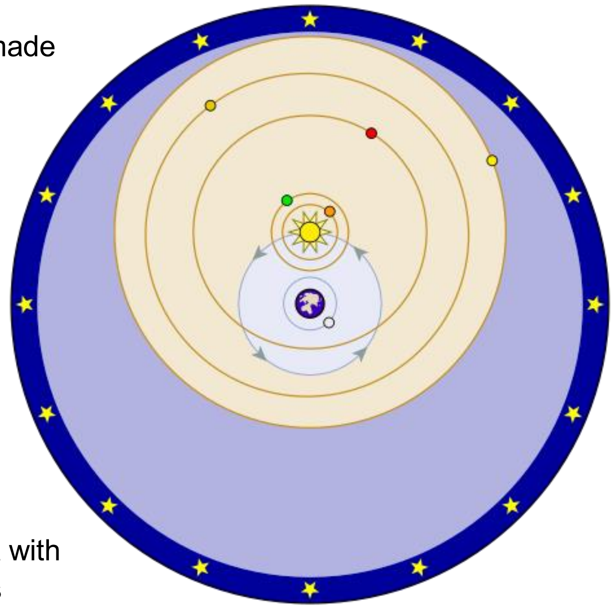
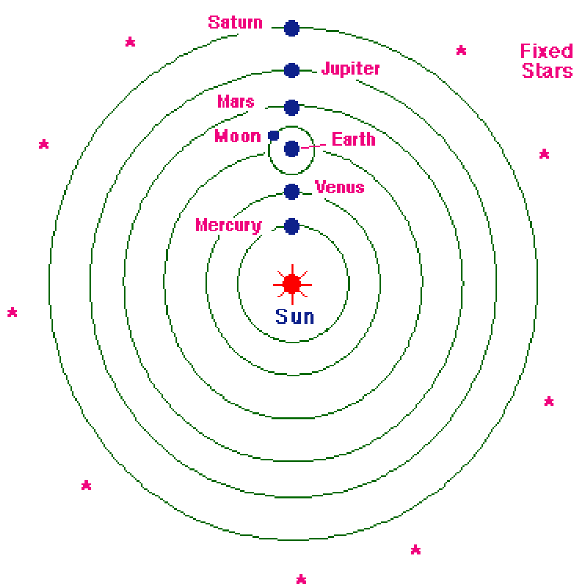
Summary Notes - Topic 8: Planetary Motion & Gravity

8.1 The Contribution of Tycho Brahe



- Tycho Brahe was a **Danish astronomer** who made extremely precise observations of planetary positions without using a telescope.
- His accurate data helped in the transition from the **geocentric (Earth-centered) model** to the **heliocentric (Sun-centered) model**.
- Brahe had issues with the Copernican model and proposed a Geo-Heliocentric Model where the Moon and Sun orbited Earth but everything else orbited the Sun.
- This system removed the epicycles of Ptolemy.
- Brahe made thousands of naked eye observations over many years. He said that no parallax was visible - indeed it would be difficult with the naked eye to measure any, Brahe made his observations without aid.

8.2 The Contributions of Copernicus and Kepler



- **Copernicus** proposed the first **heliocentric model** where planets orbit the Sun in perfect circles.

- **Johannes Kepler** refined this model using Brahe's data and introduced **elliptical orbits.**

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- Kepler's work showed that planets move **faster when closer to the Sun** and **slower when farther away**.

8.3 The Role of Gravity in Stable Orbits

- Velocity is speed **in a given direction**.
- It is a **vector** quantity, so when we talk about an object's velocity we always specify a direction.
- When an object changes direction, its **velocity is changing**, even if its speed remains constant.

