Collins

Cambridge IGCSE™

Physics

STUDENT'S BOOK

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Humans are curious beings. We cannot look at the stars in the night sky, without asking questions. How did the stars get there? Is the Earth the only habitable planet in the Universe? The frontiers of science and technology are being pushed forward all the time. We can now send space probes to distant planets, and even land them on comets hurtling through space. We are learning more about the objects that are close to the Earth. We can use complex telescopes orbiting the Earth to study distant objects in space using not only visible light, but also X-rays. The Chandra X-ray Observatory was launched in 1999, and is still operational and orbiting the Earth. It continues to provide astronomers with stunning images – helping them to test their theories and advance our knowledge and understanding of space.

STARTING POINTS

1. What causes day and night on the Earth?
2. What is the name of the force that keeps the Moon in its orbit around the Earth?
3. How can you tell if a speck of light in the night sky is a planet and not a star?
4. What is a galaxy?

SYLLABUS SECTIONS COVERED

6.1 Earth and the Solar System

6.2 Stars and the Universe

6 Space physics

∆ The Chandra X-ray Observatory continues to help astronomers learn about Space.

Δ Fig. 6.1 Stunning image of the swirling atmosphere of Jupiter taken from the camera aboard NASA's Juno spacecraft.

Earth and the Solar System

INTRODUCTION

Our developing understanding of the Solar System, and the space beyond, has largely come from observations. In the past, these observations were Earth-based and simple instruments were used to measure and record the motion of the planets and our Moon across the night sky. Predictions were made based on these observations – such as the phases of the Moon by the Iranian scholar Al-Biruni some thousand years ago. We can learn more about our Moon, and the planets beyond, by using powerful telescopes onboard space probes, see Fig. 6.1.

KNOWLEDGE CHECK

✓ Conservation of energy can be applied to any system.
✓ Gravitational field strength is the force per unit mass.
✓ Gravitational force acts on an object that has mass.
✓ Speed is distance travelled per unit time.
✓ **SUPPLEMENT** Speed of light is 3.0×10^8 m/s in a vacuum.

LEARNING OBJECTIVES

✓ Know that the Earth is a planet that rotates on its axis, which is tilted, once in approximately 24 hours, and use this to explain observations of the apparent daily motion of the Sun and the periodic cycle of day and night.
✓ Know that the Earth orbits the Sun once in approximately 365 days and use this to explain the periodic nature of the seasons.
✓ Know that it takes approximately one month for the Moon to orbit the Earth and use this to explain the periodic nature of the Moon's cycle of phases.
✓ **SUPPLEMENT** Define average orbital speed from the equation $v = \frac{2\pi r}{T}$ where r is the average radius of the orbit; recall and use this equation.
✓ Describe the Solar System as containing: one star, the Sun; the named planets and know their order from the Sun; dwarf planets that orbit the Sun, including asteroids; moons, that orbit the planets; and smaller Solar System bodies, including comets and natural satellites.
✓ Know that, in comparison to each other, the four planets nearest the Sun are rocky and small and the four planets furthest from the Sun are gaseous and large, and explain this difference by referring to an accretion model for solar system formation to include: the model's dependence on gravity, the presence of many elements in interstellar clouds of gas and dust and the rotation of material in the cloud and the formation of an accretion disc.

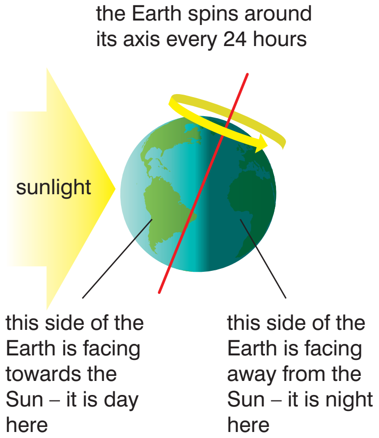
✓ Know that the strength of the gravitational field: at the surface of a planet depends on the mass of the planet and around a planet decreases as the distance from the planet increases.
✓ Calculate the time it takes light to travel a significant distance such as between objects in the Solar System.
✓ Know that the Sun contains most of the mass of the Solar System and this explains why the planets orbit the Sun.
✓ Know that the force that keeps an object in orbit around the Sun is the gravitational attraction of the Sun.
✓ **SUPPLEMENT** Know that planets, minor planets and comets have elliptical orbits, and recall that the Sun is not at the centre of the elliptical orbit, except when the orbit is approximately circular.
✓ **SUPPLEMENT** Analyse and interpret planetary data about orbital distance, orbital duration, density, surface temperature and uniform gravitational field strength at the planet's surface.
✓ **SUPPLEMENT** Know that the strength of the Sun's gravitational field decreases and that the orbital speeds of the planets decrease as the distance from the Sun increases.
✓ **SUPPLEMENT** Know that an object in an elliptical orbit travels faster when closer to the Sun and explain this using the conservation of energy.

THE EARTH

The length of a day and a year is determined by the motion of the Earth through space. A day is the time it takes for the Earth to spin on its axis – this is approximately 24 hours. A year is the time it takes for the Earth to make one orbit around the Sun – this is approximately 365 days.

Day and night

As Fig. 6.2 shows, it is day-time on the side of the Earth that is directly facing the Sun, and night-time on the opposite side of the Earth. The rotation of the Earth on its axis gives rise to the periodic cycle of day and night. The Earth rotates towards the east. This is why the Sun, Moon, planets and all the stars, rise in the east and move through the sky towards the west.



Δ Fig. 6.2 Day and night are caused by the Earth spinning on its axis.

