

IGCSE/GCE O-LEVEL

Earth and the Solar System

By: Aamir Yasin

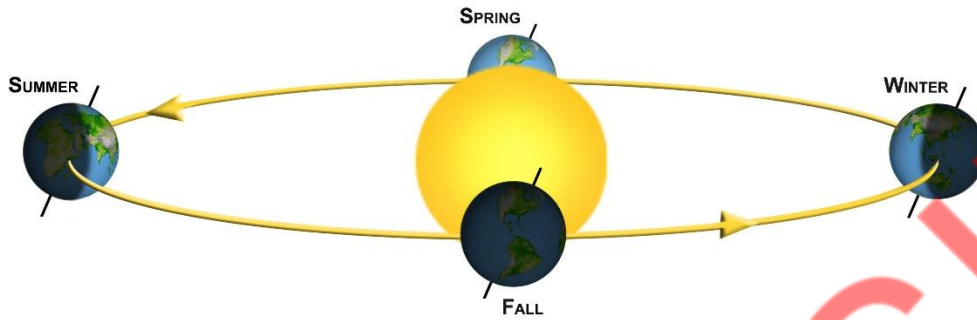
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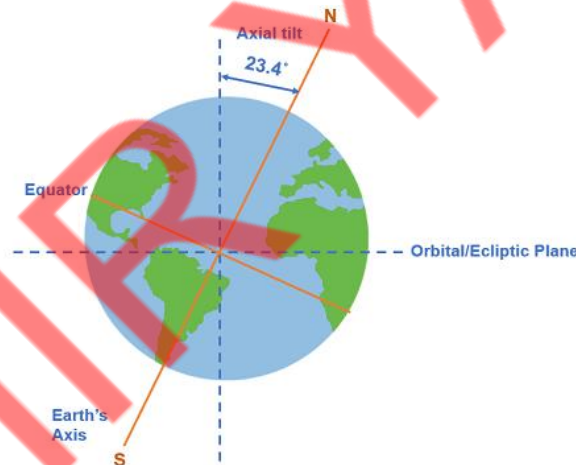
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The Earth's Axis

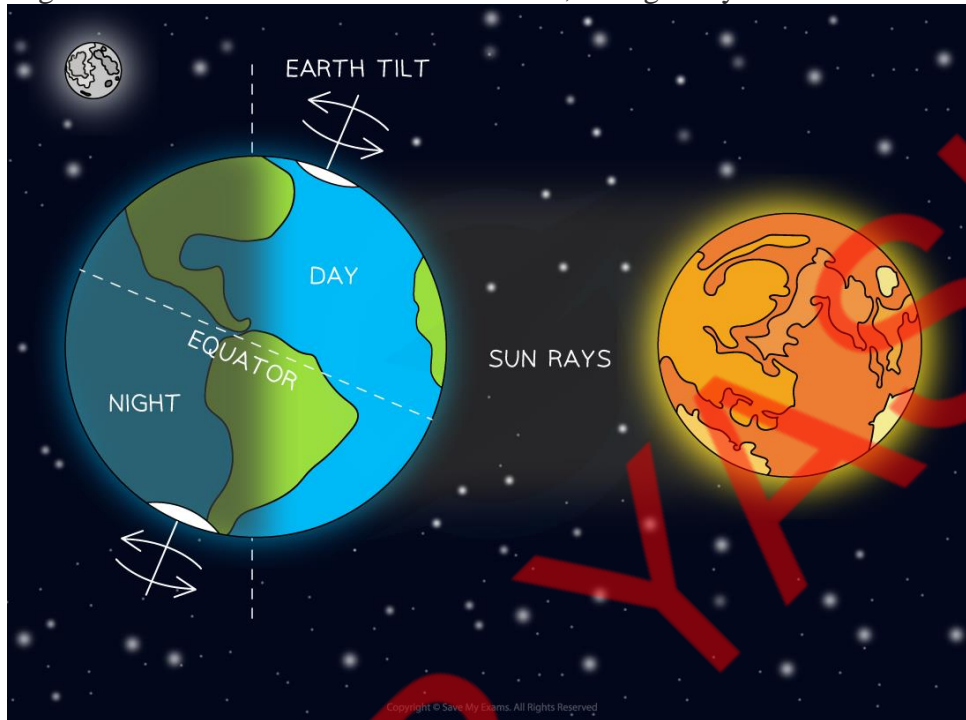


- The Earth is a planet which rotates in a circular orbit around the Sun
- It rotates on its axis, which is a line through the north and south poles
- The axis is tilted at an angle of approximately 23.4° from the vertical
- The Earth completes one full rotation (revolution) in approximately 24 hours (1 day)
- This rotation creates the apparent daily motion of the Sun rising and setting
- Rotation of the Earth on its axis is therefore responsible for the **periodic cycle** of day and night