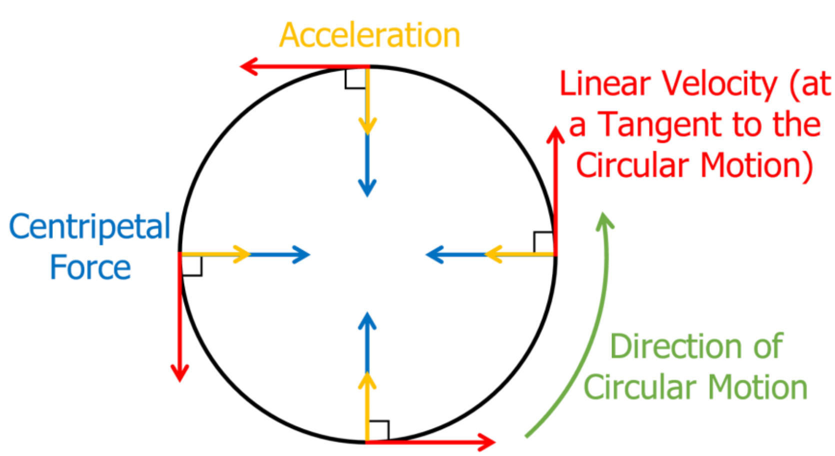
- An object is **accelerating** whenever its velocity is changing.
- An accelerating object can be speeding up, slowing down or changing direction.
- Objects accelerate when subjected to **a resultant force**.

- The **resultant force** acting on an object is a single force which could be used to replace all of the forces acting on the object and would have the **same effect** as all the other forces combined.
- When an object has a **resultant force** on it (i.e. the forces on it are **unbalanced**), the object will **accelerate** in the **direction** of the resultant force.

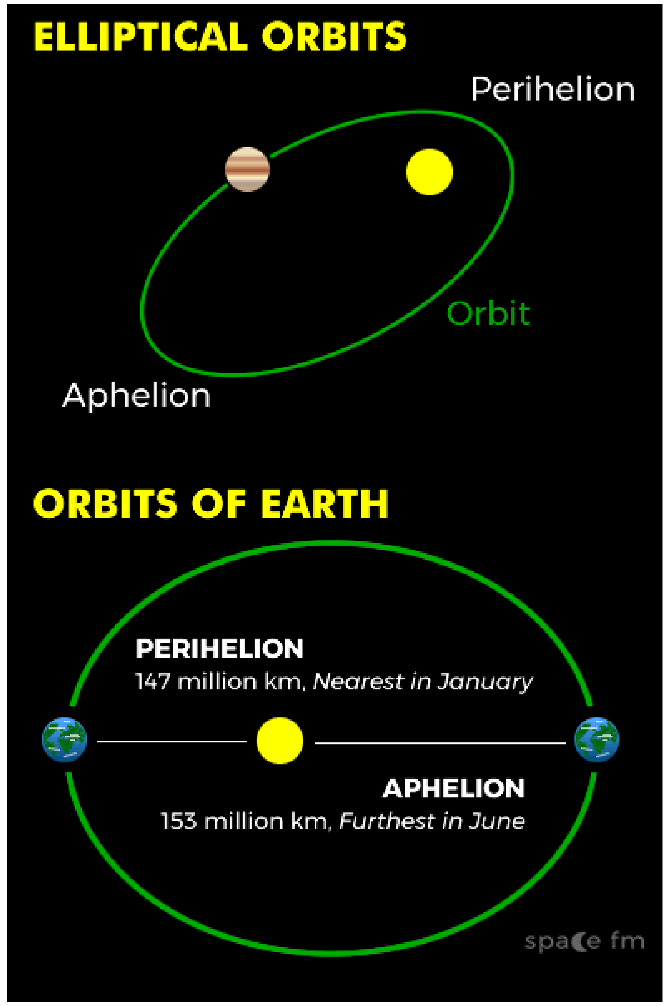
- A gravitational field is a **region of space** around a mass where another mass experiences an **attractive** force.

- A stars **gravitational field** exerts a force of **weight** on each planet, which keeps planets in orbit around the Sun.
- The weight acts as a **centripetal force**, acting perpendicular to the motion of the planet, pulling planets toward the Sun while their velocity keeps them moving forward.
- Without gravity, planets would **move in straight lines** into space.

- We can mathematically model orbits as circular using the mathematics of circular motion.