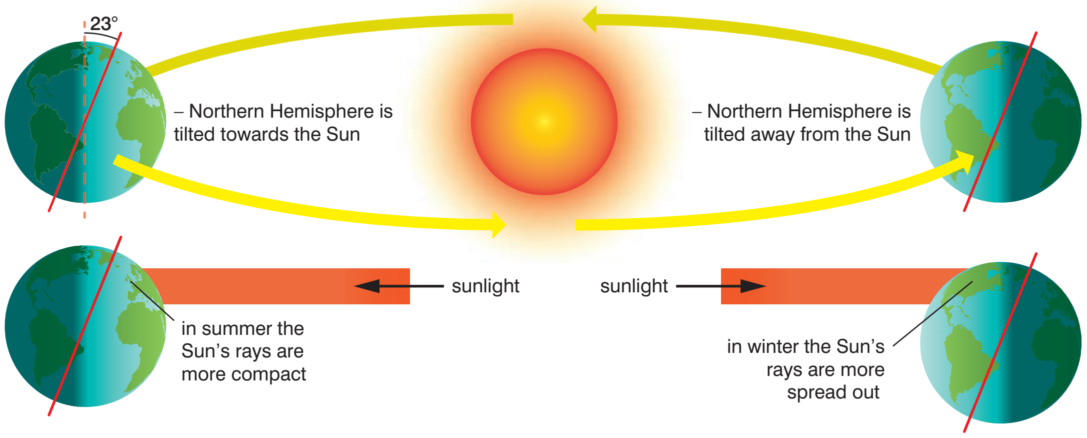
The seasons

The Earth's axis of rotation is tilted at 23°. In the winter, the Northern Hemisphere is tilted away from the Sun. The Sun is above the horizon for shorter times each day, so there is less daylight. The Sun is low in the sky and the amount of heat from the Sun is reduced.

Six months later, in the summer, the Earth is on the other side of the Sun and the Northern Hemisphere is tilted towards the Sun. The Sun is high in the sky, there is more daylight and the heat from the Sun is increased.

As you can see from Fig. 6.3, the Southern Hemisphere has seasons that are opposite to those in the Northern Hemisphere. Winter in Northern Hemisphere means it is summer in the Southern Hemisphere.

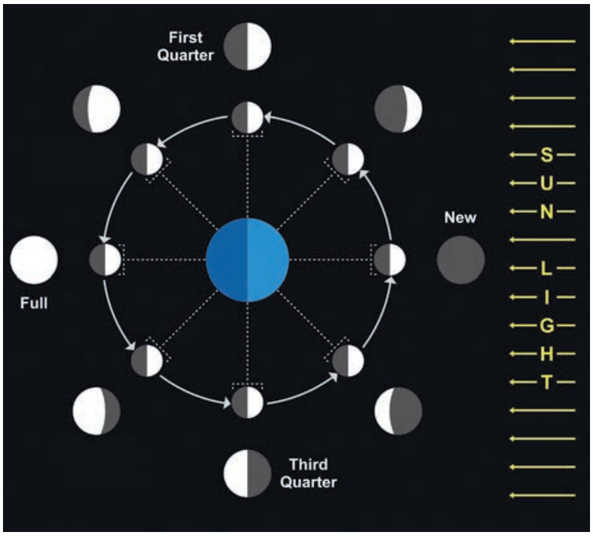
Regions very close to the North Pole experience 24 hours of daylight in the summer time, and 24 hours of darkness in the winter time.



Δ Fig. 6.3 The seasons are caused by the Earth's tilt.

THE MOON'S CYCLE OF PHASES

The Moon is a natural satellite that orbits the Earth in about 30 days. This period is called a month. The Moon is the second brightest object in the sky (after the Sun) but it does not emit any of its own light. Instead, it reflects the light from the Sun.



Δ Fig. 6.4 The phases of the Moon.

The Moon's appearance changes at different times of the month. These changes in shape are known as the 'phases' of the Moon. Regardless of its position, one half of the Moon is always illuminated by the Sun. The way we see it depends on how much of the illuminated half we can see from the Earth. When we see all the illuminated half, we see a complete disc, known as a full Moon. When we only see part of the illuminated half, we see an increasing phase (waxing) or decreasing phase (waning) of the Moon. The changing position of the Moon as it orbits the Earth allows us to see the different phases, see Fig. 6.4.

QUESTIONS

1. It is winter in the Southern Hemisphere. State the season in the Northern Hemisphere.
2. Estimate the time in days between one full Moon and the next half-Moon.
3. Explain why the Sun rises in the east and sets in the west.

THE SOLAR SYSTEM

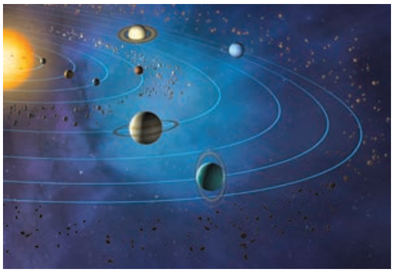
The Solar System is the general name for the Sun and all the objects that orbit it. The Sun is a yellow star. It is a hot ball of glowing gases.

The Sun's enormous gravitational pull is responsible for trapping all of the eight planets, minor planets, millions of asteroids and comets in their orbits around it. Some of the planets have smaller objects orbiting them. These are called moons or natural satellites. Our planet Earth has one moon (called the Moon). The two closest planets to the Sun, Mercury and Venus, have no moons. The ringed planet Saturn may have as many as 82 moons.

