Cambridge (CIE) IGCSE Physics

Your notes

Effects of Forces

Contents

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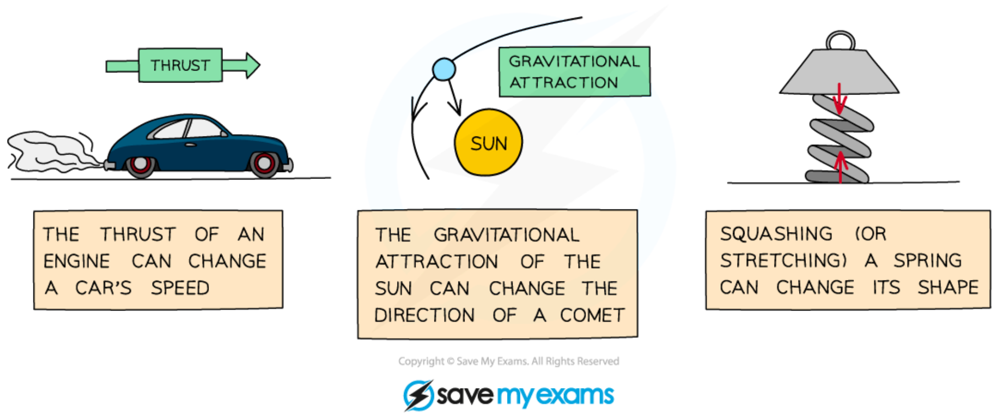
Effects of forces

- A **force** is defined as:

  A push or a pull that acts on an object due to the interaction with another object

- Forces can have a variety of effects on an object
- Forces can change an object's
  - **speed**
  - **direction**
  - **shape**
  - **size**

Effects of forces on different objects



A thrust force can cause a car to speed up, a gravitational force can cause a comet to change direction, compression forces can cause a spring to change shape

- The effects of forces on an object often depend on the type of force acting
  - The push force (thrust) of an engine can cause a car to speed up, whilst the force exerted by the brakes (friction) can cause it to slow down
  - The gravitational pull of the Sun on a comet causes the comet to change direction
  - When two opposing forces push on each end of a spring, the spring changes shape (it compresses)

Resultant forces on a straight line

What is a resultant force?

- A **resultant force** is a single force that describes all of the forces operating on a body
- When multiple forces act on one object, the forces can be combined to produce one net force that describes the **combined action** of all of the forces
- This single resultant force determines:
  - The **direction** in which the object will move as a result of all of the forces
  - The **magnitude** of the net force experienced by the object

Balanced and unbalanced forces

- The forces acting on an object can be described as **balanced** or **unbalanced**
- Forces are **balanced** if multiple forces act in **opposing directions** with an **equal magnitude** in each direction
  - The effects of the forces then **cancel out**
  - There is **no resultant force** in that plane of direction
- Forces are **unbalanced** if the effects of the forces acting in each plane do **not** cancel out
  - There is a **resultant force** in one or more planes of direction
- A book is at rest on a table
  - The gravitational pull of the Earth on the book (weight) acts in a downward direction
  - The push force of the table on the book (normal contact force) acts in the upward direction
  - The forces are equal in magnitude and opposite in direction
  - The forces are therefore balanced
  - There is no resultant force acting on the book

Zero resultant force on a book resting on a table

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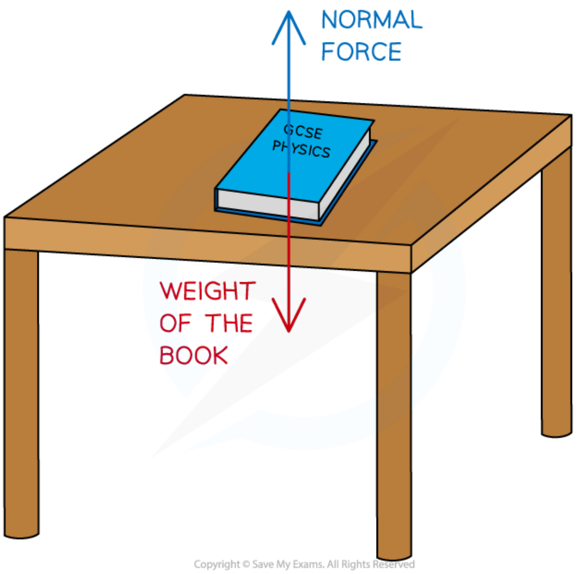

A book resting on a table is an example of balanced forces

Calculating resultant force

- Force is a **vector** quantity; it has both **magnitude** and **direction**
- When adding forces together, it is important to assign positive and negative values to show the direction in which the forces are acting
- If a 5 N force acts to the right and a 5 N force acts to the left on an object, then we assign one of the values as **positive** and one as **negative**
- So the resultant force acting on the object is

$$\text{resultant force} = 5 + (-5)$$

$$\text{resultant force} = 0 \text{ N}$$

- The forces acting on the object are equal in magnitude and opposite in direction; therefore, they cancel one another out
- This is like two people pushing a box with equal force from opposite sides; the box doesn't move
- If two people push the box from the same side in the same direction, one with a 3 N force and one with a 7 N force, then the forces will add together, and the box will move in the direction of the resultant force

$$\text{resultant force} = 3 + 7$$

$$\text{resultant force} = 10 \text{ N}$$

- If two people push the box in opposite directions, one with a 7 N force to the left (negative) and one with a 3 N force to the right (positive), then the forces will add together and the box will move in the direction of the resultant force

