

AQA GCSE Physics (Separate Science) Unit 5: Forces

Scalar and Vector Quantities

A scalar quantity has **magnitude** only. Examples include temperature or mass.

A vector quantity has both **magnitude** and **direction**. Examples include velocity.

Speed is the scalar magnitude of velocity.

A vector quantity can be shown using an **arrow**. The size of the arrow is relative to the magnitude of the quantity and the direction shows the associated direction.

Contact and Non-Contact Forces

Forces either **push** or **pull** on an object. This is as a result of its interaction with another object.

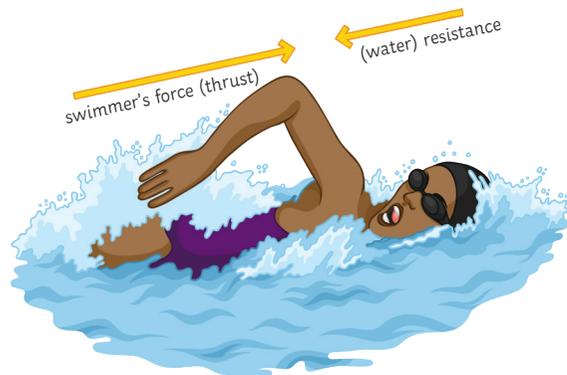
Forces are categorised into two groups:

Contact forces – the objects are touching e.g. friction, air resistance, tension and contact force.

Non-contact forces – the objects are not touching e.g. gravitational, electrostatic and magnetic forces.

Forces are calculated by the equation: $\text{force (N)} = \text{mass (kg)} \times \text{acceleration (m/s}^2\text{)}$

Forces are another example of a **vector quantity** and so they can also be represented by an arrow.



Gravity

Gravity is the natural phenomenon by which any object with mass or energy is drawn together.

- The **mass** of an object is a scalar measure of how much matter the object is made up of. Mass is measured in **kilograms (kg)**.
- The **weight** of an object is a vector measure of how gravity is acting on the mass. Weight is measured in **newtons (N)**.

$$\text{weight (N)} = \text{mass (kg)} \times \text{gravitational field strength (N/kg)}$$

(The gravitational field strength will be given for any calculations. On earth, it is approximately 9.8N/kg).

An object's **centre of mass** is the point at which the weight of the object is considered to be acting. It does not necessarily occur at the centre of the object.

The **mass** of an object and its **weight** are **directly proportional**. As the mass is increased, so is the weight. Weight is measured using a **spring-balance** (or **newton metre**) and is measured in **newtons (N)**.

Resultant Forces

A **resultant force** is a single force which replaces several other forces. It has the same effect acting on the object as the combination of the other forces it has replaced.

The forces acting on this object are represented in a **free body diagram**. The arrows are relative to the magnitude and direction of the force.

The car is being pushed to the left by a force of 30N. It is also being pushed to the right by a force of 50N.



The resultant force is $50\text{N} - 30\text{N} = 20\text{N}$

The 20N resultant force is pushing to the right, so the car will move right.

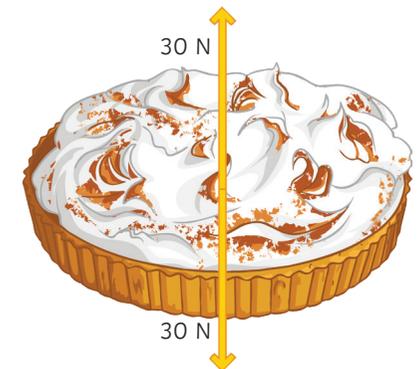
When a resultant force is not zero, an object will **change speed** (accelerate or decelerate) or **change direction** (or both).

When an object is stationary, there are still forces acting upon it.

In this case, the resultant force is $30\text{N} - 30\text{N} = 0\text{N}$.

The forces are in **equilibrium** and are **balanced**.

When forces are balanced, an object will either **remain stationary** or if it is moving, it will continue to move at a **constant speed**.

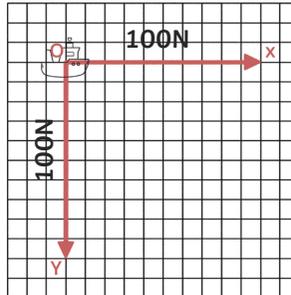


Resultant Forces

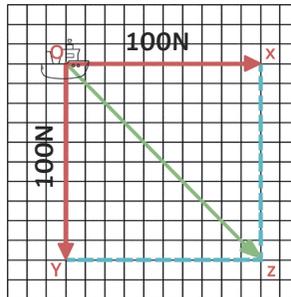
A **vector diagram** can be used to determine the resultant of two forces that are not acting in a straight line.