Some of the stars we see in the night sky may also have their own system of orbiting planets.

Planets and asteroids

The planets in order of increasing distance from the Sun are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Small rocky objects, the asteroids, occupy a region of space mainly between the orbits of Mars and Jupiter. This region is known as the asteroid belt. The largest asteroid, Vesta, is about 500 km in diameter and the smallest asteroids are only a few metres wide. Although spread over a vast region of space, the total mass of all the asteroids is less than the mass of our Moon.



Δ Fig.6.5 The Solar System. In order of increasing distance from the Sun we have Mercury, Venus, Earth, Mars, asteroid belt, Jupiter, Saturn, Uranus and Neptune.

A minor planet is an object that orbits around the Sun that is neither a planet nor a comet. Dwarf planets are minor planets. A dwarf planet is an object where its own gravity forms an ellipsoid (spherical or squashed sphere) object.

Currently there are five officially recognised dwarf planets. The most famous of these is Pluto. It was demoted from a planet to a dwarf planet in 2006. The others are Ceres, Eris, Haumea and Makemake. Makemake was discovered in 2015 in the frozen regions beyond the orbit of Neptune. There are many more dwarf planets waiting to be officially recognised by astronomers.

Comets

Comets are mainly found beyond Neptune, at the frozen outer edges of the Solar System. They move around the Sun in oval-shaped orbits. Comets are small objects made mainly of ice and rock. As a frozen comet gets closer to the hot Sun, it heats up and its icy material turns into gas, creating a long visible tail that points away from the Sun. The most famous comet is Halley's comet. It makes an appearance in the night sky every 75 years, and it has been doing this possibly for billions of years. Many comets are named after their discoverers, like the Churyumov–Gerasimenko comet, which is named after two astronomers Klim Ivanovych Churyumov and Svetlana Ivanovna Gerasimenko. It was the first comet to have a space probe land on its surface in 2014. The landing provided important information on the composition of this comet.

∆ Fig. 6.6 Halley's comet with its long tail in the night sky.

∆ Fig. 6.7 The space probe Philae landed on the peanut-shaped Churyumov–Gerasimenko comet in 2014.

QUESTIONS

1. Name the most distant planet.
2. Name the two closest planets to the Earth.
3. State what is a comet.
4. Describe the location of most of the asteroids in the Solar System.

SCIENCE IN CONTEXT

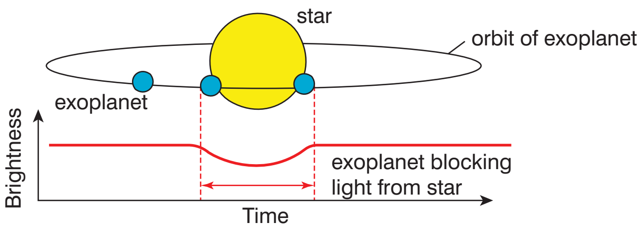
LIFE BEYOND OUR SOLAR SYSTEM

How do astronomers know that some stars may have their own system of orbiting planets? The planets beyond our own Solar System are called exoplanets.

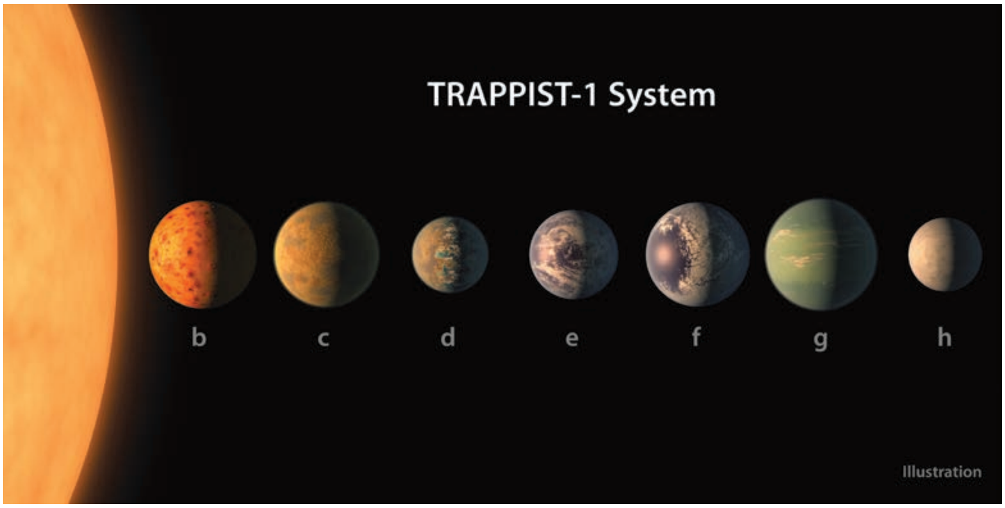
Even the most powerful telescopes on the Earth, or in space, cannot physically see exoplanets. They are just too small and too far away. The brightness of a star, even a dim star, can be accurately measured using large telescopes. Its brightness will show a tiny dip every time an exoplanet crosses over the star, see Fig. 6.8.

In 2017, observations collected by NASA's Spitzer Space Telescope, orbiting high above the Earth's atmosphere, led to the discovery of seven Earth-sized exoplanets around the red star called TRAPPIST-1. All of these exoplanets have the potential of having water on their surface, and hence the potential for life.

Challenge Question: Why do you think it is harder to discover exoplanets using telescopes on the Earth's surface?



Δ Fig. 6.8 The variation in brightness of a star is used to discover an exoplanet.

