

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



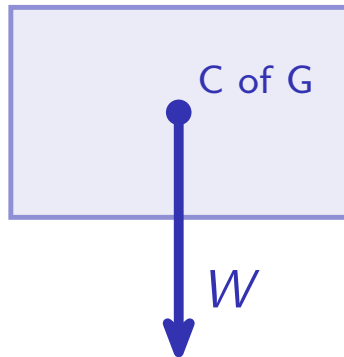
1

Turning effects

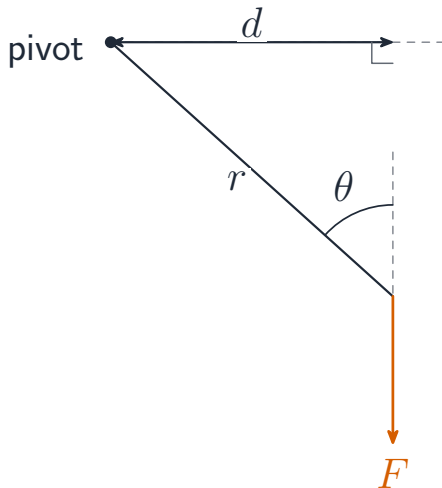
Centre of gravity

The whole **weight** 重力 can be treated as acting at one point – the **centre of gravity** 重心, which is the **centre of mass** 质心 in a uniform field.

- 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 $\times$ the **perpendicular distance** d from the **pivot** 支点 to the force's **line of action** 作用线:

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

where r is the **lever arm** 力臂. Only the part of F **perpendicular** to it turns anything.

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

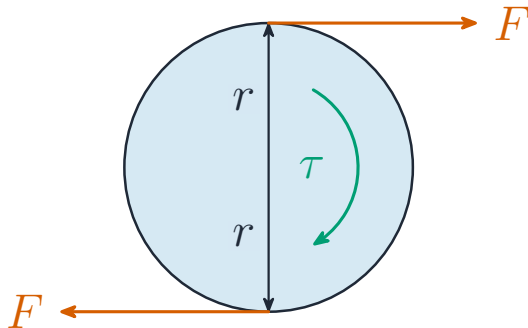
$$M = 50 \times 0.40 \times \sin 30^\circ = 10 \text{ N m}$$

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.



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Equilibrium

Two conditions for equilibrium

Both must hold at once:

$$\sum F = 0$$

no acceleration of
the **translation** 平动

$$\sum M = 0$$

no **angular accelera-**
tion 角加速度, 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 :

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

How to solve a balance problem

1. Choose a pivot

Usually where an *unknown* force acts – its distance is then zero, so it drops out of the moment equation.

2. List the forces

Every force, with its **perpendicular** distance from that pivot. Include the rod's own weight at its centre of gravity.

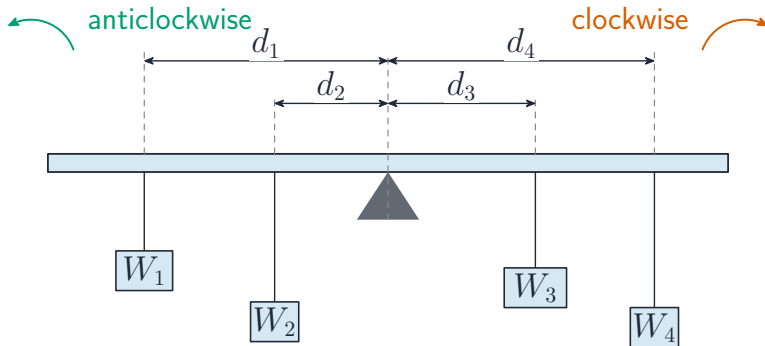
3. Balance moments $\sum M_{\text{clockwise}} = \sum M_{\text{anticlockwise}}$ about the chosen pivot.

4. Add $\sum F = 0$

Use it when a second equation is needed – typically to find the force at the pivot itself.

A uniform rod's weight acts at its centre: place the pivot there and it contributes no moment at all.

Principle of moments, in detail

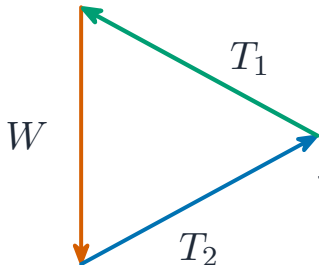


Not turning $\Rightarrow$ total clockwise = total anticlockwise moment.

Vector triangle

Three coplanar forces in equilibrium form a **closed vector triangle** 矢量三角形 – tip to tail, back to the start.

- solve with the sine / cosine rule, or
- split each force into **horizontal** 水平 and **vertical** 竖直 **components** 分量:
 $\sum F_x = 0, \sum F_y = 0$



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

The closed vector triangle

Tip to tail

Three coplanar forces in equilibrium, drawn tip-to-tail, return to the start – a **closed vector triangle**.

Solve it

Use the **sine rule** 正弦定理 or **cosine rule** 余弦定理 for unknown sizes and directions, or draw it to scale on graph paper.