Worked example 1:

A boat is being pulled toward the harbour by two winch motors. Each motor is pulling with a force of 100N and they are working at right angles to each other. These forces are represented by lines OX and OY.



Construction lines can be added to the diagram to form rectangle OXZY. The line OZ is the diagonal of this rectangle.



OZ is the resultant force. It is the hypotenuse of the right-angle triangles OYZ and OXZ.

We can use the Pythagoras' theorem to calculate its length.

$$a^2 + b^2 = c^2$$

$$100^2 + 100^2 = OZ^2$$

$$100^2 + 100^2 = 20\,000$$

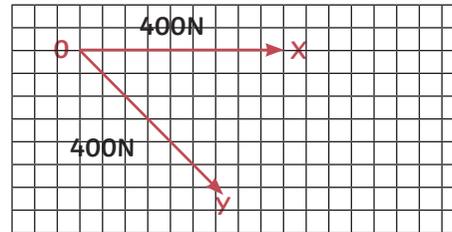
$$\sqrt{20\,000} = 141.42$$

The resultant force is 141.42N.

Alternatively, you can measure line OX and work out how many newtons are represented by each cm. Then measure the length of OZ and use your scale to calculate how many newtons the length represents.

Worked example 2:

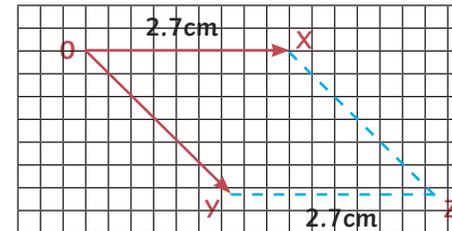
A horse drawn carriage is pulled by two horses with a force of 400N each. The horses are pulling in different directions and are not acting at an angle of 90°. OX and OY represent the force from each horse respectively, they represent the same magnitude of force so they will be the same length.



To calculate the resultant force in this situation we must use a **parallelogram of forces**.

First, measure the length of OX. In this example it is 2.7cm.

Draw a line 2.7cm long from Y, parallel to OX. Connect the end of this line to X to form a parallelogram.



The line OZ is the diagonal of this parallelogram. OZ is the resultant force.

The length of OX is 2.7cm and the force is 400N.

We can work out how many newtons are represented by each cm by doing the calculation:

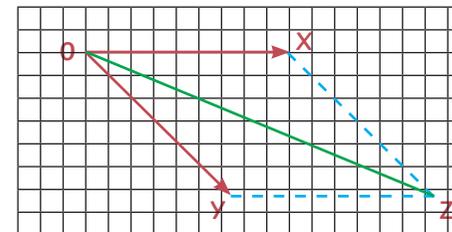
$$400 \div 2.7 = 148.15$$

$$1\text{cm} = 148.15\text{N}$$

Measure OZ. In this example it is 5cm.

$$5 \times 148.15 = 740.74$$

The resultant force is 740.74N.



Work Done and Energy Transfer

When an object is moved by a force, the force transfers energy to the object. The amount of energy transferred to the object is the work done.

The work done on an object depends on the size of the force and the distance moved. It can be calculated using the equation:

$$\text{work done} = \text{force} \times \text{distance}$$

$$W = F s$$

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

$$1 \text{ joule} = 1 \text{ newton metre}$$

Worked example

A man's car has broken down and he is pushing it to the side of the road. He pushes the car with a force of 160N and the car is moved a total of 8m.

Calculate the work done.

$$\begin{aligned} \text{work done} &= \text{force} \times \text{distance} \\ &= 160 \times 8 \\ &= 1280\text{J} \end{aligned}$$

Not all of the energy transferred when work is done on an object is useful. For example, work done against the frictional forces of an object causes a rise in temperature of the object.



Required Practical Investigation Activity 6: Investigate the Relationship Between Force and Extension for a Spring

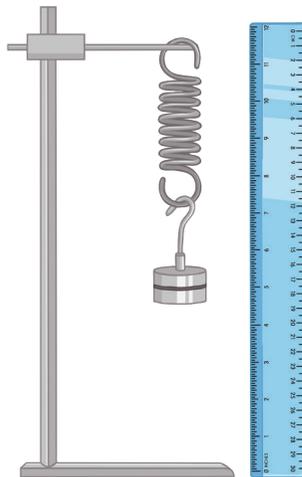
$$F = k \times e$$

force applied (N) = spring constant (N/m) \times extension (m)

You should be familiar with the equation above and the required practical shown to the right.

