Edexcel GCSE Physics

Your notes

Forces

Contents

Newton's First Law

Your notes

Newton's First Law of Motion

- Newton's **first 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 the resultant force acting on an object is zero:
  - The object will **remain stationary** if it was stationary before
  - The object will continue to move at the **same velocity** if it was moving
- When the resultant force is **not** zero
  - The speed of the object can change
  - The direction of the object can change

Applying Newton's First Law

- Newton's first law is used to explain why things move with a **constant** (or **uniform**) **velocity**
  - If the **forces** acting on an object are **balanced**, then the **resultant force** is **zero**
  - The velocity (i.e. speed and direction) **can only change** if a **resultant force** acts on the object
- A few examples with uniform velocity are shown below:

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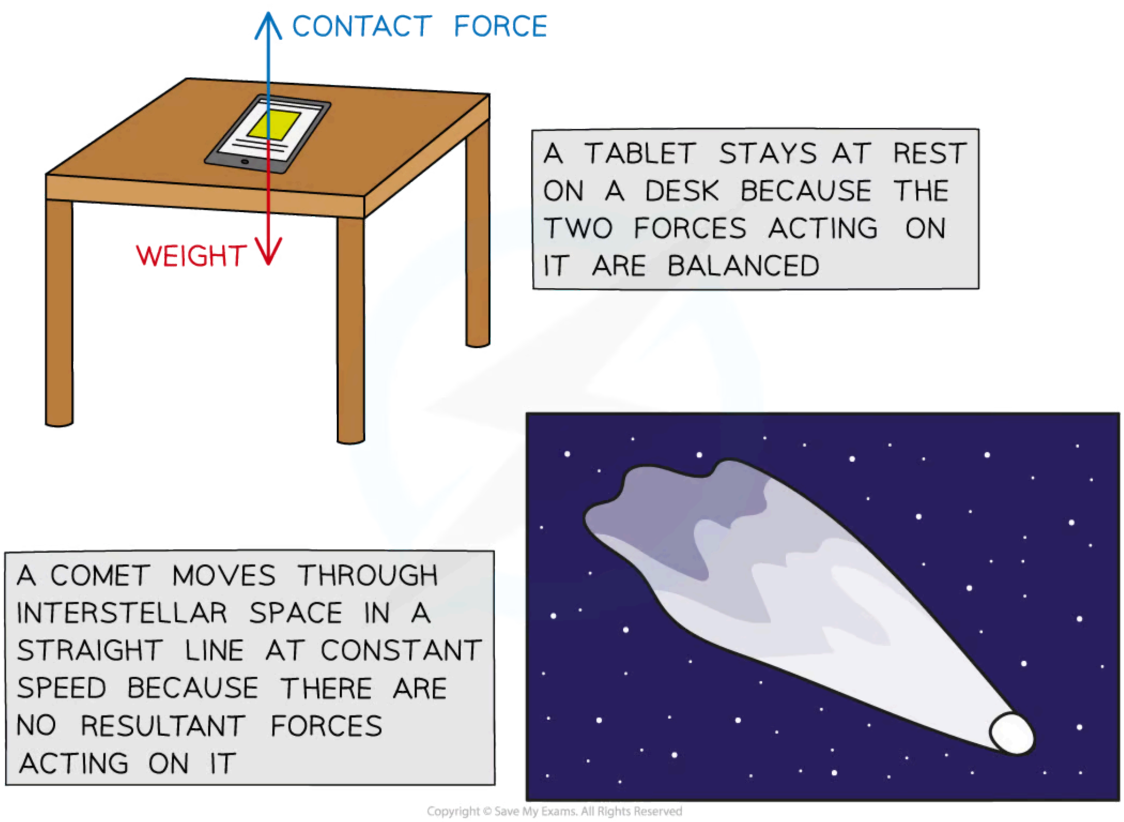

Constant velocity can only be achieved when the forces on an object are balanced – in other words, when the resultant force is zero

Worked Example

Lima did some online research and found out that the Moon orbits the Earth at a constant speed of around 2000 mph. She says that this is not an example of Newton's first law of motion. Is Lima 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 Lima is correct

- Lima 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

If there are no external forces acting on the car and it is moving at a constant velocity, what is the value of the frictional force, *F*?

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**

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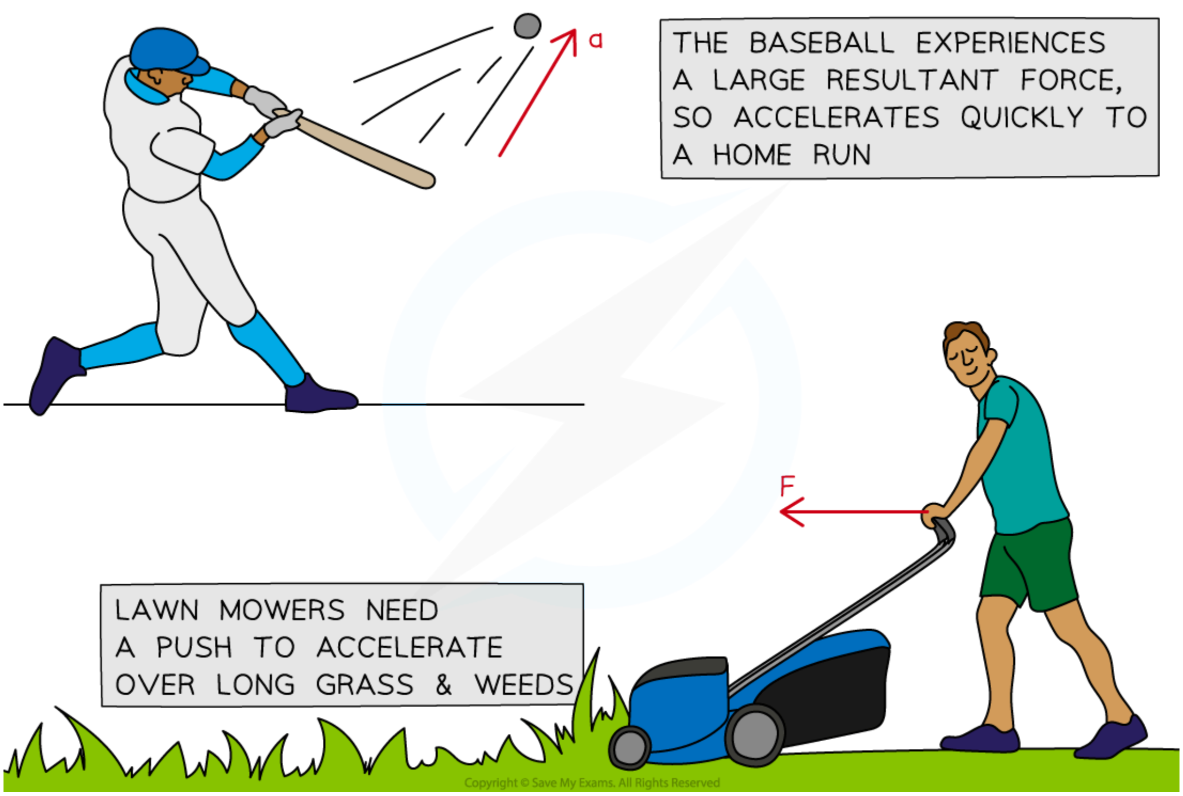
Newton's Second Law

