Cambridge (CIE) IGCSE Physics

Your notes

Mass, Weight & Density

Contents

Your notes

Mass & weight

Mass

- Mass is defined as:

  A measure of the quantity of matter in an object at rest relative to the observer

- Consequently, mass is the property of an object that resists change in motion
- The greater the mass of an object, the more difficult it is to speed it up, slow it down, or change its direction
- Mass is a **scalar** quantity that has **magnitude** but no direction
- Mass is measured in **kilograms** (kg)
  - Sometimes mass may be given in **grams** (g) but this will need to be converted to kilograms when used in calculations
    - 1000 g = 1 kg
    - 1 g = 0.001 kg
  - To convert **g to kg**, **divide** the mass in g by 1000
  - To convert **kg to g**, **multiply** the mass in g by 1000

Weight

- Weight is a gravitational **force** on an object with mass
- Since weight is a force, it is a **vector** quantity with both **magnitude** and **direction**
- Weight is measured in **newtons** (N)

Worked Example

An object has a mass of 4.5 kg.

State the mass of the object in grams (g).

Answer:

Step 1: State the conversion between g and kg

- 1 kg = 1000 g

Step 2: Convert kg into g by multiplying

$$m = 4.5 \times 1000$$

$$m = 4500 \text{ g}$$

Your notes

Examiner Tips and Tricks

Students commonly confuse mass and weight because the terms are used interchangeably in everyday speech. In Physics, mass and weight mean very different things, and you must be confident that you can explain the difference.

- Mass is the amount of **matter** an object has; it is a **scalar** quantity, and it is measured in **kg**.
- Weight is a **force**; it is a **vector** quantity, and it is measured in **N**.

Weight & gravity

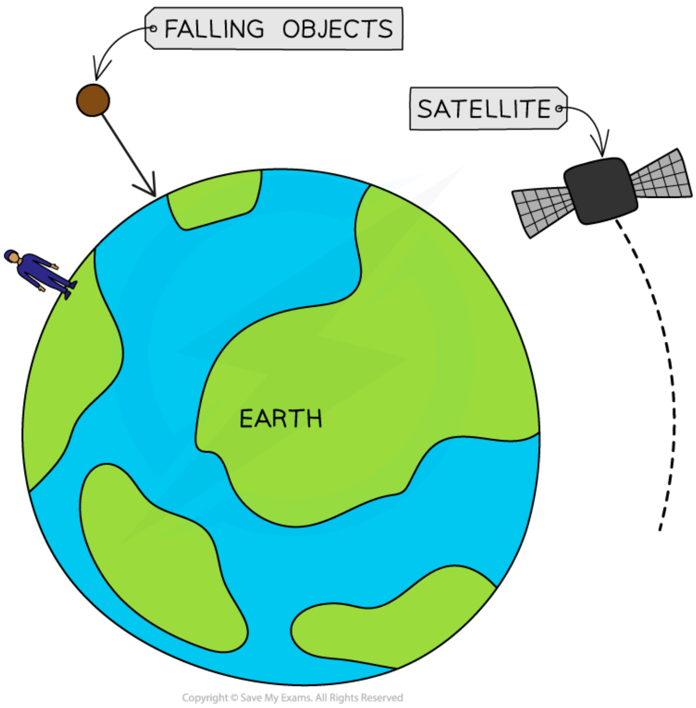
Extended tier only

Weight and gravitational field strength

- Weight is the effect of a **gravitational field** on a mass
- Weight is defined as:

  The force acting on an object with mass when placed in a gravitational field

- Planets have strong gravitational fields
  - Hence, they attract nearby masses with a strong gravitational force
- Because of weight:
  - Objects stay firmly on the ground
  - Objects will always fall to the ground
  - Satellites are kept in orbit



Some of the phenomena associated with gravitational attraction and the weight force

Defining gravitational field strength

- **Gravitational field strength** is defined as:

The force per unit mass acting on an object in a gravitational field

- On Earth, this is equal to **9.8 N/kg**

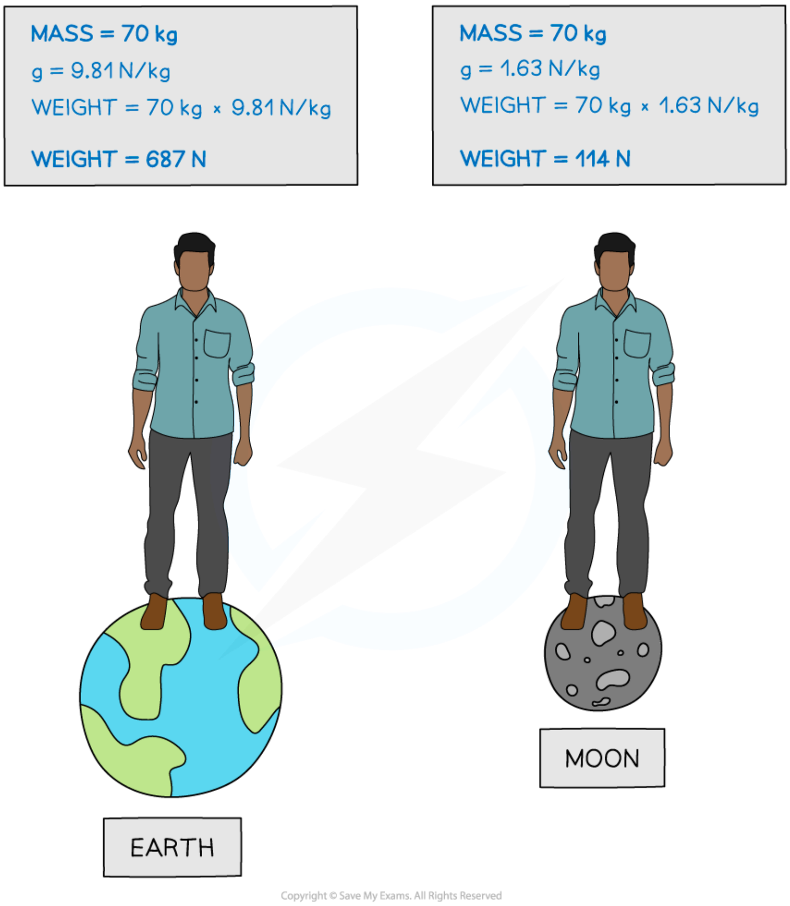
$$g = \frac{W}{m}$$

- Where:
  - g = gravitational field strength, measured in newtons per kilogram (N/kg)
  - W = force of weight, measured in newtons (N)
  - m = mass of object, measured in kilograms (kg)
- An object in free fall in a vacuum, in a uniform gravitational field, will **accelerate** at a rate also known as g
  - Where g = acceleration of free fall
  - In this context, g = 9.8 m/s^2
  - Gravitational field strength and acceleration of free fall are **equivalent** quantities

Mass vs. weight

Your notes

- An object's mass **always** remains the same, regardless of its location in the Universe
- The weight force exerted on the object will differ depending on the strength of the gravitational field in its location
- For example, the gravitational field strength on the Moon is **1.63 N/kg**, meaning an object's weight will be about **6 times** less than on Earth



On the Moon, a person's mass will stay the same but their weight will be much lower

- You can find more information about the gravitational field strength on different planets in the revision note Gravitational field strength

Worked Example

NASA's Artemis mission aims to send the first woman astronaut to the Moon. Isabelle hopes to one day become an astronaut. She has a mass of 42 kg.

Compare the difference between Isabelle's weight on Earth, and her weight on the Moon.

Your notes

Take the Earth's gravitational field strength as 9.8 N/kg, and the Moon's gravitational field strength as 1.6 N/kg.

Answer:

Step 1: List the known values

- Mass, $m = 42 \text{ kg}$
- Gravitational field strength on Earth, $g_E = 9.8 \text{ N/kg}$
- Gravitational field strength on Moon,

Step 2: State the equation linking weight, mass and gravitational field strength

$$g = \frac{W}{m}$$

Step 3: Rearrange to make weight the subject

$$W = mg$$

Step 3: Calculate the weight force exerted on Isabelle on Earth

$$W_E = mg_E$$

$$W_E = 42 \times 9.8$$

$$W_E = 411.6 \text{ N} = 410 \text{ N (2 s.f.)}$$

Step 4: Calculate the weight force exerted on Isabelle on the Moon

$$W_M = mg_M$$

$$W_M = 42 \times 1.6$$

$$W_M = 67.2 \text{ N} = 67 \text{ N (2 s.f.)}$$

Step 5: Compare the two values of weight

- The weight force is **greater** on Earth than on the Moon
- This is because the Earth has a **larger** gravitational field strength than the Moon, so Isabelle's weight force is larger on Earth than on the Moon

Examiner Tips and Tricks

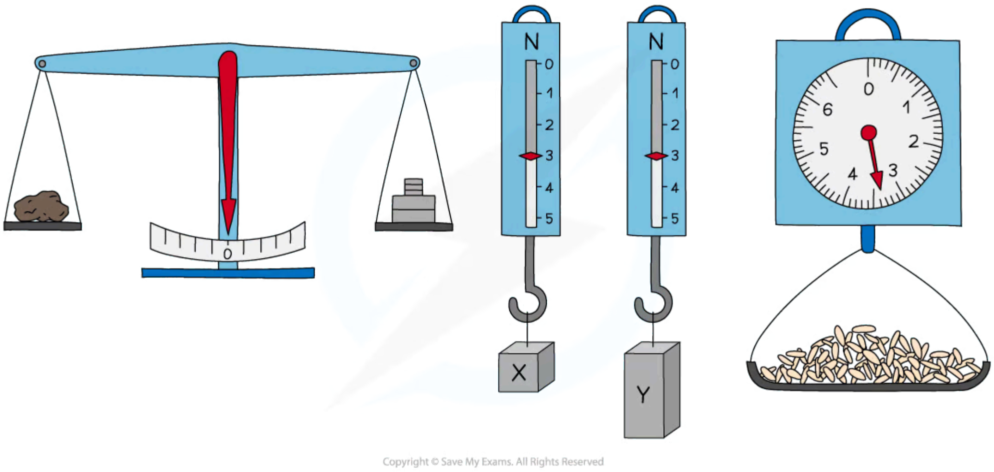
You won't be expected the learn the **exact** value of *g* (9.81 N/kg), but you will be expected to remember that **g = 9.8 N/kg** and use it in calculations