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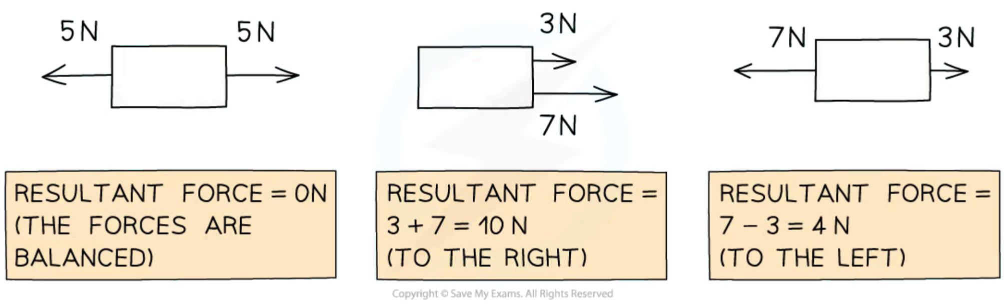
$$\text{resultant force} = (-7) + 3$$

$$\text{resultant force} = -4 \text{ N}$$

- In this case, the box will move to the left with a force of 4 N

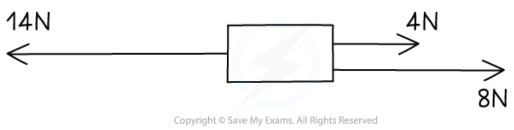
Zero and non-zero resultant forces



Zero and non-zero resultant forces acting on three objects

Worked Example

Calculate the magnitude and direction of the resultant force in the diagram below.



Answer:

Step 1: Assign a direction to the forces

- Forces acting to the right are positive
- Forces acting to the left are negative

Step 2: Add together all the forces acting on the object

$$\text{resultant force} = (-14) + 4 + 8$$

$$\text{resultant force} = (14) + 12$$

$$\text{resultant force} = -2 \text{ N}$$

Step 3: State the magnitude and direction of the resultant force

- The resultant force is 2 N to the left

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Examiner Tips and Tricks

Mathematically, it doesn't matter which direction you assign to be positive or negative, as long as you are consistent throughout your calculation.

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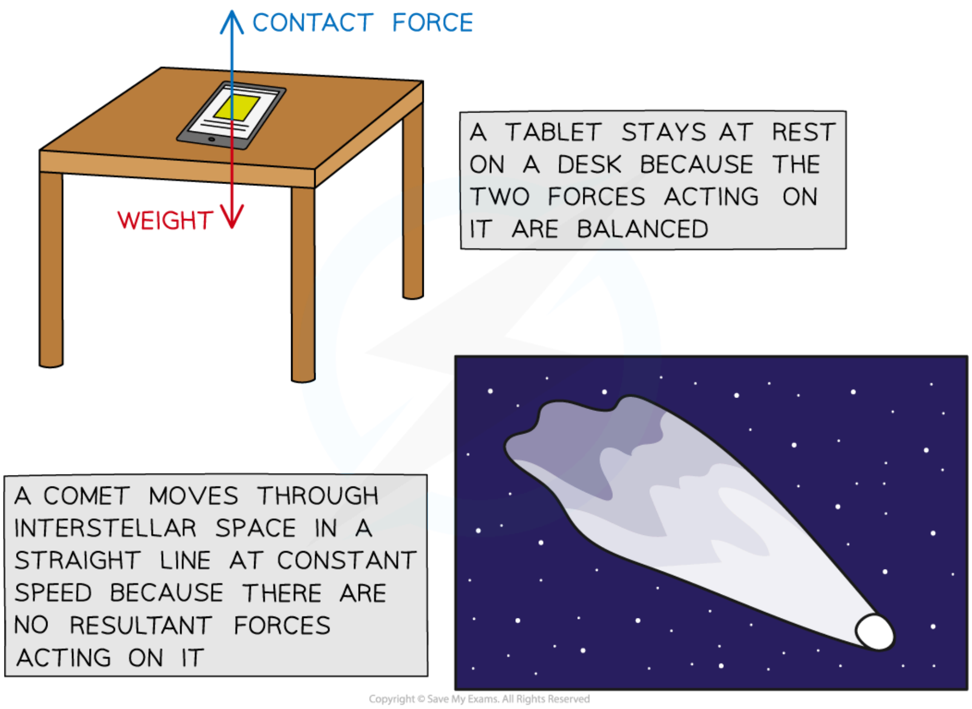
Newton's first law

- Newton's **1st law of motion** states:

Objects will remain at rest, or move with a constant velocity unless acted on by a resultant force

- This means if that:
  - A **stationary** object will **remain** stationary
  - An object **moving** with a **constant** velocity will continue to move at that constant velocity
  - Unless the object is acted upon by a **resultant force**
- Conversely, that means that if an object is at rest, or has a constant velocity, **no** resultant force **can** be acting on it
- Remember that a **constant velocity** means:
  - No change in **speed**
  - No change in **direction**

Objects with Zero Resultant Force



Constant velocity can only be achieved when the forces on an object are balanced – in other words, when the resultant force is zero

Examples of Newton's first law

- A mug on a table will remain stationary on the table unless acted upon by a resultant force
  - For example, if someone picks up the mug, or knocks into the table
- A piece of space debris will continue moving in a straight line at a constant speed unless acted upon by a resultant force
  - For example, if it enters the gravitational field of a planet or collides with an asteroid
- A car travelling in a straight line at a constant speed will continue to travel in a straight line at a constant speed unless acted upon my a resultant force
  - For example, if the driver brakes or accelerates

Worked Example

A student did some online research and found out that the Moon orbits the Earth at a constant speed of around 2000 mph.

The student says that this is not an example of Newton's first law of motion. Is the student correct? Explain your answer.

Answer:

Step 1: Recall Newton's first law of motion

- Newton's first law of motion states that **objects will remain at rest, or move with a constant velocity, unless acted on by a resultant force**

Step 2: Determine if the object in the question is at rest, or if it is moving with a constant velocity

- The Moon, in this case, is **not** at rest
- It is moving at a **constant speed**
- But it is **not** moving in a **constant direction** - it continually orbits the Earth
- Hence, it is not moving with a constant velocity, because velocity is a **vector** quantity

Step 3: State and explain whether the student is correct

- The student is **correct**
- The Moon moves with a **constant speed**, but always **changes direction**
- So it is **not** moving with a **constant velocity**, and is **not** an example of Newton's first law of motion

Worked Example

A car moves at a constant velocity. The driving force from the engine is 3 kN.

