

Forces, density and pressure

A-Level Physics 9702 · Topic 4 revision notes · AS

Moments, couples and centre of gravity, the two conditions for equilibrium, and density, fluid pressure and upthrust. 10 definitions to learn word for word, 9 equations in their own column, 6 diagrams and graphs. Read it, cover it, test yourself.

1. 4.1 Turning effects of forces
2. 4.2 Equilibrium of forces
3. 4.3 Density and pressure

Definitions (mark-scheme wording) Equations Exam traps

4.1 Turning effects of forces

Definitions

Moment of a force: the product of the force and the perpendicular distance from the pivot to the line of action of the force.

Couple: a pair of forces that are equal in magnitude, opposite in direction and act along parallel but different lines of action.

Torque of a couple: the product of one of the forces and the perpendicular distance between the lines of action of the two forces.

Centre of gravity: the point at which the whole weight of an object may be considered to act.

Equations

$$\text{moment} = F d$$

force $\times$ perpendicular distance from pivot
 N m

$$\text{moment} = F d \sin \theta$$

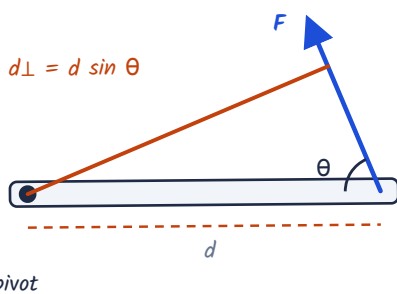
force at angle θ to the lever arm
 N m

$$\text{torque} = F s$$

one force of a couple $\times$ perpendicular separation
 N m

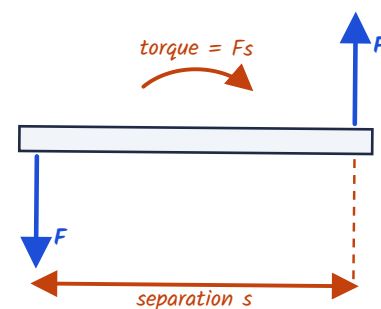
Key points

- ✓ Moment unit: N m (not J, even though the base units match).
- ✓ A slanted force: $\text{moment} = F \sin \theta \times d$, using only the perpendicular component.
- ✓ A couple gives **zero resultant force** but a non-zero torque: pure rotation, no translation.
- ✓ Torque of a couple is the **same about any point**.
- ✓ Uniform object: centre of gravity at its **geometric centre**.
- ✓ Freely suspended object hangs with its centre of gravity **directly below** the pivot.



Moment of a slanted force: use the perpendicular distance $d_{\perp} = d \sin \theta$ to the line of action.

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A couple: forces cancel (no acceleration) but give torque $F \times s$.

Watch out!

- ! Using the distance to the point of application instead of the **perpendicular** distance to the line of action.
- ! Torque of a couple is $F \times s$, **not** $2F \times s$.

4.2 Equilibrium of forces

Definitions

Equilibrium: the state in which there is no resultant force and no resultant moment (torque) on an object.

Principle of moments: for an object in equilibrium, the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point.

Equations

$$\Sigma \text{ clockwise moments} = \Sigma \text{ anticlockwise moments}$$

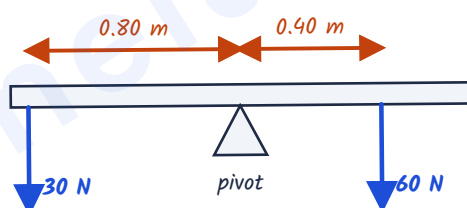
principle of moments
N m

$$\Sigma F_x = 0, \Sigma F_y = 0$$

no resultant force
N

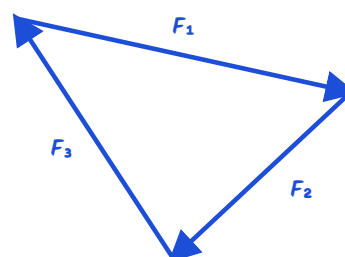
Key points

- ✓ Two conditions: **resultant force = 0** (no linear acceleration) **and** **resultant torque = 0** (no angular acceleration).
- ✓ Take moments about the point where an **unknown force acts**: it drops out.
- ✓ Resolve forces into two perpendicular directions; each sum must be zero.
- ✓ Three coplanar forces in equilibrium form a **closed vector triangle** when drawn tip-to-tail.
- ✓ Three non-parallel forces in equilibrium have lines of action that pass through **one point**.
- ✓ Weight of a uniform beam acts at its **midpoint**.



$$24 \text{ N m anticlockwise} = 24 \text{ N m clockwise}$$

Beam balanced on a pivot: take moments about the pivot.
Here $30 \text{ N} \times 0.80 \text{ m} = 60 \text{ N} \times 0.40 \text{ m}$.



closed: $\Sigma F = 0$

Three forces in equilibrium drawn tip-to-tail close the triangle: zero resultant.

Watch out!

- ! Zero resultant force alone is not equilibrium: a couple has zero resultant force but still rotates.
- ! Forgetting the beam's own weight, acting at its centre of gravity.

4.3 Density and pressure

Definitions

Density: mass per unit volume.

Pressure: force per unit area, where the force acts normal (perpendicular) to the area.

Upthrust: the upward force exerted by a fluid on a submerged or floating object, due to the pressure difference between its lower and upper surfaces.

Archimedes' principle: the upthrust on an object in a fluid equals the weight of fluid it displaces.

Equations

$$\rho = m / V$$

density = mass / volume
 kg m^{-3}

$$p = F / A$$

pressure = normal force / area
 Pa

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

pressure change with depth in a fluid
 Pa

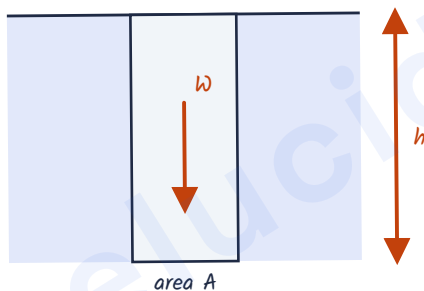
$$F = \rho g V$$

upthrust (ρ of fluid, V submerged)
 N

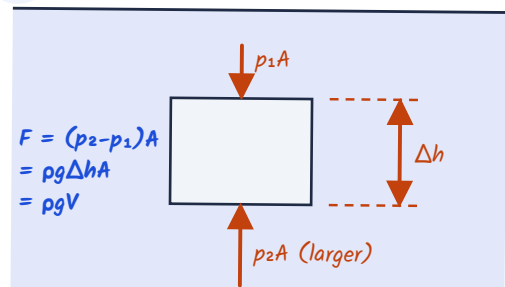
Key points

- ✓ $\text{Pa} = \text{N m}^{-2}$; density of water = 1000 kg m^{-3} .
- ✓ Fluid pressure acts **equally in all directions** at a given depth.
- ✓ Pressure increases linearly with depth; it does not depend on the **shape** of the container.
- ✓ Total pressure at depth h = atmospheric pressure + ρgh .
- ✓ Upthrust arises because pressure on the bottom face exceeds that on the top: $F = \rho g V$.
- ✓ Floating object: **upthrust = weight**.

surface



Deriving $p = \rho gh$: the column above area A has mass ρAh and weight ρAhg , so $p = W/A = \rho gh$.



Upthrust: the bottom face is deeper, so the upward force exceeds the downward force by $\rho g V$.

Watch out!

- ! In $F = \rho g V$, ρ is the density of the **fluid** and V the **submerged** volume, not the object's.
- ! $\Delta p = \rho g \Delta h$ gives the pressure **difference**; add atmospheric pressure for the total pressure.