Module 3 Section 2: Forces in Action

Types of force

Normal contact force (reaction force) if an object exerts a force on a surface, the surface exerts an equal but opposite force on the object. The force acts normal to the surface

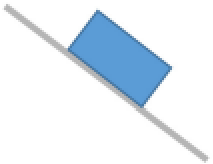
Tension if a string is pulled tight, tension is the force pulling equally on the objects at either end of the string

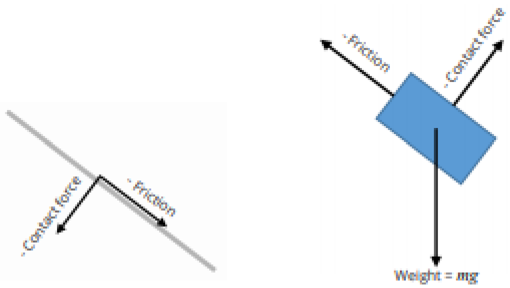
Friction if an object is moving, it usually has a friction force acting on it in the opposite direction to motion

Upthrust if an object is submerged (or partially submerged) in a fluid, it experiences an upwards force

Free body diagrams

In most situations there are many forces acting on an object one time and trying to draw a diagram of every force, including N3 pairs will become very cluttered and unclear. **Free body diagrams** help avoid this by **separating the objects** and drawing the forces on each independently. For the diagram above of a box on a slope we can separate them to look at the forces on the box and the slope separately.





Density

Density is a measure of how concentrated the mass in a material is. It can be calculated using this equation;

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

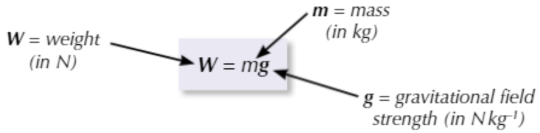
Remember to give your answer in SI units, kg m^{-3}. Often information about density is given in g and cm^3.

Mass and Weight

The **mass** of an object is the amount of 'stuff' (or matter) in it. It's measured in kg. The greater an object's mass, the greater its resistance to a change in velocity (called its inertia). The mass of an object doesn't change if the strength of the gravitational field changes.

Weight is a force. It's measured in newtons (N), like all forces. Weight is the force experienced by a mass due to a gravitational field. The weight of an object does vary according to the size of the gravitational field acting on it.

Weight is given by the equation:



Net Forces

The **net force** (or **resultant force**) on an object is the sum of all of the forces acting on the object, accounting for their relative directions. An object can only accelerate (change speed, change direction, or both — see page 48) if a non-zero net force is acting on it. In other words, a net force is needed for an object to accelerate.

The acceleration of an object is proportional to the net force acting on it. This can be written as the well-known equation:

The acceleration given by this equation is always in the same direction as the net force used to calculate it.

Moments and Torques

A moment, or torque, is a turning effect of a force about a point. It is calculated using this equation,

$$Moment = F \times d$$

Where F is the force and d is the perpendicular distance to the force. It is expressed in units of N m.

Principle of moments:

If an object is in equilibrium;

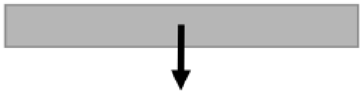
- The **resultant force** on it must be zero.
- The **resultant moment** about any point must be zero. (The clockwise and anticlockwise moments must be equal in magnitude.)

Remember when making calculations with these conditions, you may need to use some trigonometry to calculate **components of the force** or **perpendicular distances** from the pivot.

Centre of gravity:

When using weight of an object in principle of moment questions, you must consider where the weight is acting. Although gravity acts on the whole object its weight can be considered as acting on one point, the **centre of gravity**.

For example, the C of G for this rod is the mid-point.



Net Forces

For two-dimensional problems, with two forces acting at an angle to each other, you can find the net force by drawing a vector triangle. Draw the forces as vector arrows tip-to-tail, then draw in the third side to represent the net force (as shown on page 41).

You can then use trigonometry, such as Pythagoras' theorem (p.252) or the sine and cosine rules (p.488), to calculate the net force.

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Equilibrium

If an object is in **equilibrium**, all the forces acting on it are balanced and cancel each other out. In other words, there's no net force on an object in equilibrium, so it isn't accelerating.

