Topic Guide:

Building Planetary Systems

GCSE (9-1) Astronomy

Pearson Edexcel Level 1/Level 2 GCSE (9-1) in Astronomy (1AS0)

Building Planetary Systems

Contents

Specification Points

12.1 Be able to identify the operation of each of the following in our Solar System:

a) gravitational attraction producing regular motion, including the orbits of planets and moons

b) tidal gravitational forces producing effects, including ring systems, asteroid belts and internal heating

c) gravitational interactions of multiple bodies producing effects such as gradual shifts in orbits, chaotic motion, resonances and the significance of Lagrangian Points (detailed mathematical descriptions not required)

d) accidental collisions causing impact craters, changes to orbital motions or planetary orientations

e) solar wind affecting comets, planetary atmospheres and the heliosphere

12.2 Be able to identify the operation of each of the following interactions in the formation of planets and moons:

a) the interaction between tidal gravitational and elastic forces to determine whether a body is broken apart (Roche Limit)

b) the interaction between attractive gravitational and elastic forces in determining a body's spherical or irregular shape

c) the interaction between gravitational and thermal factors in determining the presence of an atmosphere

12.3 Understand the main theories for the formation of gas giant planets in planetary systems

The Astronomy

The Sun formed approximately 4.6 billion years ago and a protoplanetary disc of material was left orbiting the Sun. **Accretion** of this material (the electrostatic and then gravitational attraction of small particles to form larger ones) resulted in the formation of metallic and silicate planetary cores after 100 million years. It has been suggested that there were originally as many as 50 bodies (planetesimals) but **collisions** and reformation eventually gave us the 8 planets we have today. Evidence of these collisions possibly includes the large axial tilt of Uranus, the 'backward' (retrograde) spin of Venus, the formation of the Moon and large impact basins observed throughout the Solar System.

Planets are (approximately) spherical. This requires a sufficiently large mass. **Gravity must be greater than the elastic forces** preventing this collapse. Therefore, smaller bodies remain irregular in shape.

Students could be given a list of planets and dwarf planets to determine the approximate minimum diameter for a body to become spherical (400 – 600 km diameter)

The **Frost Line** is an imaginary boundary from the Sun. At distances less than 5 AU from the Sun, the high temperatures meant that only silicates and even closer only metals could condense to form small grains and particles. At distances greater than 5 AU, the low temperatures allowed the volatile compounds (ices and gases) to condense into solid grains. Therefore, the gas giants are now found in the outer Solar System. Students can be asked to determine where the frost line is located given their knowledge of the Solar System.

Planetary atmospheres are determined by two factors, the distance from the Sun (temperature) and the mass of the planet (gravity). A planet closer to the Sun will naturally have a higher surface temperature. The average kinetic energy of the gas molecules within the atmosphere will be higher. If the gas molecules exceed the escape velocity of the planet then they can and will eventually 'escape'. Therefore, for a planet to maintain the lighter elements (H, He) it must be relatively cold (far from the Sun) and have a relatively high mass.

Gravitational tidal forces occur because the side of a moon nearest its parent planet will experience a larger gravitational force of attraction (and therefore want to have a greater orbital velocity) than the side further from the planet. This can result in two tidal bulges. Tidal bulges are fairly obvious to see if the surface is predominantly liquid (like the Earth's oceans) but these forces can also be sufficiently strong to distort solid bodies as well.

Tidal forces can result in:

- **tidal heating**

The tidal bulge of a moon must lie in line with the planet it is orbiting. If the moon is spinning on its axis then this results in the tidal bulge migrating around the moon. The resulting internal friction generates large amounts of thermal energy known as 'tidal heating'.

- **synchronous orbital rotation**

The loss of energy from tidal heating is at the expense of the rotational kinetic energy of the Moon. Therefore, the Moon's rotational period slows down to a point where its orbital and rotational period are equal (synchronous orbital rotation). The same face of the Moon will now always point to the planet.

Tidal heating can continue if the Moon's orbit is elliptical (it has a changing orbital velocity) and the tidal bulge will oscillate.

Teachers can link this topic with lunar (longitudinal) libration, Jupiter's moon Io, gravity and Kepler's 3rd Law.

- **The Roche limit** and tidal forces resulting in ring systems

If a moon is close to a large mass planet, the tidal forces could be sufficiently strong to overcome the moon's gravitational and elastic forces. This results in the moon being 'ripped' apart by the tidal forces. The minimum distance for a body to withstand this tidal force is called the Roche limit. It is approximately 2.5 planetary radii for bodies of similar composition and is probably the cause of planetary ring systems.

