CAIE Physics A-level

Topic 5: Forces, Density and Pressure

Notes

5 - Forces, Density and Pressure

5.1 - 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}**.

A **uniform electric field** exerts the **same** electric force on a charge everywhere in the field. This force (F) can be calculated using the following equation:

$$F = EQ$$

Where Q is the charge of the object experiencing the force and E is the electric field strength.

Note that the electric field strength for a uniform field is **constant**, and can be calculated using the following equation:

$$E = \frac{V}{d}$$

(for uniform fields formed by parallel plates)
Where V is the potential difference across the plates and d is the distance between the plates.

Objects in fluids may experience an **upthrust force** due to different pressures exerted on the surface of the object. In order to fully understand this you must be aware of the following equation used to calculate pressure (p) (this equation is further explored in section 5.4):

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

Where ρ is the density of the fluid, g is the gravitational field strength and h is the depth of the object in the fluid.

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 cube.** 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 cube is larger than the top of the cube and it is **pushed upwards**.

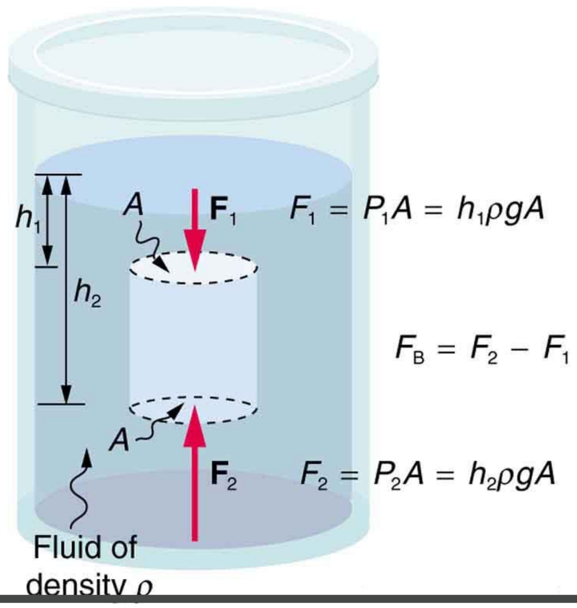


Image source (right): OpenStax College,CC BY 4.0

Friction is a force which **opposes the motion of an object**. It is known as drag or air resistance when considering the friction experienced in a fluid. Frictional forces **convert** kinetic energy into other forms such as heat and sound.

The **viscosity** of a fluid is a measure of the **fluid's resistance to flow/deform**. The larger the viscosity of a fluid, the larger the viscous (frictional) forces experienced by objects moving through the fluid. **As the speed of an object travelling through a fluid increases, the viscous force increases.**

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.

5.2 - Turning Effects 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**.

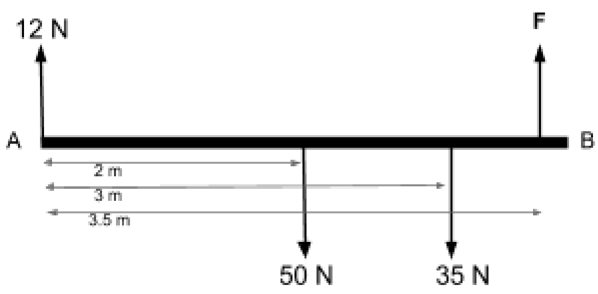
To find the **torque of a couple**, you **multiply one of the forces by the perpendicular distance between the lines of action of the forces**.

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

5.3 - Equilibrium 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:

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

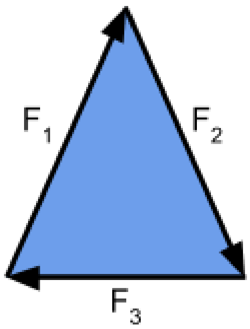
$$205 = 3.5F \qquad F = 58.6\,N$$

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.



5.4 - 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 $\Delta p = \rho g \Delta h$ used in section 5.1:

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:

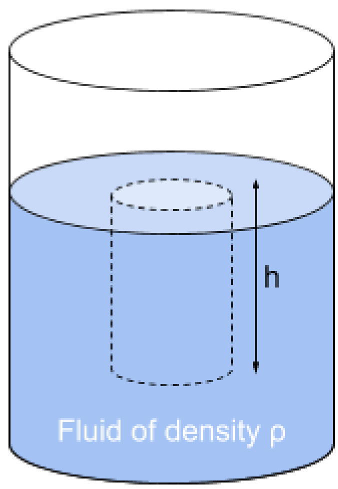
$Volume = A \times h$

$Mass = \rho \times A \times h$ 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 on the previous page 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 1.01×10^5 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.

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

Total pressure = $1.47 \times 10^5 + 1.01 \times 10^5 = 2.48 \times 10^5$ **Pa**