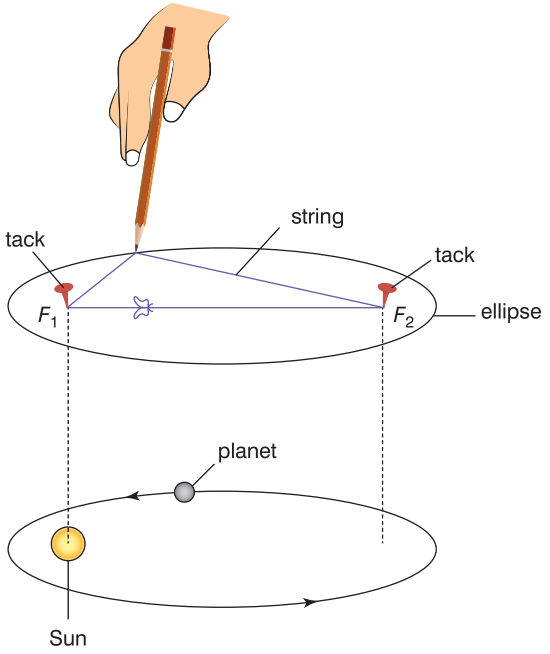


Δ Fig. 6.9 The TRAPPIST-1 system with its exoplanets.

SUPPLEMENT

ELLIPTICAL ORBITS

Most objects, including planets, minor planets and comets move around the Sun in elliptical orbits. The model that all planets move in ellipses was first proposed by the Danish mathematician and astronomer Johann Kepler around 1609. The Sun is at one of the two foci of the ellipse. The Sun is not at the centre of the ellipse. You can draw your own ellipse using a length of string, pencil and two thumb tacks, see Fig. 6.10. Comets in our Solar System have the most elliptical orbits.



Δ Fig. 6.10 To draw an ellipse, loop the string around the tacks (placed at the points F_1 and F_2 called foci) and move the pencil keeping the string tight. The Sun is at one of the foci of the ellipse – there is nothing at the other foci.

QUESTIONS

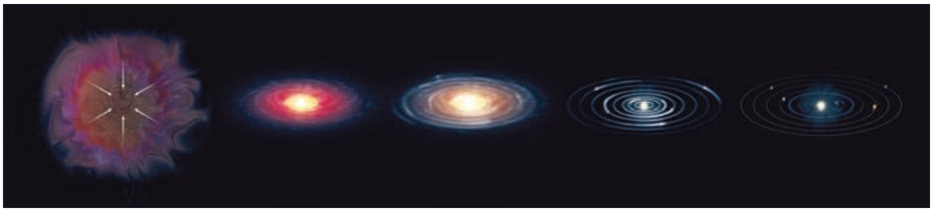
1. **SUPPLEMENT** Which is correct for a planet orbiting the Sun?
   A All planets have circular orbits.
   B The Sun is at the centre of the elliptical orbit.
   C The distance between the Sun and the planet never changes.
   D The Sun is at one of the foci of the elliptical orbit.
2. **SUPPLEMENT** Suggest the special name of the eclipse when the foci are on top of each other.
3. **SUPPLEMENT** State the objects orbiting the Sun with the most elliptical orbits.

FORMATION OF THE SOLAR SYSTEM – ACCRETION MODEL

The Solar System was formed some 4.5 billion years ago from a dense cloud of interstellar gas and dust. The gas in the cloud was mostly hydrogen, with some helium. Interstellar dust is no ordinary dust. It has tiny grains of matter formed from metallic elements such as magnesium, silicon, iron and also molecules such as ammonia, carbon monoxide, methane and nitrogen.

A shockwave from an exploding star (supernova) began the process of this cloud coming together and collapsing under its own gravity. As the cloud collapsed further, it started to swirl and spin faster and faster and also generated lots of heat. Gravity caused most of the gas and dust to form a thin rotating accretion disc. Astronomers use the term accretion to imply the gathering of smaller particles into bigger objects by gravitational attraction. The centre of the accretion disc was bulged because it contained most of the mass of the cloud. High pressure and temperature at the centre of this bulge forced hydrogen nuclei to join (or fuse) together to make helium nuclei. In this process of fusion, enormous energy is released. The centre of the cloud was now a star – our Sun.

Gas and dust further away from the centre of the rotating accretion disc first clumped together into small pieces. These smaller pieces then smashed into each other to make larger pieces. The planets, minor planets and dwarf planets were formed from these larger pieces. The asteroids and comets are the leftover pieces that could not form larger objects. Any remaining gas and dust were gently blown away by the radiant energy of the Sun.



∆ Fig. 6.11 The formation of the Solar System.

Structure

The four planets nearest to the Sun (Mercury, Venus, Earth and Mars) were formed in the hotter inner parts of the accretion disc where the lumped pieces contained matter with high melting points, such as rocks and iron. The outer cooler regions of the accretion disc had frozen matter such as ammonia, methane, nitrogen and water. These materials produced the gas-giant planets of Jupiter and Saturn and the ice-giant planets of Uranus and Neptune.

QUESTIONS

1. Name the force responsible for the collapse of the interstellar gas and dust cloud.
2. Name the four 'rocky' planets.
3. Name a material that may be found in the planets beyond Mars.
4. Describe what happened as the gas and dust cloud collapsed to form the accretion disc.
5. Suggest why planets closest to the Sun cannot be made entirely of gas.

SUPPLEMENT

PLANETARY DATA

Through direct observations with telescopes and information collected from space probes, astronomers have managed to gather detailed data on the planets, see Table 6.1.