Using a balance

Your notes

- The **weight** of two objects can be compared using a **balance**
  - Because the gravitational field strength is **constant** everywhere on Earth, this also allows us to measure the **mass** of an object

$$m = \frac{W}{g}$$



A balance can be used to compare two different weights

- **Balances** can be digital or analogue
  - The object being measured is placed on the balance
  - The reading given is **mass** in kg or g
- **Force meters**, or **newton meters**, consist of a spring and hook
  - The object being measured is hung from the hook
  - The reading given is **weight** in N

Your notes

Your notes

Density

- Density is defined as:

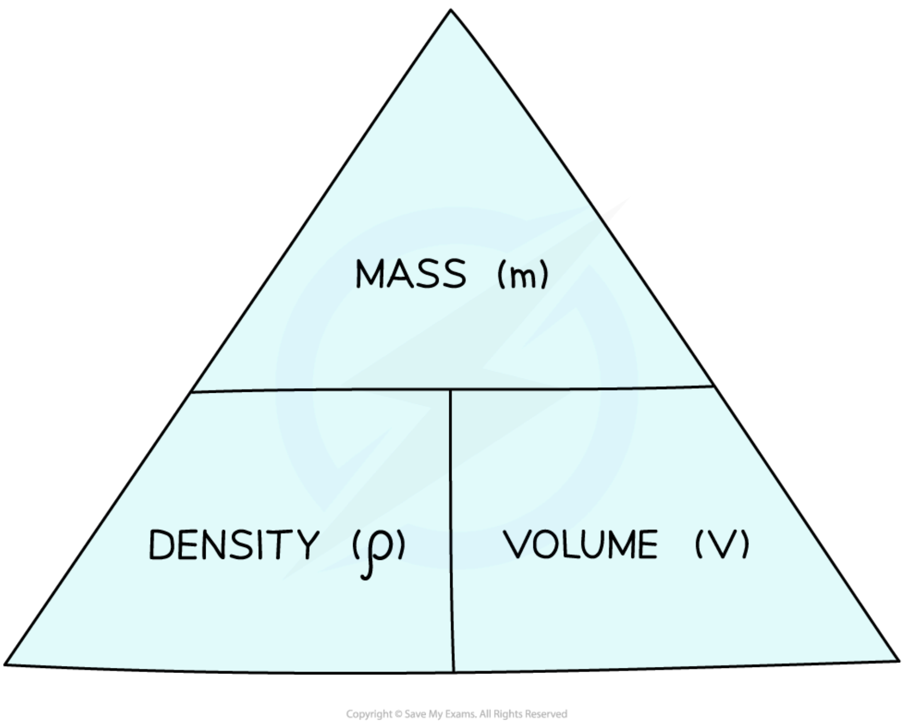
The mass per unit volume of a material

- Density is related to mass and volume by the following equation:

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

- Where:
  - ρ = density, measured in kilograms per metre cubed (kg m^{-3})
  - m = mass, measured in kilograms (kg)
  - V = volume, measured in metres cubed (m^3)

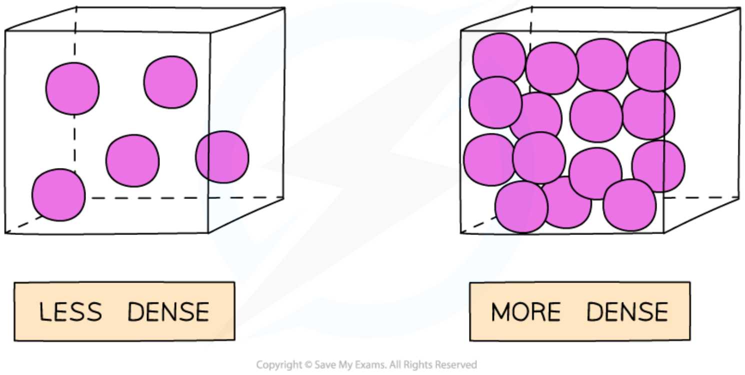
Formula triangle for density, mass and volume



To use a formula triangle, simply cover up the quantity you wish calculate and the structure of the equation is revealed

- Objects made from **low density** materials typically have a **low mass**
- Similarly sized objects made from **high density** materials have a **high mass**
  - For example, a bag full of feathers is far lighter compared to the same bag full of metal
  - Or another example, a balloon is less dense than a small bar of lead despite occupying a larger volume
- Gases, for example, are generally less dense than solids because the particles in a gas are more spread out (same mass, over a larger volume)

Comparing the density of solids and gases



A gas is less dense than the same substance in liquid or solid form

- The units of density depend on what units are used for mass and volume:
  - If the mass is measured in g and volume in cm^3, then the density will be in g/cm^3
  - If the mass is measured in kg and volume in m^3, then the density will be in kg/m^3

Determining volume to calculate density

- The volume of an object may not always be given directly, but can be calculated with the appropriate equation depending on the object's shape