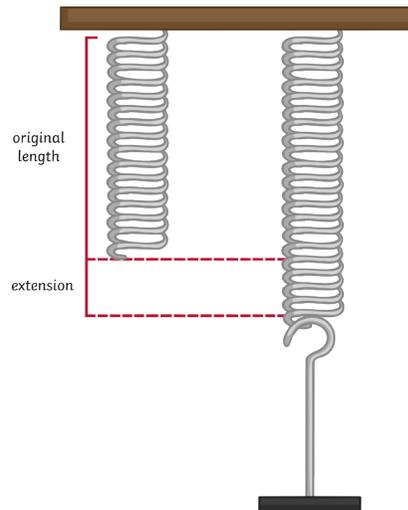
The spring constant is a value which describes the elasticity of a material. It is specific to each material. You can carry out a practical investigation and use your results to find the spring constant of a material.

1. Set up the equipment as shown.
2. Measure the original length of the elastic object, e.g. a spring, and record this.
3. Attach a mass hanger (remember the hanger itself has a weight). Record the new length of the spring.
4. Continue to add masses to the hanger in regular intervals and record the length each time.



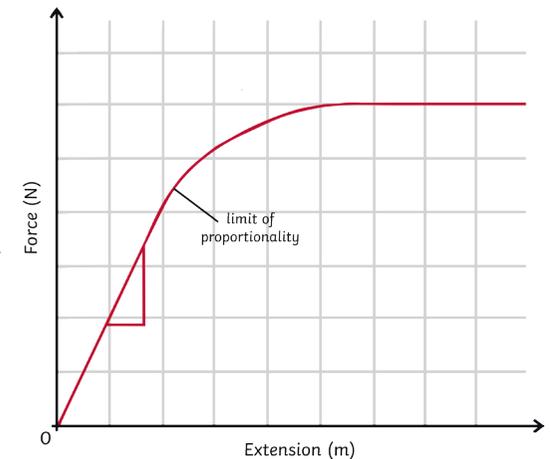
Once you have your results, you can find the extension for each mass using this formula: $\text{spring length} - \text{original length}$

The data collected is continuous so you would plot a **line graph** using the x-axis for extension (m) and the y-axis for force (N). As a result of Hooke's Law, you should have a **linear graph**. The **gradient of the graph is equal to the spring constant**. You can calculate it by rearranging the formula above or by calculating the gradient from your graph.



Spring Constant and Hooke's Law

Hooke's Law describes that the extension of an elastic object is **proportional** to the force applied to the object. However, there is a maximum applied force for which the extension will still increase proportionally. If the **limit of proportionality** is exceeded, then the object becomes **permanently deformed** and can no longer return to its original shape. This can be identified on a graph of extension against force when the gradient stops being linear (a straight line) and begins to **plateau**. The limit is shown on the graph above and this is the specific object's **elastic limit**.



Forces and Elasticity

When work is done on an elastic object, such as a spring, the energy is stored as elastic potential energy.

When the force is applied, the object changes shape and stretches. The energy is stored as elastic potential and when the force is no longer applied, the object returns to its original shape. The stored elastic potential energy is transferred as kinetic energy and the object recoils and goes back to its original shape.



Work Done: Elastic Objects

Work is done on elastic objects to stretch or compress them.

To calculate the work done (elastic potential energy transferred), use this equation:

$$E (J) = 0.5 \times k \times e^2$$

(elastic potential energy = $0.5 \times$ spring constant \times extension²)

You might need to use this equation also: $F = k \times e$

Worked example:

A bungee jumper jumps from a bridge with a weight of 800N. The elastic cord is stretched by 25m. Calculate the work done.

Step 1: find the spring constant using $F = k \times e$

Rearrange to $k = F \div e$

$$800 \div 25 = 32\text{N/m}$$

Step 2: use the value for k to find the elastic potential energy (work done) using

$$E (J) = 0.5 \times k \times e^2$$

$$0.5 \times 32 \times 25^2$$

$$E = 10\,000\text{J}$$

Moments, Levers and Gears

A moment is the turning effect produced by a force. To find the size of a moment, use the equation:

$$\text{moment (Nm)} = \text{force (N)} \times \text{distance (m)}$$

Remember that the distance is the perpendicular distance from the pivot to the line of action of the force.