Your notes

Your notes

Determine the frictional force acting on the car.

Answer:

Step 1: Recall Newton's first law of motion

- Newton's first law of motion states that **objects will remain at rest, or move with a constant velocity unless acted on by a resultant force**

Step 2: Relate Newton's first law to the scenario

- Since the car is moving at a constant velocity, there is no resultant force
- This means the driving and frictional forces are balanced

Step 3: State the value of the frictional force

- Frictional force, F = driving force = **3 kN**

Examiner Tips and Tricks

Students often struggle to understand how an object can move when there is no resultant force acting on it. You may even have this misconception without realising it.

It is important to fully understand Newton's first law, because it underpins a lot of physics content and can cause you to make mistakes in seemingly unrelated questions.

Usually, students are comfortable with the idea that an object at rest on a table will not move unless something or someone physically moves it. The issue comes from the idea of an object in motion.

A rock drifting through the vacuum of deep space away from the gravitational pull of any large bodies, will continue to drift at that same speed, in that same direction, potentially forever. The only way to change its motion is for a force to be exerted upon it.

On Earth, there are always forces acting on objects, so in our everyday experience we need to think in terms of resultant forces and balanced forces.

A car can maintain a constant velocity when the force from the engine is balanced with the frictional forces opposing its motion (friction between the tyres and road, and air resistance). If nothing changes with these forces, it will continue travelling at a constant velocity. If you do want to change the motion of the car, to speed up or slow down, you need to provide a resultant force. By increasing the force from the engine, you can cause the car to speed up. By either decreasing the force from the engine, or increasing the frictional force (using the brakes) the car will slow down.

When the forces acting on an object are not balanced (a resultant force is exerted) this will cause a change in the object's motion.

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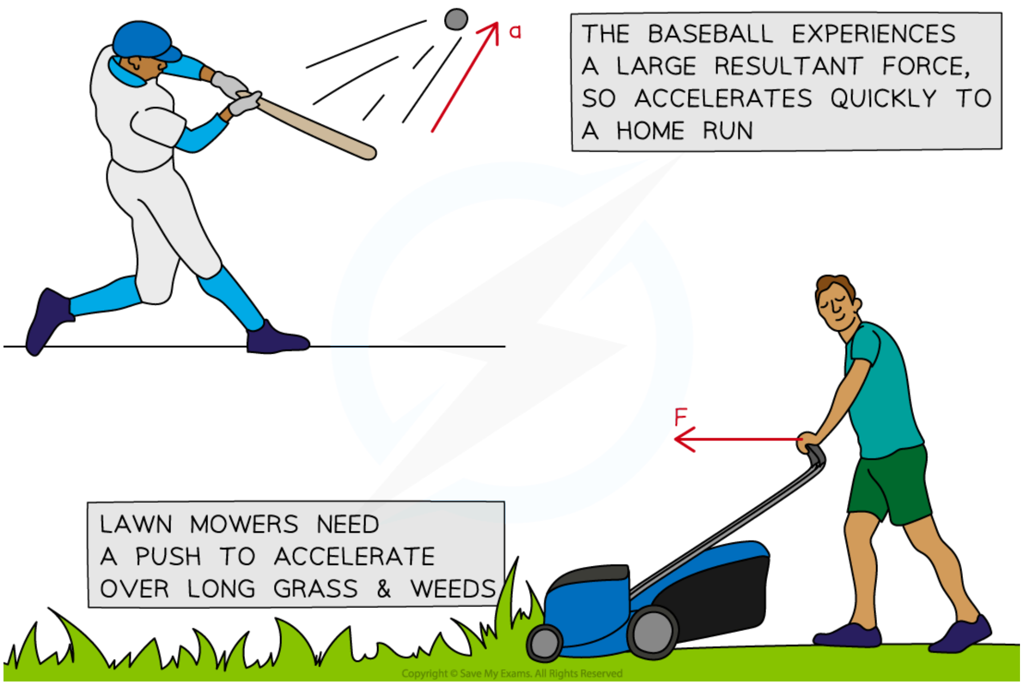
Newton's second law

- Newton's **second law of motion** states:

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

- Newton's second law of motion explains what happens when a **non-zero resultant force** acts on an object
- A resultant force occurs when the forces acting on an object are **not balanced**
- A resultant force acting on an object will cause a **change in the object's motion**
- This change in motion is an **acceleration**:
  - Speeding up
  - Slowing down
  - Changing direction
- If the resultant force on an object is not zero, the object will **accelerate** in the **direction** of the **resultant force**
- The **bigger** this resultant force, the **larger** the acceleration
- For a given force, the **greater** the object's mass, the **smaller** the acceleration experienced

Examples of Newton's second law



Objects like baseballs and lawnmowers accelerate when a resultant force is applied on them. The size of the acceleration is proportional to the size of the resultant force

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Calculations using Newton's second law