Common formulae required to calculate the volumes of objects

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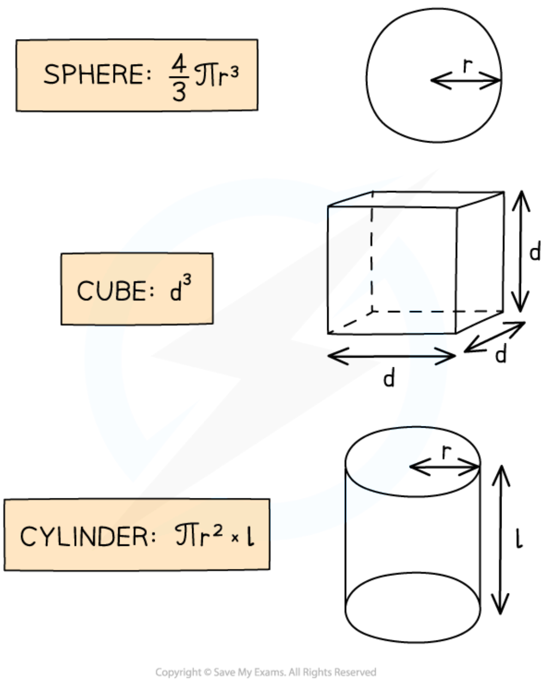


Volumes of common 3D shapes

Worked Example

A paving slab has a mass of 73 kg and dimensions 0.04 m × 0.5 m × 0.85 m.

Calculate the density, in kg/m^3, of the material from which the paving slab is made.

Answer:

Step 1: List the known quantities

- Mass of slab, m = 73 kg
- Volume of slab, V = 0.04 m × 0.5 m × 0.85 m = 0.017 m^3

Step 2: Write out the equation for density, mass and volume

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

Step 3: Substitute in values

$$\rho = \frac{73}{0.017}$$

$$\rho = 4294 \text{ kg/m}^3$$

Step 4: Round the answer to two significant figures

$$\rho = 4300 \text{ kg/m}^3$$

Your notes

Examiner Tips and Tricks

Make sure you are comfortable converting between units such as metres (m) and centimetres (cm) or grams (g) and kilograms (kg).

- When converting a **larger** unit to a **smaller** one, you **multiply (×)**
  - E.g. 125 m = 125 × 100 = 12 500 cm
- When you convert a **smaller** unit to a **larger** one, you **divide (÷)**
  - E.g. 5 g = 5 ÷ 1000 = 0.005 or 5×10^{-3} kg

Measuring density

Equipment list

Apparatus	Purpose
Regular and irregularly shaped objects	Objects used to measure the density of
A suitable liquid (e.g. sugar or salt solution)	Liquid to use to measure the density
A 30 cm ruler	To measure objects up to 30 cm in length
Vernier Calipers	To measure objects to around 15 cm in length
Micrometer	To measure objects to around 3 cm in length
Digital Balance	To measure the mass of objects
Displacement "Eureka" can	To measure the displacement of water of irregularly shaped objects
Measuring cylinders	To measure the volume of liquid

- **Resolution** of measuring equipment:
  - 30 cm ruler = 1 mm
  - Vernier calipers = 0.01 mm
  - Micrometer = 0.001 mm
  - Digital balance = 0.01 g

Experiment 1: measuring the density of regularly shaped objects

- The aim of this experiment is to determine the densities of regular objects by using measurements of their dimensions

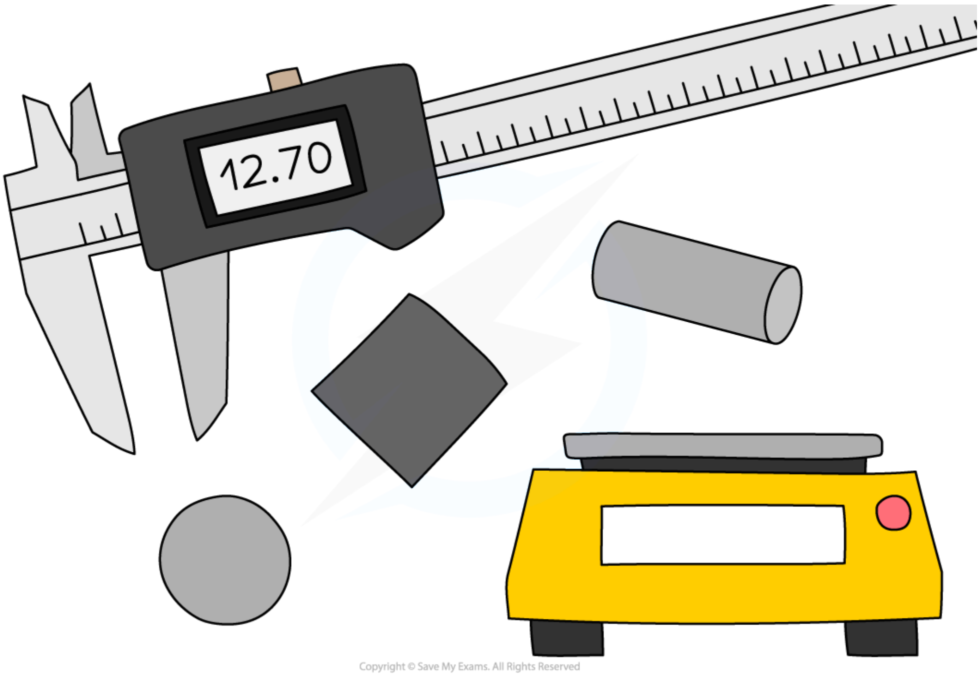
Variables:

- **Independent variable** = Type of shape / volume

- **Dependent variable** = Mass of the object

Method

Equipment needed to measure the density of regularly shaped objects



1. Place the object on a digital balance and note down its mass
2. Use either the ruler, Vernier callipers or micrometer to measure the object's dimensions (width, height, length, radius) – the apparatus will depend on the size of the object
3. Repeat these measurements and take an average of these readings before calculating the density

Results

An example results table to measure the density of regularly shaped objects

Your notes

	CUBOID	SPHERE	CYLINDER
MASS READINGS / g			
AVERAGE MASS / g			
AVERAGE MASS / kg			
DIMENSION READING / cm	HEIGHT WIDTH LENGTH	RADIUS	RADIUS LENGTH
AVERAGE DIMENSIONS / m	HEIGHT = WIDTH = LENGTH =	RADIUS =	RADIUS = LENGTH =
VOLUME / m^3	$H \times W \times L$	$\frac{4}{3} \times \pi \times R^3$	$\pi \times R^2 \times L$

CONVERT FROM g TO kg (DIVIDE BY 1000)

CONVERT FROM cm TO m (DIVIDE BY 100)

REPEAT READINGS

REPEAT READINGS

A suitable results table must contain space for multiple readings and any calculations that need to performed

Analysis of results

- Calculate the volume of the object depending on whether it is a cube, sphere, cylinder (or other regular shape)
- Then use the formula for density to calculate the density of each object
  - The formulae for volume and density are explained in the revision note Density

Experiment 2: measuring the density of irregularly shaped objects

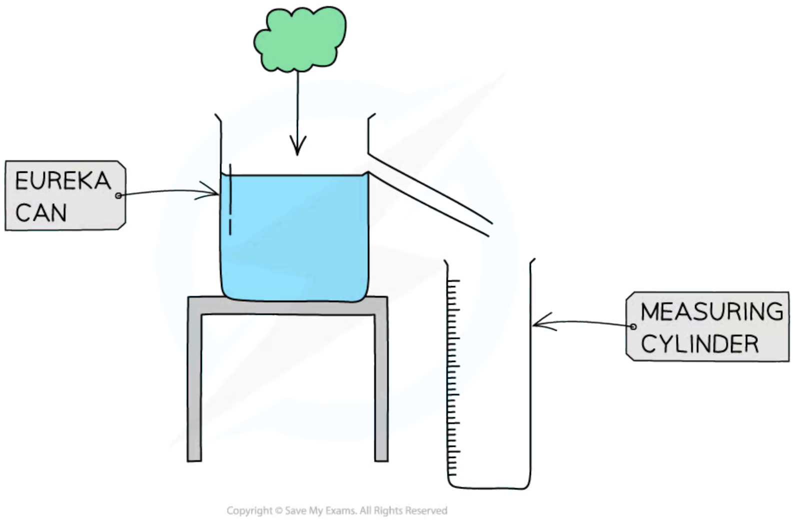
- This experiment aims to determine the densities of irregular objects using a displacement technique

Variables:

- **Independent variable** = Different irregular shapes / mass
- **Dependent variable** = Volume of displaced water

Method

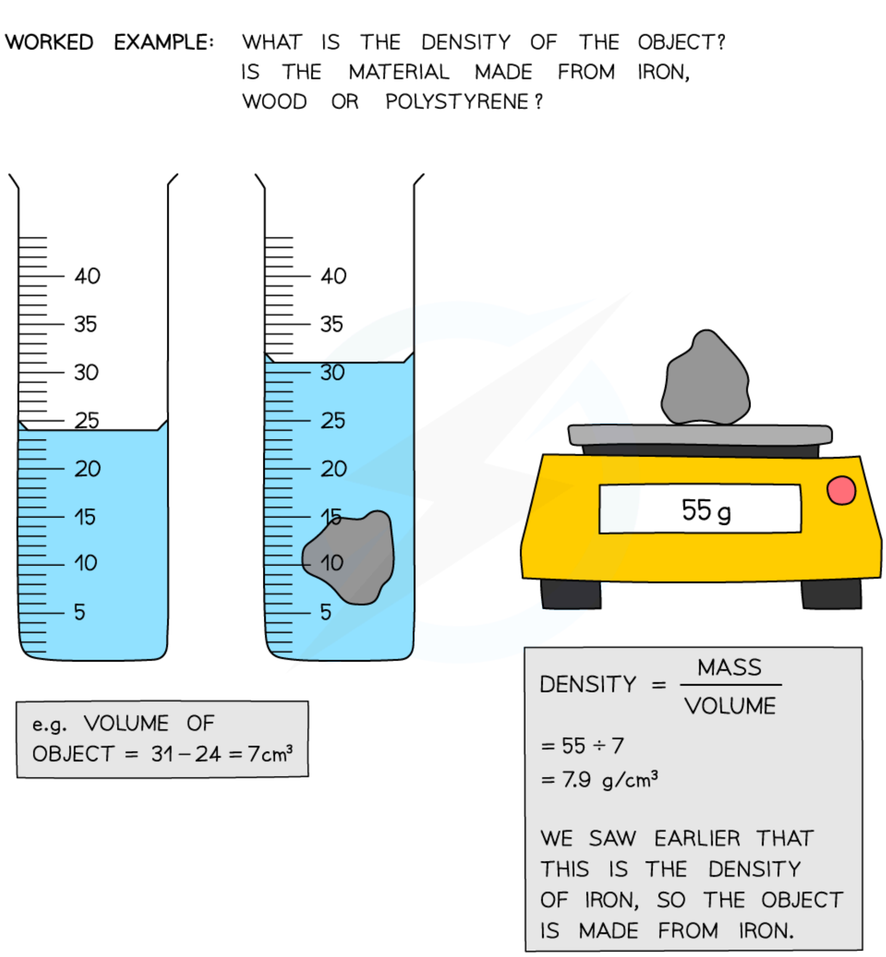
Equipment needed to measure the density of irregularly shaped objects