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 explains the following important principles:
  - An object will **accelerate** (change its velocity) in response to a **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
- The image below shows some examples of Newton's second law in action:



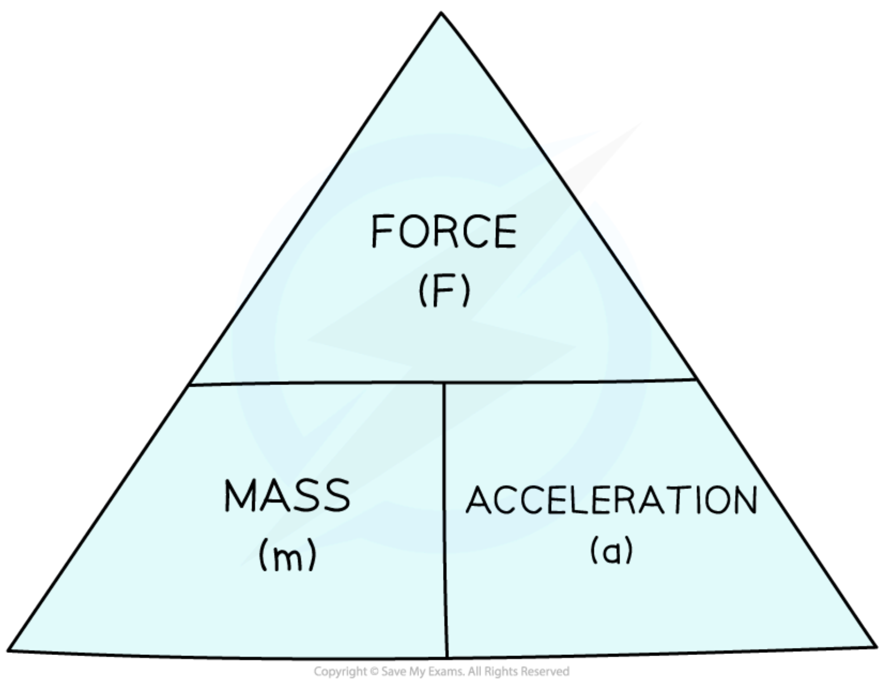
Objects like baseballs and lawnmowers accelerate when a resultant force is applied on them. The size of the acceleration is proportional to the size of the resultant force

Calculating Force & Acceleration

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

$$F = ma$$

- Where:
  - F = resultant force on the object in Newtons (N)
  - m = mass of the object in kilograms (kg)
  - a = acceleration of the object in metres per second squared (m/s^2)
- This equation can be rearranged with the help of a formula triangle:



Force, mass, acceleration formula triangle

Worked Example

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

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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 = 0 m/s
- Final velocity = 27 m/s
- Time, t = 3 s

Step 2: Calculate the change in velocity

$$\text{change in velocity} = \Delta v = \text{final velocity} - \text{initial velocity}$$

$$\Delta v = 27 - 0 = 27 \text{ m/s}$$

Step 3: State the equation for acceleration

$$a = \frac{\Delta v}{t}$$

Step 4: Calculate the acceleration

$$a = 27 \div 3 = \mathbf{9\ m/s^2}$$

Part (b)

Step 1: List the known quantities

- Mass of the car, m = 900 kg
- Acceleration, a = 9 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

$$F = 900 \times 9 = \mathbf{8100\ N}$$

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Worked Example

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

Which trolley will have the smallest acceleration? Explain your answer.

Answer:

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 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

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Core Practical 1: Investigating Force & Acceleration

Equipment List

Apparatus	Purpose
Metre ruler	To measure intervals of distance
A toy car (or trolley)	The object for which acceleration is measured
Pencil or chalk	To mark intervals of distance
Bench pulley & string	To connect masses to the toy car / trolley
Weights & weight hanger	To provide a force on the toy car / trolley
Stopwatch	To time the toy car / trolley between distance intervals
Blu tac	To attach extra weight to the toy car / trolley if needed

- **Resolution** of measuring equipment
  - Metre ruler = 1 mm
  - Stopwatch = 0.01 s

