen	0.09
polythene	0.90	carbon dioxide	2.0

Calculations

Using the symbols ρ (rho) for density, m for mass and V for volume, the expression for density is

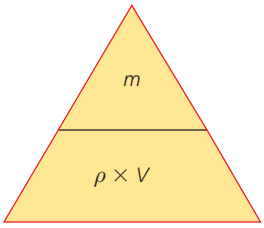
$$\rho = \frac{m}{V}$$

Rearranging the expression gives

$$m = V \times \rho \text{ and } V = \frac{m}{\rho}$$

These are useful if ρ is known and m or V have to be calculated. If you do not see how they are obtained refer to the *Mathematics for physics* section on p. 295.

The triangle in Figure 1.4.1 is an aid to remembering them. If you cover the quantity you want to know with a finger, such as m, it equals what you can still see, i.e. $\rho \times V$. To find V, cover V and you get $V = m/\rho$.



▲ **Figure 1.4.1**

Worked example

Taking the density of copper as 9 g/cm^3, find **a** the mass of 5 cm^3 and **b** the volume of 63 g.

a $\rho = 9\,\text{g/cm}^3$, $V = 5\,\text{cm}^3$ and m is to be found.
$m = V \times \rho = 5\,\text{cm}^3 \times 9\,\text{g/cm}^3 = 45\,\text{g}$

b $\rho = 9\,\text{g/cm}^3$, $m = 63\,\text{g}$ and V is to be found.

$$\therefore V = \frac{m}{\rho} = \frac{63\,\text{g}}{9\,\text{g/cm}^3} = 7\,\text{cm}^3$$

Now put this into practice

1 A sheet of aluminium has a mass of 200 g and a volume of 73 cm^3. Calculate the density of aluminium.
2 Taking the density of lead as 11 g/cm^3, find
  a the mass of 4 cm^3
  b the volume of 55 g.

Simple density measurements

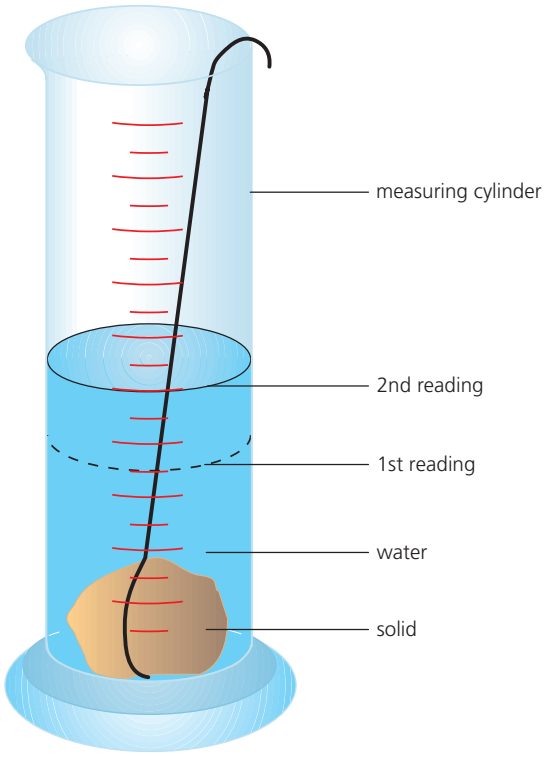
If the mass m and volume V of a substance are known, its density can be found from $\rho = m/V$.

Regularly shaped solid

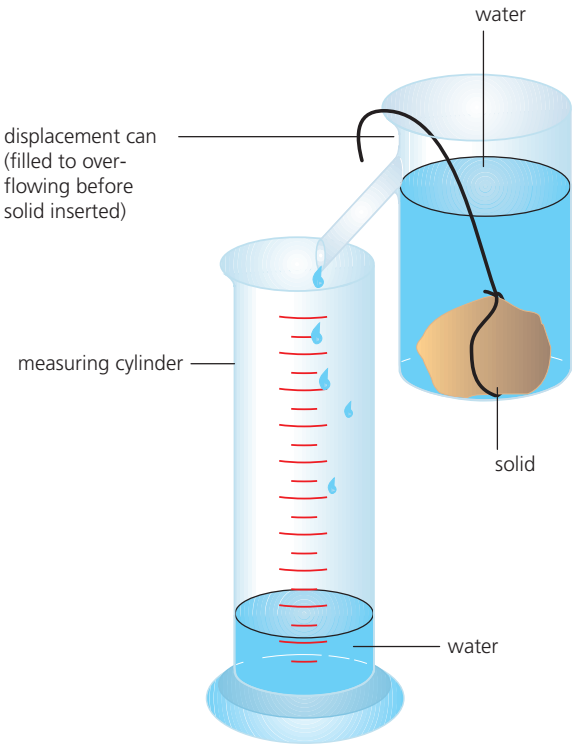
The mass is found on a balance and the volume by measuring its dimensions with a ruler.

