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.

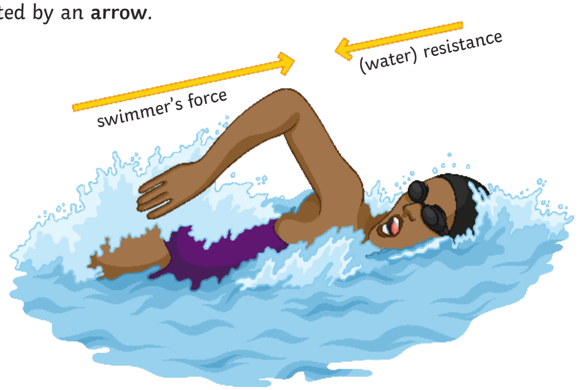
Forces are categorised into two groups:

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: **force (N) = mass (kg) × acceleration (m/s²)**

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)**.

weight (N) = mass (kg) × gravitational field strength (N/kg)

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

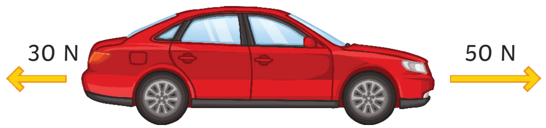
An object's **centre of mass** is the point at which the weight of the object is considered to be acting. It does not necessarily occur at the centre of the object.

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.

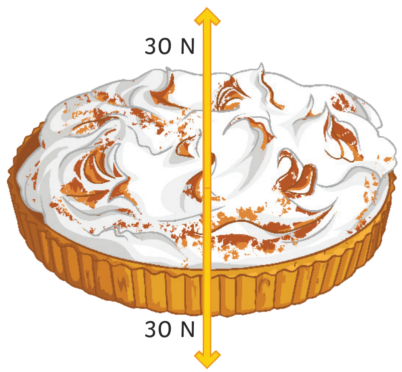


The car is being pushed to the left by a force of 30N. It is also being pushed to the right by a force of 50N.

The **resultant force is 50N – 30N = 20N**

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 30N – 30N = 0N**.

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**.

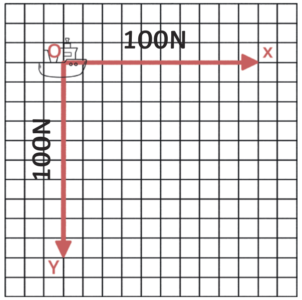
When resultant forces act along the same line, you calculate the resultant force as shown below.

Resultant Forces

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

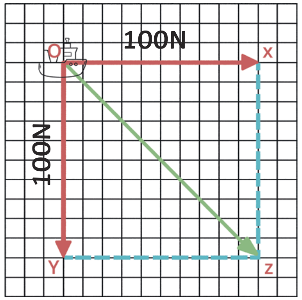
Worked example 1:

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.

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

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

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

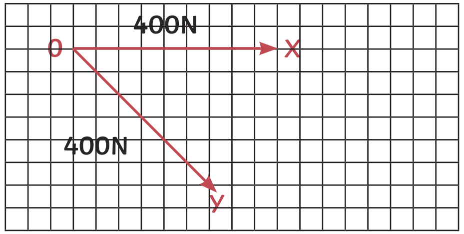
$\sqrt{20\,000} = 141.42$

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:

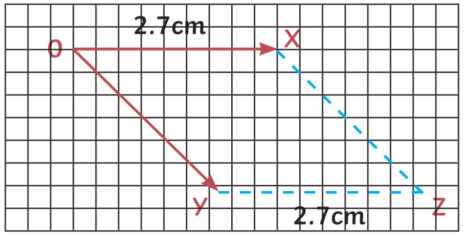
A horse drawn carriage is pulled by two horses with a force of 400N each. The horses are pulling in different directions and are not acting at an angle of 90°. OX and OY represent the force from each horse respectively, they represent the same magnitude of force so they will be the same length.



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.