When only two forces act on an object, the object is in equilibrium if they're equal and opposite. If there are three forces acting on an object, there are two ways you can go about solving equilibrium problems:

Triangle of forces

Forces acting on an object in equilibrium form a closed loop when you draw them to scale and tip-to-tail. For the case of three coplanar forces, this will form a triangle of forces.

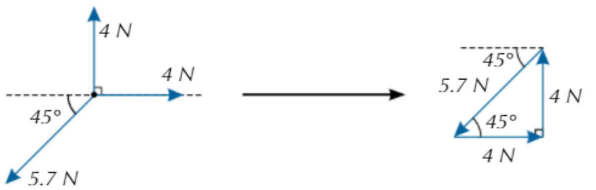
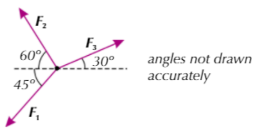


Figure 1: Three balanced force vectors shown acting from a point and in a triangle of forces.



Vertical components	Horizontal components
$-\sin 45° \times F_1$	$-\cos 45° \times F_1$
$\sin 60° \times F_2$	$-\cos 60° \times F_2$
$\sin 30° \times F_3$	$\cos 30° \times F_3$

Pressure

Pressure is the amount of force applied per unit area. It is measured in pascals (Pa), which are equivalent to newtons per square metre ($N\,m^{-2}$). You can calculate the pressure over an area for a solid, liquid or gas using:

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

p = pressure (in Pa), F = force (in N), A = area (in m^2)

The pressure acting on an object due to a fluid can be calculated from the depth of the object in the fluid (h), the density of the fluid (ρ) and the gravitational field strength (g).

$$p = h\rho g$$

p = pressure (in Pa), g = gravitational field strength (in $N\,kg^{-1}$), h = depth (in m), ρ = density (in $kg\,m^{-3}$)

Terminal Velocity

Terminal velocity happens when frictional forces equal the driving force. An object will reach a terminal velocity at some point if there's a driving force that stays the same all the time, and a frictional or drag force (or collection of forces) that increases with speed.

You need to be able to recognise and sketch the graphs for velocity against time and acceleration against time for the terminal velocity situation.

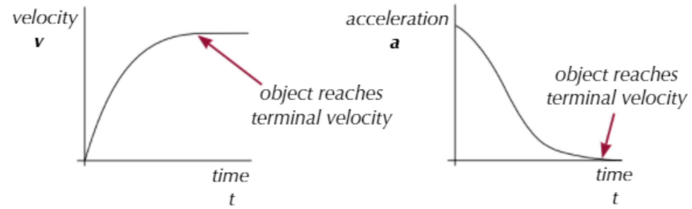


Figure 1: The velocity-time and acceleration-time graphs for an object reaching terminal velocity.

Required Practical 1

Things falling through any fluid will reach a terminal velocity (if it falls for long enough). You can calculate the terminal velocity of a ball bearing in a viscous (thick) liquid (e.g. wallpaper paste) by setting up an experiment like this:

- Put elastic bands around the tube of viscous liquid at fixed distances from the top of the tube (measured with a ruler). Then drop a ball bearing into the tube, and use a stopwatch to record the time at which it reaches each band.
- Repeat this a few times to reduce the effect of random errors on your results, using a strong magnet to remove the ball bearing from the tube.
- Calculate the times taken by the ball bearing to travel between consecutive elastic bands and calculate an average for each reading. Use the average times and the distance between bands to calculate the average velocity between each pair of elastic bands.
- You should find that the average velocity increases at first, then stays constant — this is the ball bearing's terminal velocity in the viscous liquid used.
- Use your average velocity data to plot a graph of velocity against time. Draw a smooth curve and use it to estimate the terminal velocity.

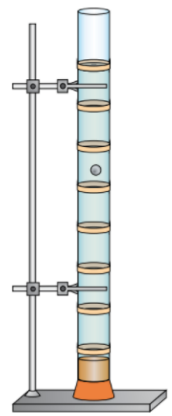


Figure 4: A possible set-up for an investigation into terminal speed in a viscous liquid.