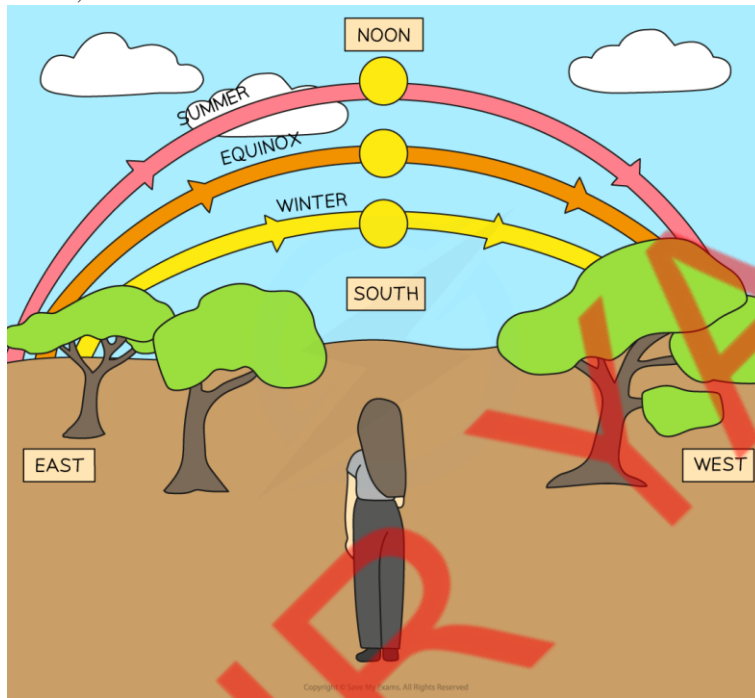
Day and Night

- The Earth's rotation around its axis creates day and night
- Day is experienced by the half of the Earth's surface that is facing the Sun
- Night is the other half of the Earth's surface, facing away from the Sun



Rising and Setting of the Sun

- The Earth's rotation on its axis makes the Sun look like it moves from east to west
- At the equinoxes the Sun rises **exactly** in the east and sets exactly in the west
- **Equinox** (meaning '**equal night**') is when day and night are approximately of equal length
- However, the exact locations of where the Sun rises and sets changes throughout the seasons
- In the northern hemisphere (above the equator):
 - In summer, the sun rises north of east and sets north of west
 - In winter, the sun rises south of east and sets south of west

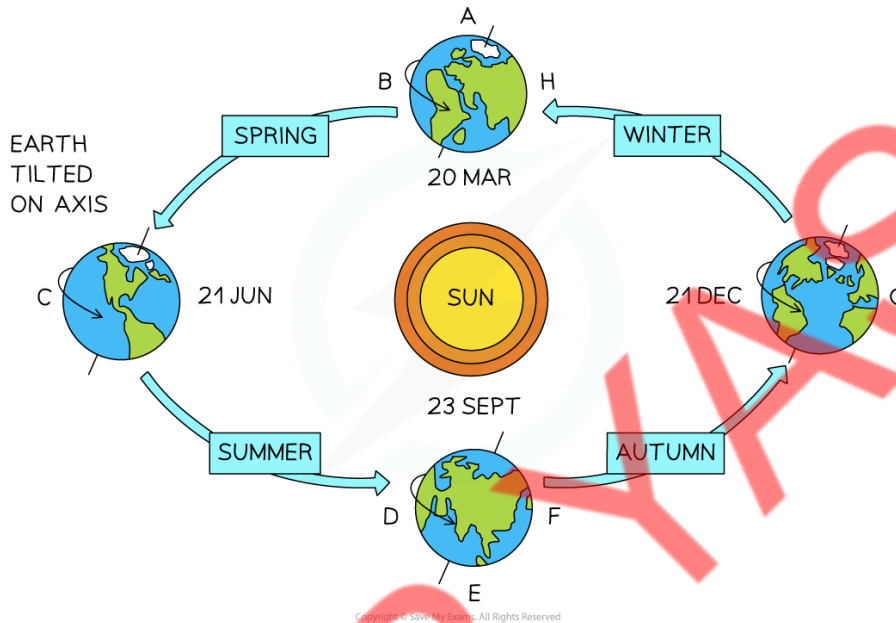


The Sun rises in the east and sets in the west. Its approximate area changes throughout the year

- The Sun is highest above the horizon at noon (12 pm)
- In the northern hemisphere, the daylight hours are longest up until roughly the **21st June**
- This day is known as the **Summer Solstice** and is where the Sun is at its highest point in the sky all year
- The daylight hours then decrease to their lowest around **21st December**
- This is known as the **Winter Solstice** and is where the Sun is at its lowest point in the sky all year

The Earth's Orbit

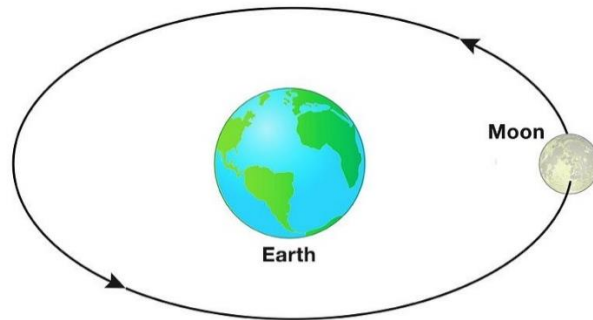
- The Earth orbits the Sun once in approximately 365 days.
- This is 1 year
- The combination of the orbiting of the Earth around the Sun and the Earth's tilt creates the **seasons**