Planet	Mass/ 10^{24} kg	Mean orbital distance from Sun/10^6 km	Closest distance to Sun/ 10^6 km)	Furthest distance from the Sun/ 10^6 km	Orbital duration or period/ Earth days	Mean surface temperature/°C	Density/ kg/m^3	Surface gravitational field strength/ N/kg
Mercury	0.33	57.9	46.0	69.8	88.0	167	5427	3.7
Venus	4.87	108.2	107.5	108.9	224.7	464	5243	8.9
Earth	5.97	149.6	147.1	152.1	365.2	15	5514	9.8
Mars	0.64	227.9	206.6	249.2	687.0	–65	3933	3.7
Jupiter	1900	778.6	740.5	816.6	4331	–110	1326	23.1
Saturn	570	1433.5	1352.6	1514.5	10 747	–140	687	9.0
Uranus	87	2872.5	2741.3	3003.6	30 589	–195	1271	8.7
Neptune	100	4495.1	4444.5	4545.7	59 800	–200	1638	11.0

∆ Table 6.1 Some planetary data.

Average orbital speed

The average **orbital speed** v of any object in an orbit can be calculated using the equation:

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

Where r is the average radius of the orbit and T is the orbital period. This equation may be used for both circular and elliptical orbits. It is worth noting that for a circular orbit, the distance travelled in one period T is the circumference $2\pi r$ of the circle.

Worked example

The orbital period of the Moon around the Earth is about 30 days. The average radius of its orbit is 380 000 km. Calculate the orbital speed of the Moon in m/s.

First, convert the period into seconds and the radius into metres.

$T = 30 \text{ days} = 30 \times 24 \times 3600 = 2.59 \times 10^6 \text{ s}$

$r = 380\,000 \times 10^3 = 3.8 \times 10^8 \text{ m}$

Now substitute these values into the equation and solve.

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 3.8 \times 10^8}{2.59 \times 10^6} = 920 \text{ m/s}$$

This is almost 1 km per second. Even at this speed it takes 30 days to complete one orbit.

QUESTIONS

Use Table 6.1 to answer the questions.

1. **SUPPLEMENT** State the relationship between:
   a) mean surface temperature of a planet and its mean distance from the Sun
   b) orbital duration (period) of a planet and its mean distance from the Sun.
2. **SUPPLEMENT** The density of rocks found on the Earth's surface is about 5000 kg/m³. Identify two other planets with similar density.
3. **SUPPLEMENT** Name the planet with the most elliptical orbit.
4. **SUPPLEMENT** The Earth takes one year to orbit the Sun. Calculate Neptune's orbital period in years.
5. **SUPPLEMENT** The mass of the Sun is 2.0×10^{30} kg. Determine:
   a) how many times massive is Jupiter than the Earth
   b) the total mass of all the planets in the Solar System
   c) $\frac{\text{total mass of planets}}{\text{mass of the Sun}}$ and comment on your answer.
6. **SUPPLEMENT** Calculate the mean orbital speed in m/s of Mars.

THE ROLE OF GRAVITY

The surface gravitational field strength of a planet depends on its mass and its radius. The greater the mass, the greater the surface field strength.

The field strength beyond the surface of a planet decreases with increasing distance from its centre. For example, the field strength on the Earth's surface is about 10 N/kg. At a height of about one radius from its surface, this drops to about 2.5 N/kg. At the position of the Moon, the field strength is about 0.0028 N/kg. The field strength is almost zero very far away from the Earth.

The planets orbit the Sun because the Sun has most of the mass in the Solar System. The Sun's gravitational force at the positions of the planets is big enough to make each planet move around the Sun. The Moon only orbits the Earth, and not the Sun, because the Earth's gravitational force on the Moon is much larger than that from the Sun.

SUPPLEMENT

SPEED OF OBJECTS IN THE SOLAR SYSTEM

The gravitational field of the Sun at its surface is about 290 N/kg. The field strength decreases as the distance from the Sun increases. The field strength at Mercury's position is much greater than that at

Neptune's position. This is why the orbital speed of Mercury is much greater than that of Neptune. In summary, as the distance from the Sun increases:

- the Sun's gravitational field strength decreases
- the orbital speed of a planet decreases.

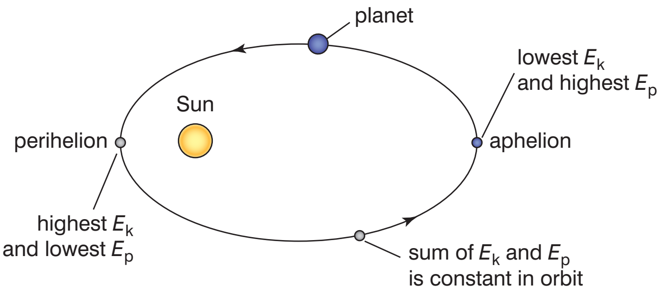
Table 6.2 shows the mean orbital distance from the Sun and the mean orbital speed of all the planets.

Planet	Mean orbital distance from Sun/10^6 km)	Mean orbital speed/km/s
Mercury	57.9	47.4
Venus	108.2	35.0
Earth	149.6	29.8
Mars	227.9	24.1
Jupiter	778.6	13.1
Saturn	1433.5	9.7
Uranus	2872.5	6.8
Neptune	4495.1	5.4

Δ Table 6.2 Orbital speed data for the planets.

All objects travel in elliptical orbits around the Sun.

