A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 4 · ~8 MIN READ

Forces, density and pressure

Centre of gravity, moments, couples and torque, the principle of moments and the two conditions for equilibrium, vector triangles, density, pressure, deriving Δp = ρgΔh, and upthrust.

Centre of gravity | Moment of a force | Couple & torque | Principle of moments | Equilibrium | Vector triangles | Density | Pressure

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Moment of a force** = force × perpendicular distance from the pivot to the line of action of the force.
- **A couple** is a pair of equal, opposite, parallel forces that don't act along the same line. It causes rotation only: torque = one force × perpendicular distance between them.
- **Equilibrium needs two conditions:** no resultant force (forces balance in every direction) **and** no resultant torque (moments balance about every point).
- **Pressure in a fluid** increases with depth: Δp = ρgΔh. The pressure difference between the top and bottom of an object causes **upthrust** = ρgV, the weight of fluid displaced.

BY THE END YOU CAN

- Use centre of gravity, moments and the principle of moments.
- Define a couple and calculate its torque.
- Apply both conditions for equilibrium, including with vector triangles.
- Define density and pressure, derive Δp = ρgΔh and use it.
- Explain upthrust and calculate it with F = ρgV.

1 Moments and couples

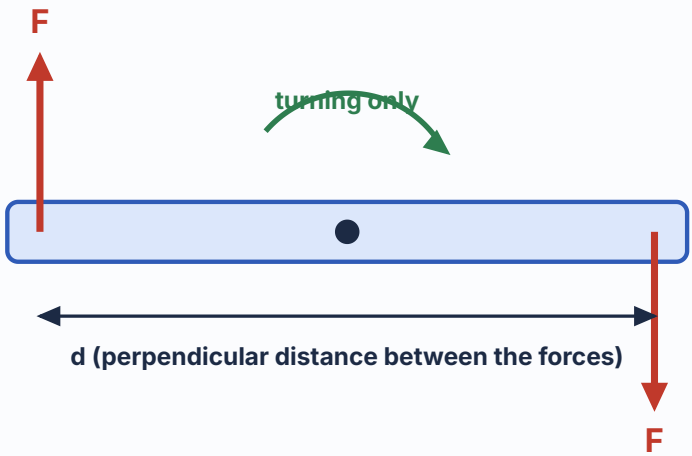
Definitions

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

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 parallel, but do not act along the same line.

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



Couple: two equal, opposite, parallel forces. Resultant force = 0; torque = F × d.

A couple has zero resultant force, so it can turn an object but cannot accelerate it along a line.

- **Unit:** N m (newton metre). Not joules: a torque is not energy, even though the base units match.
- **The perpendicular distance is the key word.** For a force F at angle θ to a lever of length r, the moment is Fr sin θ (or resolve F and use only the perpendicular component).

WORKED EXAMPLE

A steering wheel of diameter 0.40 m is turned by two equal and opposite forces of 15 N applied tangentially at opposite ends of a diameter. Find the torque.

1. **torque = F × d = 15 × 0.40 = 6.0 N m** C1 A1

COMMON MISTAKE

Choosing a couple as an example of equilibrium. A couple has zero resultant force but a non-zero torque, so the object is not in equilibrium. This appeared in the 2024 Paper 1 report.

2 Equilibrium

Two conditions

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.

- **Equilibrium:** (1) resultant force = 0 and (2) resultant torque = 0.
- **Take moments about the point where an unknown force acts:** that force then has zero moment and drops out.

WORKED EXAMPLE

A uniform plank of length 4.0 m and weight 200 N rests on supports X and Y at its ends. A person of weight 600 N stands 1.0 m from X. Find the forces from the supports.

1. moments about X: $R_Y \times 4.0 = 200 \times 2.0 + 600 \times 1.0$ C1
2. $R_Y = 1000/4.0 =$ **250 N** A1
3. **vertical forces: $R_X + 250 = 800 \Rightarrow R_X = 550$ N** A1

WORKED EXAMPLE

A uniform rod of length 1.2 m and weight 50 N is hinged to a wall and held horizontal by a cable attached to its far end at 40° to the rod. Find the tension.

1. moments about the hinge (the hinge force drops out): $T \sin 40° \times 1.2 = 50 \times 0.60$ C1
2. **$T = 30/(1.2 \times 0.643) = 39$ N** A1

Vector triangles

- **Three coplanar forces in equilibrium** form a closed triangle when drawn tip-to-tail. Use trigonometry (sine or cosine rule) or resolve in two directions.

WORKED EXAMPLE

A lamp of weight 30 N hangs from two cords, each at 25° to the horizontal. Find the tension in each cord.

1. vertical: $2T \sin 25° = 30$ C1
2. **$T = 30/(2 \times 0.423) = 35$ N** A1 **(much more than half the weight, because the cords are nearly horizontal)**

3 Density and pressure

Definitions

Density — mass per unit volume, $\rho = m/V$ (kg m^{-3}).