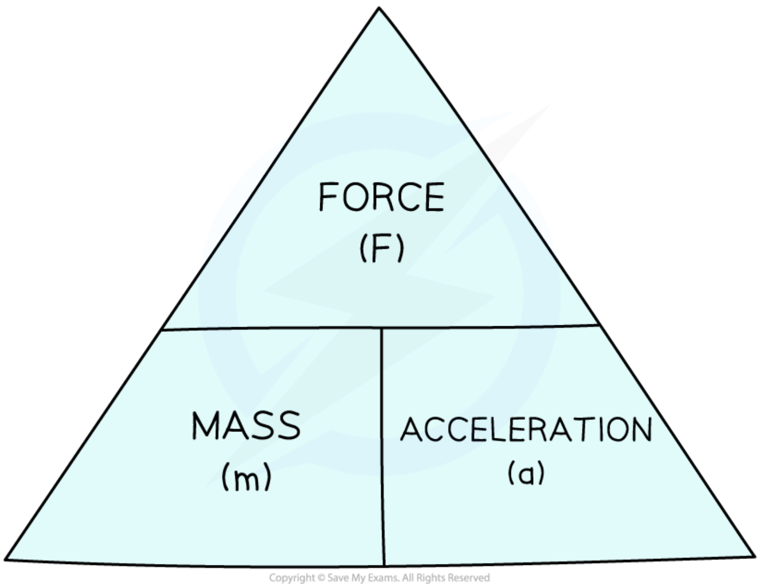
Extended tier only

- Newton's second law can be expressed as an equation:

$$F = ma$$

- Where:
  - F = resultant force on the object, measured in newtons (N)
  - m = mass of the object, measured in kilograms (kg)
  - a = acceleration of the object, measured in metres per second squared (m/s^2)
- The **acceleration** occurs in the **same direction** as the **resultant force**

Formula triangle for acceleration, mass and resultant force



To use a formula triangle, simply cover up the quantity you wish calculate and the structure of the equation is revealed

- A more detailed explanation of how to use formula triangles is covered in the revision note Speed and velocity

Worked Example

A car salesman says that their best car has a mass of 900 kg and can accelerate from 0 to 27 m/s in 3 seconds.

Calculate:

a) the acceleration of the car in the first 3 seconds.

b) the force required to produce this acceleration.

Answer:

Part (a)

Step 1: List the known quantities

- Initial velocity, $v = 0 \text{ m/s}$
- Final velocity, $u = 27 \text{ m/s}$
- Time, $t = 3 \text{ s}$

Step 2: State the equation for acceleration, in terms of change in velocity

$$a = \frac{v - u}{t}$$

$$a = \frac{27 - 0}{3}$$

$$a = 9 \text{ m/s}^2$$

Part (b)

Step 1: List the known quantities

- Mass of the car, $m = 900 \text{ kg}$
- Acceleration, $a = 9 \text{ m/s}^2$

Step 2: Identify which law of motion to apply

- The question involves quantities of **force**, **mass** and **acceleration**, so Newton's second law is required:

$$F = ma$$

Step 3: Calculate the force required to accelerate the car

$$F = 900 \times 9$$

$$F = 8100 \text{ N}$$

Worked Example

Three shopping trolleys, **A**, **B** and **C**, are being pushed using the same force. This force causes each trolley to accelerate.

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State which trolley would have the smallest acceleration. Explain your answer.

Answer: C

Step 1: Identify which law of motion to apply

- The question involves quantities of **force** and **acceleration**, and the image shows trolleys of different **masses**, so **Newton's second law** is required:

$$F = ma$$

Step 2: Re-arrange the equation to make acceleration the subject

$$a = \frac{F}{m}$$

Step 3: Explain the inverse proportionality between acceleration and mass

- Acceleration is **inversely proportional** to mass
- This means that for the **same amount of force**, a **large mass** will experience a **small acceleration**
- Therefore, trolley **C** will have the smallest acceleration because it has the largest mass

Your notes

Investigating springs

Aim of the experiment

- The aim of this experiment is to investigate the relationship between force and extension for a spring

Variables

- **Independent variable** = Force, F
- **Dependent variable** = Extension, x
- Control variables:
  - Spring with spring constant, k

Equipment

Equipment list

Equipment	Purpose
Clamp stand, boss and clamp	To apply an upward force on the spring
Ruler	To measure the extension of the spring
Spring	To measure the extension of
6 × 100 g masses	To apply a downward force on the spring
100 g mass hanger	To hold the additional masses
Pointer	To accurately read the extension from the ruler

Resolution of measuring equipment:

- Ruler = 1 mm

Method

Equipment for investigating the extension of a spring

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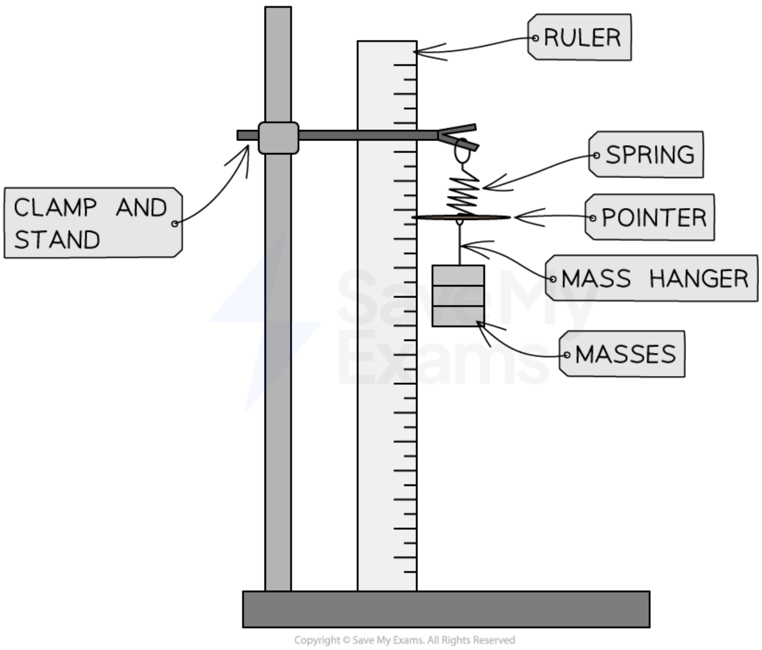

Fixing the ruler to the clamp stand will reduce movement in the ruler and, therefore, reduce errors in measurement

1. Align the marker to a value on the ruler with no mass added to the spring, and record this initial length of the spring
2. Add the 100 g mass hanger onto the spring
3. Record the mass (in kg) and position (in cm) from the ruler now that the spring has extended
4. Add another 100 g to the mass hanger
5. Record the new mass and position from the ruler now that the spring has extended further
6. Repeat this process until all masses have been added
7. The masses are then removed and the entire process is repeated again until it has been carried out a total of three times, and an average length is calculated

