

Forces, Density & Pressure

AS Physics ■ Topic 4

A-Level Physics



What we will cover

1 Turning effects: moments

2 Equilibrium of forces

3 Density

4 Pressure

5 Upthrust & floating

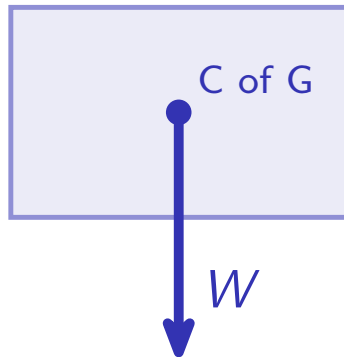
6 Recap



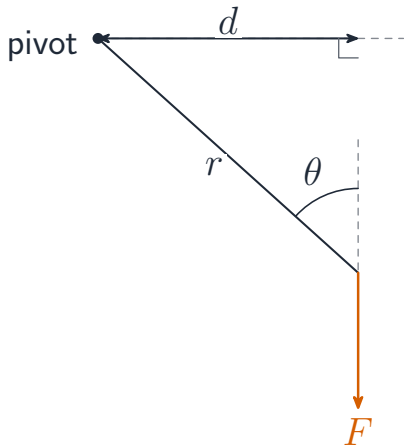
Centre of gravity

The whole **weight** 重力 can be treated as acting at one point – the **centre of gravity** 重心.

- uniform regular shape → at the middle
- draw the weight arrow there on a **free-body diagram** 受力图



Moment of a force



Moment 力矩 = force $\times$ perpendicular distance:

$$M = Fd = Fr \sin \theta.$$

Spanner: $F = 50 \text{ N}$, $r = 0.40 \text{ m}$, $\theta = 30^\circ$

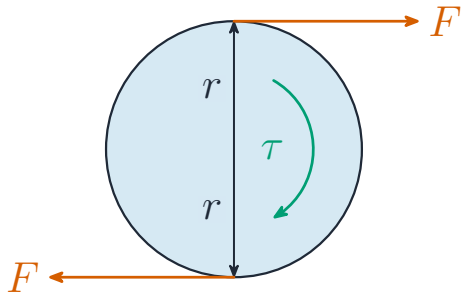
$$M = 50 \times 0.40 \times \sin 30^\circ = 10 \text{ N m}$$

Couple and torque

A **couple** 力偶: two **equal, opposite** forces, lines of action a distance apart.

$$\tau = Fd.$$

A couple **turns only** – zero resultant force. Same forces in the *same* direction is **not** a couple.



Two conditions for equilibrium

Both must hold at once:

$$\sum F = 0$$

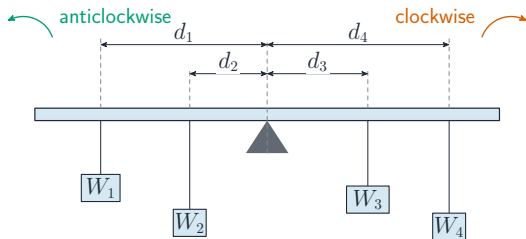
no straight-line acceleration

$$\sum M = 0$$

no turning (about any point)

Zero force can still turn; zero moment can still move in a line.

Principle of moments



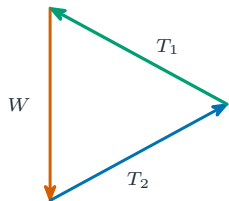
Not turning $\Rightarrow$ total clockwise = total anticlockwise moment.

Beam pivoted at centre

40 N at 1.5 m balances 30 N at d :

$$40(1.5) = 30d \Rightarrow d = 2.0 \text{ m.}$$

Vector triangle



the three forces
form a **closed**
triangle → equilibrium

Three forces in equilibrium form a **closed** triangle (tip to tail).

- solve with the sine / cosine rule, or
- resolve: $\sum F_x = 0$, $\sum F_y = 0$

Density

Density 密度 = mass per unit volume
(a **scalar**):

