

CAIE Physics A-level

Topic 4: Forces, Density and Pressure Notes

This work by [PMT Education](https://www.pmt.education) is licensed under [CC BY-NC-ND 4.0](https://creativecommons.org/licenses/by-nc-nd/4.0/)



4 - Forces, Density and Pressure

4.1 - Types of Force

A **uniform gravitational field** exerts the **same** gravitational force on a mass everywhere in the field. This force (F , also known as weight) can be calculated using the following equation:

$$F = mg$$

Where m is the mass of the object experiencing the force and g is the gravitational field strength.

Note that the gravitational field strength for a uniform field is **constant**.

The gravitational field strength on the Earth's surface is approximately **9.81 Nkg⁻¹**.

The **centre of gravity** of an object is the **point at which an object's weight acts**.

If an object is described as **uniform**, its centre of gravity will be exactly at its centre.

4.2 - Equilibrium of Forces

The **moment** of a force about a point is the **force multiplied by the perpendicular distance from the line of action of the force to the point**.

Moment = Force X Perpendicular distance to line of action of force from the point

A **couple** is a pair of **coplanar forces** (meaning they are forces within the same plane), where the two forces are **equal in magnitude but act in opposite directions**. A couple tends to only produce **rotation**.

To find the **torque of a couple**, you multiply **one of the forces by the perpendicular distance between the lines of action of the forces**.

Moment of a couple = Force X Perpendicular distance between the lines of action of forces

The **principle of moments** states that **for an object in equilibrium, the sum of anticlockwise moments about a pivot is equal to the sum of clockwise moments**.

You can use this fact to answer certain questions, for example:

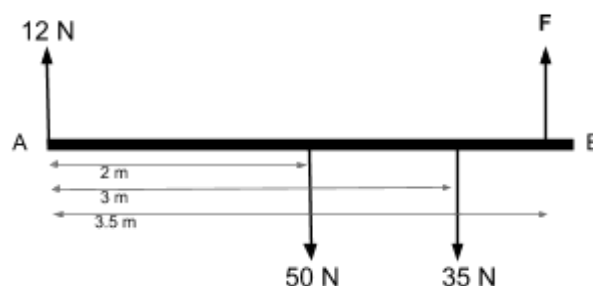
Find the value of F from the diagram on the right.

Σ clockwise moments = Σ anticlockwise moments

Taking moments around A:

$$(2 \times 50) + (3 \times 35) = (3.5 \times F)$$

$$205 = 3.5F \quad F = 58.6 \text{ N}$$



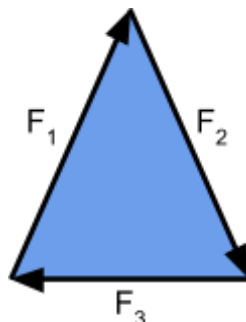
Note, in the example moments are taken about A, as the distance from A to A is 0, the moment caused by the 12 N force is also 0, therefore it can be ignored.

Note that a system is in **equilibrium** if there is **no resultant force and no resultant torque**.



You can show an object is in equilibrium by either:

- Adding the **horizontal and vertical components** of the forces acting on it and showing they equal zero
- Or if there are 3 **coplanar** forces acting on the object, you can draw a scale diagram and if the scale diagram forms a **closed triangle**, then the object is in equilibrium.



4.3 - Density and Pressure

The **density (ρ)** of a material is its **mass per unit volume**, and it's a measure of how compact a substance is. You can calculate density using the following equation:

$$\rho = \frac{m}{V}$$

Where m is the mass of the object and V is its volume.

Pressure (p) is defined as the **force perpendicular to a surface per unit area**, and can be calculated using the following equation:

$$p = \frac{F}{A}$$

Where F is the force acting perpendicular to the surface and A is its area.

Using the defining equations of pressure and density, you can derive the formula $\Delta p = \rho g \Delta h$

Consider a beaker containing a fluid of density ρ , and a small cylinder as shown in the diagram to the right.

The pressure on the bottom face of the cylinder, which has an area A , is due to the weight of the column of the fluid above it.

You can calculate this mass of this fluid by multiplying its density by its volume:

$$Volume = A \times h$$

$$Mass = \rho \times A \times h$$

As $Weight = mg$, you can calculate the

weight of this fluid as shown below:

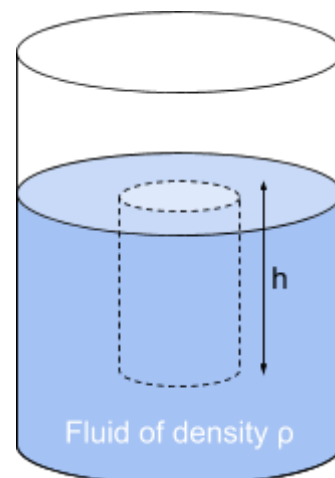
$$Weight = \rho \times A \times h \times g$$

Finally you can calculate pressure using the equation shown above:

$$p = \frac{Weight}{Area} = \frac{\rho \times A \times h \times g}{A} = \rho h g$$

Therefore,

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



You can use the equation above to calculate the pressure exerted by a fluid on an object when you know the fluid's density and the height of the fluid above the object.

Note: this equation does not give you a value of total pressure.

Total pressure is the **sum of the pressure exerted by the fluid and atmospheric pressure.**

For example, a stone is thrown into a lake and sinks to the bottom, 15.0 m below the surface. The density of the lake water is 997 kgm^{-3} and the atmospheric pressure is $1.01 \times 10^5 \text{ Pa}$. Find the total pressure experienced by the stone.

Firstly, calculate the pressure exerted by the water using $\Delta p = \rho g \Delta h$.

$$997 \times 9.81 \times 15.0 = 1.47 \times 10^5 \text{ Pa}$$

Next, find the total pressure.

$$\text{Total pressure} = \Delta p + \text{Atmospheric pressure}$$

$$\text{Total pressure} = 1.47 \times 10^5 + 1.01 \times 10^5 = 2.48 \times 10^5 \text{ Pa}$$

Consider a cylinder which is submerged in water. The bottom of the cylinder is deeper down in the fluid therefore **h is larger than it is for the top of the cylinder.** This means that the **pressure at the bottom of the cylinder will also be larger.** As the two faces of the cylinder have an equal area, and $P = F/A$, the force experienced by the bottom of the cylinder is larger than the top of the cube and it is **pushed upwards.**

Image source (right): [OpenStax College, CC BY 4.0](https://openstax.org/r/college)

Archimedes' Principle states that the weight of the fluid displaced by a submerged body equals the upthrust force exerted on the body. As such the buoyant force F can be written as $F = \rho g V$ where ρ is the density of the fluid, g is the gravitational acceleration, and V is the volume of fluid displaced by the object.