8.5 Understanding Orbital Terms



- Whilst we often model using circular motion, planets and comets do not orbit in perfect circles. They orbit in ellipses.
- The point at which they are nearest the Sun (or focus, such as a moon around a planet) is called **perihelion**. Body NEARER to Sun
- The point at which they are furthest from the Sun is called **aphelion.** Body FURTHER from Sun

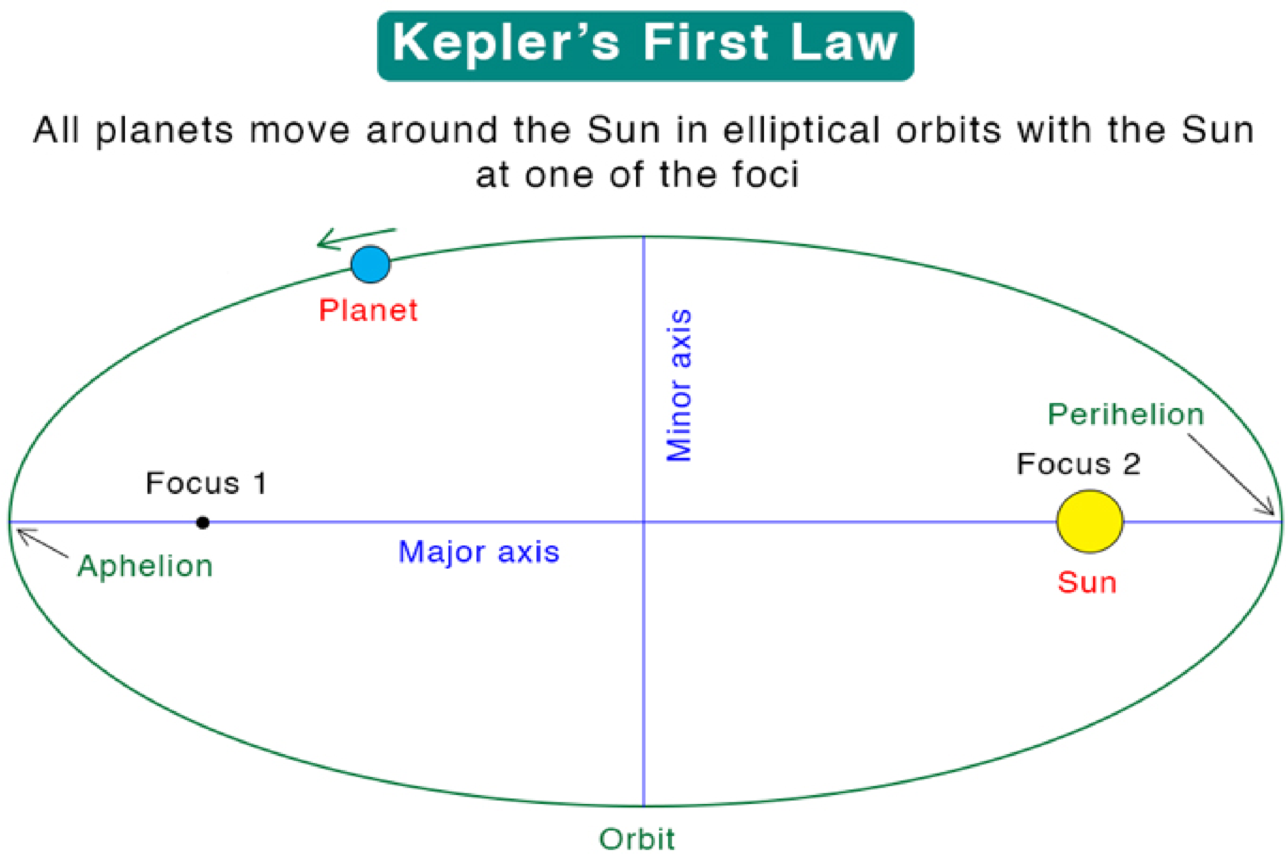
- When the Earth is nearest to the Sun (in January) it is in PERIHELION or **perigee** and is 147,000,000 km from it.
- When it is furthest from the Sun (in July) it is in APHELION or **apogee**. It is then 153,000,000 km from the Sun.
- The mean average distance is approximately 150,000,000 km. This is called the Astronomical Unit, or AU.