Worked example:

A crowbar is being used to lift a manhole cover. Calculate the moment produced.

$$M = F \times d$$

$$M = 10 \times 0.4$$

$$m = 40\text{Nm}$$

To increase the turning effect achieved without increasing the amount of force applied, you would need to increase the distance between the force and the pivot.

For example, if the crowbar in the example above was 0.5m, then the moment would be:

$$M = F \times d$$

$$M = 10 \times 0.5$$

$$M = 50\text{Nm}$$

Levers can be used to increase the effect of a force applied, acting as a force multiplier. Some everyday examples include:

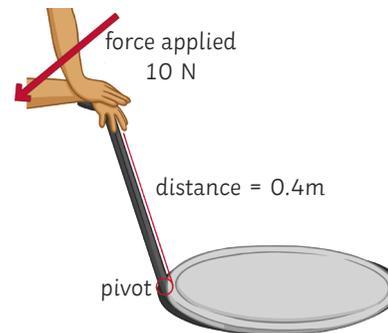
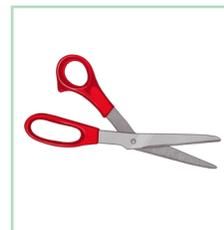
spanner



wheelbarrow



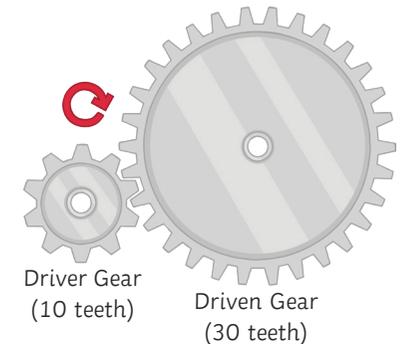
pair of scissors



A force multiplier makes it easier to do work because the same force applied at a greater distance from the pivot increases the moment produced.

A gear is a wheel which has 'teeth' around the circumference.

The teeth of different gears lock together and the gear can turn on an axle, turning the other gears it is connected to. Where the teeth meet, they must move in the same direction. This means that the gears rotate in **opposite directions**. If one gear is turning clockwise, it will turn the connected gear anticlockwise.



When gears are connected, the same force is applied to each; however, if they are different sizes, they will produce **different moments**. This is because the moment is calculated using the distance from the pivot (the radius of the gear) and if the gear is smaller, it will move a shorter distance. If the gear is larger, it will move a greater distance.

Worked example:

A gear has a radius of 0.25m. It turns a second gear with a radius of 1.5m. The moment of the smallest gear is 30Nm. Calculate the moment of the largest gear.

Step 1: calculate the force using $M = F \times d$

Rearrange to $F = M \div d$

$$F = 30 \div 0.25$$

$$F = 120\text{N}$$

Step 2: use the force to calculate the moment of the larger gear.

$$M = F \times d$$

$$M = 120 \times 1.5$$

$$M = 180\text{Nm}$$



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Balanced Moments

When the anticlockwise moment on an object is equal to the clockwise moment, the **resultant moment** is zero and the object does not move or turn.

To balance moments: **total anticlockwise moments = total clockwise moments**

Worked example:

An elephant sits on a seesaw. It has a weight of 750N and is sat 2.5m from the pivot. A mouse with a weight of 60N is sitting on the other side of the seesaw. The seesaw is balanced.

What distance is the mouse from the pivot?

Step 1:	Step 2:	Step 3:
Calculate the anticlockwise moment.	total anticlockwise moments = total clockwise moments	Use the value calculated for the moment to find the distance on the clockwise side.
$M = F \times d$	$1875\text{Nm} = 1875\text{Nm}$	rearrange: $d = M \div F$
$= 750\text{N} \times 2.5\text{m}$		$d = 1875 \div 60$
$= 1875\text{Nm}$		$d = 31.25\text{m}$

Pressure and Pressure Difference in Fluids

A **fluid** is any material in a state of matter which flows; it is a **liquid** or a **gas**.

The pressure in a fluid causes a force at a **right angle** (normal) to the surface.

