Space Physics

The Earth, Moon and Sun, orbital speed, the Solar System and its planets, gravitational field strength, the Sun as a star, the life cycle of stars, galaxies and light-years, redshift and the Big Bang.

6.1.1 The Earth

- The Earth is a **planet** that orbits the Sun once in about **365 days** (one year). Its orbit is an **ellipse** that is very nearly a circle.
- The Earth **rotates on its axis** once in about **24 hours** (one day). This gives day and night. The axis is **tilted**, which is the cause of the seasons.
- The **Moon** orbits the Earth about once a **month**.
- Light takes about **500 s** to reach the Earth from the Sun.

Orbital speed

The distance travelled in one orbit is the circumference of the orbit, $2\pi r$, and the time taken is the orbital period T.

> average orbital speed $v = \dfrac{2\pi r}{T}$, **where r is the average radius of the orbit and T is the orbital period.**

TRY IT

The average radius of the Earth's orbit is 1.5×10^{11} m and the period is 365 days. Find the orbital speed.

$T = 365 \times 24 \times 3600 = 3.15 \times 10^{7}$ s $\qquad v = \frac{2\pi \times 1.5 \times 10^{11}}{3.15 \times 10^{7}} = 3.0 \times 10^{4}$ m/s

That is about 30 km/s.

TRY IT

Light from the Sun takes 500 s to reach the Earth. Use 3.0×10^{8} m/s to find the distance from the Earth to the Sun.

$d = 3.0 \times 10^{8} \times 500 = 1.5 \times 10^{11}$ m

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6.1.2 The Solar System

The Solar System contains:

- one star, the **Sun**;
- the **eight planets**, in order from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune;
- **minor planets** that orbit the Sun, including **dwarf planets** such as Pluto and the **asteroids** of the asteroid belt (between Mars and Jupiter);
- **moons**, which orbit planets;
- smaller bodies, including **comets** (balls of ice and dust in very elongated orbits) and other natural satellites.

Planetary data

Planet	Distance from the Sun (million km)	Orbital period	Density ($\mathrm{g/cm^3}$)	Surface gravitational field strength ($\mathrm{N/kg}$)
Mercury	58	88 days	5.4	3.7
Venus	108	225 days	5.2	8.9
Earth	150	365 days	5.5	9.8
Mars	228	687 days	3.9	3.7
Jupiter	778	11.9 years	1.3	24.8
Saturn	1430	29.5 years	0.7	10.4
Uranus	2870	84 years	1.3	8.9
Neptune	4500	165 years	1.6	11.2

Trends to look for when you interpret data:

- The **further** a planet is from the Sun, the **longer** its orbital period, and the **slower** its orbital speed.
- The four planets nearest the Sun (rocky planets) are **dense** and the four furthest (gas giants and ice giants) have a **low density**.
- Planets further from the Sun are generally **colder**. (Venus is hotter than Mercury because its thick atmosphere traps heat.)

> **TRY IT**

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Using the table, find the orbital speed of Mars. (Radius 2.28×10^{11} m, period 687 days.)

$T = 687 \times 24 \times 3600 = 5.94 \times 10^{7}$ s $\qquad v = \frac{2\pi \times 2.28 \times 10^{11}}{5.94 \times 10^{7}} = 2.4 \times 10^{4}$ m/s

This is less than the Earth's speed of about 3.0×10^{4} m/s, as expected for a planet further from the Sun.

Gravitational fields in the Solar System

- The strength of the gravitational field at the **surface of a planet** depends on the **mass of the planet**. A planet with more mass has a stronger field, which is why Jupiter's surface gravity is much larger than the Earth's.
- Around any planet, the field gets **weaker** as the distance from the planet **increases**.
- The **Sun** contains most of the mass of the Solar System, so the gravitational field at its surface is much greater than at any planet.
- The force that keeps a planet in orbit is the **gravitational attraction of the Sun**. This is the force towards the centre that makes the planet go in a circle (see circular motion in chapter 1).
- The Sun's gravitational field becomes weaker with distance, so planets further out orbit more slowly.

6.2.1 The Sun as a star

The Sun is a **star of medium size**. It is made mostly of **hydrogen and helium**. Most of the energy it radiates is in the **infrared, visible and ultraviolet** parts of the electromagnetic spectrum.

Stars are powered by **nuclear reactions**. In a stable star such as the Sun, the nuclear reaction is the **fusion of hydrogen into helium** in the core, which releases a huge amount of energy.

6.2.2 Stars

- A **galaxy** is made of many billions of stars.
- The Sun is one star in the galaxy called the **Milky Way**.
- The other stars in the Milky Way are much further from the Earth than the Sun is.
- Astronomical distances are measured in **light-years**. One light-year is the distance travelled by light in a vacuum in one year.

TRY IT

How far is one light-year in metres? (speed of light 3.0×10^{8} m/s, one year $= 3.15 \times 10^{7}$ s)

$3.0 \times 10^{8} \times 3.15 \times 10^{7} = 9.5 \times 10^{15}$ m

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The life cycle of a star

1. **A star forms** from a cloud of gas and dust (an interstellar cloud) that contains hydrogen.
2. The cloud collapses because of its own gravitational attraction, and its temperature rises. This is a **protostar**.
3. When the centre is hot enough for hydrogen to fuse into helium, the star becomes **stable**: the inward force of gravity is balanced by an outward force from the high temperature in the core.
4. All stars eventually **run out of hydrogen** in the core as fuel.
5. Most stars then expand to form **red giants**, and the more massive stars expand to form **red supergiants**.

After that, the path depends on the mass of the star.

Star	What happens next
a less massive star (like the Sun)	the red giant throws off its outer layers as a **planetary nebula**, leaving a **white dwarf** at its centre
a more massive star	the red supergiant explodes as a **supernova**, forming a **nebula** that contains hydrogen and new, heavier elements, and leaving a **neutron star** or a **black hole** at its centre

The nebula from a supernova can collect together and form **new stars**, with orbiting planets.

6.2.3 The Universe

The Milky Way is one of many billions of galaxies that make up the **Universe**. Its diameter is about **100 000 light-years**.

Redshift

> **Redshift is an increase in the observed wavelength of light (or other electromagnetic radiation) from a star or galaxy that is moving away from us.**

The wavelength of the light gets longer, so it shifts towards the red end of the spectrum. (Sound does the same: the pitch of a siren drops as it moves away from you.)

- The light from **distant galaxies** is redshifted, so they are moving away from us.
- The **further away** a galaxy is, the **greater its redshift**, and the **faster** it is moving away from the Earth.

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The Big Bang

The redshift of galaxies shows that the Universe is **expanding**. If the galaxies are all moving apart now, then in the past they were closer together. Tracing the expansion back, everything was once in a very small, hot, dense place. The **Big Bang theory** says that the Universe began from this state about 14 billion years ago and has been expanding ever since. Redshift is evidence for the Big Bang theory.

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