Seasons in the Northern hemisphere caused by the tilt of the Earth

- Over parts B, C and D of the orbit, the northern hemisphere is tilted **towards** the Sun
 - This means daylight hours are more than hours of darkness
 - This is **spring and summer**
- The southern hemisphere is tilted **away** from the Sun
 - This means there are shorter days than night
 - This is **autumn and winter**
- Over parts F, G and H of the orbit, the northern hemisphere is tilted **away** from the Sun
 - The situations in both the northern and southern hemisphere are reversed
 - It is **autumn and winter** in the northern hemisphere, but **at the same time** it is spring and **summer** in the southern hemisphere
- At C:
 - This is the **summer solstice**
 - The northern hemisphere has the longest day, whilst the southern hemisphere has its shortest day
- At G:
 - This is the **winter solstice**
 - The northern hemisphere has its shortest day, whilst the southern hemisphere has its longest day
- At A and D:
 - Night and day are equal in **both** hemispheres
 - These are the **equinoxes**

Moon & Earth

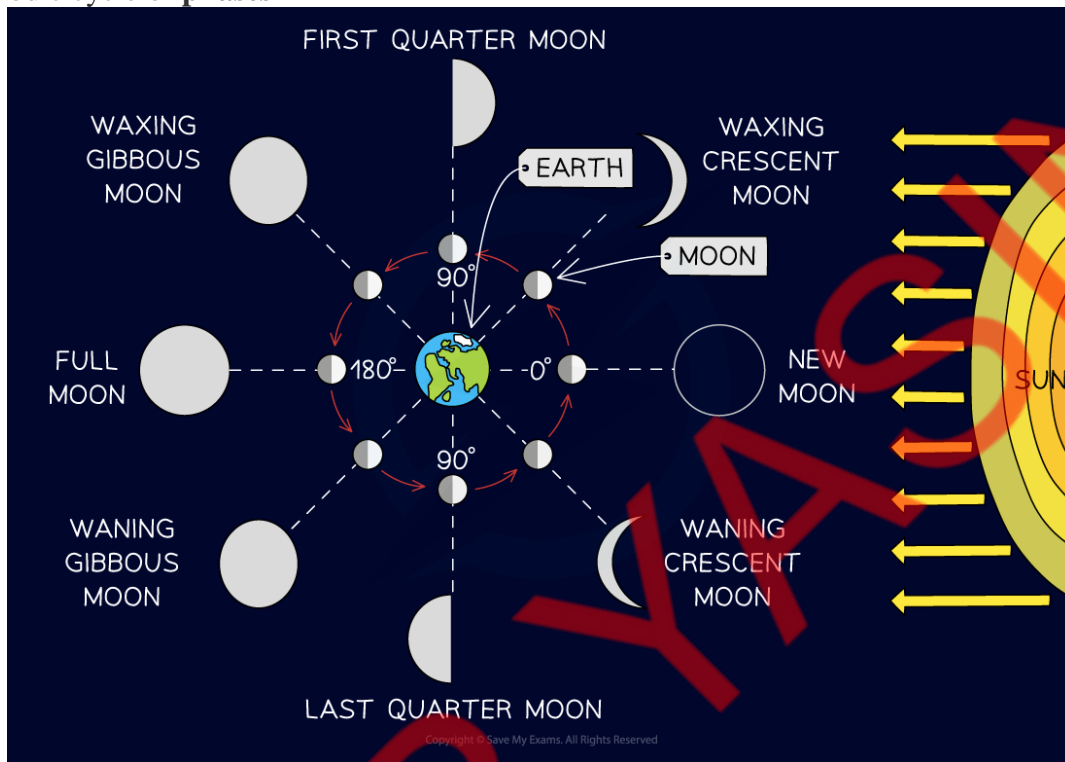


- The Moon is a **satellite** around the Earth
- It travels around the Earth in roughly a circular orbit once a month
- This takes 27-28 days
- The Moon revolves around its own axis in a month so always has the **same** side facing the Earth
- We never see the hemisphere that is always facing away from Earth, although astronauts have orbited the Moon and satellite have photographed it
- The Moon shines with reflected light from the Sun, it does not produce its own light

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Phases of the Moon

- The way the Moon's appearance changes across a month, as seen from Earth, is called its periodic cycle of **phases**



Phases of the Moon as it orbits around Earth

- In the image above, the inner circle shows that exactly half of the Moon is illuminated by the Sun at all times
- The outer circle shows how the Moon looks like from the Earth at its various positions
- In the New Moon phase:
 - The Moon is between the Earth and the Sun
 - Therefore, the sunlight is only on the opposite face of the Moon to the Earth
 - This means the Moon is unlit as seen from Earth, so it is not visible
- At the Full Moon phase:
 - The Earth is between the Moon and the Sun
 - The side of the Moon that is facing the Earth is completely lit by the sunlight
 - This means the Moon is fully lit as seen from Earth
- In between, a crescent can be seen where the Moon is partially illuminated from sunlight

Orbital Speed

- When planets move around the Sun, or a moon moves around a planet, they orbit in **circular motion**
 - This means that in one orbit, a planet travels a distance equal to the circumference of a circle (the shape of the orbit)
 - This is equal to $2\pi r$ where r is the radius of a circle
- The relationship between speed, distance and time is:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