8.4 Kepler's Laws of Planetary Motion

First Law (Law of Ellipses): Planets orbit the Sun in **elliptical paths** with the Sun at one focus.

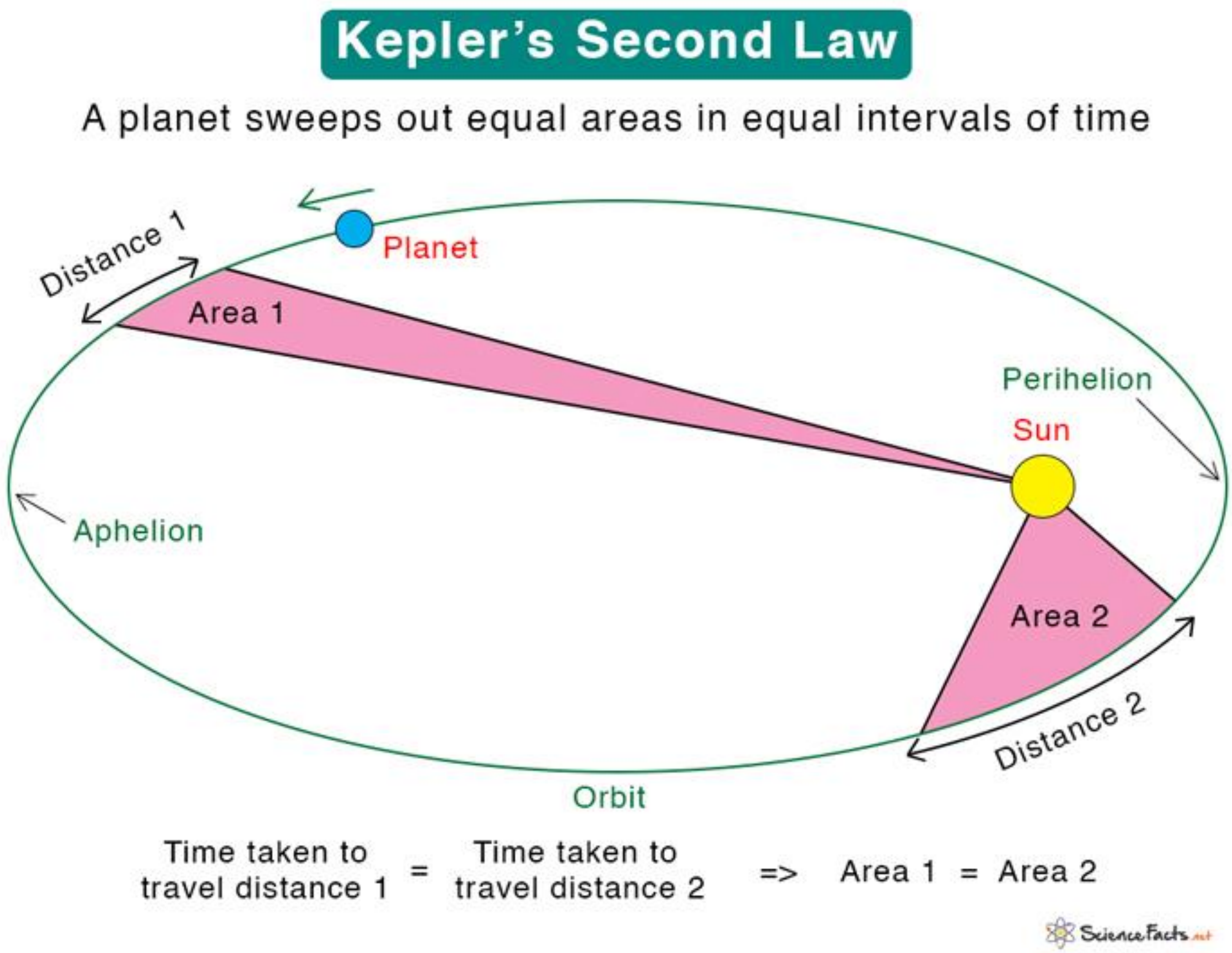
They do not move in circular orbits (although we often model the orbits as circular). Before Kepler astronomers didn't recognise this and so their computations were flawed.