A planet moves slowest at its most distant point (aphelion) and fastest at its closest point (perihelion). The kinetic energy E_k of a planet, which is directly proportional to speed^2, increases as it gets closer to the Sun. As kinetic energy increases, the gravitational potential energy E_p of the planet decreases. The sum of the kinetic and potential energies remains constant – as required by the principle of conservation of energy, see Fig. 6.12. The change in speeds is much more dramatic for the comets because of their very elliptical orbits.



Δ Fig. 6.12 The total energy of an object, such as a comet, moving in an elliptical orbit around the Sun remains constant, but its kinetic energy E_k and gravitational potential energy E_p change.

QUESTIONS

1. **SUPPLEMENT** State why the planets orbit the Sun.
2. **SUPPLEMENT** State how gravitational field strength changes as the distance from an object increases.
3. **SUPPLEMENT** Name the fastest moving planet.
4. **SUPPLEMENT** Explain why the speed of a comet changes as it gets closer to the Sun.

TIME TAKEN BY LIGHT TO TRAVEL ACROSS THE SOLAR SYSTEM

The speed of light is immense at 300 million metres per second. Even at this speed, because of the vast distances involved, it can take many hours for the light to travel the length of the Solar System.

The Moon is our closest neighbour. The light from it takes about 1 second to reach us. The Sun is further away, and it takes several minutes for the light to reach us. If a solar flare erupts now on the Sun's surface, then we will see this event much later. The distant events we see have already happened – we are glimpsing into the past.

The distance d travelled by light in a space in a time t is given by the equation $d = c \times t$, where c is the speed of light in a vacuum (3.0×10^8 m/s).

Worked example

The Sun is 150 million km away from the Earth.

Calculate the time, in minutes, it takes light to travel from the Sun to us.

Convert the distance into metres.

$d = 150 \text{ million km} = 150 \times 10^6 \times 10^3 = 1.5 \times 10^{11}$ m

Substitute into the equation and rearrange.

$d = c \times t$

$1.5 \times 10^{11} = 3.0 \times 10^8 \times t$

$$t = \frac{1.5 \times 10^{11}}{3.0 \times 10^8} = 500\,\text{s}$$

Convert the time into minutes; 1 minute = 60 s.

$$t = \frac{500}{60} = 8.3 \text{ minutes}$$

The light from the Sun takes about 8.3 minutes to reach the Earth.

QUESTIONS

1. The light from the Moon takes 1.28 s to reach the Earth. Calculate how far the Moon is from the Earth.
2. The most distant planet Neptune is about 4.4×10^{12} m from the Earth. Calculate the time, in hours, it takes light to travel from it to us.

End of topic checklist

Key terms

accretion disc, asteroid, comet, dwarf planet, interstellar gas and dust, minor planet, moons, phases (of the Moon), planet, seasons, Solar System, Sun

SUPPLEMENT average orbital speed, elliptical orbit, gravitational field strength gravity, orbital duration

During your study of this topic you should have learned:

- ❍ The Earth rotates on its axis once in approximately 24 hours (1 day).
- ❍ Periodic cycle of day and night is because of the Earth rotating on its axis.
- ❍ The Earth orbits the Sun once in approximately 365 days (1 year).
- ❍ Seasons are the result of the Earth's tilted axis and its motion around the Sun.
- ❍ The Moon orbits the Earth in approximately 1 month.
- ❍ The phases of the Moon are the results of observing its half-lit face at different positions in its orbit around the Earth.
- ❍ **SUPPLEMENT** The average orbital speed is defined by the equation $v = \frac{2\pi r}{T}$, where r is the average radius of the orbit and T is the orbital period.
- ❍ The Solar System has one star (the Sun) and all the objects (planets, minor planets, asteroids and comets) that orbit it.
- ❍ Some planets have moons orbiting them.
- ❍ The accretion model of the Solar System explains the formation of the Solar System from a collapsing cloud of interstellar gas and dust.
- ❍ Gravitational field strength at the surface of a planet depends on its mass.
- ❍ Gravitational field strength around a planet decreases as the distance from the planet increases.
- ❍ Most of the mass of the Solar System is contained by the Sun – this is why planets orbit the Sun.
- ❍ Gravitational attraction from the Sun keeps the planets moving around the Sun in their orbits.
- ❍ **SUPPLEMENT** Planets, minor planets and comets have elliptical orbits around the Sun.
- ❍ **SUPPLEMENT** An object in an elliptical orbit travels faster when closer to the Sun.

- **SUPPLEMENT** The gravitational field strength from the Sun decreases with increasing distance from it.
- **SUPPLEMENT** The orbital speed of a planet decreases as its distance from the Sun increases.

End of topic questions

Note: the marks in brackets give an indication of the level of detail you should include in your answers.

1. a) Name the force that keeps the Earth moving in its orbit around the Sun. (1 mark)

b) The diagram below shows some observations made by a student on the phases of the Moon.