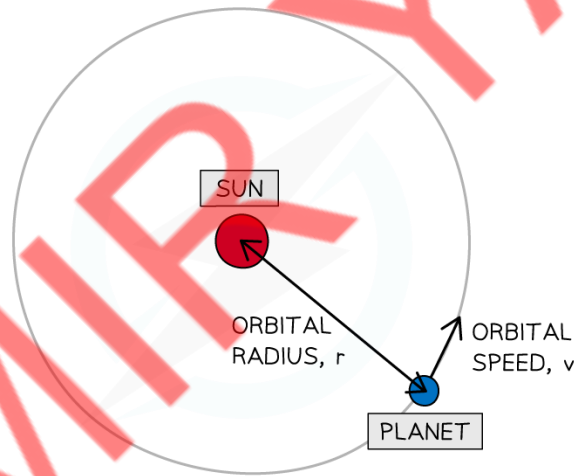
- the average orbital speed of an object can be defined by the equation:

$$v = \frac{2\pi r}{T}$$

- Where:
 - v = orbital speed in metres per second (m/s)
 - r = average radius of the orbit in metres (m)
 - T = orbital period in seconds (s)
- This orbital period (or time period) is defined as:

The time taken for an object to complete one orbit

- The orbital radius r is always taken from the **centre** of the object being orbited to the object orbiting



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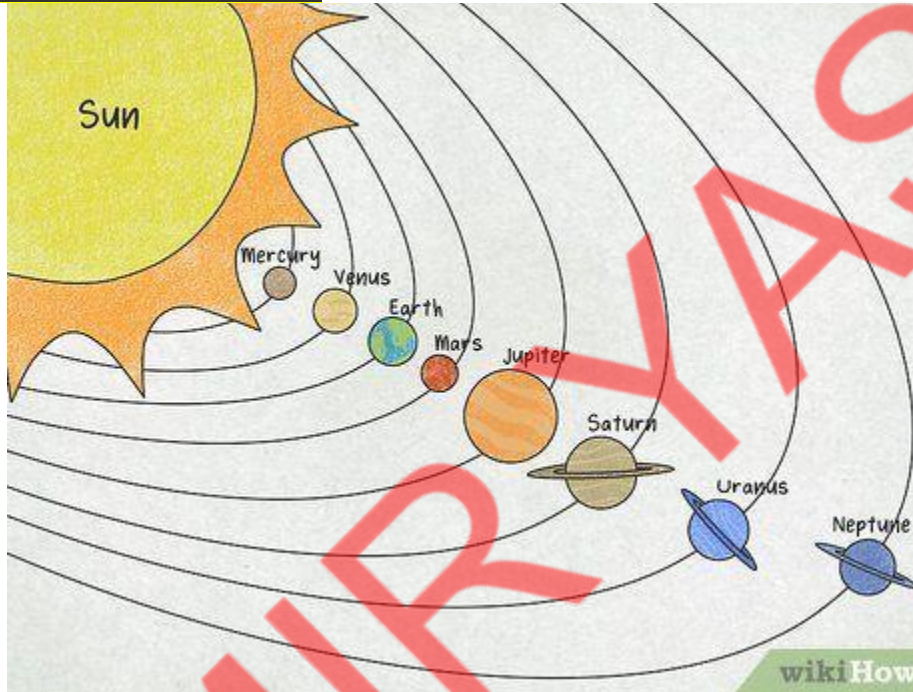
Orbital radius and orbital speed of a planet moving around a Sun

The Solar System

The Solar System consists of:

1. The Sun
2. Eight planets
3. Natural and artificial satellites
4. Dwarf planets
5. Asteroids and comets

The Sun & the Planets



- The **Sun** lies at the **centre** of the Solar System
 - The Sun is a **star** that makes up over 99% of the mass of the solar system
- There are **eight planets** and an unknown number of **dwarf planets** which **orbit** the Sun
 - The **gravitational field** around planets is strong enough to have pulled in all nearby objects with the exception of natural **satellites**
 - The gravitational field around a **dwarf planet** is **not strong enough** to have pulled in nearby objects
- The 8 planets in our Solar System in ascending order of the distance from the Sun are:
 - Mercury
 - Venus
 - Earth
 - Mars
 - Jupiter
 - Saturn
 - Uranus
 - Neptune

Satellites

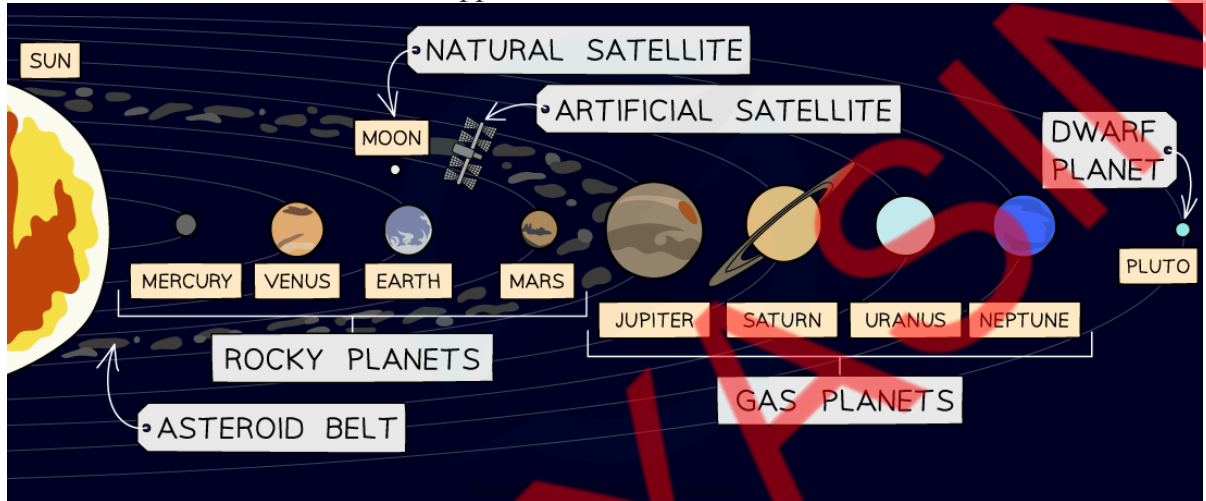
- There are two types of satellite:
 - Natural
 - Artificial
- Some planets have **moons** which orbit them
 - Moons are an example of **natural satellites**