The pressure is calculated using the equation:

$$\text{pressure (Pa)} = \frac{\text{force (N)}}{\text{surface area (m}^2\text{)}}$$

Worked example:

Find the pressure exerted by an elephant on a frozen pond. The force exerted by the elephant is 4500N and the area of the pond is 30m².

$$p = 4500 \div 30$$

$$p = 150\text{Pa}$$

Pressure in Fluids

You can find the pressure produced by a column of liquid using the equation:

$$\text{pressure (Pa)} = \text{height of column (m)} \times \text{density of liquid (kg/m}^3\text{)} \times \text{gravitational field strength (N/kg)}$$

The more water above an object, then the greater the force applied and the greater the pressure exerted. Scuba divers have to monitor the pressure as they dive to ensure they are not endangering their lives by going too deep.

This can be demonstrated by placing holes in a bucket or other container of water at two different heights.

Water leaking from the hole higher up the bucket will be at a lower pressure than water leaking from the hole lower in the bucket.

When an object is **submerged partially**, it will have a greater pressure on the bottom surface than on the top surface (there is more water behind the force acting upwards). This creates an upwards resultant force called **upthrust** and this is what causes an object to float.



Atmospheric Pressure

Surrounding the earth is a layer of air called the **atmosphere**. Compared to the size of the planet, this layer is relatively thin. The air becomes less dense the farther from the planet's surface you are (with increasing **altitude**).

When the air molecules collide with the surface of the earth, pressure is exerted and this is called **atmospheric pressure**. The amount of air molecules above a surface **decreases with altitude** and so the pressure exerted also **decreases with increasing height**.

Velocity

Velocity is a **vector** quantity. It is the **speed** of an object in a **given direction**.

Circular Motion (Higher tier only)

Objects moving in a **circular path** don't go off in a straight line because of a **centripetal** force caused by another force acting on the object.

For example, a car driving around a corner has a centripetal force caused by **friction** acting between the surface of the road and the tyres. When the Earth orbits around the Sun, it is held in orbit by **gravity** which causes the centripetal force.

When an object is moving in a circular motion, its **speed** is **constant**. Its **direction changes** constantly and because direction is related to **velocity**, this means that the velocity of the object is constantly changing too. The changes in velocity mean that the object is **accelerating**, even though it travels at a constant speed.

The acceleration occurs because there is a **resultant force** acting on the object. In this case, the resultant force is the velocity, which is greater than the centripetal force acting.



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Forces and Motion: Distance vs Displacement

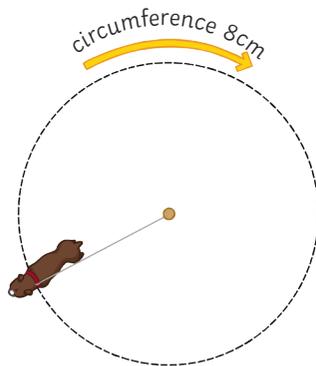
Distance is a scalar quantity. It measures how far something has moved and does not have any associated direction.

Displacement is a vector quantity. It measures how far something has moved and is measured in relation to the direction of a straight line between the starting and end points.

E.g. A dog is tethered to a post. It runs 360° around the post three times. Each 360° lap is 8m

$$\text{distance} = 8 \times 3 = 24\text{m}$$

displacement = 0m (The dog is in the same position as when it started.)



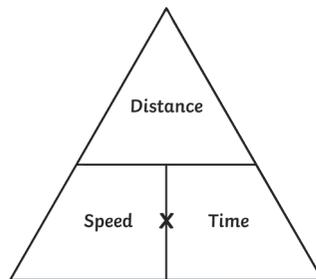
Speed

You should be able to recall the typical speed of different transportation methods.

Activity	Typical Value
walking	1.5m/s
running	3m/s
cycling	6m/s
driving a car	25mph (40km/h)
train travel	60mph (95km/h)
aeroplane travel	550mph (885km/h)
speed of sound	330m/s

These values are average only. The speed of a moving object is rarely constant and always fluctuating.

$$\text{speed} = \text{distance} \div \text{time}$$



You should be able to use this equation and rearrange it to find the distance or time.

Worked example:

John runs 5km. It takes him 25 minutes. Find his average speed in metres per second.

Step 1: convert the units

$$\text{km} \rightarrow \text{m} (\times 1000) = 5000\text{m}$$

$$\text{min} \rightarrow \text{s} (\times 60) = 1500\text{s}$$

Step 2: calculate $s = d \div t$

$$s = 5000 \div 1500$$

$$s = 3.33\text{m/s}$$

Worked example 2:

Zi Xin has driven along the motorway. Her average speed is 65mph. She has travelled 15 miles. How long has her journey taken? Give your answer in minutes.

