Density of materials

4.3.1.1 · Particle model of matter · revision notes

Density tells you how much mass is packed into each unit of volume of a material. You need to use and rearrange ρ = m / V, explain the different densities of solids, liquids and gases using the particle model, and describe the density required practical. Expect calculations (often with unit conversions), particle-diagram questions and 4 to 6 mark method questions.

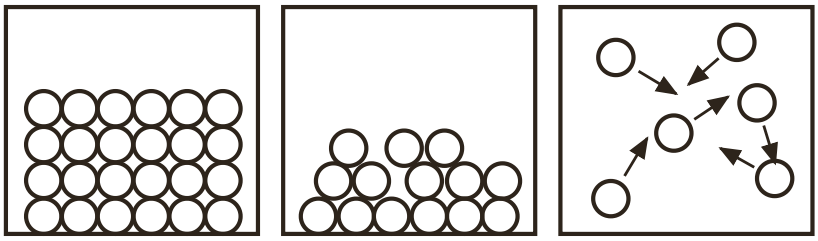
Key facts

- density = mass ÷ volume, ρ = m / V (practise rearranging it)
- 1 g/cm^3 = 1000 kg/m^3
- Solid: regular, touching, vibrate about fixed positions
- Gas: random, far apart, move quickly in all directions
- Volume of an irregular object: displacement of water (eureka can and measuring cylinder)
- ρ in kg/m^3, m in kg, V in m^3
- 1 m^3 = 1 000 000 cm^3; 1 cm^3 = 1 ml
- Liquid: random, close together, move past each other
- Gases have a much lower density: particles far apart, so less mass per m^3

Notes

The particle model of solids, liquids and gases

- In a **solid**, the particles are touching and packed in a regular arrangement. They vibrate about fixed positions.
- In a **liquid**, the particles are still close together (mostly touching) but in a random arrangement. They can move past each other.
- In a **gas**, the particles are far apart in a random arrangement. They move quickly in all directions.
- In particle diagrams, draw the particles the same size in all three states: only their arrangement and spacing change.



solid
regular, vibrate about fixed positions

liquid
touching, random, move past each other

gas
far apart, random, move quickly

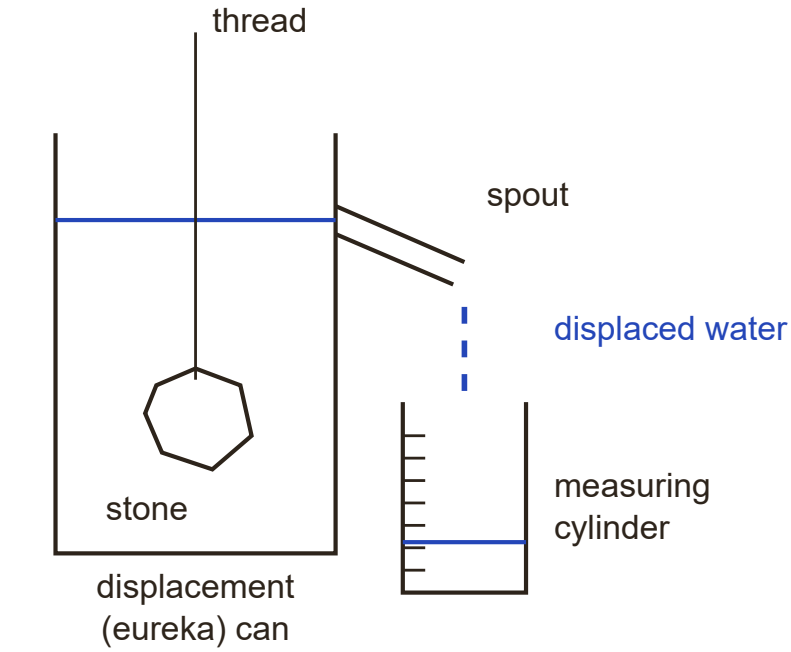
Same-sized particles in all three states: only the arrangement and spacing change.