Date	2 Feb	4 Feb	7 Feb	16 Feb	19 Feb	22 Feb
Phase of the Moon						

i) Use the observations to estimate the orbital duration (period) of the Moon. (2 marks)

ii) State how you can improve the observations to get a better value of the orbital period. (1 mark)

2. SUPPLEMENT Some data on the three innermost planets in the Solar System is shown below.

Planet	Mass/10^{24} kg	Mean orbital distance from Sun/10^6 km	Closest distance to Sun/10^6 km	Furthest distance from the Sun/10^6 km	Density/ kg/m^3	Surface gravitational field strength/N/kg
Mercury	0.33	57.9	46.0	69.8	5427	3.7
Venus	4.87	108.2	107.5	108.9	5243	8.9
Earth	5.97	149.6	147.1	152.1	5514	9.8

a) Explain why these planets have the same density according to the accretion model for the formation of the Solar System. (2 marks)

b) Suggest how the density of Jupiter may differ from the densities of these innermost planets. (1 mark)

c) State one reason why the surface gravitational field strength is not the same for each of the planets. (1 mark)

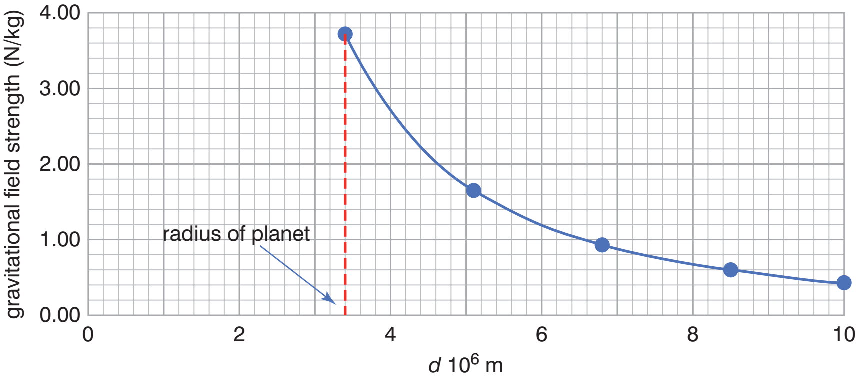
d) SUPPLEMENT Name the planet with the most elliptical orbit. (1 mark)

3. a) Which of the following objects does **not** orbit around the Sun? (1 mark)

A Jupiter B Comet C Moon D Asteroid

b) Name a dwarf planet. (1 mark)

c) A graph of gravitational field strength of Mars against distance *d* from its centre is shown below.



i) Describe the variation of gravitational field strength with *d*. (1 mark)

ii) Suggest how the graph will change for a minor planet of the same radius but different mass. (2 marks)

iii) A student suggests that the gravitational field strength is inversely proportional to *d*. Use the graph to deduce whether or not this suggestion is correct. (2 marks)

4. Halley's comet orbits around the Sun in an elliptical orbit. Its average distance from the Sun is 2.7×10^{12} m and its orbital duration (period) is 75 years.

a) SUPPLEMENT State when the comet will be fastest in its orbit. (1 mark)

b) SUPPLEMENT Calculate the mean orbital speed in m/s of the comet. Assume 1 year = 3.15×10^7 s. (3 marks)

c) SUPPLEMENT We will next see Halley's comet in the night sky in 2061. Its distance from the Earth will then be about 2.3×10^{11} m.

Calculate the time light will take to travel a distance of 2.3×10^{11} m. (2 marks)

Δ Fig. 6.13 The bright patches of light are not stars, but thousands of distant galaxies imaged by the Hubble Space Telescope.

Stars and the Universe

INTRODUCTION

A galaxy is a collection of billions of stars held together in space by their own gravity. Our Sun belongs to a galaxy we call the Milky Way. Astronomers believe that there could be as many as a hundred billion galaxies in the space around us. Some are so far away that light from them has yet to reach us on the Earth. Our nearest galaxy is Andromeda Galaxy. The gravitational force between our Milky Way and Andromeda Galaxy will one day make them collide into each other. We do not need to worry about this, because it will happen many billions of years from now.

KNOWLEDGE CHECK

✓ Microwaves, infrared, visible and ultraviolet are regions of the electromagnetic spectrum.
✓ **SUPPLEMENT** Nuclear fusion is the joining of nuclei.
✓ Like charges repel and unlike charges attract.
✓ **SUPPLEMENT** Speed of light is 3.0×10^8 m/s in a vacuum.

LEARNING OBJECTIVES

✓ Know that the Sun is a star of medium size, consisting mostly of hydrogen and helium, and that it radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.
✓ **SUPPLEMENT** Know that stars are powered by nuclear reactions that release energy and that in stable stars the nuclear reactions involve the fusion of hydrogen into helium.
✓ State that: galaxies are made up of many billions of stars; the Sun is a star in the galaxy known as the Milky Way; other stars that make up the Milky Way are much further away from the Earth than the Sun is from the Earth; astronomical distances can be measured in light-years, where one light-year is the distance travelled in (the vacuum of) space by light in one year.
✓ **SUPPLEMENT** Know that one light-year is equal to 9.5×10^{15} m.
✓ **SUPPLEMENT** Describe the life cycle of a star: a star is formed from interstellar clouds of gas and dust that contain hydrogen; a protostar is an interstellar cloud collapsing and increasing in temperature as a result of its internal gravitational attraction; a protostar becomes a stable star when the inward force of gravitational attraction is balanced by an outward force due to the high temperature in the centre of the star; all stars eventually run out of hydrogen as fuel for the nuclear reaction;

most stars expand to form red giants and more massive stars expand to form red supergiants when most of the hydrogen in the centre of the star has been converted to helium; a red giant from a less massive star forms a planetary nebula with a white dwarf star at its centre; a red supergiant explodes as a supernova, forming a nebula containing hydrogen and new heavier elements, leaving behind a neutron star or a black hole at its centre; the nebula from a supernova may form new stars with orbiting planets.