Step 1: calculate $t = d \div s$

$$t = 15 \div 65$$

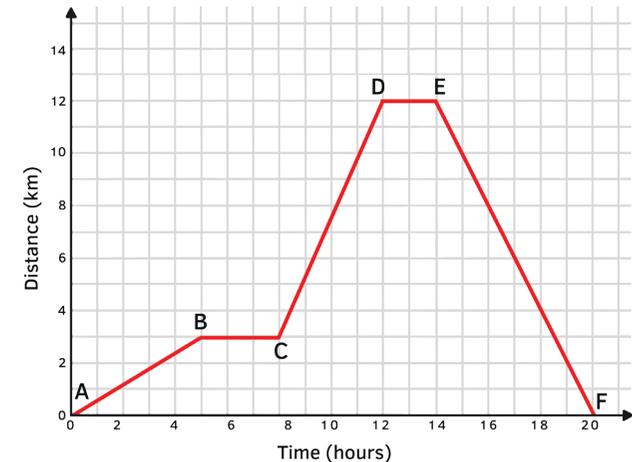
$$t = 0.23 \text{ (hours)}$$

Step 2: convert units

$$\text{hr} \rightarrow \text{min} (\times 60) = 13.8 \text{ minutes}$$

Distance-Time and Velocity-Time Graphs

When an object travels in a straight line, we can show the distance which has been covered in a distance-time graph.

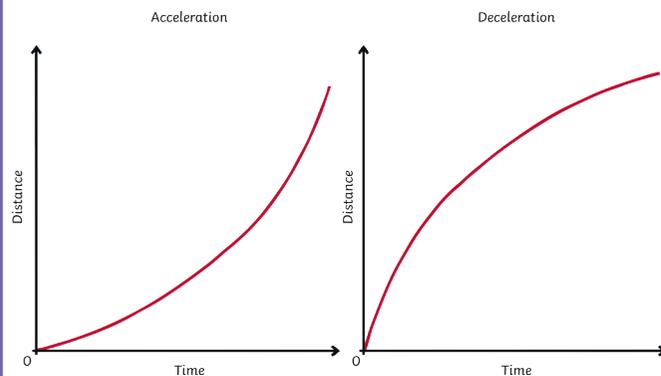


You should be able to understand what the features of the two types of graph can tell you about the motion of an object.

Graph Feature	Distance-Time Graph	Velocity-Time Graph
x-axis	time	time
y-axis	distance	velocity
gradient	speed	acceleration (or deceleration)
plateau	stationary (stopped)	constant speed
uphill straight line	steady speed moving away from start point	acceleration
downhill straight line	steady speed returning to the start point	deceleration
uphill curve	acceleration	increasing acceleration
downhill curve	deceleration	increasing deceleration
area below graph		distance travelled



Changing Speed on a D-T graph



When the graph is a **straight line**, it is representing a **constant speed**. A curve represents a changing speed, either acceleration or deceleration. The speed at any given point can be calculated by drawing a **tangent** from the curve and finding the **gradient** of the tangent.

Terminal Velocity

When an object begins moving, the force **accelerating** the object is much greater than the force resisting the movement. A resistant force might be **air resistance** or **friction**, for example.

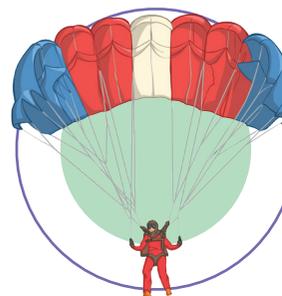
As the **velocity** of the object increases, the force **resisting** the movement also increases. This causes the acceleration of the object to be reduced gradually until the forces become **equal** and are **balanced**. This doesn't cause the object to stop moving. As the object is already in motion, balanced forces mean it will continue to move at a **steady speed**. This steady speed is the maximum that the object can achieve and is called the **terminal velocity**.

The terminal velocity of an object depends on its shape and weight. The shape of the object determines the amount of resistant force which can act on it. For example, an object with a large surface area will have a greater amount of resistance acting on it.

Consider a skydiver and his parachute. When the skydiver first jumps from the aeroplane, he has a small area where the air resistance can act. He will fall until he reaches a terminal velocity of approximately 120mph.



After the skydiver releases his parachute, the shape and area has been changed and so the amount of air resistance acting is increased. This causes him to decelerate and his terminal velocity is reduced to about 15mph. This makes it a much safer speed to land on the ground.