An ellipse is an oval shape with two foci (plural of focus). The Sun is at one focus and the other is in space.



Second Law (Law of Equal Areas): A line from the Sun to a planet sweeps out **equal areas in equal time**, meaning planets move **faster near the Sun** and **slower when farther away**.

If you imagine a line connecting the Sun to the planet, this line sweeps out equal areas in equal times. If you look at the image on the right you will see that the time it takes for the planet to orbit A is the same time for the planet to orbit B.



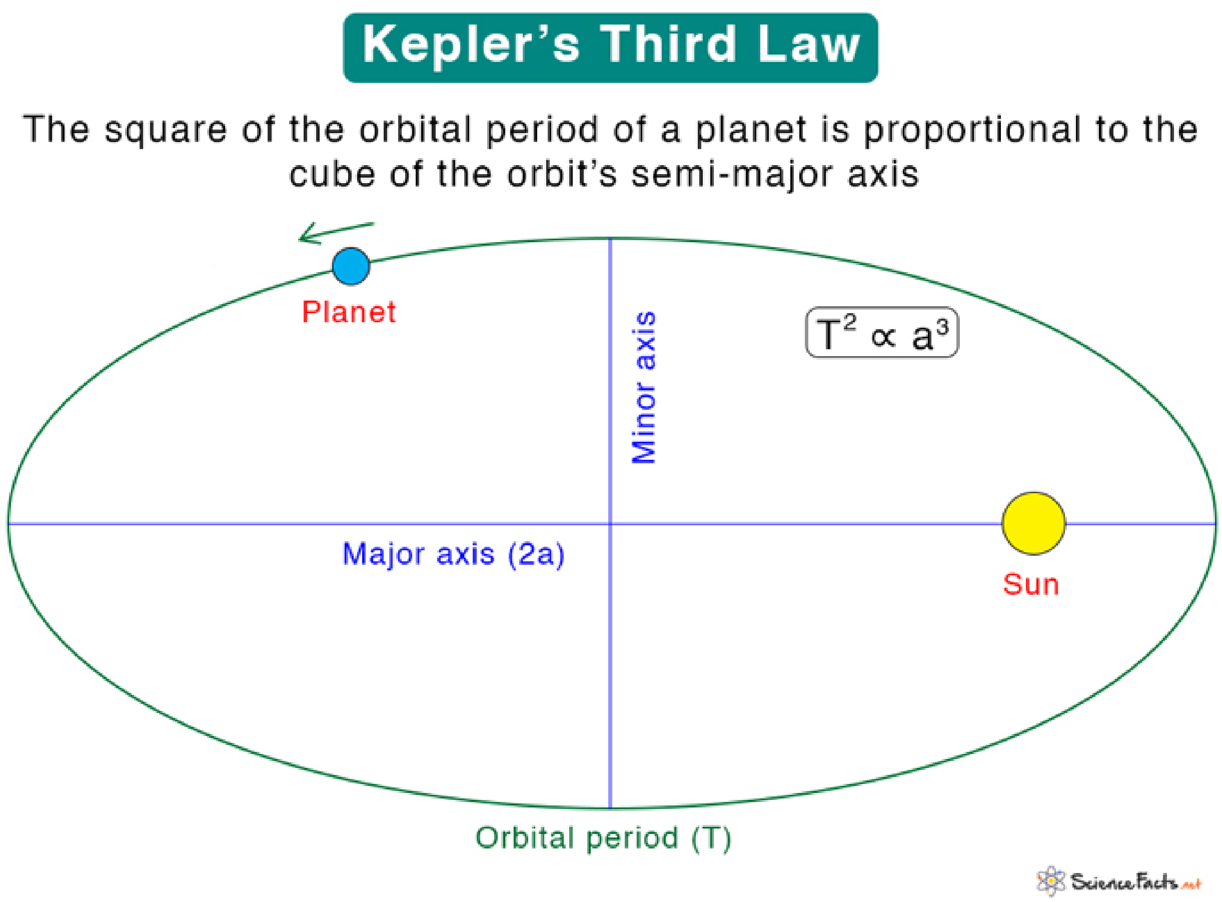
Third Law (Law of Harmonies): The square of a planet's orbital period (T^2) is directly proportional to the cube of its average distance from the Sun (r^3).