Apparatus for measuring the density of irregular objects

1. Place the object on a digital balance and note down its mass
2. Fill the eureka can with water up to a point just below the spout
3. Place an empty measuring cylinder below its spout
4. Carefully lower the object into the eureka can
5. Measure the volume of the displaced water in the measuring cylinder
6. Repeat these measurements and take an average before calculating the density

- Alternatively, the object can be placed in a measuring cylinder containing a known volume of liquid, and the change in volume then measured



When an irregular solid is placed in a measuring cylinder, the level of the liquid will rise by an amount equal to the volume of the solid

- Once the mass and volume of the shape is known, its density can be calculated

Results

An example results table to measure the density of irregularly shaped objects

OBJECT	MASS OF OBJECT / g			AVERAGE MASS / kg	VOLUME OF WATER DISPLACED / m^3			AVERAGE VOLUME OF WATER DISPLACED / m^3
	1	2	3		1	2	3	
1								
2								
3								

Your notes

A suitable results table must contain space for multiple readings and any calculations that need to performed

Your notes

Analysis of results

- The volume of the water displaced is equal to the volume of the object
- Once the mass and volume of the shape are known, the density can be calculated using:

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

Experiment 3: measuring the density of liquids

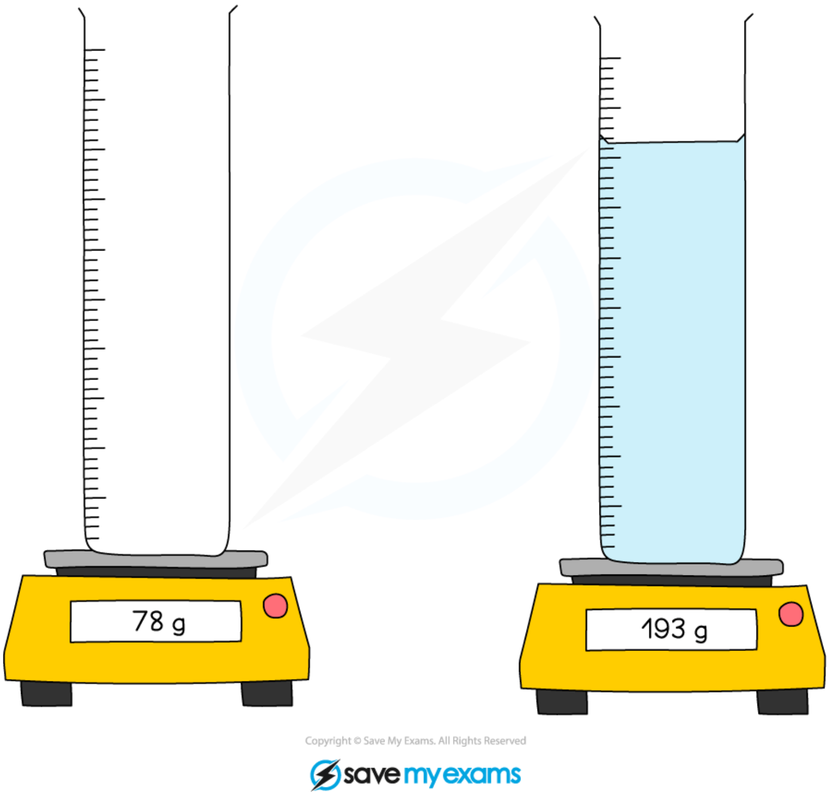
- This experiment aims to determine the density of a liquid by finding a difference in its mass

Variables:

- **Independent variable** = Volume of water added
- **Dependent variable** = Mass of cylinder