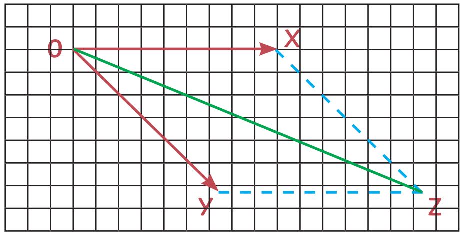
The line OZ is the diagonal of this parallelogram. OZ is the resultant force.

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 ÷ 2.7 = 148.15

1cm = 148.15N



Measure OZ. In this example it is 5cm.

5 × 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:

work done = force × distance

W = F s

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

1 joule = 1 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.

work done = force × distance

= 160 × 8

= 1280J

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.

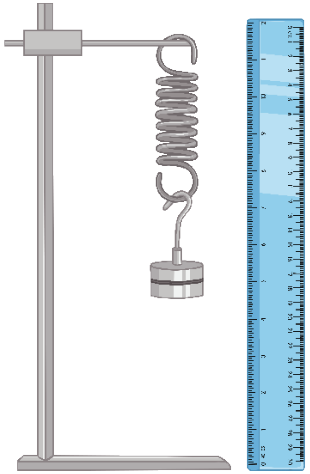
Required Practical Investigation Activity 6: Investigate the Relationship Between Force and Extension for a Spring

F = k × e

force applied (N) = spring constant (N/m) × extension (m)

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

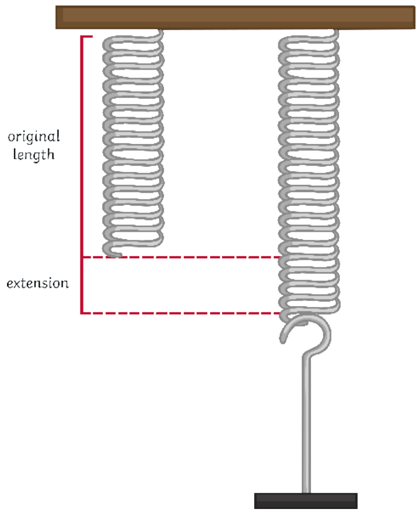
The spring constant is a value which describes the elasticity of a material. It is specific to each material. You can carry out a practical investigation and use your results to find the spring constant of a material.



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.

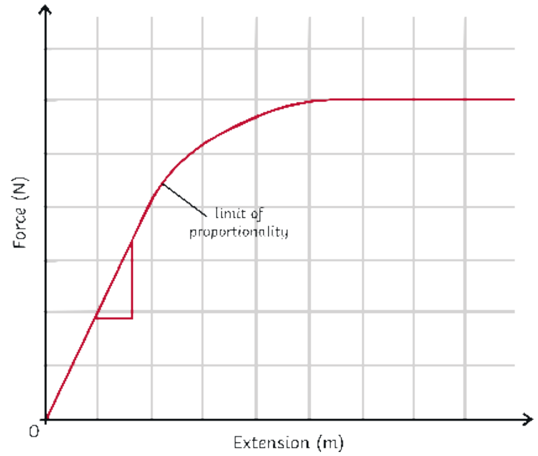
Once you have your results, you can find the extension for each mass using this formula: **spring length – original length**

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

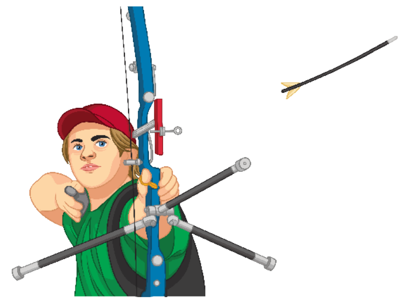
Hooke's Law describes that the extension of an elastic object is **proportional** to the force applied to the object. However, there is a maximum applied force for which the extension will still increase proportionally. If the **limit of proportionality** is exceeded, then the object becomes **permanently 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 × k × e^2

(elastic potential energy = 0.5 × spring constant × extension^2)

You might need to use this equation also: F = k × 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 × e

Rearrange to k = F ÷ e

800 ÷ 25 = 32N/m

Step 2: use the value for k to find the elastic potential energy (work done) using E (J) = 0.5 × k × e^2

0.5 × 32 × 25^2

E = 10 000J

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.

