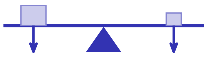
Forces, Density & Pressure

AS Physics ▪ Topic 4

A-Level Physics



What we will cover

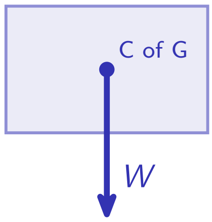
1. Turning effects: moments
2. Equilibrium of forces
3. Density
4. Pressure
5. Upthrust & floating
6. Recap

1 Turning effects

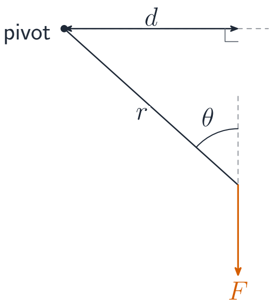
Centre of gravity

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 × perpendicular distance:

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

Spanner: $F = 50\,\mathrm{N}$, $r = 0.40\,\mathrm{m}$, $\theta = 30°$

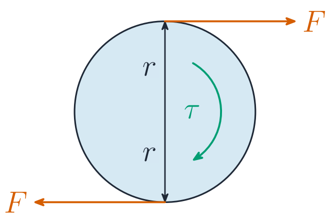
$M = 50 \times 0.40 \times \sin 30° = 10\,\mathrm{N\,m}$

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.



2 Equilibrium

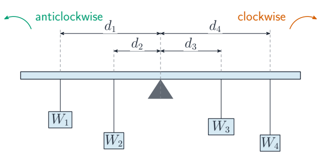
Two conditions for equilibrium

Both must hold at once:

$\sum F = 0$	$\sum M = 0$
no straight-line acceleration	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

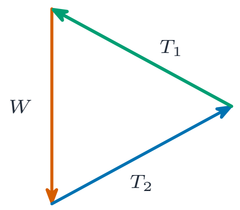
$40\,\mathrm{N}$ at $1.5\,\mathrm{m}$ balances $30\,\mathrm{N}$ at d:

$$40(1.5) = 30\,d \;\Rightarrow\; d = 2.0\,\mathrm{m}.$$

Vector triangle

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

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



the three forces form a **closed** triangle $\to$ equilibrium

3 Density and pressure

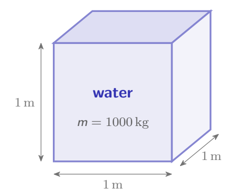
Density

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

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

water 1000 | air ~ 1.2 | iron ~ 7800

all in $\mathrm{kg\,m^{-3}}$



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

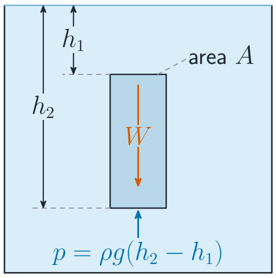
Pressure

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

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

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

Hydrostatic pressure



Extra pressure with depth Δh:

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

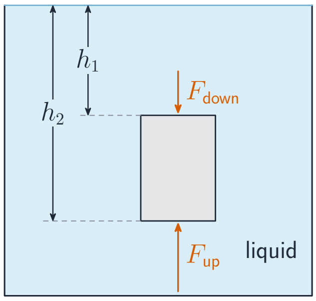
> Depends only on density and depth – the shape of the container does not matter.

Pool $2.5\,\mathrm{m}$ deep

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

4 Upthrust

Upthrust – Archimedes' principle



Pressure is greater on the bottom than the top ⇒ a net **upthrust** 浮力:

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

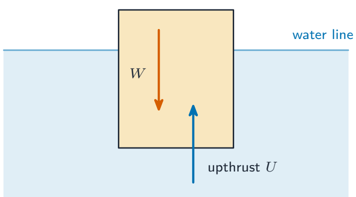
> **Archimedes' principle** 阿基米德原理: upthrust = weight of fluid pushed aside.

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

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

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 = $W - F_{\text{up}}$

5 Recap

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

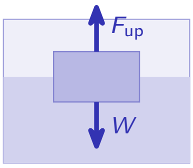
$p = F/A$; in a fluid $\Delta p = \rho g \Delta h$

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 $3\,\mathrm{m}$ down in water (to 1 s.f.)?
4. What does the upthrust on a body equal?



Answers **1.** $\mathrm{N\,m}$ **2.** no (they have a resultant force) **3.** $\approx 3 \times 10^4\,\mathrm{Pa}$ **4.** weight of fluid displaced