Method

Equipment needed to measure the density of liquid



Apparatus for determining the density of a liquid

1. Place an empty measuring cylinder on a digital balance and note down the mass
2. Fill the cylinder with the liquid and note down the volume
3. Note down the new reading on the digital balance
4. Repeat these measurements and take an average before calculating the density

Results

An example results table to measure the density of a liquid

MASS OF CYLINDER BEFORE / g			AVERAGE MASS / kg	VOLUME OF WATER ADDED / m^3	MASS OF CYLINDER WITH WATER /g			AVERAGE MASS OF CYLINDER WITH WATER / kg
1	2	3			1	2	3	

A suitable results table must contain space for multiple readings and any calculations that need to performed

Analysis of results

- Find the mass of the liquid by subtracting the final reading from the original reading

Mass of liquid = Mass of cylinder with water – mass of cylinder

- Once the mass and volume of the liquid are known, the density can be calculated using the equation for calculating density
  - This is explained in the revision note Density

Evaluating the experiments

Systematic errors

- Ensure the digital balance is set to zero before taking measurements of mass
  - This includes when measuring the density of the liquid – remove the measuring cylinder and zero the balance before adding the liquid

Random errors

- A main cause of error in this experiment is in the measurements of length
  - Ensure to take repeat readings and calculate an average to keep this error to a minimum

- Place the irregular object in the displacement can carefully, as dropping it from a height might cause water to splash, which will lead to an incorrect volume reading

Safety considerations

- There is a lot of glassware in this experiment, ensure this is handled carefully
- Water should not be poured into the measuring cylinder when it is on the electric balance
  - This could lead to electric shock
- Make sure to stand up during the whole experiment, to react quickly to any spills

Examiner Tips and Tricks

There is a lot of information to take in here! When writing about experiments, a good sequence is as follows:

- If you need to use an equation to calculate something, start off by giving it as this will give you some hints about what you need to mention later
- List the apparatus that you need
- State what measurements you need to make (your equation will give you some hints) and how you will measure them
- Finally, state that you will repeat each measurement several times and take averages

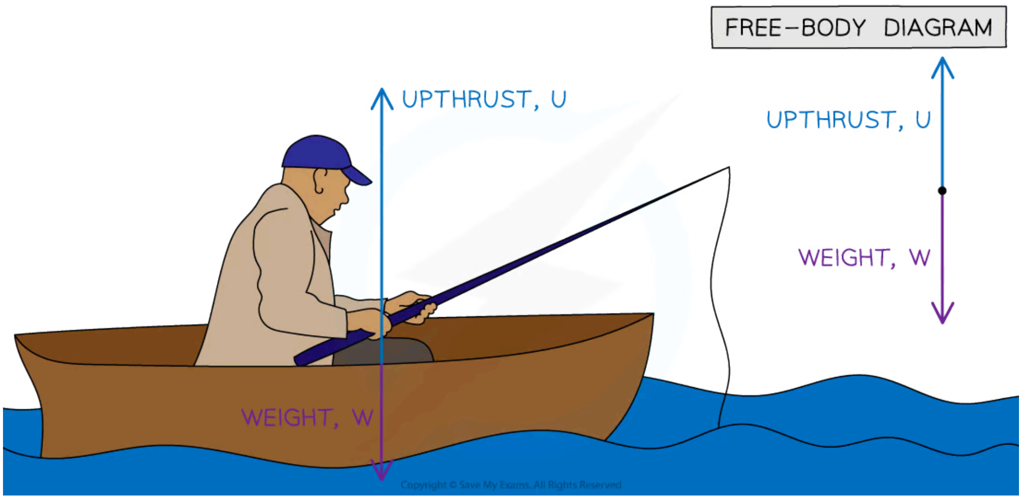
Your notes

Floating objects

Density and floating

- Whether an object **floats** or **sinks** depends on the **relative densities** of the object and the fluid it is submerged in
  - If the object is **denser** than the fluid, it will **sink**
  - If the object is **less dense** than the fluid, it will **float**
- **Upthrust** is a **force** that **pushes** upwards on an object submerged in a **fluid**
- Upthrust always acts in the **opposite direction** to the object's **weight** force
  - This is how objects float
- The size of the upthrust force depends on:
  - the **density** of the fluid
  - the **volume** of fluid that is displaced (which is equal to the volume of the object)
  - The **denser** the liquid, the **greater** the force of upthrust exerted on the object

