



Forces – Part 2

Keyword	Definition
Balanced (forces)	When forces are equal and opposite each other also called equilibrium
Deformation	A change in shape or size
Force	Something that makes a change happen
Force arrows	Show direction and size of a force
Magnitude	The value of a force in newtons
newton (N)	Unit that force is measured in
Newtonmeter	A spring calibrated so it has a scale to measure force
Pivot	The central point, pin, or shaft on which a mechanism turns
Resultant (force)	The overall force once all the forces are considered
Unbalanced (forces)	When opposing forces are not equal to each other
Vector	Things that have a magnitude and a direction. Forces are always vectors

Work done

When a force causes an object to move through a distance work is done on the object.

work done = force × distance (along line of action of force)

W, = joules, J force, F, = newtons, N. distance, s, = metres

Work done = Force x distance = 25 x 2 = 50Nm (Joules)

One joule of work is done when a force of one newton causes a displacement of one metre. 1 joule = 1 newton-metre

Doing work = increasing energy in gravitational store = 10N x 2m = 20Nm (Joules)

10N (Weight = mg)

Moments (Physics only)

A force or a system of forces may cause an object to rotate. The turning effect of force is called the moment of the force. The size of the moment is defined by the equation:

moment of a force = force × distance

moment of a force, M, in newton-metres, Nm, force, F, in newtons, N, distance, d, is the perpendicular distance from the pivot to the line of action of the force, in metres, m.

Resultant forces

Several forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together. This single force is called the resultant force.

This single resultant force determines:

- The **direction** in which the object will move as a result of all the forces
- The **magnitude** of the final force experienced by the object.

Resultant forces can be calculated by adding or subtracting all of the forces acting on the object

- Forces working in opposite directions are **subtracted** from each other
- Forces working in the same direction are **added** together

Resultant force = 0N Forces balanced

Resultant force = 3N + 7N = 10N Right

Resultant force = 7N – 3N = 4N Left

Free body diagrams – HT only

Each force is represented as a **vector** arrow, where each arrow:

- Is scaled to the **magnitude** of the force it represents
- Points in the **direction** that the force acts
- Is **labelled** with the name of the force it represents

Decide whether the resultant force is approx. up or down

Decide whether the resultant force is approx. left or right

The resultant force is directed **up** and to the **right**

Resolving forces – HT only

A single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.

Example: The tension force in the tow rope causes a horizontal force forwards and a vertical force upwards on the dinghy.

horizontal force forwards = 150 N

vertical force upwards = 50 N

You need a scale example 10N = 1 cm

horizontal force forwards = 150 N = 15cm

vertical force upwards = 50 N = 5cm

Measure this line with a ruler and x 10 to give the force

Horizontal line 150 N = 15cm

vertical line 50 N = 5cm

Gears (Physics only)

Gears

They consist of wheels with toothed edges that rotate on an axle or shaft, which acts as the **pivot**

The teeth of one gear fit into the teeth of another gear. This lets one gear turn the other, meaning one axle or shaft can be used to turn another shaft

As one gear turns, the other must also turn.

Where the gears meet, the teeth will then move in the **same** direction. One of the gears will then move clockwise, and the other anticlockwise (in opposite directions)

Although the force will be the same on both gears, the **moment** will not be. This depends on the size of the gear, which changes the distance of the teeth to the pivot.

- If a larger gear is driven by a smaller gear, the large gear will rotate slower than the smaller gear but will have a greater moment. E.g., a low gear on a bike or car
- If a smaller gear is driven by a larger gear, the smaller gear will rotate quicker than the larger gear but will have a smaller moment. E.g., a high gear on a bike.

This is because the turning force on the larger gear wheel acts further from its pivot than the turning force of the smaller gear wheel acting on its own pivot

Forces and elasticity

Forces can cause stretching, bending or compression of an object. Stretching, bending and compression require **multiple forces** to be acting on an object.

e.g., if you pushed a spring, it would move one direction. But if you pushed both ends of the spring, the spring would compress.

Deformation is a change in shape. An object is said to be deformed when it has changed shape and length, this is due to the effect of the forces. There are two types of deformation: elastic and inelastic.

Elastic deformation is reversible. If an object completely returns to ‘normal’ once all forces are removed, it is said to be elastically deformed. (normal = the object has completely returned to its original shape, size and length).

Inelastic deformation is irreversible. if an object doesn’t completely return to ‘normal’ once all forces are removed, it is said to be inelastically deformed.