Pressure — normal force per unit area, $p = F/A$ (Pa = N m^{-2}).

Pressure in a fluid

- **Derivation:** a column of liquid of height Δh and cross-sectional area A has volume $A\Delta h$, mass $\rho A\Delta h$ and weight $\rho A\Delta hg$. Pressure = weight/area = $\rho g\Delta h$.

$\Delta p = \rho g \Delta h$ **DATA & FORMULAE**

pressure difference between two points a vertical distance Δh apart

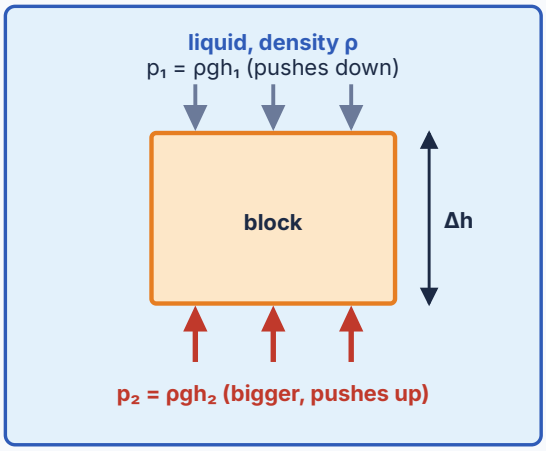
- **Total pressure** at depth h = atmospheric pressure + ρgh. Pressure acts equally in all directions at a given depth.

WORKED EXAMPLE

Find the total pressure at a depth of 12 m in sea water of density 1030 kg m^{-3}. Atmospheric pressure is 1.01×10^5 Pa.

1. $\Delta p = 1030 \times 9.81 \times 12 = 1.21 \times 10^5$ Pa **C1**
2. **total = $1.01 \times 10^5 + 1.21 \times 10^5 = 2.22 \times 10^5$ Pa** **A1**

Upthrust



Δp = ρgΔh
upthrust = Δp × A
= ρg(AΔh)
= ρgV
= weight of fluid displaced

Pressure increases with depth, so the push up on the base beats the push down on the top.

The pressure on the bottom face is greater than on the top face, so there is a net upward force.

$$F = \rho g V$$ **DATA & FORMULAE**

upthrust; ρ is the FLUID's density, V the volume submerged

- **Why:** for a block of height Δh and area A, the net upward force = Δp × A = ρgΔh × A = ρgV. This is **Archimedes' principle**: upthrust = weight of fluid displaced.
- **Floating:** upthrust = weight. For ice (917 kg m^{-3}) in sea water (1025 kg m^{-3}), 917/1025 = 89% of the volume is submerged.

WORKED EXAMPLE

A metal block of volume 1.0×10^{-3} m^3 and density 2700 kg m^{-3} hangs from a newton-meter, fully submerged in water. Find the reading.

1. weight = $2700 \times 1.0 \times 10^{-3} \times 9.81 = 26.5$ N **C1**
2. upthrust = $1000 \times 9.81 \times 1.0 \times 10^{-3} = 9.81$ N **C1**
3. **reading = 26.5 − 9.8 = 16.7 N** **A1**

COMMON MISTAKE

Using the object's density for the upthrust. Upthrust depends on the density of the fluid and the volume displaced, not on the object's density.

LINKING QUESTION

Forces in equilibrium link to resolving vectors in Physical quantities and units; pressure in gases comes from molecular collisions in Ideal gases; and moments explain the stability questions in Dynamics.

Test yourself — cover the answers first

QUICK CHECK

1. Define the moment of a force.
2. State the two conditions for equilibrium.
3. What is the unit of torque?
4. Write the equation for upthrust.
5. Find the pressure due to 0.50 m of oil of density 850 kg m^{-3}.

EXAM-STYLE

6. Derive Δp = ρgΔh, stating the definitions used.
7. A uniform ladder of weight 250 N and length 5.0 m leans against a smooth vertical wall at 60° to the ground. Find the force from the wall.
8. Explain why a helium balloon rises, and why it eventually stops rising.

Show answers

1. force × perpendicular distance from the pivot to the line of action of the force
2. no resultant force and no resultant torque
3. N m
4. $F = \rho g V$ (ρ = density of the fluid)
5. $850 \times 9.81 \times 0.50 = 4.2$ kPa
6. weight of column = $\rho A \Delta h g$ (from $\rho = m/V$); pressure = force/area = $\rho A \Delta h g / A = \rho g \Delta h$
7. moments about the foot: $F \times 5.0 \sin 60° = 250 \times 2.5 \cos 60° \Rightarrow F = 72$ N
8. upthrust ($\rho_{air} gV$) is greater than the weight; as it rises the air density falls, so the upthrust falls until it equals the weight

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