Irregularly shaped solid: volume by displacement

Use one of these methods to find the volume of a pebble or glass stopper, for example. The mass of the solid is found on a balance. Its volume is measured by one of the displacement methods shown in Figure 1.4.2. In Figure 1.4.2a the volume is the difference between the first and second readings. In Figure 1.4.2b it is the volume of water collected in the measuring cylinder.



▲ **Figure 1.4.2a** Measuring the volume of an irregular solid: method 1



▲ **Figure 1.4.2b** Measuring the volume of an irregular solid: method 2

Liquid

The mass of an empty beaker is found on a balance. A known volume of the liquid is transferred from a burette or a measuring cylinder into the beaker. The mass of the beaker plus liquid is found and the mass of liquid is obtained by subtraction.

Air

Using a balance, the mass of a 500 cm^3 round-bottomed flask full of air is found and again after removing the air with a vacuum pump; the difference gives the mass of air in the flask. The volume of air is found by filling the flask with water and pouring it into a measuring cylinder.

Floating and sinking

An object sinks in a liquid of lower density than its own; otherwise it floats, partly or wholly submerged. For example, a piece of glass of density 2.5 g/cm^3 sinks in water (density 1.0 g/cm^3) but floats in mercury (density 13.6 g/cm^3). An iron nail sinks in water but an iron ship floats because its average density is less than that of water, due to the low-density air enclosed in the hull.

A liquid of low density will float on a liquid of higher density if the two liquids do not mix.

Test yourself

1 **a** Calculate the density of a substance of
   i mass 100 g and volume 10 cm^3
   ii volume 3 m^3 and mass 9 kg.
   b The density of gold is 19 g/cm^3. Find the volume of
   i 38 g
   ii 95 g of gold.

2 A rectangular steel bar is 4 cm long, 3 cm wide and 1 cm thick. When weighed it is found to have a mass of 96 g. Calculate its density in
   a g/cm^3
   b kg/m^3.

3 The water in a measuring cylinder is at the 50 cm^3 level. A pebble is dropped into the water and the water level rises to 60 cm^3. The pebble is completely covered by water.
Calculate
   a the volume of the pebble
   b the density of the pebble, if it weighs 60 g.

4 Liquid A has a density of 0.8 g/cm^3 and water has a density of 1.0 g/cm^3. If the two liquids do not mix, which liquid will float on top of the other?

Revision checklist

After studying Topic 1.4 you should know and understand the following:

✓ how density is defined and how to perform calculations using $\rho = m/V$.

After studying Topic 1.4 you should be able to:

✓ describe methods to measure the density of a liquid and a regularly shaped solid
✓ describe the method of displacement to measure the density of an irregularly shaped solid
✓ predict whether an object will float, based on density data

✓ predict whether one liquid will float on another if they do not mix.

Exam-style questions

1 a Choose which of the following definitions for density is correct.

A mass/volume
B mass × volume
C volume/mass
D weight/area [1]

b Calculate

i the mass of 5 m^3 of cement of density 3000 kg/m^3 [3]

ii the mass of air in a room measuring 10 m × 5.0 m × 2.0 m if the density of air is 1.3 kg/m^3. [3]

[Total: 7]

2 a Describe how you could determine the density of a liquid. [4]

b An empty beaker is weighed and found to have a mass of 130 g. A measuring cylinder contains 50 cm^3 of an unknown liquid. All the liquid is poured into the beaker which is again weighed and found to have a mass of 170 g. Calculate the density of the liquid. [4]

c Explain why ice floats on water. [1]

d Explain why oil floats on water. [1]

[Total: 10]

3 a A block of wood has dimensions of 10 cm × 8 cm × 20 cm.

i Calculate the volume of the block in cubic metres. [2]

ii The block is placed on a balance and found to weigh 1.2 kg. Calculate the density of the block in kg/m^3. [3]

b When a golf ball is lowered into a measuring cylinder of water, the water level rises by 30 cm^3 when the ball is completely submerged. If the ball weighs 33 g in air, calculate its density in kg/m^3. [3]

[Total: 8]