- **Artificial satellites** are man-made and can orbit any object in space
 - The International Space Station (ISS) orbits the Earth and is an example of an artificial satellite

Asteroids & Comets

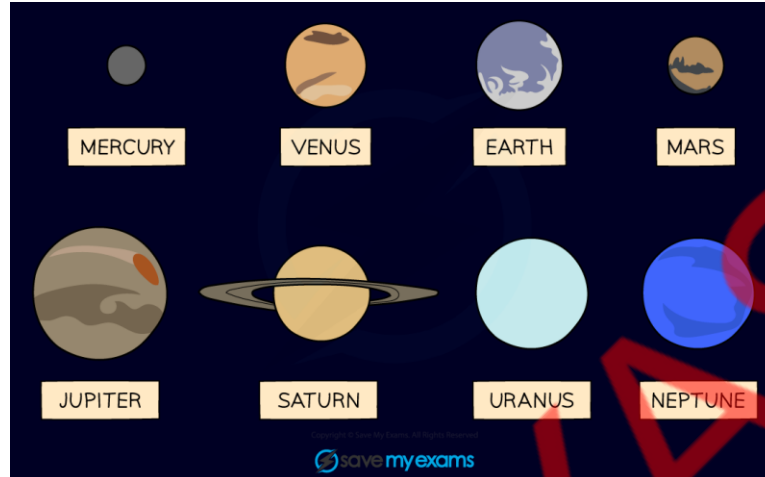
- Asteroids and comets also orbit the sun
- An asteroid is a small rocky object which orbits the Sun
 - The asteroid belt lies between Mars and Jupiter
- Comets are made of dust and ice and orbit the Sun in a different orbit to those of planets
 - The ice melts when the comet approaches the Sun and forms the comet's tail



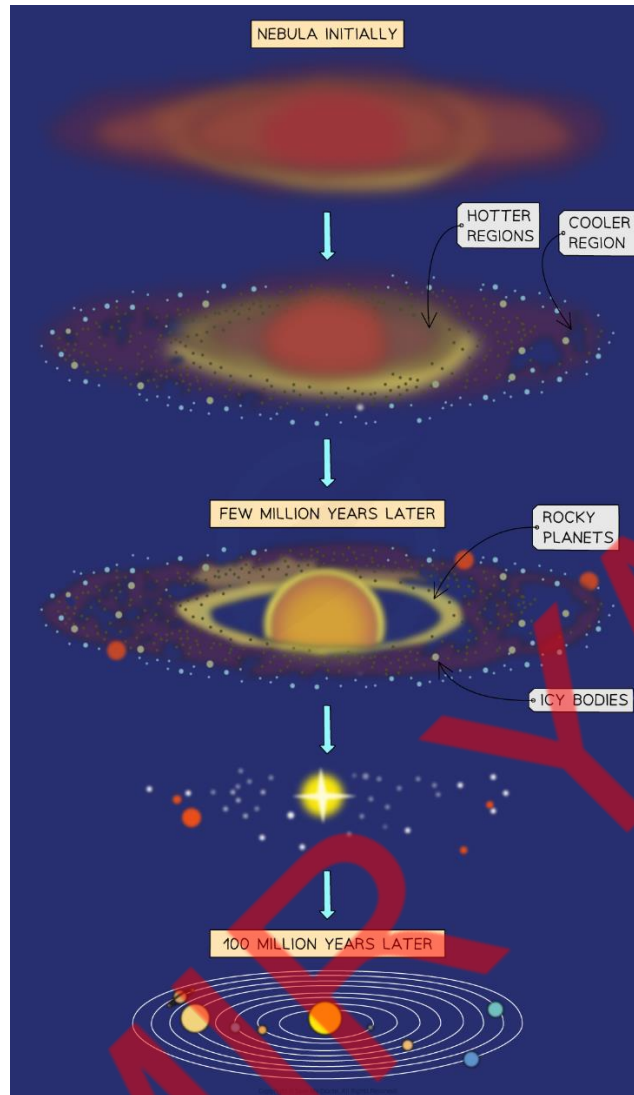
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Accretion Model of the Solar System