Experiment 1: Investigating the Effect of Force on Acceleration

Aim of the Experiment

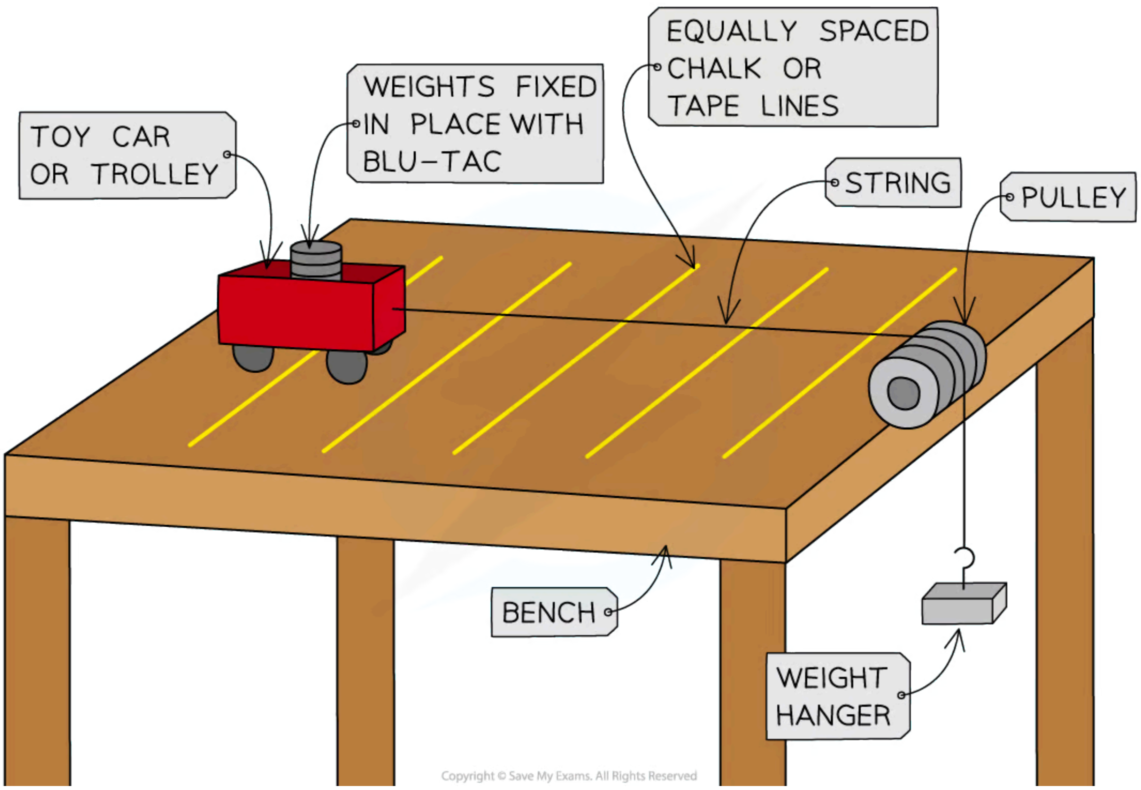
- The aim of this experiment is to investigate the effect of varying force on the acceleration of an object of constant mass

Variables

- **Independent variable** = force, F
- **Dependent variable** = acceleration, a

- Control variables:
  - Mass, m

Method



Force and acceleration apparatus setup

1. Use the metre ruler to measure out intervals on the bench, e.g. every 0.2 m for a total distance of 1 m. Draw straight lines with pencil or chalk across the table at these intervals
2. Attach the bench pulley to the end of the bench
3. Tie some string to the toy car or trolley
4. Pass the string over the pulley and attach the mass hanger to the other end of the string
5. Make sure the string is horizontal (i.e. parallel to the bench) and is in line with the toy car or trolley
6. Hold the toy car or trolley at the start point
7. Attach the full set of weights (total = 1.0 N) to the end of the string

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8. Release the toy car or trolley at the same time as you or a partner starts the stopwatch. Press the stopwatch (in lap mode) at each measured interval on the bench and for the final time at 1.0 m
9. Record the results in the table and repeat step 8 to calculate an average time for each interval
10. Repeat steps 6–9 for decreasing weights on the weight hanger, e.g. 0.8 N, 0.6 N, 0.4 N, and 0.2 N. Make sure you place the masses that you remove from the weight stack onto the top of the car, using the Blu-tac, each time you decrease the weight

- A possible results table is illustrated as an example below:

	FORCE APPLIED ON TOY CAR / TROLLEY (N)														
DISTANCE TRAVELLED (m)	1			0.8			0.6			0.4			0.2		
	TIME (s)			TIME (s)			TIME (s)			TIME (s)			TIME (s)		
0.2															
0.4															
0.6															
0.8															
1.0															

Analysis of Results

- Use the table of results to determine the average speed of the trolley between intervals
- Use the distance between each interval (0.2 m) and the average time it takes for the toy car or trolley to travel that distance to calculate the average speed per interval
  - This is done using the equation:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

- Compare the average speed between the first and last intervals for different weights
- Use the equation below to calculate the acceleration between the first and the last intervals:

Your notes

Your notes

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

- Do this for each different weight, comparing how the acceleration varies

Experiment 2: Investigating the Effect of Mass on Acceleration

Aim of the Experiment

- The aim of this experiment is to investigate the effect of varying mass on the acceleration of an object produced by a constant force

Variables

- **Independent variable** = mass, *m*
- **Dependent variable** = acceleration, *a*
- Control variables:
  - Force, *F*

Method

1. Use the metre ruler to measure out intervals on the bench, e.g. every 0.2 m for a total distance of 1 m. Draw straight lines with pencil or chalk across the table at these intervals
2. Attach the bench pulley to the end of the bench
3. Put a 200 g mass on the car
4. Tie some string to the toy car or trolley
5. Pass the string over the pulley and attach the mass hanger to the other end of the string
6. Make sure the string is horizontal (i.e. parallel to the bench) and is in line with the toy car or trolley
7. Select a weight to put on the weight hanger that will gently accelerate the car along the bench. This provides the constant force on the car or trolley and will not change
8. Hold the car at the start point
9. Release the car at the same time as you or a partner start the stopwatch. Press the stopwatch (in lap mode) at each measured interval on the bench and for the final time at 1.0 m
10. Record the results in the table and repeat step 8 to calculate an average time for each interval

11. Repeat steps 6–9 for increasing mass on the car, e.g. 400 g, 600 g, 800 g and 1000 g

- A possible results table is illustrated as an example below:

	MASS ON TOP OF TOY CAR / TROLLEY (g)														
DISTANCE TRAVELLED (m)	200			400			600			800			1000		
	TIME (s)			TIME (s)			TIME (s)			TIME (s)			TIME (s)		
0.2															
0.4															
0.6															
0.8															
1.0															

Analysis of Results

- As in Experiment 1, use the table of results to determine the average speed of the trolley between intervals
- Use the distance between each interval (0.2 m) and the average time it takes for the toy car or trolley to travel that distance to calculate the average speed per interval
  - This is done using the equation

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

- Compare the average speed between the first and last intervals for different weights
- Use the equation below to calculate the acceleration between the first and the last intervals:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

- Do this for each different mass on top of the toy car or trolley, comparing how the acceleration varies

Evaluating the Experiments

Systematic Errors:

- In Experiment 1, ensure any weights removed from the weight hanger are transferred to the toy car or trolley
  - This is to ensure the total mass of the system remains constant

Random errors:

- A main cause of error in this experiment is the measurements of time
  - Ensure to take repeat readings when timing intervals and calculate an average to keep this error to a minimum
- Start the toy car by releasing it, allowing it to accelerate under the force of the weights attached by the string
  - Ensure not to give it a 'push'

Safety Considerations

- Don't stand directly beneath the weight hanger, in case any weights become loose and fall off the stack
  - Place a crash mat underneath the weight hanger just in case this happens

Examiner Tips and Tricks

There is a lot of information to take in here! When writing about experiments, a good sequence is as follows:

- If you need to use an equation to calculate something, start off by giving it as this will give you some hints about what you need to mention later
- List the apparatus that you need
- State what measurements you need to make (your equation will give you some hints) and how you will measure them
- Finally, state that you will repeat each measurement several times and take averages

Your notes

Newton's Third Law

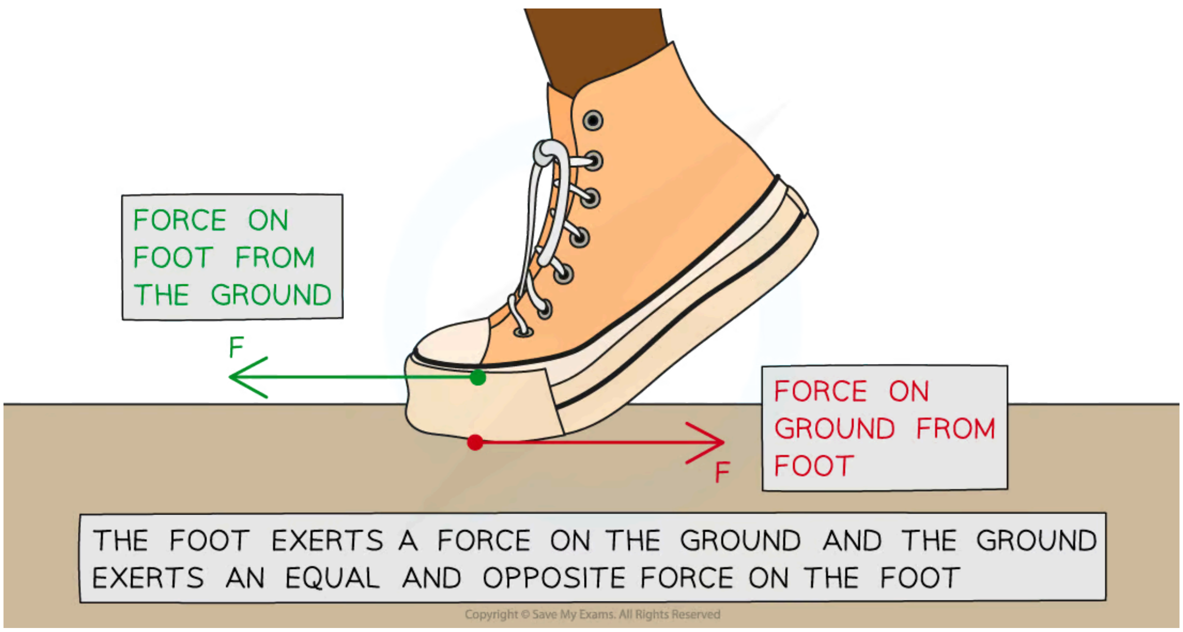
Your notes

Newton's Third Law

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

  Whenever two bodies interact, the forces they exert on each other are equal and opposite

- The **pair of forces** exerted by the interacting objects are known as **force pairs**
- Newton's third law explains the forces that enable someone to walk
  - The **foot** exerts a push force on the **ground**
  - The **ground** exerts a push force force on the **foot**
  - The forces are equal in magnitude and opposite in direction



The foot pushes the ground backwards, and the ground pushes the foot forwards. Newton's third law explains the forces that enable people to walk

- Vector diagrams can be used to represent Newton's third law
- Use the following three rules to help you identify a third law pair:

1. The two forces in a third law pair act on **different objects**

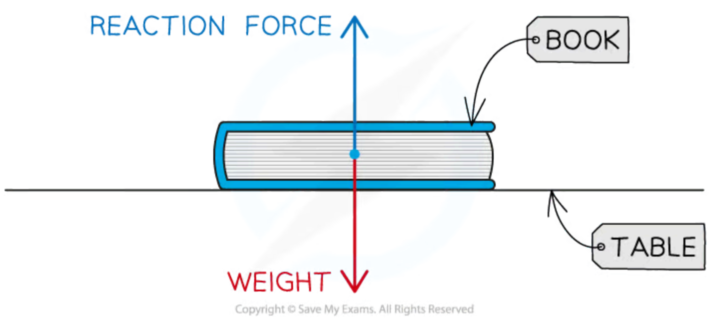
2. The two forces in a third law pair always are equal in size but act in opposite directions

3. The two forces are always the **same type**: weight, normal contact force, etc.

Your notes

Worked Example

A physics textbook is at rest on a table. Student A draws a force diagram for the book and labels the forces acting on it as weight and normal contact force.



