

Density

What is density, and how do you measure it?

●○○ Beginner

Foundations

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Before you start: it helps to understand [SI Units and Unit Conversions](#) and [Significant Figures and Measurement](#).

What is it?

Density is the mass of a substance per unit volume. It tells you how tightly matter is packed:

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

where ρ (the Greek letter rho) is density, m is mass and V is volume. In chemistry, density is usually given in **g/cm³** for solids and **g/mL** for liquids (these are the same, since 1 mL = 1 cm³). The SI unit is kg/m³, and 1 g/cm³ = 1000 kg/m³.

Substance (20 °C)	Density (g/cm ³)
Air	0.00120
Ethanol	0.789
Ice (0 °C)	0.917
Water	0.998
Aluminium	2.70
Iron	7.87
Copper	8.96
Lead	11.3
Gold	19.3

KEY IDEA

Density is a **property of the substance**, not of the object. A paper clip and a steel girder have very different masses, but the same density. That's why density helps to **identify** a substance.

Why does it matter?

- **Identifying substances.** Measuring density is a quick test of what a material is, or whether it is pure: an alloy or a diluted liquid has a different density.
- **Floating and sinking.** An object floats in a liquid if it is **less dense** than the liquid. Ice floats on water, oil floats on vinegar, and a ship floats because its average density, including the air inside, is less than that of water.
- **Converting between mass and volume.** Density is a conversion factor: from a volume of liquid you can find its mass without weighing it, and the reverse.

How does it work?

1. Calculating density

Measure the **mass** on a balance and the **volume** by one of the methods below, then divide. Rearranging the formula gives the other two forms:

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

2. Measuring volume

- **Regular solid** (cube, block, cylinder): measure the dimensions and calculate. For a block, $V = \text{length} \times \text{width} \times \text{height}$.
- **Irregular solid** (a stone, a key): use **displacement**. Part-fill a measuring cylinder with water, read the volume, lower the object in and read again. The **rise** in volume equals the volume of the object.
- **Liquid**: measure a volume accurately with a pipette or measuring cylinder, and weigh it.

3. Floating and sinking

Compare densities. If $\rho_{\text{object}} < \rho_{\text{liquid}}$ the object floats; if $\rho_{\text{object}} > \rho_{\text{liquid}}$ it sinks. Liquids that don't mix form layers, with the densest at the bottom.

4. Replicate measurements

As with any measurement, repeat it at least three times (**triplicate**), then report the **mean** and the **standard deviation**. Compare the mean with the accepted value to judge **accuracy**, and use the standard deviation to judge **precision** (see Significant Figures and Measurement).

∞ THINK OF IT LIKE THIS

Think of a lift. Ten people in a big lift and ten people in a small lift are the same “mass”, but the small lift is more crowded. Density is how crowded the matter is: the same mass squeezed into a smaller volume means a higher density.

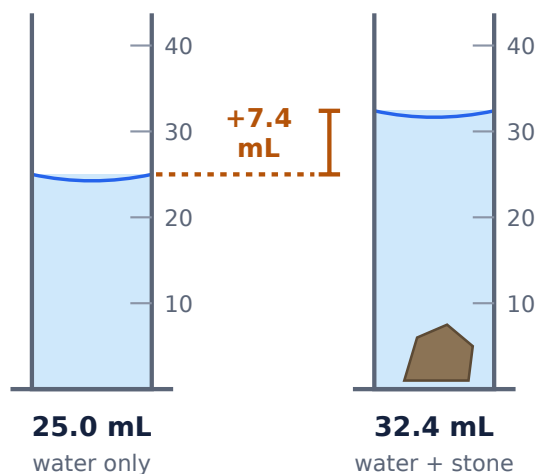
Q MORE PRECISELY

Density changes with **temperature**, because most substances expand when heated: their volume increases while their mass stays the same. That's why careful work states the temperature. Water is unusual: it is densest at about 4 °C (1.000 g/mL), and ice is **less** dense than liquid water, so lakes freeze from the top down and fish survive the winter underneath. Gases are about a thousand times less dense than liquids, and their density depends strongly on pressure too.

Visualise it

Volume by displacement

The rise in the water level is the volume of the stone.



Measuring the volume of an irregular solid by displacement: the rise in the water level is the volume of the object.

Worked example

WORKED EXAMPLE: A regular solid

Question: A metal block measures 2.00 cm × 3.00 cm × 5.00 cm and has a mass of 81.0 g. Find its density and suggest which metal it is.