There is a relationship between the distance of a planet and the time it takes to orbit the Sun.

T = Period/ Time it takes to orbit the Sun
r = mean radius from Sun

Although we use the Sun as our example, this equally applies to any primary body e.g. the Earth and calculating the orbit of the Moon around it.

(Note: Incidentally some astronomers, textbooks and websites use "P" for Period rather than "T" for Time. Don't worry if you see this being used elsewhere, some also use a (as below) to represent half the length of the semi-major axis, rather than the radius)



8.6 Kepler’s Third Law in Mathematical Form

Question

For thousands of years, humans have observed objects in the night sky and used models to predict their positions.

The German astronomer Johannes Kepler proposed three laws.

These laws helped to predict the positions of objects in the solar system.

Figure 15 shows an image of Comet Encke, near to its perihelion position on March 10th 2017.

The mean distance between Comet Encke and the Sun is 2.22AU.

Figure 15

(i) Show that Comet Encke has a sidereal period of about 3.3 years.

You are advised to show your working clearly.

(3)

(ii) Estimate the first date when Comet Encke reached aphelion, after March 2017.

(2)

Month: .... Year: ....

(iii) Estimate the month in 2023 when Comet Encke will reach its perihelion position.

(2)

Month of perihelion = ...

(iv) Comet Encke orbits the Sun at a mean distance of 2.22AU and has an orbital period of 3.3 years.

Calculate the orbital period of Comet Encke if it orbited a star with a mass three times that of the Sun, at a mean distance of 2.22AU.

(2)

Orbital period = ...

(Total for question = 9 marks)

Question number	**Answer**	**Mark**
	i) Statement of $T^2=r^3$ $2.22^3 = 10.941$ $\sqrt{10.941} = 3.3077$	**(1)** **(1)** **(1)**
	ii) October/November 2018 3.3/2 = **1.65** years (March 2017 + 1.65 years = October / November 2018)	**(2)** *(1)*
	iii) October Idea of two orbits to reach 2023	**(2)** *(1)*
	iv) **1.9 years** (or equivalent) *Any 1 from:* T^2/r^3 reduces to 1/3. 3.647	**(2)** (1)

8.7 The Effect of Central Body Mass

- The constant in Kepler's third law depends **inversely on the mass of the central body**.
- Larger masses create stronger gravitational fields, affecting **orbital speed and distance**

8.8 Newton's Explanation of Kepler's Laws

- **Isaac Newton** explained Kepler's laws using his **law of universal gravitation**.
- He showed that planetary motion results from:
    - **Gravity** pulling planets toward the Sun.
    - **Inertia** keeping planets moving forward.
- Inertia is defined as: The tendency of an object to resist changes to its motion (meaning it stays at rest or continues moving at a constant velocity unless a resultant force acts on it).

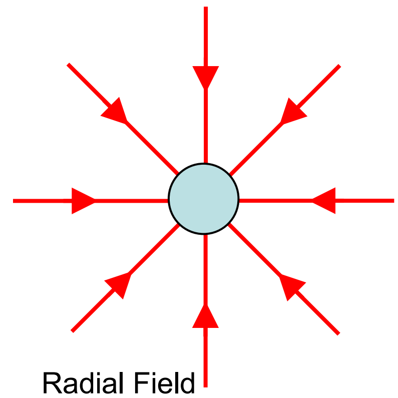
- Newton's work helped mathematically confirm the heliocentric model.

8.9 Newton's Law of Universal Gravitation

Gravitational Field Strength, *g*

- Definition of gravitational field strength:

The **gravitational field strength** at any given point in a gravitational field is the size of the force the field would produce on a unit mass if it were placed at that point.