The relationship between force and extension (Required Practical)

Hooke’s Law

Hooke’s law is used to describe the relationship between **force applied** to an elastic object and the **extension (or compression)** of the elastic object. It is a linear relationship, where force is directly proportional to the extension. If an object doesn’t obey Hooke’s law, there is a non-linear relationship between force and extension.

force = spring constant × extension

F = k x e

(F) = newtons (N)

(k) = newtons per metre (N/m)

(e), or increase in length, = metres (m)

A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not inelastically deformed, the work done on the spring and the elastic potential energy stored are equal

The work done in stretching (or compressing) a spring (up to the limit of proportionality) can be calculated using :

E_e = ½ k e²

E_e = elastic potential energy (J)

K = spring constant (N/m)

e = extension (m)

You should be able to apply this equation which is given on the Physics equation sheet.

Elastic Potential Energy

When compressed or stretched, the energy in the elastic store of the spring increases.

Levers (Physics only)

Levers

Levers **increase** the size of a **force** acting on an object to make the object turn more easily.

To make a lever work better:

Increase the **size** of the force applied

Increase the **distance** of the force from the pivot.



Forces – Part 2

Keyword	Definition
Conservation of momentum	In an isolated system the total momentum of two or more bodies acting upon each other remains constant unless an external force is applied. Therefore, momentum can neither be created nor destroyed.
Momentum (HT)	Vector quantity that is a property of moving objects [momentum = mass x velocity] (kg m/s) also written as $p = mv$
speed	Speed is a measure of the distance travelled by an object in a given length of time
velocity	The velocity. of an object is its speed in a particular direction. Velocity is a vector.

Momentum – Physics only

Force and momentum

When a force acts on an object that is moving, or able to move, there is a change in **momentum**:

- in equations, change in momentum is shown as $m\Delta v$
- Δv is the change in velocity (Δ is the Greek letter delta, representing 'change in')

Calculating rate of change of momentum

You can combine two equations to show how to calculate the force involved when a change in momentum happens:

force = mass x acceleration

$F = m \times a$

$a = \text{change in velocity/time taken} = \Delta v / \Delta t$

So;

$F = (m \times \Delta v) / \Delta t$

Force = change in momentum/time taken

force (F) in newtons (N)

change in momentum ($m\Delta v$) in kilogram metres per second (kg m/s)

time taken (Δt) is measured in seconds (s)

The equation shows that the force involved is equal to the **rate of change** of momentum.

Example calculation

A 1,500 kg car accelerates from rest to a velocity of 30 m/s. This takes 20 seconds. Calculate the force acting on the car.

$F = (m \times \Delta v) / \Delta t$

$\Delta v = 30 - 0 = 30\text{m/s}$

$F = (1,500 \times 30) / 20$

$F = 2,250\text{N}$

Car safety features

During a collision there is a change in momentum. The force of the collision is equal to the rate of change of momentum. Car safety features such as seatbelts, airbags and crumple zones all work to change the shape of the car, which increases the time taken for the collision.. These different safety features decrease the rate of change of momentum, which decreases the force of the collision on any people within the car.

Stopping distances

In an emergency, a driver must bring their vehicle to a stop in the shortest distance possible:

stopping distance = thinking distance + braking distance

The diagram shows some typical stopping distances for an average car in normal conditions.

Speed (miles per hour)	Thinking distance (m)	Braking distance (m)	Total Stopping distance (m)
10	6	6	12
20	12	24	36
30	18	54	72
40	24	96	120
50	30	150	180
60	36	216	252
70	42	294	336

Reaction times

Reaction time varies from person to person but is between typically 0.2 s and 0.9 s. Longer reaction times increase the **thinking distance** when stopping from a given speed.

There are different ways to **measure reaction times**. One **simple method** involves dropping a ruler between someone’s open thumb and forefinger. The higher the reaction time needed to grasp the falling ruler, the further the ruler falls before being stopped, This is a required practical studied in the Homeostasis unit in Biology.

Braking distance

Forces and braking	
Stopping distance	thinking distance + braking distance
Thinking distance	The distance travelled in the time it takes to react (typically 0.2s)
Factors affecting thinking distance	1. Tiredness 2. Drugs 3. Alcohol 4. Distractions (phones)
Braking distance	The distance travelled under a braking force
Factors affecting braking distance	1. Road conditions (ice, water) 2. Tyre condition 3. Brake condition

Typical stopping distances

It is important to be able to:

- estimate how the stopping distance for a vehicle varies with different speeds
- interpret graphs relating speed to stopping distance

Physics only

Momentum – Higher tier only

Momentum is the product of **mass** and **velocity**. Momentum is also a **vector** quantity - this means it has both a **magnitude** and an associated direction.

For example, an elephant has no momentum when it is standing still. When it begins to walk, it will have momentum in the same direction as it is travelling. The faster the elephant walks, the larger its momentum will be.