Student A says the diagram is an example of Newton's third law of motion. Student B disagrees with Student A. By referring to the vector diagram, state and explain who is correct.

Answer:

Step 1: Identify the forces and objects involved

- The gravitational pull of the Earth acts downwards on the book (weight) and the push force of the table acts upwards on the book (normal contact force)

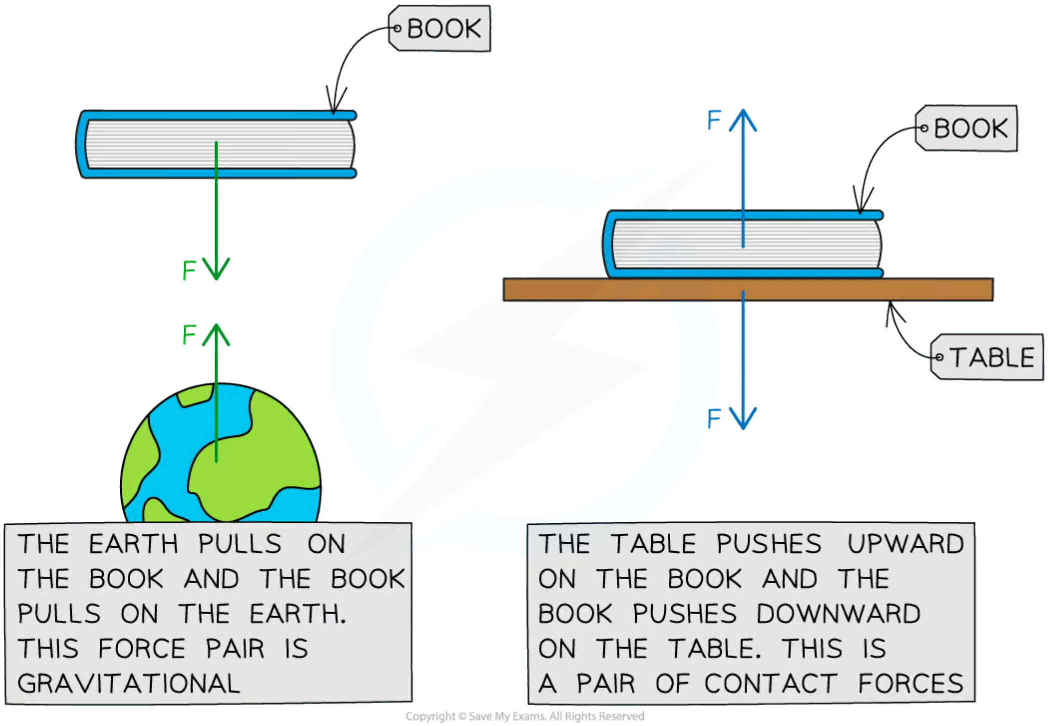
Step 2: State Newton's third law of motion

- Whenever two objects interact, the forces they exert on each other are equal in magnitude and opposite in direction

Step 3: Check if the diagram satisfies the two conditions for identifying Newton's third law

- Newton's third law identifies pairs of equal and opposite forces, of the same type, acting on two different objects
- In this example:
  - Both forces are acting on the book
  - The forces acting on the book are different forces- normal contact force and weight
- The image below shows how to apply Newton's third law correctly in this case, considering the pairs of forces acting:

Your notes



- The third law pairs in this scenario would be:
    - The gravitational pull of the Earth on the book (weight) and the gravitational pull of the book on the Earth (weight)
    - Both forces are the same type (weight)
    - Both forces are equal and opposite
- The arrows in the vector diagram of the book on the table are equal and opposite, which is where lots of students get confused
    - This is because the forces are balanced

Step 4: Conclude who is correct

- In this case, Student B is correct
    - The vector diagram in the question is an example of Newton's first law
    - In the vector diagram of the book on the table, both forces are acting on one object and the forces are not the same type

Examiner Tips and Tricks

Third law pairs will always be different objects exerting the same type of force on each other. Once you have identified a set of third law pairs, then you know that the forces will be equal in magnitude and opposite in direction.

Your notes

Weight, Mass & Gravity

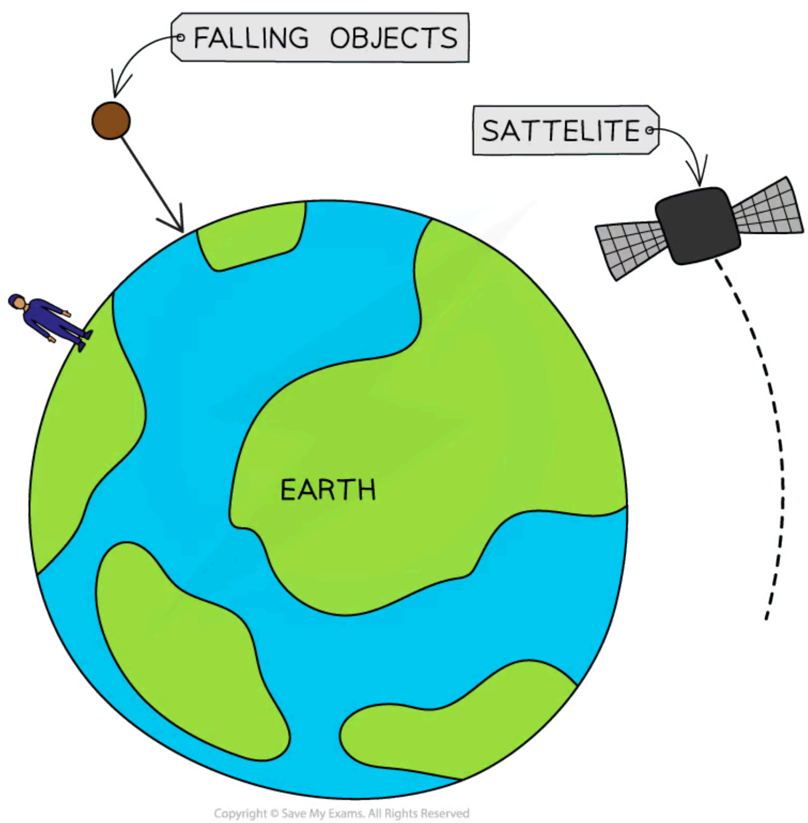
Your notes

Weight

- Weight is defined as:

  The force acting on an object due to gravitational attraction

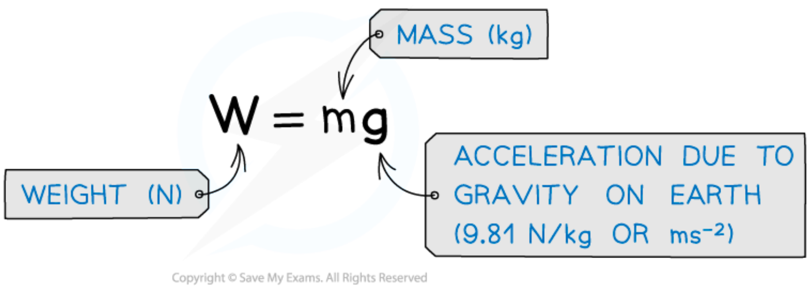
- Planets have strong gravitational fields
  - Hence, they attract nearby masses with a strong gravitational force
- Because of weight:
  - Objects stay firmly on the ground
  - Objects will always fall to the ground
  - Satellites are kept in orbit



Some of the phenomena associated with gravitational attraction and the weight force

Your notes

- Weight, mass and gravitational field strength are related using the equation:



- *g* is known as the acceleration due to gravity or the **gravitational field strength**
  - On Earth, this is equal to **9.81 m/s^2** (or N/kg)
- The weight that an object experiences depends on:
  - The **object's** mass
  - The mass of the **planet** attracting it
- **Mass** (measured in kilograms, **kg**) is related to the **amount of matter in an object**
- **Weight** (measured in newtons, **N**) is the **force of gravity on a mass**
  - The weight of an object and the mass of an object are **directly proportional**
  - The size of this force depends on the **gravitational field strength** (often called gravity, g, for short)

Examiner Tips and Tricks

It is a common misconception that mass and weight are the same, but they are in fact **very different**

- Since weight is a **force** - it is a **vector** quantity
- Since mass is an **amount** - it is a **scalar** quantity

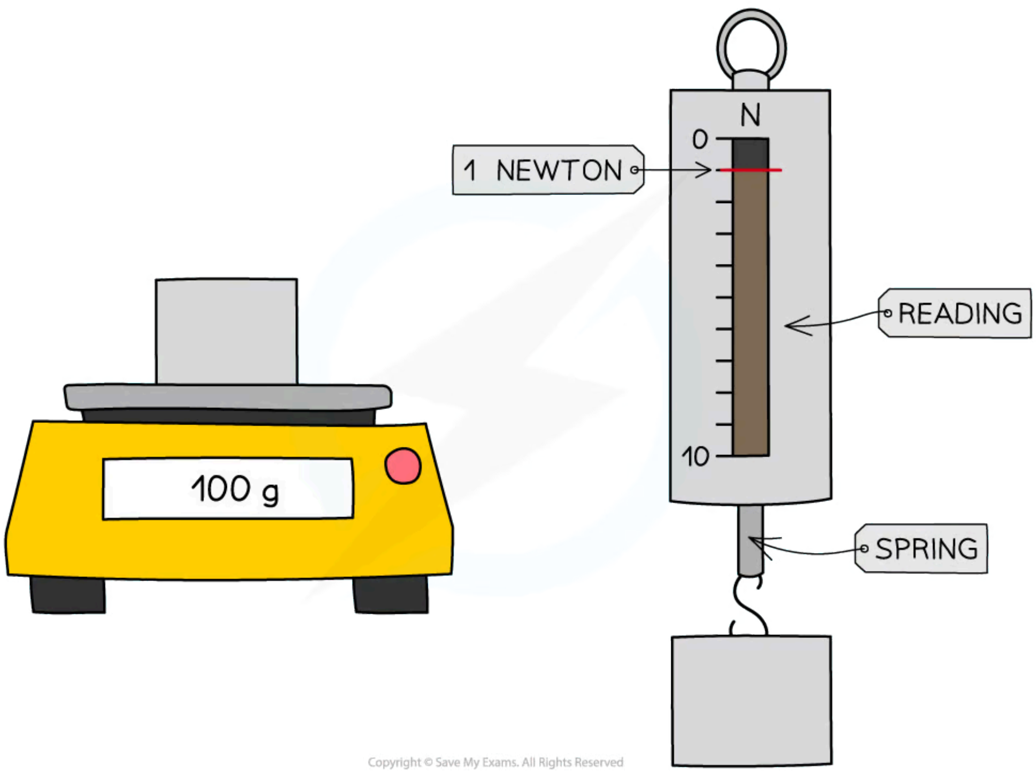
Measuring Weight

- Mass is commonly measured using a top pan balance
  - The weight can then be indirectly found through calculation using:

$$W = mg$$

- Where g on Earth is ≈ 10 N/kg
- Weight can be measured **directly** using a calibrated spring-balance, also known as a **newton-meter**
  - This device is a type of weighing scale which measures force in Newtons
  - It consists of a spring fixed at one end with a hook to attach an object at the other