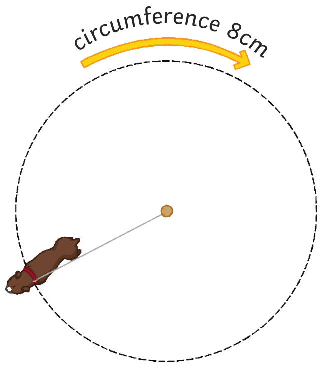
When an object is moving in a circular motion, its **speed** is **constant.** Its **direction changes** constantly and because direction is related to **velocity**, this means that the velocity of the object is constantly changing too. The changes in velocity mean that the object is **accelerating**,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

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

distance = 8 × 3 = 24m

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

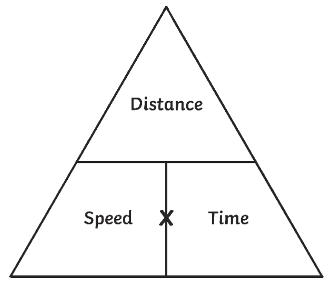
Speed

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.

speed = distance ÷ 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

km → m (×1000) = 5000m

min → s (×60) = 1500s

Step 2: calculate s = d ÷ t

s = 5000 ÷ 1500

s = 3.33m/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 ÷ s

t = 15 ÷ 65

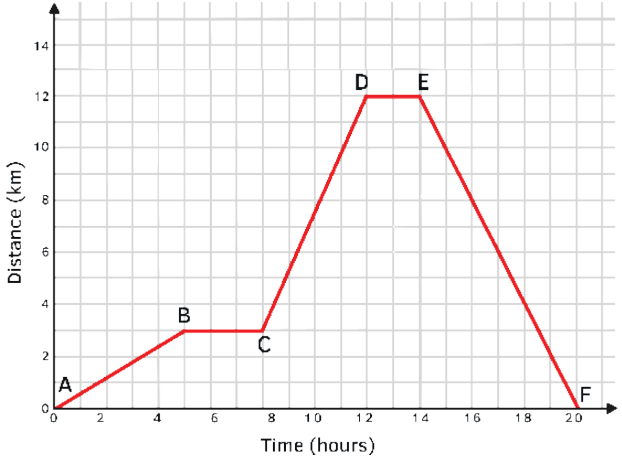
t = 0.23 (hours)

Step 2: convert units

hr → min (×60) = 13.8 minutes

Distance-Time and Velocity-Time Graphs

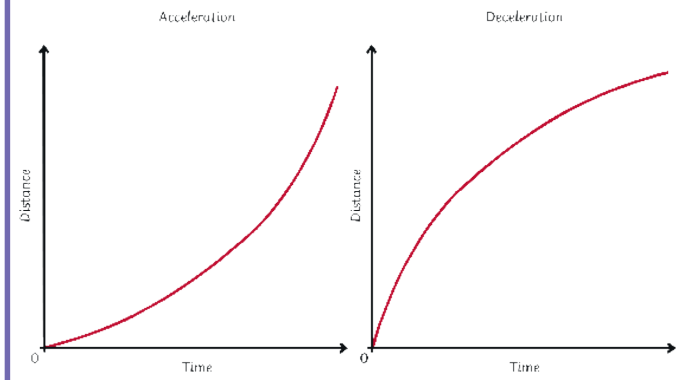
When an object travels in a **straight line**, we can show the distance which has been covered in a **distance-time graph**.