Example results table

Your notes

F = mg

AVERAGE LENGTH – ORIGINAL

MASS/kg	FORCE/N	LENGTH 1/m	LENGTH 2/m	LENGTH 3/m	AVERAGE LENGTH/m	EXTENSION/m
0						
0.1						
0.2						
0.3						
0.4						
0.5						
0.6						

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A suitable table of results must contain space for the calculations of force and extension

Analysis of results

- The force, F added to the spring is the weight of the mass
- The weight is calculated using the equation:

$$W = mg$$

- Where:
  - W = weight, measured in newtons (N)
  - m = mass, measured in kilograms (kg)
  - g = gravitational field strength, measured in newtons per kilogram (N/kg)
- Therefore, multiply each mass by gravitational field strength, g = 9.8 N/kg, to calculate the force, F
- The extension of the spring is calculated using the equation:

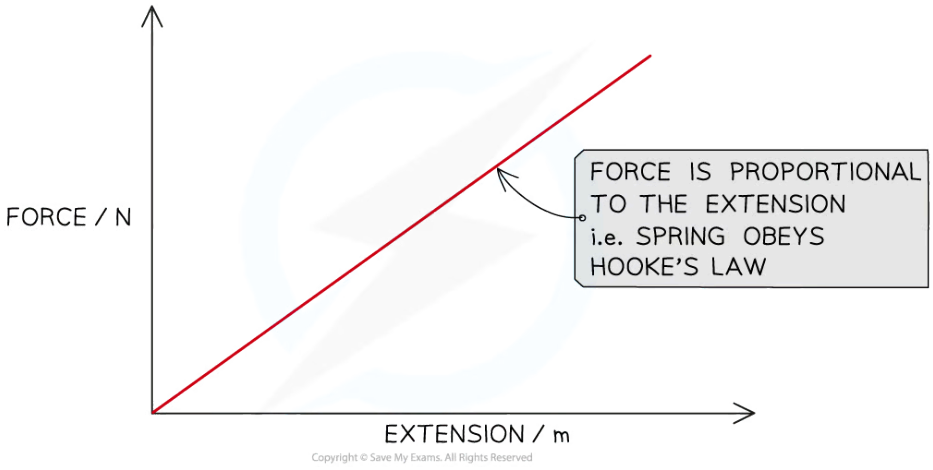
$$\text{extension} = \text{final length} - \text{original length}$$

- The final length is the length of the spring recorded from the ruler when the masses were added
- The original length is the length of the spring when there were no masses

1. Plot a graph of the force against extension
2. Draw a line of best fit
3. If the graph has a linear region (is a straight line), then the force is proportional to the extension in this region

Example force-extension graph

Your notes



The graph is a straight line that goes through the origin which shows that the extension of the spring is directly proportional to the force applied (Hooke's Law)

Evaluating the experiment

Systematic errors

- Make sure the measurements on the ruler are taken at eye level to avoid **parallax error**

Random errors

- The precision of the experiment is improved with the use of a pointer at the bottom of the spring
- Wait a few seconds for the mass to become stationary after it is added, before taking the readings for its length
- Check that the spring has not gone past its **limit of proportionality** otherwise, it has been stretched too far and will no longer obey this relationship
- Make sure the measurements are taken from the same point on the bottom of the spring every time

Safety considerations

- Wear **goggles** during this experiment in case the spring snaps
- **Stand up** while carrying out the experiment making sure no feet are directly under the masses
- Place a mat or a soft material below the masses to prevent any **damage** in case they fall
- Use a **G clamp** to secure the clamp stand to the desk so that the clamp and masses do not fall over
    - As well as this, place each mass carefully on the hanger and do not pull the spring too hard that it breaks or pulls the apparatus over

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Examiner Tips and Tricks

Remember, the extension measures how much the object has stretched by and can be found by subtracting the original length from each of the subsequent lengths.

A common mistake is to calculate the increase in length instead of the total extension. If each of your extensions is roughly the same, then you might have made this mistake!

The proportional relationship between force and extension is known as Hooke's law. You do not need to remember the name of the law for your exam, but you do need to remember the relationship.

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Hooke's law

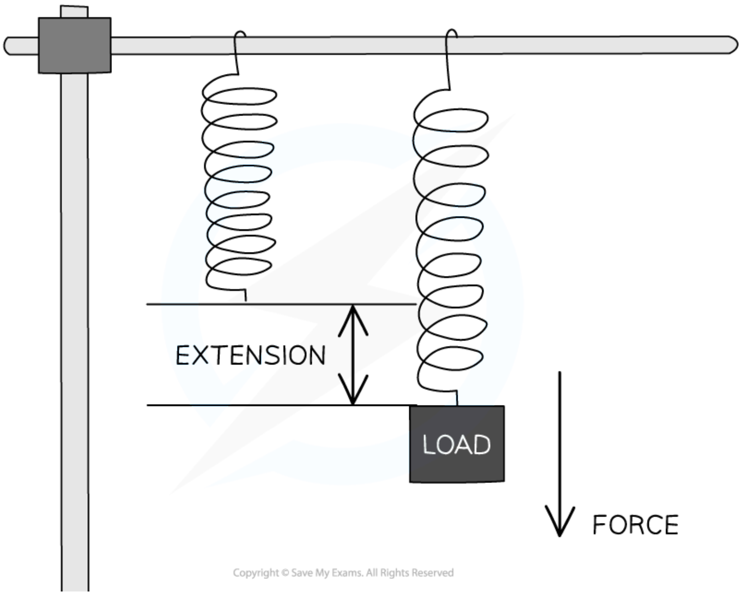
Extended tier only

- The relationship between the extension of an elastic object and the applied force is defined by **Hooke's Law**
- Hooke's Law states that:

The extension of an elastic object is directly proportional to the force applied, up to the limit of proportionality

- **Directly proportional** means that as the force is increased, the extension increases
  - If the force is doubled, then the extension will double
  - If the force is halved, then the extension will also halve
- The **limit of proportionality** is the point beyond which the relationship between force and extension is no longer directly proportional
  - This limit varies according to the material

The extension of a spring due to an applied load



Hooke's Law states that a force applied to a spring will cause it to extend by an amount proportional to the force

- Hooke's law can be described by the following equation:

$$F = kx$$

- Where:
  - F = force applied, measured in newtons (N)
  - k = the spring constant, measured in newtons per metre (N/m)
  - x = extension of spring, measured in metres (m)
- The force applied to the spring is sometimes referred to as the **load**

Your notes

Spring constant

- The spring constant is defined as:

The force per unit extension

- Therefore, the units are newtons per metre (N/m)
- The spring constant is a measure of how **stiff** the spring is
  - **Stiff** springs have a **high** spring constant
  - **Stretchy** springs have a **low** spring constant
- The spring constant can be applied to objects other than springs
- The Hooke's law equation can be used to calculate the **spring constant** of a material

$$k = \frac{F}{x}$$

The force-extension graph

- Hooke's law is a **linear** relationship
  - This is represented by a **straight line** on a force-extension, or load-extension graph
- Any material beyond its **limit of proportionality** will have a non-linear relationship between force and extension

Force-extension graph for a spring

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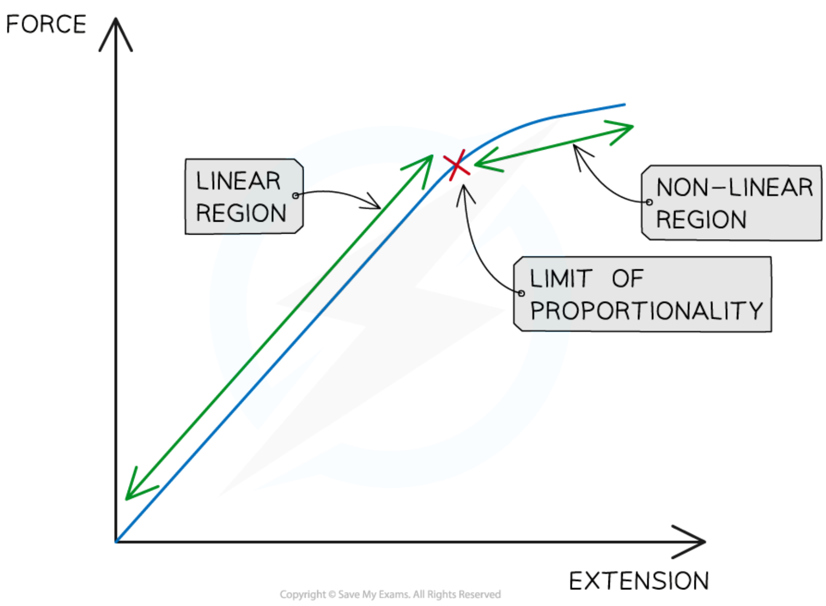

Hooke's Law is associated with the linear region of a force-extension graph. Beyond the limit of proportionality, Hooke's law no longer applies

Important features of the force-extension graph

- The **linear** portion of the graph
  - This represents the load or force under which the spring **obeys** Hooke's law
  - Force and extension are **directly proportional**
  - The **gradient** of the linear portion is equal to the spring constant for a **force-extension** graph
  - The **gradient** of the linear portion is equal to $\frac{1}{k}$ for an **extension-force** graph
- The **limit of proportionality**
  - This is the point at which the graph **begins to curve**
  - Beyond this point, force and extension are **no longer** proportional
- The **curved** portion of the graph
  - This is where the material **does not** obey Hooke's law
  - Force and extension are **not** proportional

Worked Example

The figure below shows the forces acting on a child who is balancing on a pogo stick. The child and pogo stick are not moving.

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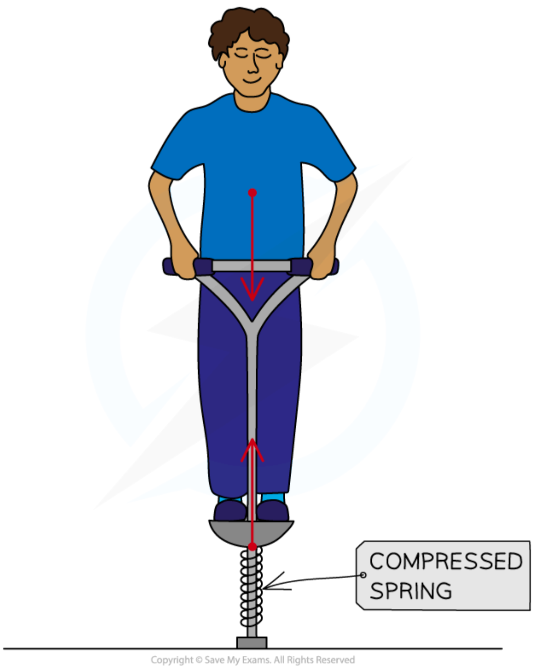

The spring constant of the spring on the pogo stick is 4900 N/m. The weight of the child causes the spring to compress elastically from a length of 40 cm to a new length of 33 cm.

Calculate the weight of the child.