Your notes



Weight can be measured using a top-pan balance or a newton-meter

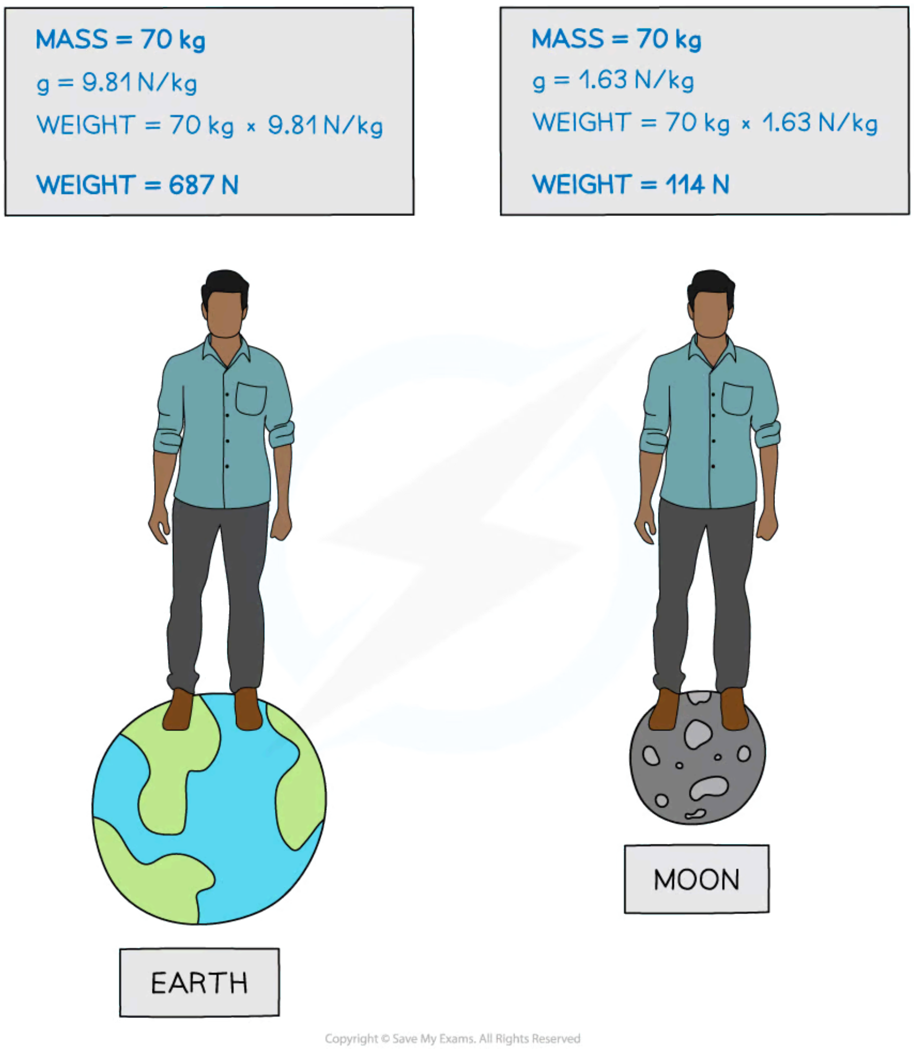
Examiner Tips and Tricks

Since mass is measured in **kilograms** in Physics, if it is given in grams make sure to convert to kg by dividing the value by 1000!

Weight & Gravity

Your notes

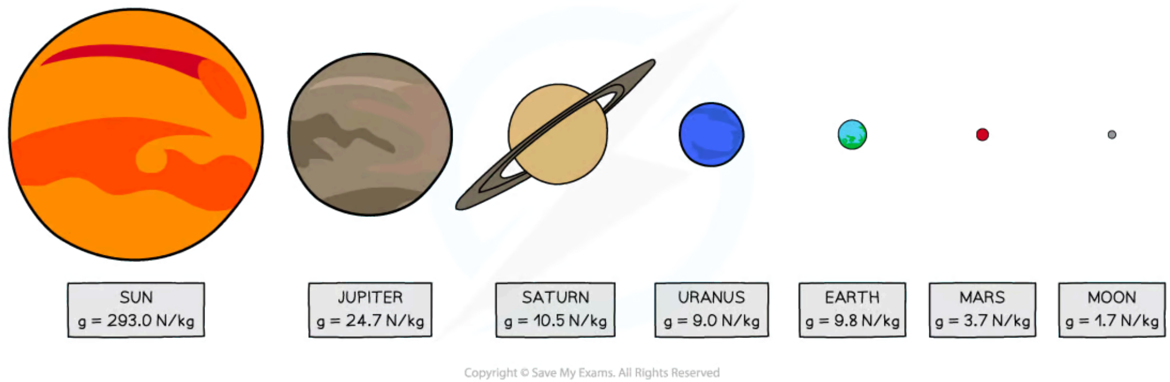
- An object's **mass** always remains the same, however, its **weight** will differ depending on the strength of the gravitational field on different planets
- For example, the gravitational field strength on the Moon is **1.63 N/kg**, meaning an object's weight will be about **6 times** less than on Earth



On the moon, your mass will stay the same but your weight will be much lower

- The value of *g* (gravitational field strength) varies from planet to planet depending on their mass and radius
- A few examples of varying gravitational field strength are shown below:

Your notes



Gravitational field strength of the planets in our solar system

Worked Example

A student estimates she would have a weight of 190 N on Mars. Calculate the weight of the student on Earth. The gravitational field strength on Earth is 9.8 N/kg The gravitational field strength on Mars is 3.8 N/kg.

Answer:

Step 1: List the known quantities

- Weight on Mars, W_M = 190 N
- Gravitational field strength on Mars, g_M = 3.8 N/kg
- Gravitational field strength on Earth, g_E = 9.8 N/kg

Step 2: Write out the equation relating mass and weight and rearrange for mass

$$W = mg$$

- Divide both sides by g:

$$m = \frac{W}{g}$$

Step 3: Calculate the student's mass

- The student's mass is the same anywhere in the universe

$$m = \frac{W_M}{g_M} = \frac{W_E}{g_E}$$

$$m = \frac{190}{3.8} = 50 \text{ kg}$$

Step 4: Calculate the student's weight on Earth

$$W_E = m \times g_E = 50 \times 9.8 = \mathbf{490\ N}$$

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Examiner Tips and Tricks

You do not have to remember the gravitational field strength *g* on other planets, but just that it increases with the mass of the planet. The value of *g* will be given in your exam questions.