Step 1 Volume:

$$\begin{aligned} V &= 2.00 \text{ cm} \times 3.00 \text{ cm} \\ &\quad \times 5.00 \text{ cm} \\ &= 30.0 \text{ cm}^3 \end{aligned}$$

Step 2 Density:

$$\begin{aligned} \rho &= \frac{m}{V} = \frac{81.0 \text{ g}}{30.0 \text{ cm}^3} \\ &= 2.70 \text{ g/cm}^3 \end{aligned}$$

Step 3 This matches **aluminium** (2.70 g/cm³).

WORKED EXAMPLE: An irregular solid, by displacement

Question: A measuring cylinder holds 25.0 mL of water. A stone of mass 18.5 g is lowered in and the level rises to 32.4 mL. Find the density of the stone.

Step 1 Volume of the stone = rise in level:

$$\begin{aligned} V &= 32.4 \text{ mL} - 25.0 \text{ mL} \\ &= 7.4 \text{ mL} = 7.4 \text{ cm}^3 \end{aligned}$$

Step 2 Density:

$$\rho = \frac{18.5 \text{ g}}{7.4 \text{ cm}^3} = 2.5 \text{ g/cm}^3$$

Step 3 The volume has only 2 significant figures, so the answer is **2.5 g/cm³**.

 WORKED EXAMPLE: Using density to find a volume

Question: What volume does 500. g of gold occupy? (density 19.3 g/cm³)

$$\begin{aligned} V &= \frac{m}{\rho} = \frac{500. \text{ g}}{19.3 \text{ g/cm}^3} \\ &= 25.9 \text{ cm}^3 \end{aligned}$$

Half a kilogram of gold is smaller than a matchbox.

 WORKED EXAMPLE: Replicate measurements of a liquid

Question: A student weighs three separate 10.00 mL samples of a colourless liquid at 20 °C and calculates densities of 0.791 g/mL, 0.789 g/mL and 0.792 g/mL. Report the result and decide whether the liquid could be ethanol (0.789 g/mL).

Step 1 Mean:

$$\begin{aligned} \bar{\rho} &= \frac{1}{3} (0.791 + 0.789 \\ &\quad + 0.792) \text{ g/mL} \\ &= \frac{2.372 \text{ g/mL}}{3} \\ &= 0.7907 \text{ g/mL} \end{aligned}$$

Step 2 Standard deviation, from the deviations +0.0003 g/mL, -0.0017 g/mL and +0.0013 g/mL:

$$\begin{aligned} s &= \sqrt{\frac{\sum(\rho_i - \bar{\rho})^2}{n - 1}} \\ s^2 &= \frac{4.67 \times 10^{-6} \text{ g}^2/\text{mL}^2}{2} \\ &= 2.33 \times 10^{-6} \text{ g}^2/\text{mL}^2 \\ s &= 0.0015 \text{ g/mL} \end{aligned}$$

Step 3 Result: **0.791 ± 0.002 g/mL (n = 3)**. The difference from ethanol, 0.791 g/mL - 0.789 g/mL = 0.002 g/mL, is about the size of the standard deviation, so the result is consistent with **ethanol**.

 WORKED EXAMPLE: Will it float?

Question: A plastic toy has a mass of 50.0 g and a volume of 62.5 cm³. Does it float in water (0.998 g/cm³)?

$$\rho = \frac{50.0 \text{ g}}{62.5 \text{ cm}^3} = 0.800 \text{ g/cm}^3$$

0.800 g/cm³ is less than 0.998 g/cm³, so it **floats**.

Common mistake

 COMMON MISTAKE: Dividing the wrong way round

Density is mass ÷ volume, not volume ÷ mass. Check the units: the answer must come out in g/cm³ (mass on top). If you get cm³/g, the fraction is upside down.

 COMMON MISTAKE: Using the final reading as the volume

In displacement, the volume of the object is the **difference** between the two readings (32.4 mL – 25.0 mL), not the final reading of 32.4 mL.

 COMMON MISTAKE: Confusing heavy with dense

A large log is heavier than a small iron nail, yet the log floats and the nail sinks. Floating depends on **density**, not on mass.

 NOTATION NOTE

- g/cm³ can also be written g cm⁻³; g/mL and g/cm³ are numerically identical.
- Always state the temperature with a precise density, for example “0.998 g/mL at 20 °C”.

Remember this

REMEMBER THIS

- $\rho = m/V$; rearranged, $m = \rho V$ and $V = m/\rho$.
- $1 \text{ mL} = 1 \text{ cm}^3$, so $\text{g/mL} = \text{g/cm}^3$; $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$.
- Volume of an irregular solid = rise in level when it is submerged (displacement).
- Less dense than the liquid: floats. Denser: sinks.
- Density depends on temperature: state it, and measure in replicate (mean $\pm$ standard deviation).

References

1. Bureau International des Poids et Mesures (BIPM). The International System of Units (SI), 9th ed.; BIPM, 2019.
[Link](#)
2. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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