Calculating momentum

Momentum can be calculated using the equation:

momentum = mass x velocity

- momentum (p) in kilogram metres per second (kg m/s)
- mass (m) in kilograms (kg)
- velocity (v) in metres per second (m/s)

Example

A lorry has a mass of 7,500 kg. It travels south at a speed of 25 m/s. Calculate the momentum of the lorry.

$p = m \times v$
 $p = 7,500 \times 25$
 $p = 187,500\text{kgm/s (south)}$

Conservation of momentum in a closed system:

total momentum before an event = total momentum after the event

A ‘closed system’ is something that is not affected by external forces. This is called the principle of **conservation of momentum**. Momentum is conserved in **collisions** and **explosions**.

Conservation of momentum explains why a gun or cannon recoils backwards when it is fired. When a cannon is fired, the cannon ball gains forward momentum, and the cannon gains backward momentum. Before the cannon is fired (the ‘event’), the total momentum is zero. This is because neither object is moving. The total momentum of the cannon and the cannon ball after being fired is also zero, with the cannon and cannon ball moving in opposite directions.

Calculations involving collisions

Collisions are often investigated using small trolleys. The diagrams show an example.

Before collision

- 2 kg trolley moving at 3 m/s
- 8 kg trolley at rest (0 m/s)

After collision

- Combined trolley mass: $2 + 8 = 10\text{ kg}$

You can use the principle of conservation of momentum to calculate the velocity of the combined trolleys after the collision.

First calculate the momentum of both trolleys before the collision:

- 2 kg trolley = $2 \times 3 = 6\text{ kg m/s}$
- 4 kg trolley = $8 \times 0 = 0\text{ kg m/s}$

Total momentum before collision = $6 + 0 = 6\text{ kg m/s}$

Total momentum (p) after collision = 6 kg m/s (because momentum is conserved)

Mass (m) after collision = 10 kg

Next, change the subject of $p = m v$ to find v :

- $v = p/m$
- $v = 6 / 10$
- $v = 0.6\text{m/s}$

Useful YouTube links:

Momentum

Change in momentum

Hooke's law RP

Moments



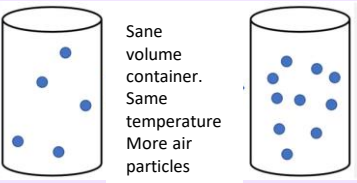
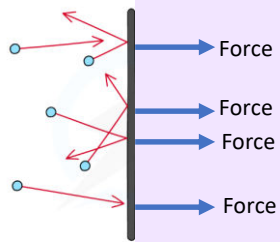


Pressure - Physics only – Paper 1 and Paper 2 content

Keyword	Definition
Force	Force is a vector quantity that affects the motion or shape of a body.
Frequency of collisions	The number of collisions per unit time
Internal energy	The total energy stored inside a system by the particles that make up the system due to their motion and positions The molecules within a substance have energy in their: Kinetic store (due to their random motion / vibration) Potential store (due to their position relative to each other)
Net force	The net force is the sum of all the forces acting on an object
Pressure p	The symbol p is the Greek letter rho. It is pronounced 'row'
Work	work is the energy transferred to or from an object via the application of force.

Pressure in Gases – from Particle Model of Matter – Paper 1

A gas can be compressed or expanded by pressure changes. The pressure produces a net force at right angles to the wall of the gas container (or any surface)



There are **more** collisions **per second** with the **surface of the container** as there are more particles. **The force** of collisions remain the same. Therefore, the pressure increases

Calculating Change in Pressure and Volume

For a fixed mass of a gas held at a constant temperature:

pV = constant

p = pressure in pascals (Pa)

V = volume in metres cubed (m³)

Therefore, pressure and volume are inversely proportional to each other

- When the volume **decreases** (compression), the pressure **increases**
- When the volume **increases** (expansion), the pressure **decreases**

This is because when the volume decreases, the same number of particles collide with the walls of a container but **more frequently** as there is **less space**

However, the particles still collide with the same amount of **force** meaning greater force per unit area (pressure)

The key assumption is that the **temperature** and the **mass** (and number) of the particles remains the same

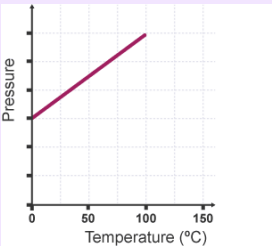
Pressure and temperature

If the volume of a gas in a container remains the same, but it has its temperature increased, the pressure will increase.

This is because the gas particles will be travelling faster and will collide with the walls of the container more frequently, and with more force.

This means that there is a relationship between pressure and temperature. If a pressure gauge is connected to a flask of air and the flask is heated, a graph of pressure against temperature can be produced.