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

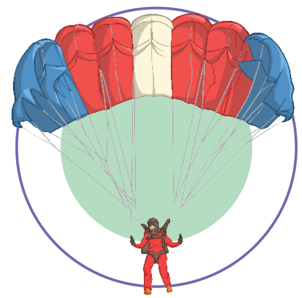
When an object begins moving, the force **accelerating** the object is much greater than the force resisting the movement. A resistant force might be **air resistance** or **friction**, for example.

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:

acceleration (m/s²) = change in velocity (m/s) / time taken (s)

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

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 = Δv ÷ t

a = (4-0) ÷ 16

A = $0.25 m/s^2$

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**.

Final velocity² (m/s) – initial velocity² (m/s) = 2 × acceleration (m/s²) × displacement (m)

or

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

Worked example:

A bus has an initial velocity of 2m/s and accelerates at $1.5 m/s^2$ 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

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

$v^2 = (150) + 4$

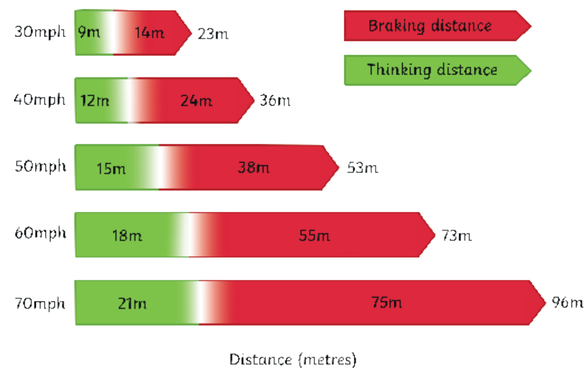
$v^2 = 154$

$v = \sqrt{154}$

v = 12.41m/s

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

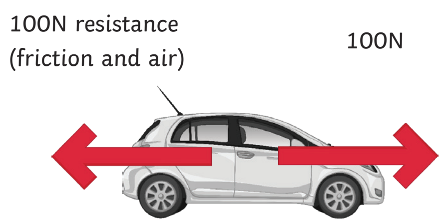
increased braking force = increased deceleration

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

Newton's Laws of Motion: Newton's First Law

If the resultant force acting on an object is zero...

- **a stationary object will remain stationary.**
- **a moving object will continue at a steady speed and in the same direction.**



Inertia – the tendency of an object to continue in a state of rest or uniform motion (same speed and direction).

Newton's Laws of Motion: Newton's Second Law

The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to the mass of the object

resultant force (N) = mass (kg) × acceleration (m/s^2)

Inertial mass – how difficult it is to change an objects velocity. It is defined as the ratio of force over acceleration.

Newton's Laws of Motion: Newton's Third Law

When two objects interact, the forces acting on one another are always equal and opposite.

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.

Stopping Distance

The **stopping distance** of a vehicle is calculated by:

stopping distance = thinking distance + braking distance

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.

Reaction time is affected by:

- **tiredness**
- **drugs**
- **alcohol**
- **distractions**

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.

Momentum

momentum (N) = mass (kg) × velocity (m/s)

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.

Worked example:

Calculate the momentum of a 85kg cyclist travelling at 7m/s.

p = m × v

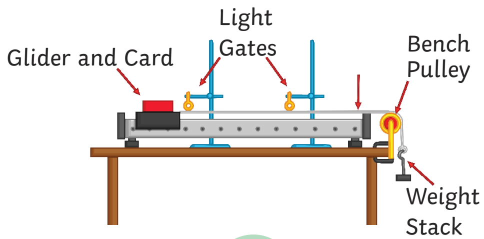
p = 85kg × 7m/s

p = 595kg m/s

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:



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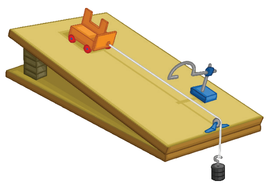

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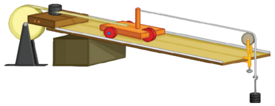

Something is a **fair test** when **only** the independent variable has been allowed to affect the dependent variable.

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**