- There are **4 rocky and small planets**: Mercury, Venus, Earth and Mars
 - These are the nearest to the Sun
- There are **4 gaseous and large planets**: Jupiter, Saturn, Uranus and Neptune
 - There are the furthest from the sun



- The differences in the types of planets are defined by the **accretion model** for Solar System formation
- The Sun was thought to have formed when gravitational attraction pulled together clouds of hydrogen dust and gas (called nebulae)
- The Solar System then formed around 4.5 billion years ago
 - The planets were formed from the remnants of the disc cloud of matter left over from the nebula that formed the Sun
 - These interstellar clouds of gas and dust included many elements that were created during the final stages of a star's lifecycle (a previous supernova)
- Gravity collapsed the matter from the nebula in on itself causing it to spin around the Sun
 - The gravitational attraction between all the small particles caused them to join together and grow in an **accretion process**
- A rotating **accretion disc** is formed when the planets emerged



The accretion model of the creation of the Solar System

- As the Sun grew in size it became hotter
- Where the inner planets were forming near the Sun, the temperature was too high for molecules such as Hydrogen, Helium, water and Methane to exist in a solid state
 - Therefore, the inner planets are made of materials with high melting temperatures such as metals (e.g. iron)
 - Only 1% of the original nebula is composed of heavy elements, so the inner, rocky planets could not grow much and stayed as a small size, solid and rocky
- The cooler regions were further away from the Sun, and temperature was low enough for the light molecules to exist in a solid state
 - The outer planets therefore could grow to a large size up and include even the lightest element, Hydrogen
 - These planets are large, gaseous and cold

Light Speed

- The planets and moons of the solar system are visible from Earth when they reflect light from the Sun
 - The outer regions of the Solar System are around 5×10^{12} m from the Sun, which means even light takes some time to travel these distances
- The Sun is so far away from Earth that the light we see actually left the Sun eight minutes earlier
 - the nearest star to us after the Sun is so far away that light from it takes four years to reach us
 - The Milky Way galaxy contains billions of stars, huge distances away, with the light taking even longer to be seen from Earth
- The speed of light is a constant 3×10^8 m/s
 - Therefore, using the equation:

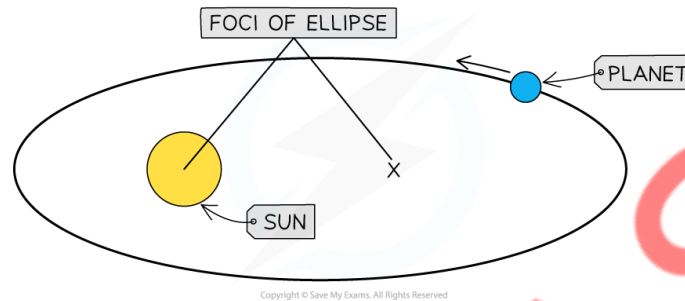
$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

- The time taken to travel a certain distance can be calculated by rearranging to:

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

Elliptical Orbits

- Orbits of planets, minor planets and comets are **elliptical**
 - An ellipse is just a 'squashed' circle
- Planets, minor planets and comets have elliptical orbits
 - However, the Sun is not at the centre of an elliptical orbit
 - This is only the case when the orbit is approximately circular



Analyzing Orbits

- Over many years, data about all the planets, moons and the Sun have been collected
- This is not just for general interest, but to indicate:
 - Factors that affect conditions on the surface of the planets
 - Environmental problems that a visit (using manned spaceships or robots) would encounter

Table of Data for Planets in our Solar System

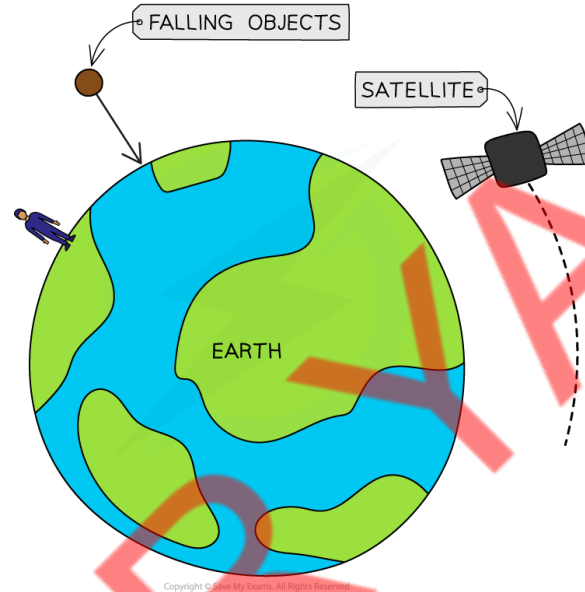
Planet	Orbital distance / million km	Orbital duration / days or years	Density / kg/m ³	Surface Temperature/ °C	Uniform Surface Gravitational Field Strength/ N/kg
Mercury	57.9	88 days	5427	350	3.7
Venus	108.2	225 days	5243	460	8.9
Earth	149.6	365 days	5514	20	9.8
Mars	227.9	687 days	3933	-23	3.7
Jupiter	778.6	11.9 years	1326	-120	23.1
Saturn	1433.5	29.5 years	687	-180	9.0
Uranus	2872.5	75 years	1271	-210	8.7
Neptune	4495.1	165 years	1638	-220	11.0