Upthrust and weight forces on a boat

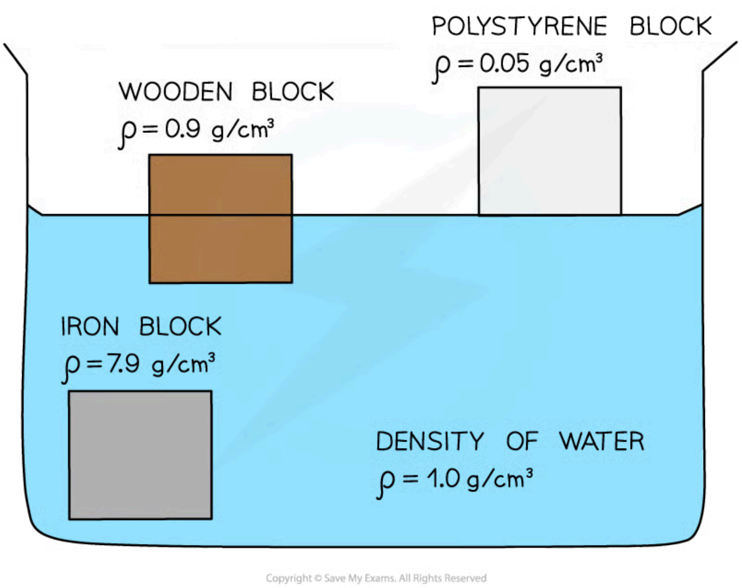


An object will float if the force of upthrust is equal to the force of weight

Factors affecting floating & sinking

- The factors affecting floating and sinking are:
  - upthrust

- density
- If the force of **upthrust** on an object is:
  - **equal** to the object's **weight**, then the object will **float**
  - **less than** the object's **weight**, then the object will **sink**
- If the **density** of the **object** is:
  - **greater than** the density of the **fluid**, then the object will **sink**
  - **less than** the density of the **fluid**, then the object will **float**
- If the density of the object is greater than the density of the fluid, the object can never displace enough fluid to create an upthrust that will equal its weight (and therefore it sinks)



Objects which are less dense than water will float in water, and those that are more dense will sink

- A polystyrene block will **float** in water
  - This is because polystyrene has a density of 0.05 g/cm^3 which is **much less** than the density of water (1.0 g/cm^3)
- A wooden block will be partially submerged but will still **float**
  - This is because the density of a wooden block (0.9 g/cm^3) is **slightly less** than the density of water
- An iron block will **sink**
  - This is because iron has a density (7.9 g/cm^3) that is **much higher** than water

Your notes

Your notes

Worked Example

Potassium is an alkali metal that reacts with oxygen and water. Potassium is therefore stored in containers filled with mineral oil. The potassium must sink in the mineral oil to ensure it has no contact with any air in the container.

A science teacher has four different mineral oils in which they could store their potassium. Potassium has a density of 0.862 g/cm^3.

Which mineral oil should the teacher choose?

A: White mineral oil, $\rho = 0.864 \text{ g/cm}^3$

B: Paraffin oil, $\rho = 0.890 \text{ g/cm}^3$

C: Liquid paraffin, $\rho = 0.825 \text{ g/cm}^3$

D: Food grade mineral oil, $\rho = 0.880 \text{ g/cm}^3$

Answer: C

- An object will sink in a fluid if the density of the object is greater than the density of the fluid
- Therefore, for the potassium to sink, the density of the oil must be less than the density of the potassium
- Liquid paraffin is less dense than potassium
  $0.825 \text{ g/cm}^3 < 0.862 \text{ g/cm}^3$
- The only oil which is less dense than potassium is **C**

Examiner Tips and Tricks

The main thing to remember is that **density is mass per unit volume**

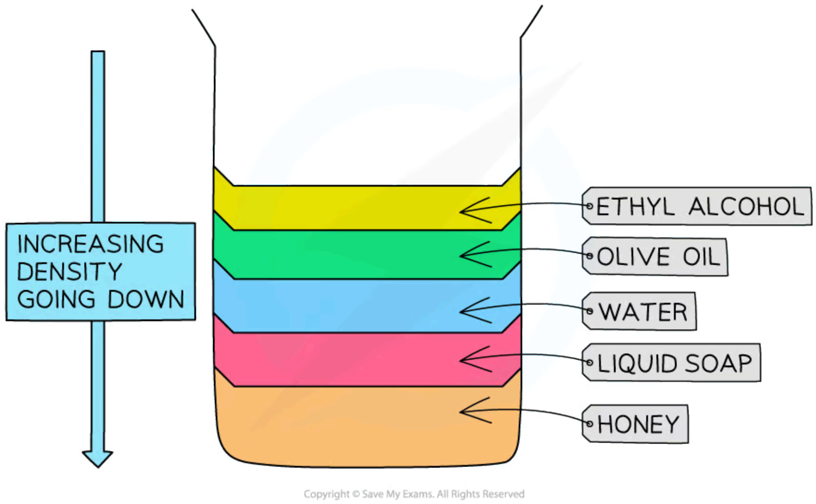
In Physics, mass is almost always measured in kg

Density is the only topic in which physicists sometimes use grams instead

Floating liquids

Extended tier only

- A liquid with a lower density will float on a liquid with a higher density if the liquids do not mix



Lower density liquids float on higher density liquids as long as the liquids do not mix

Worked Example

Liquid A has a density of 0.76 g/cm^3 and liquid B has a density of 0.93 g/cm^3.

If the two liquids do not mix, which liquid will float on top of the other?

Answer:

Step 1: List the known quantities

- Liquid A = 0.76 g/cm^3
- Liquid B = 0.93 g/cm^3

Step 2: Determine which liquid has the lowest density

- The liquid with the lowest density will float on top of the liquid with the higher density
- 0.76 is less than 0.93
- Therefore, liquid A has the lowest density

Step 3: State your answer

- **Liquid A** will float on top of liquid B

Your notes