Acceleration

Acceleration can be calculated using the equation:

$$\text{acceleration (m/s}^2\text{)} = \frac{\text{change in velocity (m/s)}}{\text{time taken (s)}}$$

Worked example:

A dog is sitting, waiting for a stick to be thrown. After the stick is thrown, the dog is running at a speed of 4m/s. It has taken the dog 16s to reach this velocity. Calculate the acceleration of the dog.

$$a = \Delta v \div t$$

$$a = (4-0) \div 16$$

$$A = 0.25\text{m/s}^2$$

Changes in velocity due to acceleration can be calculated using the equation below. This equation of motion can be applied to any moving object which is travelling in a **straight line** with a **uniform acceleration**.

$$\text{Final velocity}^2 \text{ (m/s)} - \text{initial velocity}^2 \text{ (m/s)} = 2 \times \text{acceleration (m/s}^2\text{)} \times \text{displacement (m)}$$

or

$$v^2 - u^2 = 2as$$

Worked example:

A bus has an initial velocity of 2m/s and accelerates at 1.5m/s² over a distance of 50m. Calculate the final velocity of the bus.

Step 1: rearrange the equation: $v^2 - u^2 = 2as$

$$v^2 = 2as + u^2$$

Step 2: insert known values and solve

$$v^2 = (2 \times 1.5 \times 50) + 2^2$$

$$v^2 = (150) + 4$$

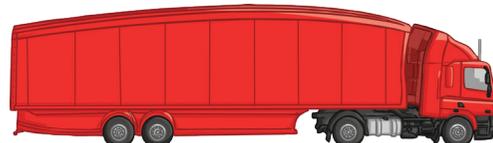
$$v^2 = 154$$

$$v = \sqrt{154}$$

$$v = 12.41\text{m/s}$$



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Stopping Distance	Newton's Laws of Motion: Newton's First Law	Newton's Laws of Motion: Newton's Second Law	Momentum
<p>The stopping distance of a vehicle is calculated by: stopping distance = thinking distance + braking distance</p> <p>Reaction time is the time taken for the driver to respond to a hazard. It varies from 0.2s to 0.9s between most people.</p> <p>Reaction time is affected by:</p> <ul style="list-style-type: none"> tiredness drugs alcohol distractions <p>You can measure human reaction time in the lab using simple equipment: a metre ruler and stopwatch can be used to see how quickly a person reacts and catches the metre ruler. The data collected is quantitative and you should collect repeat readings and calculate an average result.</p>	<p>If the resultant force acting on an object is zero...</p> <ul style="list-style-type: none"> a stationary object will remain stationary. a moving object will continue at a steady speed and in the same direction. <p>100N resistance (friction and air) 100N thrust</p>  <p>Inertia – the tendency of an object to continue in a state of rest or uniform motion (same speed and direction).</p>	<p>The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to the mass of the object</p> <p>resultant force (N) = mass (kg) × acceleration (m/s²)</p> <p>Inertial mass – how difficult it is to change an objects velocity. It is defined as the ratio of force over acceleration.</p>	<p>momentum (N) = mass (kg) × velocity (m/s)</p> <p>The law of conservation of mass (in a closed system) states that the total momentum before an event is equal to the total momentum after an event.</p> <p>Worked example:</p> <p>Calculate the momentum of a 85kg cyclist travelling at 7m/s.</p> $p = m \times v$ $p = 85\text{kg} \times 7\text{m/s}$ $p = 595\text{kg m/s}$ <p>Worked example: 2</p>
		Newton's Laws of Motion: Newton's Third Law	
		<p>When two objects interact, the forces acting on one another are always equal and opposite.</p> <p>For example, when a book is laid on the table, it experiences a reaction force from the table. The table pushes up on the book. The book also pushes down on the table. These two forces are equal and opposite.</p>	

Braking Distance

The braking distance is the distance travelled by a vehicle once the brakes are applied and until it reaches a full stop.

Braking distance is affected by:

- adverse weather conditions (wet or icy)
- poor vehicle condition (brakes or tyres)

When force is applied to the brakes, work is done by the friction between the car wheels and the brakes.