Density

- **Density** is the mass per unit volume of a material: $\rho = m / V$.
- ρ (rho) is density in kg/m^3, m is mass in kg and V is volume in m^3. It is on the equation sheet; rearranged, $m = \rho \times V$ and $V = m \div \rho$.
- Density is often given in g/cm^3. 1 g/cm^3 = 1000 kg/m^3. Water has a density of about 1000 kg/m^3 (1 g/cm^3).
- The solid and liquid forms of a substance have similar densities because in both the particles are close together.
- The gas form has a much lower density because its particles are far apart: each cubic metre contains far fewer particles, so much less mass.

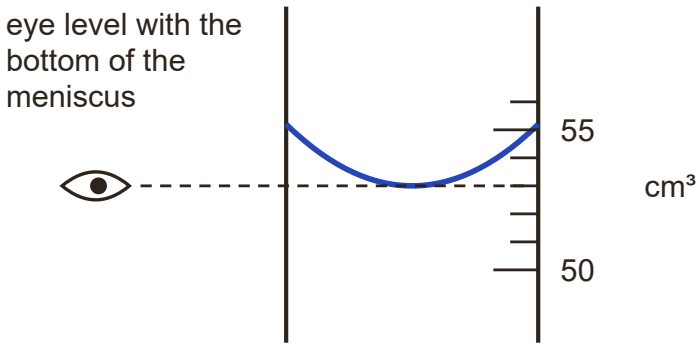
Required practical: measuring density

- Measure the mass with a top-pan balance.
- **Regular solid** (e.g. a cuboid): measure the length, width and height with a ruler (or vernier callipers or a micrometer for small lengths), then volume = length × width × height.
- **Irregular solid** (e.g. a stone): fill a **displacement (eureka) can** with water up to the spout, lower the object in and collect the water that overflows in a measuring cylinder. The volume of water displaced equals the volume of the object.



Volume of water collected = volume of the stone.

- Or lower the object into a measuring cylinder part-filled with water: volume of object = new reading − starting reading.
- **Liquid**: put an empty measuring cylinder on the balance and zero it, pour in some liquid, then read the mass and the volume.
- Read a measuring cylinder at eye level, from the bottom of the meniscus. 1 ml = 1 cm^3. Then calculate $\rho = m / V$.



reading: 53 cm³

Read from the bottom of the meniscus, with your eye level with it.

- For accurate results: wait until the eureka can stops dripping before placing the measuring cylinder, lower the object gently so no water splashes out, and repeat each measurement and take a mean.

How to answer each type of question

Calculate density (with a unit conversion)

2 to 3 marks | **Grade 5**

1. Write $\rho = m / V$.
2. Check the unit the question wants. For kg/m^3, either convert g to kg and cm^3 to m^3 first, or work in g/cm^3 and multiply by 1000 at the end.
3. Substitute, calculate and give the unit.

Example. A metal block measures 2.0 cm × 3.0 cm × 5.0 cm. Its mass is 243 g.
Calculate the density of the metal in kg/m^3.

Model answer.

Volume = 2.0 × 3.0 × 5.0 = 30 cm^3 (1)

ρ = 243 ÷ 30 = 8.1 g/cm^3 (1)

8.1 × 1000 = 8100 kg/m^3 (1)

(Or: V = 3.0 × 10^{-5} m^3 and m = 0.243 kg, so ρ = 0.243 ÷ (3.0 × 10^{-5}) = 8100 kg/m^3.)

Rearrange to calculate a mass or a volume

2 to 3 marks | **Grade 5**

1. Rearrange first: V = m ÷ ρ or m = ρ × V.
2. Make sure the units match (kg with kg/m^3, or g with g/cm^3).
3. Give the answer to the number of significant figures asked for, with its unit.

Example. The density of olive oil is 920 kg/m^3. A bottle contains 0.75 kg of olive oil.
Calculate the volume of the olive oil in m^3. Give your answer to 2 significant figures.

Model answer.