Teachers may also want to link the Roche limit to stellar evolution. The Roche limit is exceeded if red giants expand and their outer layers accrete onto a neutron star or black hole.

Orbital resonance occurs in multi-body systems where the gravitational pull of several moons can result in their mutual 'tugging' and 'pulling'. This can result in orbital periods of exact ratios. Io, Europa and Ganymede (moons of Jupiter) have orbital periods in the ratio 1 : 2 : 4. This can also account for the gaps in ring systems e.g. the Cassini Division and Kirkwood Gaps.

Lagrangian points for a particular planet are points in space at which an object moving purely under gravitational forces would orbit the Sun with the same time period as that planet orbits the Sun. There are 5 possible Lagrangian points, but only two maintain a stable equilibrium, L4 and L5, which precede and follow a planets orbit by 60^o. The SOHO satellite is located at L1, and Trojan asteroids have been discovered in the Jovian L4 and L5 points. Two moons of Saturn, Tethys and Dione, both have companions 60^o ahead and behind in their orbit.

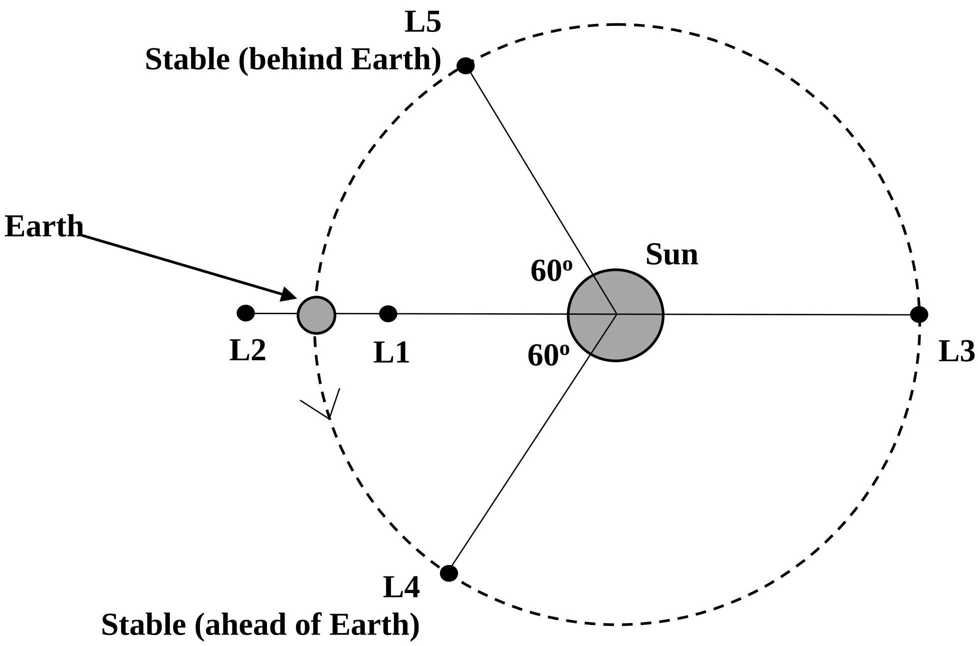

Figure 1 – The Earth’s five Lagrangian Points

Further support

University of Florida – Formation of the Solar System (pdf)
http://www.astro.ufl.edu/~freyes/classes/ast2003/FR_CH_8.pdf

STEM Learning – The Birth of the Solar System
https://www.stem.org.uk/elibrary/resource/26893

Tidal Heating Tutorial - Toby Smith
http://tobyrsmith.github.io/Astro150/Tutorials/TidalHeat/

Youtube – MinutePhysics: Why is the Solar System flat
https://www.youtube.com/watch?v=tmNXKqeUtJM

Youtube – The Formation of our Solar System in 4k
https://www.youtube.com/watch?v=x1QTc5YeO6w

Youtube – Artifexian; Formation of the Solar System
https://www.youtube.com/watch?v=sxD1iPCNuqE

Youtube – Artifexian; Dwarf Planet Orbits | Worldbuilding
https://www.youtube.com/watch?v=YGw0kQufhgM

Youtube – Artifexian; Worldbuilding - Lagrange Points and other Trojan Ramblings
https://www.youtube.com/watch?v=1YaVTWbf0bg

Topic test questions

1. Why is Io, the inner most moon of Jupiter, so volcanically active?
2. Give two reasons why the Moon has no atmosphere.
3. Why do 'gaps' form in planetary ring systems?
4. Why did the asteroid belt between Jupiter and Mars not form into a planet?

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