Gravitational Field Strength

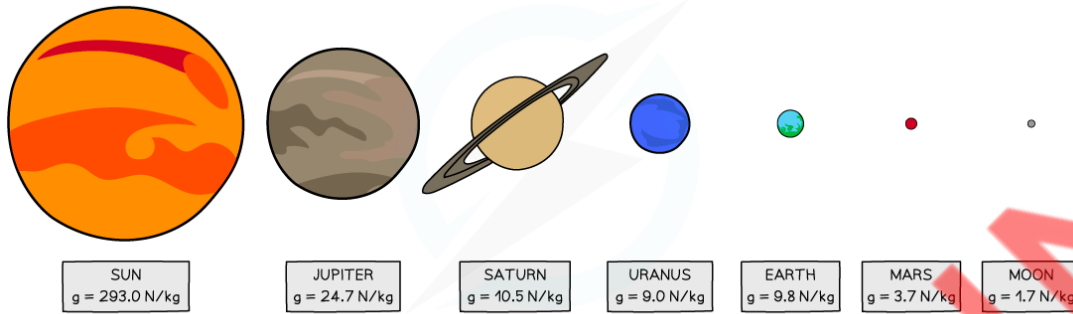
- The strength of gravity on different planets after an object's weight on that planet
- Weight is defined as:

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



- Both the weight of any body and the value of the gravitational field strength g differs between the surface of the Earth and the surface of other bodies in space, including the Moon because of the planet or moon's **mass**
 - The greater the **mass** of the planet then the greater its gravitational field strength
 - A higher gravitational field strength means a larger attractive force towards the centre of that **planet** or moon
- g varies with the **distance** from a planet, but on the surface of the planet, it is roughly the **same**
 - The strength of the field around the planet **decreases** as the distance from the planet **increases**
- However, the value of g on the surface varies dramatically for different planets and moons
 - The gravitational field strength (g) on the **Earth** is approximately 10 N/kg
 - The gravitational field strength on the surface of the **Moon** is **less** than on the Earth
 - This means it would be **easier** to lift a mass on the surface of the Moon than on the Earth
 - The gravitational field strength on the surface of the gas giants (eg. Jupiter and Saturn) is **more** than on the Earth
 - This means it would be **harder** to lift a mass on the gas giants than on the Earth

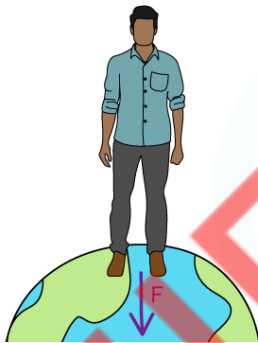


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Value for g on the different objects in the Solar System

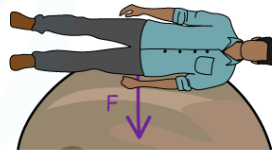
- On such planets such as Jupiter, an object’s mass remains the same at all points in space
- However, their weight will be a lot greater meaning for example, a human will be unable to fully stand up

A BODY ON EARTH HAS A MUCH SMALLER FORCE PER UNIT MASS THAN ON JUPITER



EARTH
 $g = 9.81 \text{ Nkg}^{-1}$

THIS MEANS A BODY WILL HAVE A MUCH GREATER WEIGHT ON JUPITER THAN ON EARTH



JUPITER
 $g = 25 \text{ Nkg}^{-1}$

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A person’s weight on Jupiter would be so large a human would be unable to fully stand up

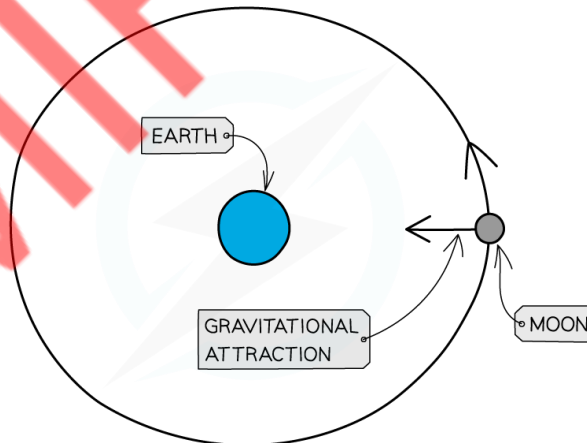
Gravitational Attraction of the Sun

- There are many orbiting objects in our solar system and they each orbit a different type of planetary body

Body or Object	What it Orbits
Planet	Sun
Moon	Planet
Comet	Sun
Asteroid	Sun
Artificial satellite	Any object or body in solar system

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- A **smaller** body or object will **orbit** a **larger** body
 - For example, a planet orbiting the Sun
- In order to orbit a body such as a star or a planet, there has to be a **force** pulling the object **towards** that body
 - **Gravity** provides this force
- Therefore, it is said that the force that keeps a planet in orbit around the Sun is the **gravitational attraction** of the Sun
- The gravitational force exerted by the larger body on the orbiting object is **always attractive**
 - Therefore, the gravitational force always acts **towards the centre** of the larger body
- Therefore, the force that keeps an object in orbit around the Sun is the **gravitational attraction** of the Sun and is always directed from the orbiting object to the centre of the Sun
 - The gravitational force will cause the body to move and maintain in a **circular path**

