Density & Measurement

Regular Solid

- **Mass** from a **beam balance**; **volume** from measured dimensions
- **Cube** = (side)^3; **cuboid** = length × breadth × height
- **Sphere** = (4/3)π(radius)^3; **cylinder** = π(radius)^2 × height
- **d = M/V** — e.g. 210 g iron cube of side 3 cm ⇒ d = 210/27 = **7.78 g/cm^3**

Irregular Solid

- **Displacement principle:** a **completely immersed** solid displaces water equal to its own volume
- **Measuring cylinder:** volume of solid = **$V_2 - V_1$** (water level after − before immersion)
- **Eureka can** (water initially filled up to the spout): water that overflows on immersion = **volume of solid**

Liquid Density & Density Bottle

- **Liquid:** for a known volume V, mass **M = $M_2 - M_1$** (beaker with liquid − empty beaker); **density = M / V**
- **Specially-designed bottle** to measure liquid density: small glass bottle with narrow neck fitted with a **glass stopper**; fixed capacity **25 or 50 mL**
- **Working principle:** stopper has a **narrow hole** ⇒ when the bottle is filled, excess liquid rises through the hole and drains out, so the bottle always holds the **same fixed volume**
- Density of water = 1 g/cm^3 ⇒ mass of water filling the bottle (in g) numerically = volume of bottle (in cm^3)
- **Readings:** M_1 = empty bottle, M_2 = bottle + water, M_3 = bottle + liquid
- **Density of liquid = ($M_3 - M_1$) / ($M_2 - M_1$) g/cm^3**

Density

- **Density d = Mass ÷ Volume** (d = M/V) — the mass per unit volume of a substance
- **SI unit: kg/m^3**; **CGS unit: g/cm^3**
- Relationship: **1 g/cm^3 = 10^3 kg/m^3** (i.e. 1 kg/m^3 = 10^{-3} g/cm^3)
- **Does not change with size or shape** — a small or large piece of iron both have density **7.8 g/cm^3**
- **Density decreases with rising temperature** (almost all substances expand on heating ⇒ same mass in more volume); **water is densest at 4°C**

Volume Vessels

- **Measuring cylinder** — graduated glass/plastic tube; capacities **50, 100, 200, 500 mL** etc.
- **Measuring beaker** — glass, plastic or metal, holds a **fixed capacity** (50/100/200/500/1000 mL)
- **Eureka can** — can with a **side spout**; excess liquid overflows through spout when an object is dropped in

Relative Density

- **RD = density of substance ÷ density of water** (water is the fixed reference)
- **Dimensionless** — a pure ratio, so it has **no unit**
- Equivalent: **RD = mass of any volume of substance ÷ mass of equal volume of water**
- RD is **numerically equal to density in g/cm^3** (because water density is 1 g/cm^3); density in kg/m^3 = 1000 × RD
- Also called **specific gravity**
- **RD = ($M_3 - M_1$) / ($M_2 - M_1$)** using the same three density-bottle readings — dimensionless

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Floatation & Applications

Law of Floatation

- **Law of floatation:** a floating body displaces liquid (by its immersed part) whose weight = the body's **total weight** (= buoyant force)
- **Apparent weight of a floating body = 0** (buoyant force exactly cancels weight)
- **Denser liquid ⇒ less submerged:** a floating body needs less of itself submerged in a denser liquid (e.g. wood floats less submerged in glycerine than in water)

Ships & Submarines

- **Iron ship:** a nail sinks, but a ship of the same iron floats — ship's **large hollow volume** holds air, making its **average density < water**, so it displaces enough water for upthrust to equal its weight
- **Submarine:** water-tight vessel with **water tanks** — tanks **filled with sea water** ⇒ density > sea water ⇒ **sinks**
- Tanks **emptied** ⇒ density < sea water ⇒ submarine **rises to the surface**

Man, Ice, Fish, Balloons

- **Man in sea water:** sea water is denser than river water ⇒ less body needs to be immersed to balance weight ⇒ **easier to swim in sea**
- **Ice** (≈0.9 g/cm^3) floats in water (1 g/cm^3) about **9/10 submerged**, 1/10 above; **icebergs** float in sea water (1.02 g/cm^3) with most of their bulk submerged — dangerous for ships
- **Fishes:** many bony fishes have a **swim bladder** — **fill with air** ⇒ average density falls ⇒ rise; **empty it** ⇒ density rises ⇒ dive
- **Balloons:** filled with **hydrogen or helium** (lighter than air) ⇒ density < air ⇒ buoyant force from air > weight ⇒ balloon **rises up**

Density in 3 States & Data

- Molecules **closely packed in solid**, more spaced in liquid, **widely spaced in gas**
- So, **for a given substance**, density is generally **solid > liquid > gas**
- **Exception:** ice = **0.917 g/cm^3** is **less dense than water (1.0)**; steam = 0.00057 g/cm^3
- **Densities (g/cm^3):** cork 0.25, wood 0.7, ice 0.92, water 1.0, aluminium 2.7, iron 7.8, lead 11.5, **mercury 13.6**

Floating & Sinking

- **Rule:** solid with **density < liquid** ⇒ **floats**; density > liquid ⇒ **sinks**
- **Iron ball** (7.8 g/cm^3) **sinks in water** (1 g/cm^3); **cork** (0.25 g/cm^3) **floats** because it is less dense than water
- Same body can float in one liquid and sink in another — depends on the liquid's density (e.g. a solid iron ball sinks in water but floats in mercury, 13.6 g/cm^3)

Principle of Floatation

- A body immersed in a liquid experiences **two forces**: **weight W** acting downward and **buoyant force F_B** (= weight of liquid displaced) acting upward
- **Case 1: W > F_B** ⇒ body **sinks** (body density > liquid density)
- **Case 2: W = F_B** ⇒ body **floats fully immersed**, just below the surface (body density = liquid density)
- **Case 3: W < F_B** if fully immersed ⇒ body **rises** and floats **partly submerged** until F_B = W (body density < liquid density)