Answer:

Step 1: List the known quantities

- Spring constant, *k* = 4900 N/m
- Original length = 40 cm
- Final length = 33 cm

Step 2: Write the relevant equation

$$F = kx$$

Step 3: Calculate the compression, *x*

$$x = \text{final length} - \text{original length}$$

$$x = 33 - 40 = -7 \text{ cm}$$

- A negative extension represents a compression of 7 cm

Step 4: Convert any units

- Since the spring constant is given in N/m, x must be in metres (m)

$$x = \frac{7}{100} = -0.07 \text{ m}$$

Step 5: Substitute the values into the Hooke's Law equation

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$$F = 4900 \times -0.07$$

$$F = -343 \text{ N}$$

- The minus sign simply indicates the direction of the force, downwards in this case
- The child's weight is 343 N

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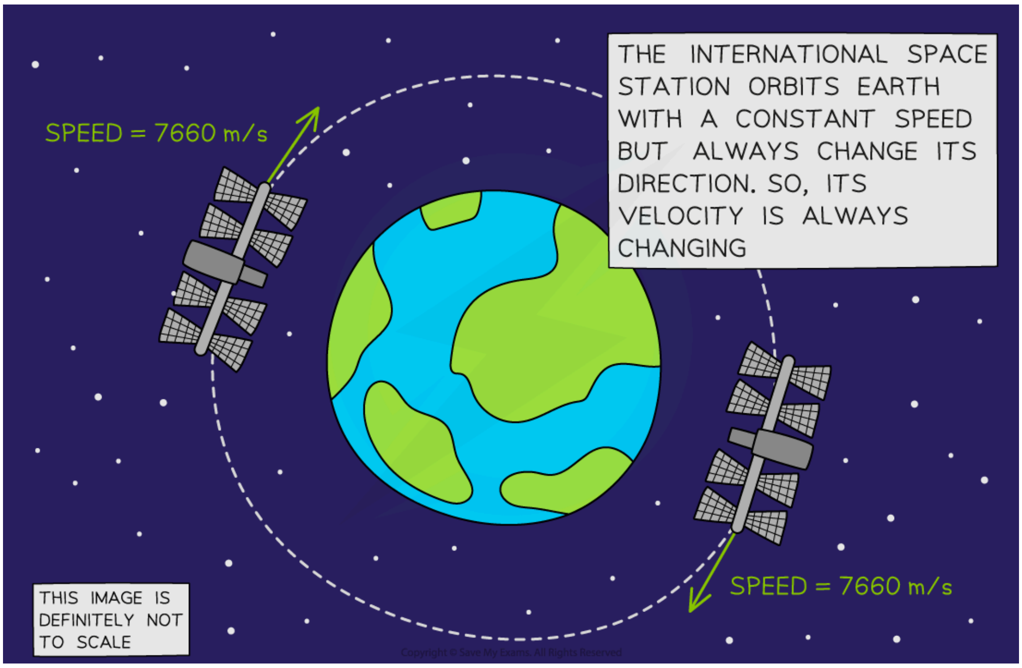
Circular motion

Extended tier only

- Velocity is a **vector** quantity with both **magnitude** and **direction**
- Therefore, the velocity of an object is its **speed** in a given **direction**
- When an object travels in **circular motion**, its **direction** is always **changing**
  - Therefore, the **velocity** of an object in circular motion is always **changing,** even if its **speed** is constant
- **Circular motion** is a type of **acceleration** since acceleration is a **change in velocity**

Circular motion of the International Space Station



The International Space Station's velocity is always changing – it whizzes around the Earth at a constant speed of about 7660 m/s but is always changing direction

- When a force acts **perpendicularly** to an object's direction of travel, the force will cause that object to change direction

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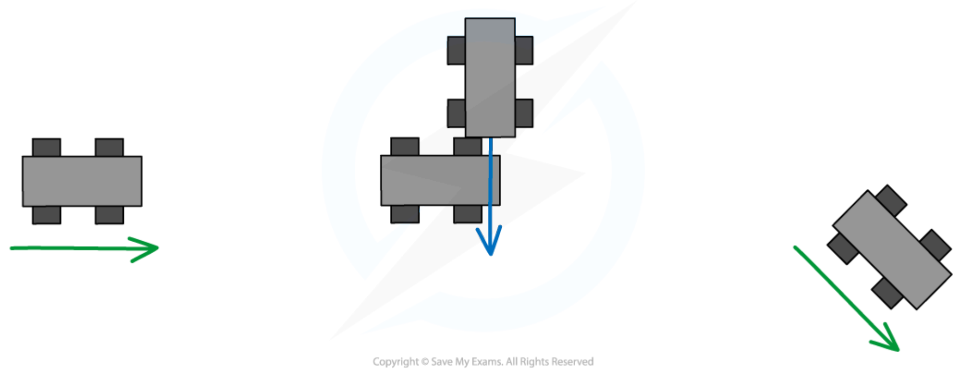
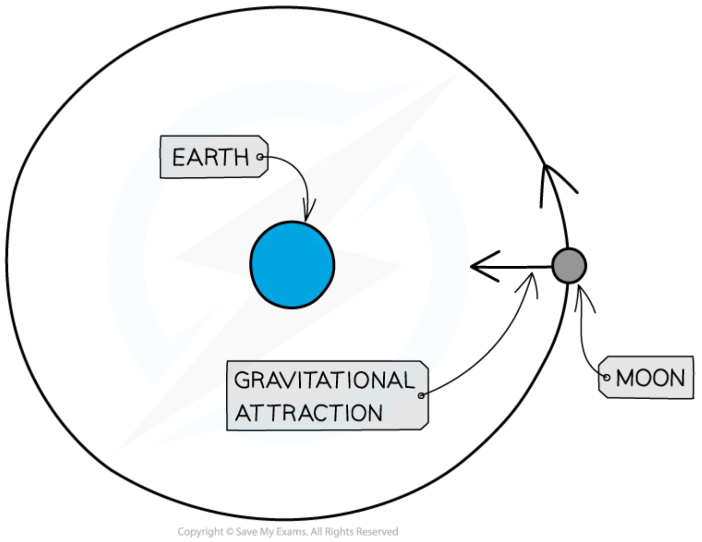


When the two cars collide, the first car changes its direction in the direction of the force

- If the force continues to act at 90 degrees to the motion, the object will keep changing its direction (whilst remaining at a constant speed) and travel in a circle
- This is what happens when a planet orbits a star, or when a satellite orbits a planet