The work done reduces the kinetic energy and it is transferred as heat energy, increasing the temperature of the brakes.

increased speed = increased force required to stop the vehicle

increased braking force = increased deceleration

Large decelerations can cause a huge increase in temperature and may lead to the brakes overheating and the driver losing control over the vehicle

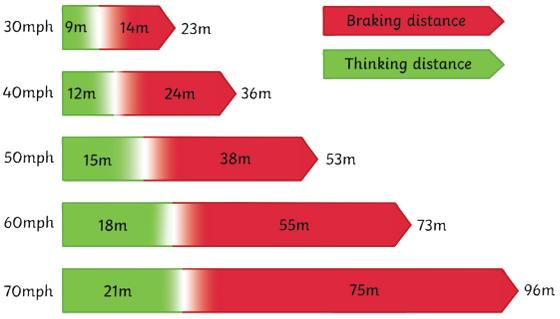
30mph 9m 14m 23m

40mph 12m 24m 36m

50mph 15m 38m 53m

60mph 18m 55m 73m

70mph 21m 75m 96m



Braking distance

Thinking distance

Distance (metres)

A lorry with a mass of 12 000kg, travelling at 20m/s, collides with a stationary car with a mass of 1500kg. After the collision, the vehicles move off together. Calculate their velocity.

Step 1: find the momentum of each vehicle before the collision.

Calculate the momentum of the lorry:

$$p = m \times v$$

$$p = 12\ 000 \times 20 = 240\ 000\text{kg m/s}$$

Calculate the momentum of the car:

$$p = m \times v$$

$$p = 1500 \times 0 = 0\text{kg m/s}$$

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Step 2: find the total momentum before the collision.

total momentum before = $240\,000 + 0 = 240\,000\text{kg m/s}$

Step 3: use the law of conservation of momentum and rearrange the equation.

total momentum before collision = total momentum after collision

$$\frac{p}{m} = v$$

$240\,000\text{kg m/s} \div (12\,000 + 1500) = 17.78\text{m/s}$.

Worked example: 3

A cannon fires a 5kg cannonball at a velocity of 90m/s. The cannon recoils at a velocity of 2m/s after the explosion. Calculate the mass of the cannon.

Step 1: find the total momentum before the explosion.

$p = m \times v$ (for the cannonball)

$p = 5 \times 90 = 450\text{kg m/s}$

Although you don't have all the information to calculate the momentum of the cannon, you know it is zero because it is stationary and therefore has a velocity of zero. Since momentum is mass \times velocity, you know the momentum will be zero regardless of the mass.

total momentum before = 450kg m/s

Step 2: use the law of conservation of momentum and rearrange the equation.

total momentum before explosion = total momentum after explosion

$$\frac{p}{v} = m$$

$450\text{kg m/s} \div 2\text{m/s} = 225\text{kg}$

Changes in Momentum

When a force acts on a moving or moveable object there is a **change of momentum**.

The equations for calculating force and acceleration can be combined:

$$F = m \times a \text{ and } a = (v - u) \div t$$

To give:

force(N) = change in momentum (kg m/s) \div time taken (s)

or

$$F = \frac{m\Delta v}{\Delta t}$$

This equation tells you that the force is equal to the rate of change of momentum in the object.

Car Safety Features

When people are travelling in a moving car, they have momentum. If the car were to crash and become stationary all of a sudden, the passengers would lose all their momentum. This would result in a large force being exerted; therefore, it is important to change the momentum gradually.

This is done by the seatbelts and the air bags which are fitted into vehicles.

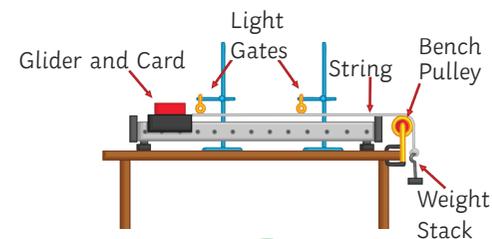
An airbag is also designed to reduce the momentum. The air bag is filled with air as is it deployed and has a small hole inside. As the person makes contact with the airbag, the air is slowly released from the hole and the person is slowed down more gradually.

The force exerted on the passenger is reduced because the time taken to slow them down is increased.

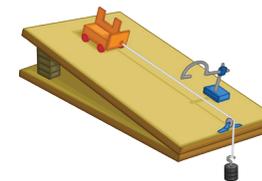
Required Practical Investigation 7

Aim: investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.

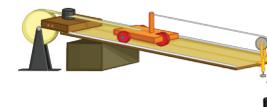
You may be given any of the following apparatus set-ups to conduct these investigations:



or



or



Something is a fair test when only the independent variable has been allowed to affect the dependent variable.

The independent variable was force.

The dependent variable was acceleration.

The control variables were:

- same total mass
- same surface/glider/string/pulley (friction)
- same gradient if you used a ramp