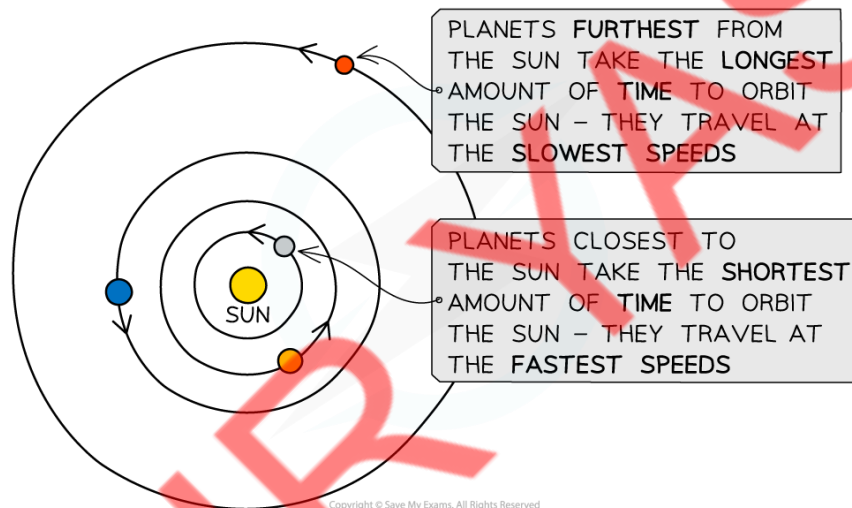


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Gravitational attraction causes the Moon to orbit around the Earth

Sun's Gravitational Field & Distance

- As the distance from the Sun increases:
 - The strength of the Sun's gravitational field on the planet decreases
 - Their orbital speed of the planet decreases
- To keep an object in a circular path, it must have a **centripetal force**
 - For planets orbiting the Sun, this force is **gravity**
- Therefore, the strength of the Sun's gravitational field in the planet affects how much centripetal force is on the planet
 - This strength **decreases** the further away the planet is from the Sun, and the weaker the centripetal force
- The centripetal force is **proportional** to the orbital speed
 - Therefore, the planets further away from the Sun have a smaller orbital speed
 - This also equates to a longer orbital duration



How the speed of a planet is affected by its distance from the Sun

This can be seen from data collected for a planet's orbital distance against their orbital speed

- E.g. Neptune travels much slower than Mercury

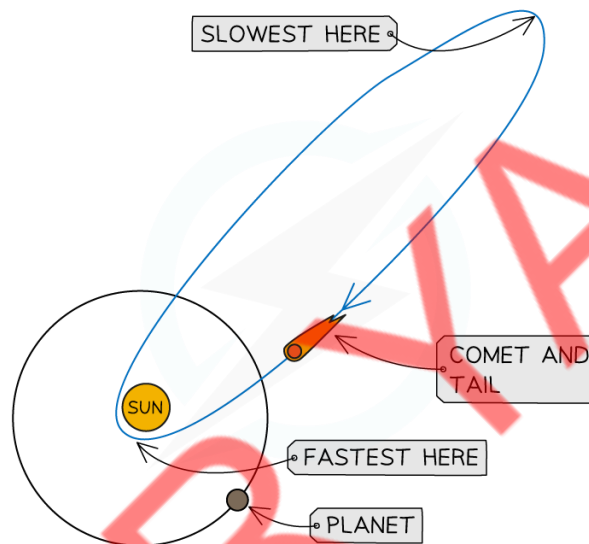
Table of Orbital Distance, Speed and Duration

Planet	Orbital distance / million km	Orbital Speed / km/s	Orbital duration / days or years
Mercury	57.9	47.9	88 days
Venus	108.2	35.0	225 days
Earth	149.6	29.8	365 days
Mars	227.9	24.1	687 days
Jupiter	778.6	13.1	11.9 years
Saturn	1433.5	9.7	29.5 years
Uranus	2872.5	6.8	75 years
Neptune	4495.1	5.4	165 years

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Orbits & Conservation of Energy

- An object in an elliptical orbit around the Sun travels at a **different** speed depending on its distance from the Sun
- Although these orbits are not circular, they are still **stable**
 - For a stable orbit, the **radius** must change if the comet's **orbital speed** changes
- As the comet approaches the Sun:
 - The radius of the orbit **decreases**
 - The orbital speed **increases** due to the Sun's strong gravitational pull
- As the comet travels further away from the Sun:
 - The radius of the orbit **increases**
 - The orbital speed **decreases** due to a weaker gravitational pull from the Sun



Comets travel in highly elliptical orbits, speeding up as they approach the Sun

Conservation of Energy

- Although an object in an elliptical orbit, such as a comet, continually changes its speed its energy must still be conserved
 - Throughout the orbit, the gravitational potential energy and kinetic energy of the comet changes
- As the comet approaches the Sun:
 - It **loses** gravitational potential energy and **gains** kinetic energy
 - This causes the comet to **speed up**
 - This increase in speed causes a **slingshot effect**, and the body will be flung back out into space again, having passed around the Sun
- As the comet moves away from the Sun:
 - It **gains** gravitational potential energy and **loses** kinetic energy
 - This causes it to **slow down**
 - Eventually, it falls back towards the Sun once more
- In this way, a **stable orbit** is formed

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