Circular motion of the Moon around the Earth



The Moon is pulled towards the Earth (at 90 degrees to its direction of travel). This causes it to travel in a circular path

- Therefore, for an object in circular motion, the **force** is always directed **toward** the **centre** of the circle
- The **force** needed to make something follow a circular path depends on a number of factors:
  - **The mass of the object**
    - A greater mass requires a greater force when the speed and radius are constant

- **The speed of the object**
  - A faster-moving object requires a greater force when the mass and radius are constant
- **The radius of the circle**
  - A smaller radius requires a greater force to keep the speed and radius constant

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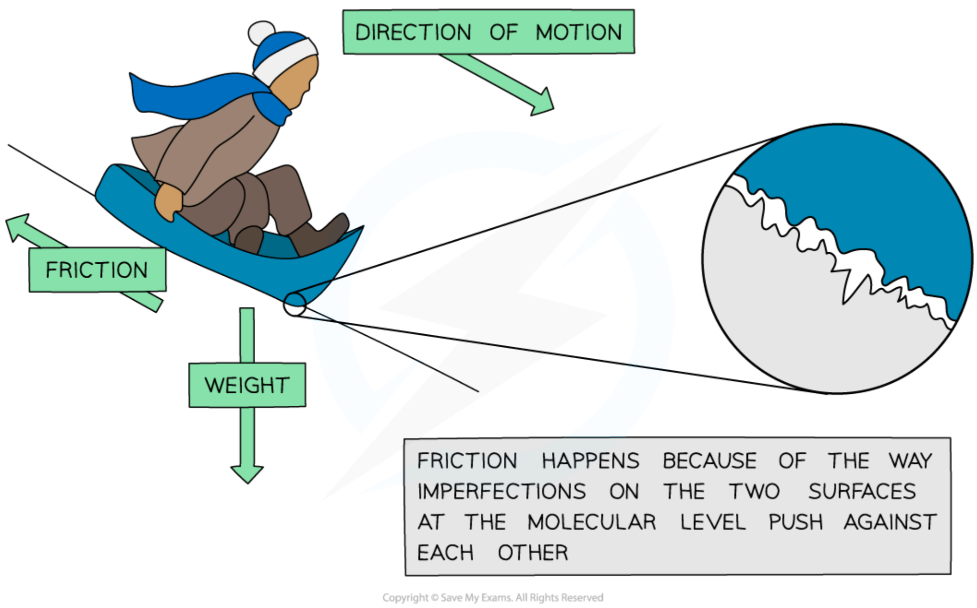
Friction in solids

- Friction is a force that works in **opposition** to the motion of an object
  - Frictional forces slow down the motion of the object
- When friction occurs, energy is transferred by **heating**
  - Friction causes an increase in **temperature** of the object and its surroundings
  - The work done against the frictional forces causes this rise in the temperature
- **Friction in solids** is caused by **imperfections** in the surfaces of the objects moving over one another
- Solid friction:
  - decreases the speed of the moving object
  - increases the temperature of the objects due to heating

Friction between surfaces

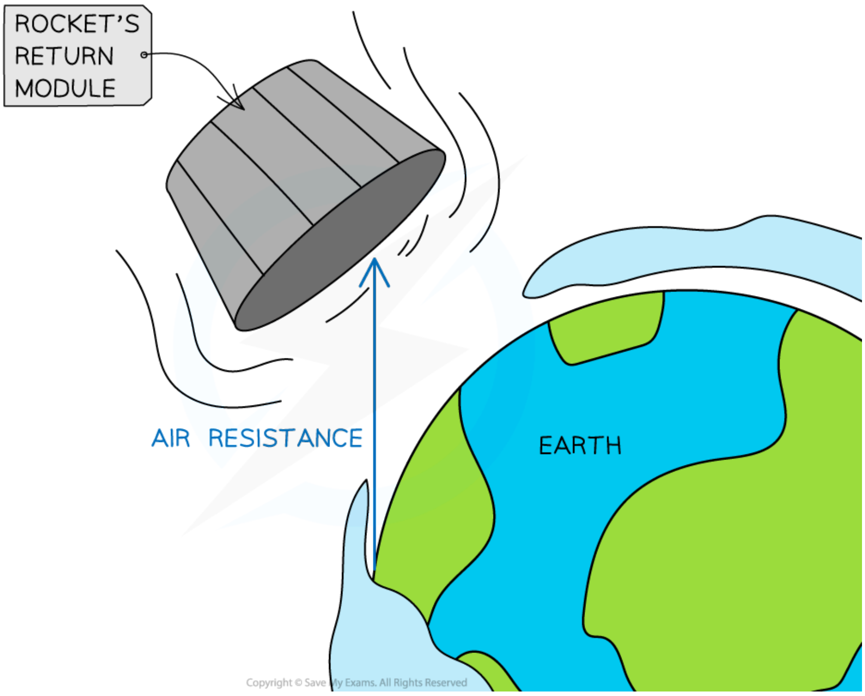


The interface between the ground and the sledge is bumpy, causing the frictional force

- Friction between solids can be reduced by:
  - lubricating the surfaces
  - smoothing the surfaces

Friction in fluids

- **Gases** and **liquids** are known as **fluids**
  - Fluids are different to solids because the **particles** in fluids are **free to move** around
- Friction acts on objects moving through gases and liquids as the particles collide with the object
  - This type of friction is called **drag**
- Air resistance is a **type of friction** that slows the motion of an object moving through **air**
- Air particles bump into the object as it moves through the air
- Air resistance:
  - reduces the speed of the object
  - increases the temperature of the object and the air particles due to heating



The return module of a rocket heats up due to the work done by air resistance as it travels a distance through the atmosphere

- Air resistance is covered in greater depth in the revision note Free fall
- Friction in fluids can be reduced by:
  - streamlining the shape of the object moving through the fluid

Your notes