Circular Motion

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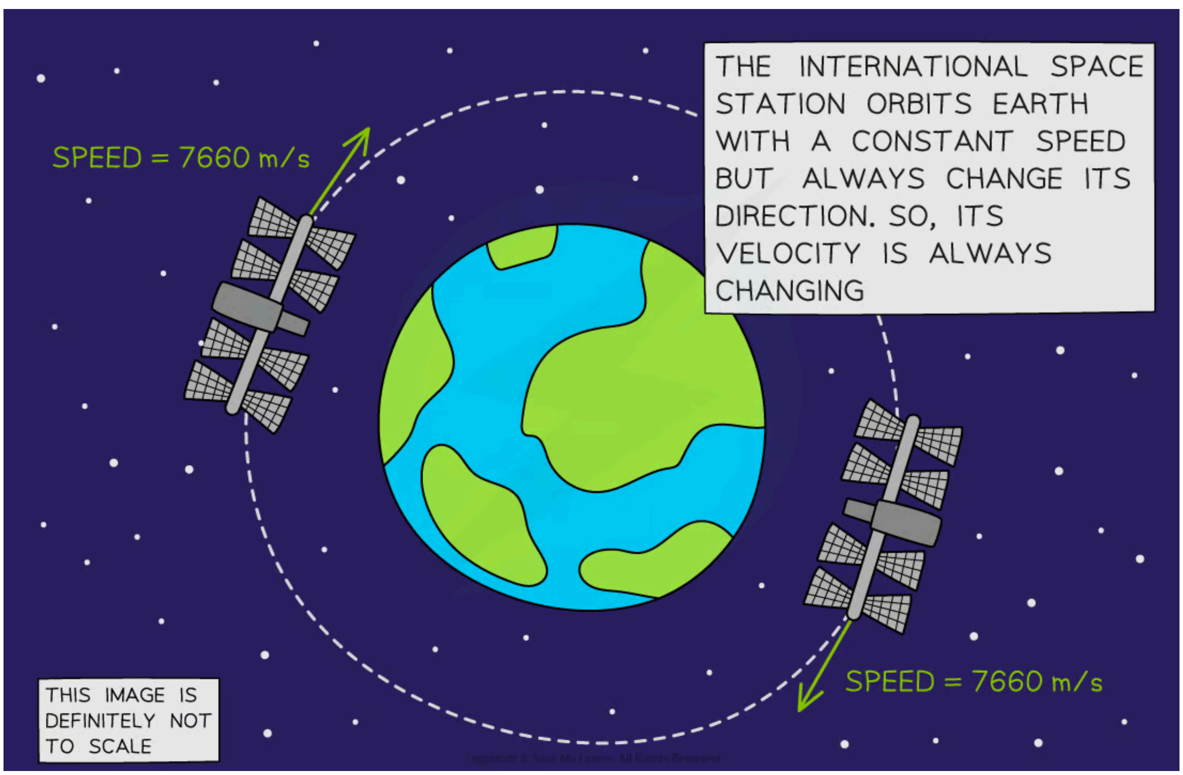
Circular Motion

Higher Tier Only

- Velocity is a vector quantity, and the velocity of an object is its **speed** in a given **direction**
- When an object travels along a circular path, its velocity is always changing
  - The **speed** of the object moving in a circle might be constant - that is, it is travelling the same distance every second
  - However, the **direction** of travel is always changing as the object moves along the circular path
- This means that an object moving in circular motion travels at a **constant speed** but has a **changing velocity**
- The image below shows an example of a famous object that moves in a circular path with a constant speed but changing direction:



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

Your notes

Examiner Tips and Tricks

You may be asked to explain why motion in a circle involves constant speed but changing velocity, so remember to mention that velocity is a **vector** quantity, so both magnitude and direction are important. Even though the magnitude (speed) doesn't change, its direction does - so the velocity itself is changing.

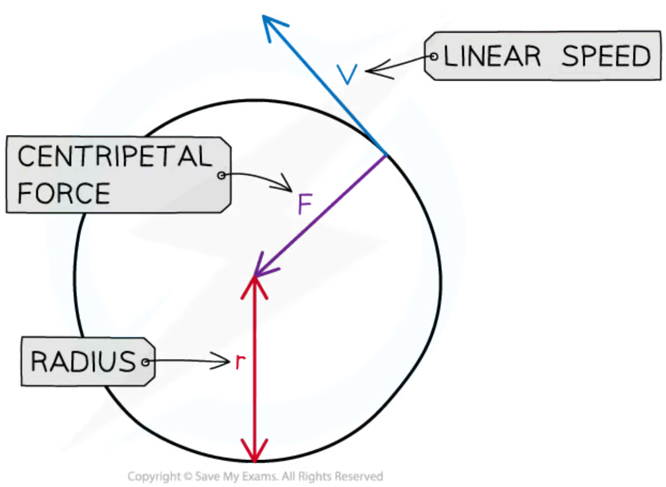
Centripetal Force

Higher Tier Only

- An object moving in a circle is not in equilibrium as it has a resultant force acting upon it
  - This is known as the **centripetal force** and is what keeps the object moving in a circle
- The centripetal force (*F*) is defined as:

  The resultant perpendicular force towards the centre of the circle required to keep a body in uniform circular motion

- The centripetal force is shown by the arrow labelled *F* in the diagram below:



Centripetal force is always perpendicular to the direction of travel and is directed towards the centre of the circle

- **Note:** centripetal force and centripetal acceleration act in the **same direction**
  - This is due to Newton's Second Law
- The centripetal force is **not** a separate force of its own
  - It can be any type of force, depending on the situation, which keeps an object moving in a circular path

Examples of Centripetal Force Table

Situation	Centripetal force
Car travelling around a roundabout	Friction between car tyres and the road
Ball attached to a rope moving in a circle	Tension in the rope
Earth orbiting the Sun	Gravitational force