V = m ÷ ρ (1)

V = 0.75 ÷ 920 (1)

V = 8.2 × 10^{-4} m^3 (1)

Explain differences in density using the particle model 2 marks **Grade 6**

1. Compare the spacing of the particles in the two states.
2. Link the spacing to mass per unit volume: the same volume contains fewer particles, so less mass.

Example. The density of liquid nitrogen is about 800 kg/m^3. The density of nitrogen gas at room temperature is about 1.2 kg/m^3.
Explain, in terms of particles, why nitrogen gas has a much lower density than liquid nitrogen.

Model answer. In the gas, the particles are much further apart than in the liquid (1). So each cubic metre of gas contains far fewer particles and so much less mass (1).

Describe how to measure the density of an object (required practical) 4 to 6 marks **Grade 5**

1. Say how you measure the mass: a top-pan balance.
2. Say how you find the volume: measure the dimensions (regular shape) or use displacement of water (irregular shape).
3. Say how you calculate the density: mass ÷ volume.
4. Add a detail that improves accuracy, e.g. read the meniscus at eye level.

Example. Describe a method a student could use to determine the density of a small, irregularly shaped stone. (4 marks)

Model answer. Measure the mass of the stone with a top-pan balance (1). Fill a displacement (eureka) can with water up to the spout and, when it stops dripping, put an empty measuring cylinder under the spout (1). Lower the stone gently into the can and collect the water that overflows in the measuring cylinder (1). The volume of water collected equals the volume of the stone, so density = mass ÷ volume (1).

Don’t lose marks

- Mixing units, e.g. grams with m^3 or kg with cm^3, which makes the answer wrong by a factor of 1000 or 1 000 000.
- Converting cm^3 to m^3 by dividing by 100 or 1000 instead of 1 000 000.
- Writing that gas particles are bigger, smaller or lighter. The particles are the same; they are just further apart.
- Drawing liquid particles spread out like a gas. Liquid particles should mostly be touching.
- Taking the final measuring cylinder reading as the object's volume instead of the change in reading.

More tips

Memory tricks

- Density triangle: m on top, ρ and V on the bottom. Cover the one you want: ρ = m ÷ V, V = m ÷ ρ, m = ρ × V.
- Sense check: water is 1000 kg/m^3. Most solids and liquids are between a few hundred and about 20 000 kg/m^3; gases at room temperature are only a few kg/m^3 or less.
- g/cm^3 to kg/m^3: multiply by 1000. kg/m^3 to g/cm^3: divide by 1000.
- cm^3 to m^3: divide by 1 000 000 (100 × 100 × 100).

Exam technique

- Write ρ = m / V down before you substitute (it is on the equation sheet): the correct equation or substitution often earns the first mark.
- Look at the unit the question asks for before you start, and convert consistently.
- In particle explanations, use comparisons: 'further apart', 'closer together', 'less mass per unit volume'.
- In practical questions, name the equipment (top-pan balance, ruler, eureka can, measuring cylinder) and say what you do with each measurement.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3

Draw particle diagrams for the three states

Solid: particles touching in regular rows; liquid: particles touching but jumbled; gas: particles far apart and random.

Grade 4

Recall and use density = mass ÷ volume

Substitute into ρ = m / V with mass in kg and volume in m^3 to get a density in kg/m^3.

Grade 5

Rearrange the density equation

Use m = ρ × V to find a mass and V = m ÷ ρ to find a volume.

Grade 5

Describe the density required practical

Measure mass on a balance and find volume from measured dimensions or by displacement of water.

Grade 6

Explain density differences between states using particles

Gas particles are far apart, so each cubic metre of gas contains much less mass than a cubic metre of solid or liquid.

Grade 6

Convert between g/cm^3 and kg/m^3

1 g/cm^3 = 1000 kg/m^3, because 1 kg = 1000 g and 1 m^3 = 1 000 000 cm^3.

Grade 7

Solve multi-step density problems

For example, find a volume from dimensions in cm, convert it to m^3, then use a density in kg/m^3 to find the mass.

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