Radial Field

- So, **gravitational field strength** is the **force per unit mass**.
- *I.e.* if an gravitational field creates a force *F* on an object of mass *m* placed inside the field then the gravitational field strength, *g*, is given by

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

- The units of gravitational field strength: N kg^{-1}.

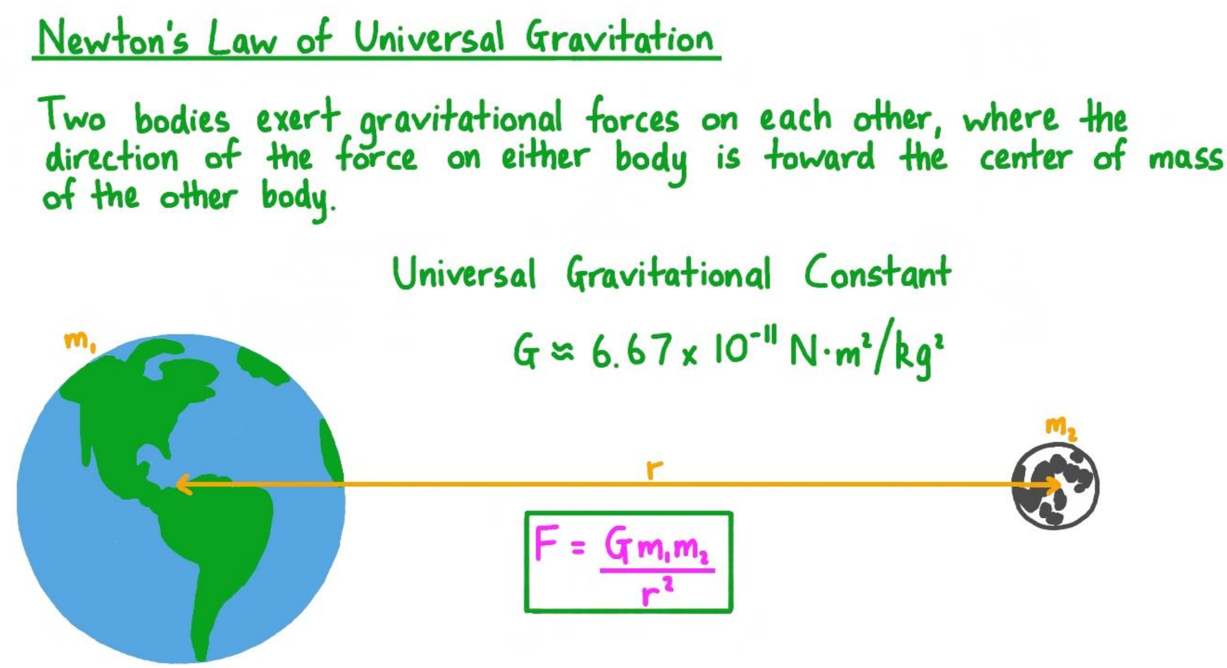
- Gravity is a force which is
  - Attractive
  - between all objects with mass

- It makes objects near the surface of the Earth fall towards it.
- It keeps the moon orbiting the Earth
- It keeps the planets orbiting the Sun
- It keeps stars orbiting around the centre of the galaxy
- Newton wanted to derive a universal law of gravity which would explain all these different phenomena

Newton Law of Gravitation:

- The force of Gravity between two point objects
  - is proportional to the product of the masses of the objects ($F \propto m_1 m_2$)
  - is inversely proportional to the square of the distance between the centre of mass of the objects. ($F \propto 1/r^2$)

- The force is attractive.
- It acts to reduce the distance, *r*, between the two masses.
- It is in the opposite direction to the displacement from one object to the other.
- The constant *G* is known as the universal gravitational constant.



Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

If the mass of the Sun and the distance between the Earth and the Sun were **both** doubled, the gravitational force between them would:

(1)

☐ **A** increase by four times
☐ **B** double
☐ **C** stay the same
☐ **D** halve

(Total for question = 1 mark)