Or components

The alternative: split each force into horizontal and vertical parts and set $\sum F_x = 0$, $\sum F_y = 0$.

If the triangle does *not* close, the forces are not in equilibrium – the gap is the resultant.

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Density and pressure

Density

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

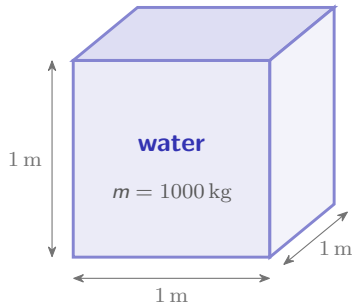
$$\rho = \frac{m}{V}, \quad [\rho] = \text{kg m}^{-3}.$$

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

Some useful densities to know

Water

1000 kg m^{-3} – and 1 g cm^{-3} is the same number: the conversion factor is 1000.

Air (room conditions)

$\sim 1.2 \text{ kg m}^{-3}$ – about $800\times$ less dense than water, which is why upthrust in air is usually ignored.

Iron / steel

$\sim 7800 \text{ kg m}^{-3}$ – roughly $8\times$ water, so a steel hull floats only because it encloses air.

Carry these three: they let you sanity-check an answer without a data sheet.

Pressure

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

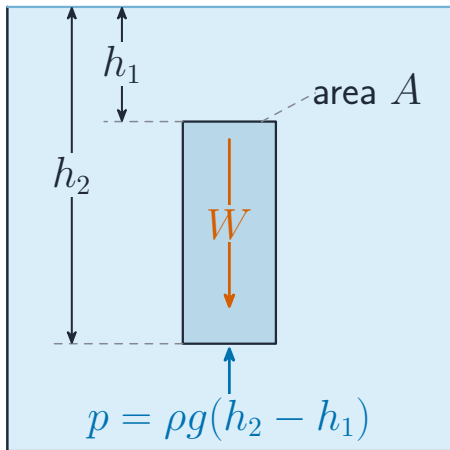
$$p = \frac{F}{A}, \quad [p] = \text{Pa} = \text{N m}^{-2}.$$

A scalar – it acts equally in all directions in a fluid. A is the **cross-sectional area** 横截面积 the force presses on.

A barometer reads **atmospheric pressure** 大气压 – about $1.0 \times 10^5 \text{ Pa}$ at sea level.



Hydrostatic pressure



Extra pressure with depth Δh :

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

Depends only on **density** and **depth**

– a liquid is nearly **incompressible** 不可压缩, so the shape of the container does not matter.

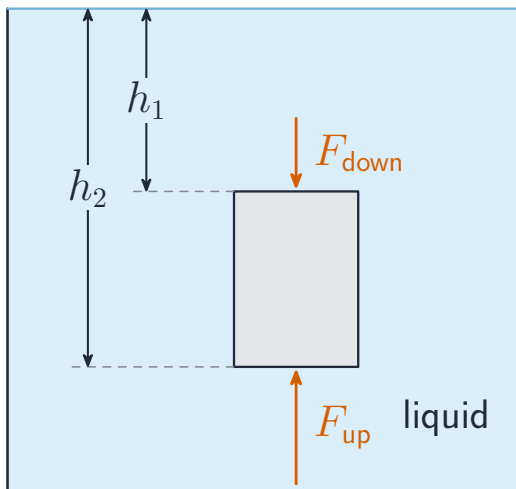
Pool 2.5 m deep

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

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Upthrust

Upthrust – Archimedes' principle



For a **submerged** 浸没 object the pressure on the bottom beats the pressure on the top $\Rightarrow$ a net **upthrust** 浮力:

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

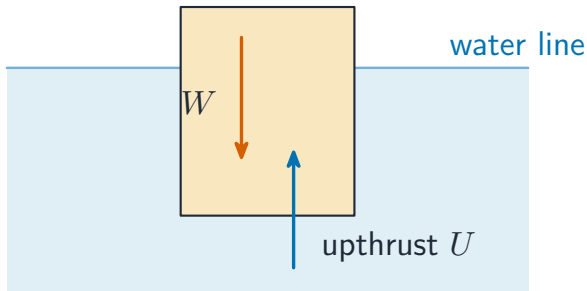
Archimedes' principle 阿基米德原理: upthrust = weight of fluid pushed aside.

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

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

Floating and weighing under water

floats when $U = W$



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

Exam tips

- Take **moments** about a chosen pivot; for equilibrium, total clockwise = total anticlockwise moments **and** the resultant force is zero.
- A body in equilibrium under three forces gives a **closed triangle** of forces.
- Fluid pressure = ρgh ; **upthrust** = **weight of fluid displaced** (Archimedes).
- Distinguish mass, weight and density, and give the base unit each time.

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

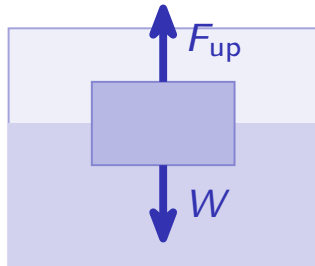
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Upthrust

$F = \rho g V$ – 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