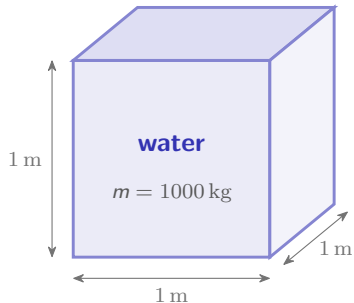
$$\rho = \frac{m}{V}, \quad [\rho] = \text{kg m}^{-3}.$$

water 1000

air ~ 1.2

iron ~ 7800

all in kg m^{-3}



$\rho = 1000 \text{ kg per m}^3$ – a cubic metre of water is
a tonne

Pressure

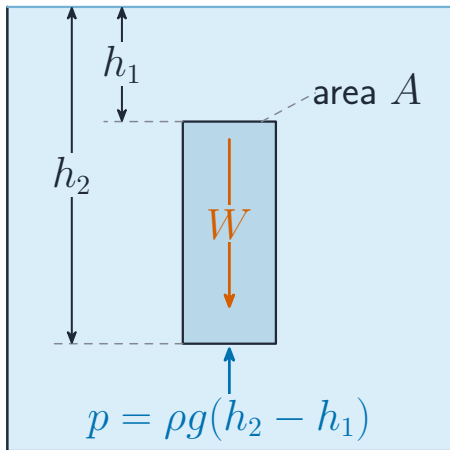
Pressure 压强 = force per unit area, **normal** to the surface:

$$p = \frac{F}{A}, \quad [p] = \text{Pa} = \text{N m}^{-2}.$$

A scalar – it acts equally in all directions in a fluid.



Hydrostatic pressure



Extra pressure with depth Δh :

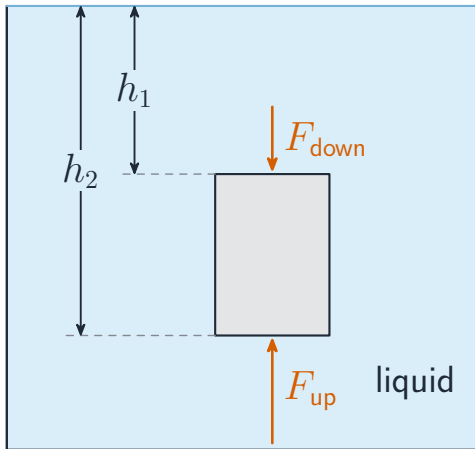
$$\Delta p = \rho g \Delta h.$$

Depends only on **density** and **depth** – the shape of the container does not matter.

Pool 2.5 m deep

$$\Delta p = 1000 \times 9.81 \times 2.5 \approx 2.5 \times 10^4 \text{ Pa}$$

Upthrust – Archimedes' principle



Pressure is greater on the bottom than the top $\Rightarrow$ a net **upthrust** 浮力:

$$F_{\text{up}} = \rho_{\text{fluid}} g V.$$

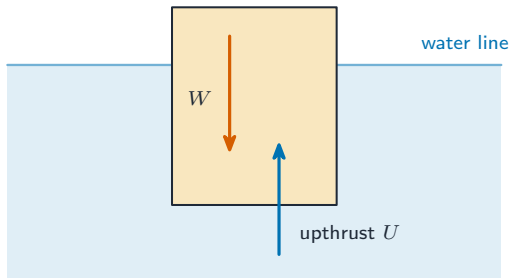
Archimedes' principle 阿基米德原理:
upthrust = weight of fluid pushed
aside.

$$V = 2.0 \times 10^{-3} \text{ m}^3 \text{ in water}$$

$$F_{\text{up}} = 1000 \times 9.81 \times 2.0 \times 10^{-3} \approx 20 \text{ N}$$

Floating and weighing under water

floats when $U = W$



- floats when upthrust = weight
(V = volume **below** the surface)
- held down by string: $F_{\text{up}} = W + T$
- **newton meter** 弹簧测力计 reading
 $= W - F_{\text{up}}$

Topic 4 – key takeaways

1 Moments

$M = Fd$; a couple gives torque
 $\tau = Fd$

2 Equilibrium

$\sum F = 0$ and $\sum M = 0$ together

3 Pressure

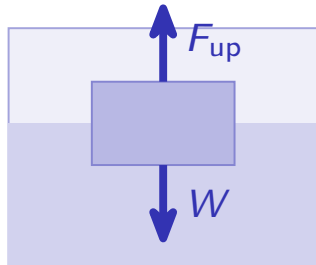
$p = F/A$; in a fluid $\Delta p = \rho g \Delta h$

4 Upthrust

$F = \rho g V$ – weight of fluid displaced

Check yourself

- 1 Unit of the moment of a force?
- 2 Are two equal forces the same way a couple?
- 3 Pressure 3 m down in water (to 1 s.f.)?
- 4 What does the upthrust on a body equal?



Answers 1. Nm 2. no (they have a resultant force) 3. $\approx 3 \times 10^4 \text{ Pa}$ 4. weight of fluid displaced