As the temperature increases, the pressure increases showing that pressure is directly proportional to temperature.



Increasing the pressure of a gas

Work is the transfer of energy by a force. Doing work on a gas increases the internal energy of the gas and can cause an increase in the temperature of the gas.

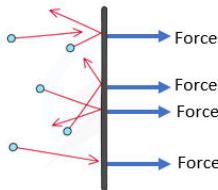
By doing work on a gas (for example increasing its pressure), we can increase the **internal energy** of the gas. In the particle model of matter unit studied previously, we learnt that the internal energy is the combination of kinetic energy and potential energy of the particles.

Internal energy affects temperature. As the internal energy of the particles increases, the **temperature** of the gas also increases. The kinetic energy has been increased and therefore the gas becomes warmer.

Pressure in a fluid – Forces – Paper 2

A fluid can be either a liquid or a gas.

The pressure in fluids causes a force normal (at right angles) to any surface.



The pressure at the surface of a fluid can be calculated using the equation:

pressure = force normal to a surface / area of that surface

$p = F/A$

pressure, p, = pascals, Pa,

force, F, = newtons, N

area, A, = metres squared, m²

Example

A fluid exerts a force of 50 N over an area of 2 m².

Calculate the pressure on the surface.

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

$$p = 50 \div 2$$

$$p = 25 Pa$$



Pressure in a fluid – Forces – Paper 2 - Higher tier only

The pressure due to a column of liquid can be calculated using the equation:

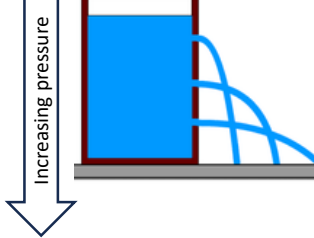
pressure = height of the column × density of the liquid × gravitational field strength [$p = h \rho g$]

pressure, p, = pascals, Pa

height of the column, h, = metres, m

density, ρ, = kilograms per metre cubed, kg/m³

gravitational field strength, g, = newtons per kilogram, N/kg



You should be able to apply this equation which is given on the Physics equation sheet.

The pressure in a liquid changes with depth. This is due to the column of water above. Since the particles in a liquid are tightly packed, this pressure acts in all directions. For example, the pressure acting on the bottom of the water tower is greater than the pressure acting near the top. This is why the jet of water travels further.

Example

The density of water is 1,000 kg/m³. Calculate the pressure exerted by the water on the bottom of a 2.0 m deep water tower. (Gravitational field strength = 9.8 N/kg).

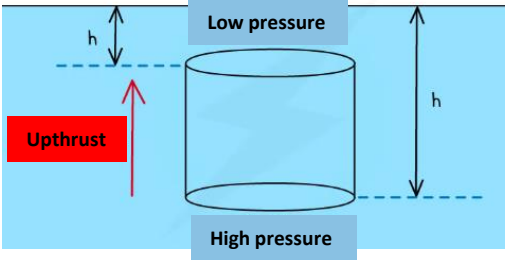
$$p = h \rho g$$

$$p = 2.0 \times 1,000 \times 9.8$$

$$p = 19,600 Pa$$

Upthrust and pressure – Forces – Paper 2 - Higher tier only

Upthrust is due to the difference in pressure between the upper and lower surfaces of a submerged object. A partially submerged object experiences greater pressure on the bottom surface than on the top of it. This is because the pressure is proportional to depth. The difference in pressure creates an overall upwards resultant force (upthrust). This is why objects appear to weigh less when in water.



Useful YouTube links:



Pressure in fluids



Pressure in gases



PV = constant

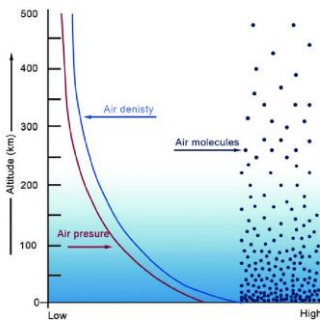


Atmospheric pressure

Atmospheric pressure – Forces – Paper 2

The atmosphere is a thin layer (relative to the size of the Earth) of air round the Earth.

The atmosphere gets less dense with increasing altitude. Air molecules colliding with a surface create atmospheric pressure. The number of air molecules (and so the weight of air) above a surface decreases as the height of the surface above ground level increases. So as height increases there is always less air above a surface than there is at a lower height. So atmospheric pressure decreases with an increase in height.



As the height above the surface increases:

- the number of gas molecules in a given volume of air decreases
- the frequency of collisions with objects in the air decreases
- the pressure decreases

This explains why a helium weather balloon expands as it rises. These balloons are only partly filled at launch. This is so that they do not expand so much that they eventually burst.