11 Materials

11.1 Density

Learning objectives:

- How do we define density?
- What is the unit of density?
- How do we measure the density of an object?

Specification reference: 3.2.2

How science works

More about units

mass:	1 kg = 1000 grams
length:	1 m = 100 cm
	= 1000 mm
volume:	$1\,m^3 = 10^6\,cm^3$
density:	$1000\,kg\,m^{-3} = \frac{10^6\,g}{10^6\,cm^3}$
	$= 1\,g\,cm^{-3}$

AQA Examiner's tip

Unit errors are commonplace in density calculations. Avoid such errors by writing the unit and the numerical value of each quantity in your working.

Table 1 *Density*

substance	density / $kg\,m^{-3}$
air	1.2
aluminium	2700
copper	8900
gold	19300
hydrogen	0.083
iron	7900
lead	11300
oxygen	1.3
silver	10500
water	1000

Density and its measurement

Lead is much more dense than aluminium. Sea water is more dense than tap water. To find how much more dense one substance is compared with another, we need to measure the mass of equal volumes of the two substances. The substance with the greater mass in the same volume is more dense. For example, a lead sphere of volume $1\,cm^3$ has a mass of 11.3 g whereas an aluminium sphere of the same volume has a mass of 2.7 g.

The density of a substance is defined as its mass per unit volume.

For a certain amount of a substance of mass m and volume V, its density ρ (pronounced 'rho'), may be calculated using the equation

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

The unit of density is the kilogram per cubic metre ($kg\,m^{-3}$).

Rearranging the above equation gives $m = \rho V$ or $V = \frac{m}{\rho}$

Table 1 shows the density of some common substances in $kg\,m^{-3}$. You can see that gases are much less dense than solids or liquids. This is because the average separation between the molecules in a gas is much greater than in a liquid or solid.

Worked example:

Using the data above, calculate:

a the mass, in kilograms, of a piece of aluminium of volume $3.6 \times 10^{-5}\,m^3$,

b the volume, in m^3, of a mass of 0.50 kg of iron.

Solution

a $\rho = 2700\,kg\,m^{-3}$; mass $m = \rho V = 2700\,kg\,m^{-3} \times 3.6 \times 10^{-5}\,m^3 = 9.7 \times 10^{-2}\,kg$

b $\rho = 7900\,kg\,m^{-3}$; volume $= \frac{m}{\rho} = \frac{0.50\,kg}{7900\,kg\,m^{-3}} = 6.3 \times 10^{-5}\,m^3$

Density measurements

An unknown substance can often be identified if its density is measured and compared with the density of known substances. The following procedures could be used to measure the density of a substance.

1 A regular solid

- Measure its mass using a top pan balance.
- Measure its dimensions using vernier callipers or a micrometer and calculate its volume using the appropriate formula (e.g. for a sphere of radius r, volume $= \frac{4}{3}\pi r^3$; see Figure 1 for other volume formulae). Calculate the density from mass/volume.

2 A liquid

- Measure the mass of an empty measuring cylinder. Pour some of the liquid into the measuring cylinder and measure the volume of the liquid directly. Use as much liquid as possible to reduce the percentage error in your measurement.
- Measure the mass of the cylinder and liquid to enable the mass of the liquid to be calculated. Calculate the density from mass/volume.

3 An irregular solid

- Measure the mass of the object.
- Immerse the object on a thread in liquid in a measuring cylinder, observe the increase in the liquid level, this is the volume of the object.
- Calculate the density of the object from its mass/volume.

Density of alloys

An alloy is a solid mixture of two or more metals. For example, brass is an alloy of copper and zinc that has good resistance to corrosion and wear.

For an alloy, of volume V, that consists of two metals A and B,

- if the volume of metal A = V_A, the mass of metal A = $\rho_A V_A$, where ρ_A is the density of metal A,
- if the volume of metal B = V_B, the mass of metal B = $\rho_B V_B$, where ρ_B is the density of metal B.

Therefore, the mass of the alloy, $m = \rho_A V_A + \rho_B V_B$

Hence the density of the alloy $\rho = \dfrac{m}{V} = \dfrac{\rho_A V_A + \rho_B V_B}{V} = \dfrac{\rho_A V_A}{V} + \dfrac{\rho_B V_B}{V}$

Worked example:

A brass object consists of $3.3 \times 10^{-5}\,m^3$ of copper and $1.7 \times 10^{-5}\,m^3$ of zinc. Calculate the mass and the density of this object. The density of copper = $8900\,kg\,m^{-3}$. The density of zinc = $7100\,kg\,m^{-3}$.

Solution

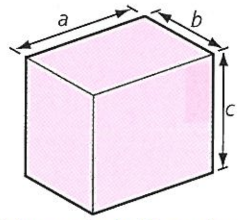
Mass of copper = density of copper × volume of copper
$= 8900 \times 3.3 \times 10^{-5}\,m^3 = 0.294\,kg$

Mass of zinc = density of zinc × volume of zinc
$= 7100 \times 1.7 \times 10^{-5}\,m^3 = 0.121\,kg$

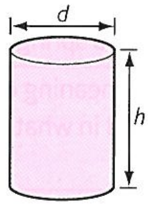
Total mass, $m = 0.294 + 0.121 = 0.415\,kg$

Total volume, $V = 5.0 \times 10^{-5}\,m^3$

Density of alloy $\rho = \dfrac{m}{V} = \dfrac{0.415\,kg}{5.0 \times 10^{-5}\,m^3} = 8300\,kg\,m^{-3}$



a *Volume of cuboid = a × b × c*



b *Volume of cylinder* $= \dfrac{\pi d^2}{4} \times h$

Figure 1 *Volume formulae*

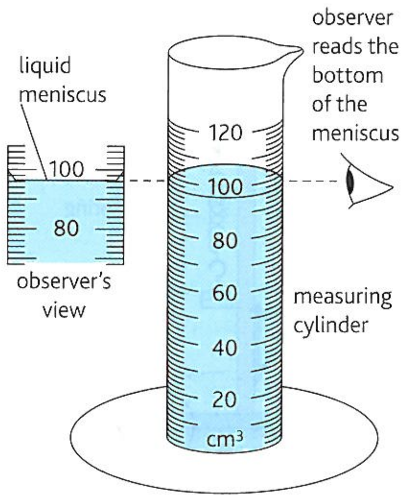


Figure 2 *Using a measuring cylinder*

AQA Examiner's tip

Make sure that you are familiar with the formulae for volumes of spheres and cylinders.

Summary questions

1. A rectangular brick of dimensions 5.0 cm × 8.0 cm × 20.0 cm has a mass of 2.5 kg. Calculate **a** its volume, **b** its density.
2. An empty paint tin of diameter 0.150 m and of height 0.120 m has a mass of 0.22 kg. It is filled with paint to within 7 mm of the top. Its total mass is then 6.50 kg. Calculate **a** the mass, **b** the volume, **c** the density of the paint in the tin.
3. A solid steel cylinder has a diameter of 12 mm and a length of 85 mm. Calculate **a** its volume in m^3, **b** its mass in kg. The density of steel = $7800\,kg\,m^{-3}$.
4. An alloy tube of volume $1.8 \times 10^{-4}\,m^3$ consists of 60% aluminium and 40% magnesium by volume. Calculate **a** the mass of **i** aluminium, **ii** magnesium in the tube, **b** the density of the alloy. The density of aluminium = $2700\,kg\,m^{-3}$. The density of magnesium = $1700\,kg\,m^{-3}$.