- ✓ Know that the Milky Way is one of many billions of galaxies making up the Universe and that the diameter of the Milky Way is approximately 100 000 light-years.
- ✓ Describe redshift as an increase in the observed wavelength of electromagnetic radiation emitted from receding stars and galaxies.
- ✓ Know that the light emitted from distant galaxies appears redshifted in comparison with light emitted on the Earth.
- ✓ Know that redshift in the light from distant galaxies is evidence that the Universe is expanding and supports the Big Bang Theory.
- ✓ **SUPPLEMENT** Know that microwave radiation of a specific frequency is observed at all points in space around us and is known as cosmic microwave background radiation (CMBR).
- ✓ **SUPPLEMENT** Explain that the CMBR was produced shortly after the Universe was formed and that this radiation has been expanded into the microwave region of the electromagnetic spectrum as the Universe expanded.
- ✓ **SUPPLEMENT** Know that the speed v at which a galaxy is moving away from the Earth can be found from the change in wavelength of the galaxy's starlight due to redshift.
- ✓ **SUPPLEMENT** Know that the distance of a far galaxy d can be determined using the brightness of a supernova in that galaxy.
- ✓ **SUPPLEMENT** Define the Hubble constant H_0 as the ratio of the speed at which the galaxy is moving away from the Earth to its distance from the Earth; recall and use the equation $H_0 = \frac{v}{d}$.
- ✓ **SUPPLEMENT** Know that the current estimate for H_0 is 2.2×10^{-18} per second.
- ✓ **SUPPLEMENT** Know that the equation $\frac{d}{v} = \frac{1}{H_0}$ represents an estimate for the age of the Universe and that this is evidence for the idea that all the matter in the Universe was present at a single point.

THE SUN AS A STAR

If you look up at the sky at night you will see stars with a range of colours and brightness. The colour of a star is linked to its surface temperature – blue stars are hotter than red stars. Most of the yellow-coloured stars are just like our Sun.

Δ Fig. 6.14 Our Sun is just a medium-size star.

Our Sun is a medium-size star consisting mostly of hydrogen and helium. It radiates its energy in the form of electromagnetic radiation mostly in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.

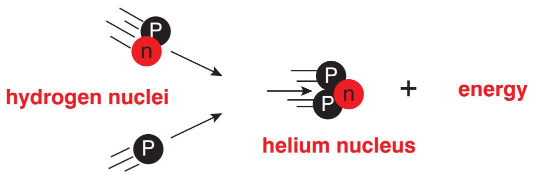
Some stars are astonishingly huge. VY Canis Majoris is a cooler red star that is about 1400 times bigger than the Sun. By contrast, some stars are tiny. The star awkwardly named EBLM J0555-57Ab, discovered in 2017, is only the size of Saturn.

SUPPLEMENT

NUCLEAR FUSION

How does the Sun produce its energy? The Sun produces energy by nuclear fusion reactions. In these reactions, enormous energy is released when hydrogen nuclei join, or fuse, together to form helium nuclei, see Fig. 6.15.

Fusion reactions take place deep within the core of the Sun where the pressures are immense and the temperature high at around 15 million °C. The positively charged hydrogen nuclei would normally stay away from each other because like charges repel. However, at these high temperatures, the hydrogen nuclei are travelling fast enough to get close enough to fuse with each other, and produce helium and lots of energy.



Δ Fig. 6.15 In a single fusion reaction, two hydrogen nuclei fuse together to produce a helium nucleus and lots of energy.

QUESTIONS

1. Other than visible light, name two other electromagnetic waves radiated from the Sun.
2. SUPPLEMENT State what is released when hydrogen nuclei fuse together.
3. SUPPLEMENT Suggest why high temperatures help with fusion reactions.

STARS

Our Sun, with its Solar System, is part of a galaxy known as the Milky Way. Far away from the bright city lights, the Milky Way can be seen in the night sky, see Fig. 6.16.

A galaxy consists of a large number of stars and dust held together by gravity. There could be as many as 100 billion stars in a galaxy. Our Milky Way is spiral in shape, very much like galaxy NGC 628 shown in Fig. 6.17. Our Sun is close to the edge of the Milky Way and is in one of the spiralling arms of the Milky Way, much like the spiralling arms of the NGC 628 galaxy.

All the stars we see in the night sky are in our own galaxy. They are all much further away from us than our Sun. It is not easy to appreciate the enormous astronomical distances in metres, so astronomers use light-years instead. One light-year is the distance travelled, in the vacuum of space, by light in one year. The nearest star to our Sun is 4.2 light-years or 630 billion metres. Our Milky Way has diameter 100 000 light-years or 9.5×10^{20} m.

∆ Fig. 6.16 The Milky Way as seen in Namibia.

∆ Fig. 6.17 The NGC 628 spiral galaxy is similar to our Milky Way.

SUPPLEMENT

LIGHT-YEAR

We know that the speed of light in a vacuum is 3.0×10^8 metres per second. This can be used to determine light-year in metres, as shown below.

light-year = speed of light in metres per second × I year in seconds

light-year = $3.0 \times 10^8 \times (365 \times 24 \times 3600)$

light-year = 9.5×10^{15} m

To convert distance from:

- light-years to metres, you multiply by 9.5×10^{15}
- metres to light-years, you divide by 9.5×10^{15}.

QUESTIONS

1. What is the Milky Way?
2. State how many stars there are in a galaxy.
3. SUPPLEMENT A star is a distance of 7.2 light-years from us. State how many years it would take for the light from this star to reach us.
4. SUPPLEMENT The star VY Canis Majoris is 3.6×10^{19} m from the Sun. Calculate this distance in light-years.
5. SUPPLEMENT The centre of the Milky Way is about 25 000 light-years from us. Calculate this distance in metres.

SUPPLEMENT

LIFE CYCLE OF A STAR

A star is formed from interstellar clouds of gas and dust. The ultimate mass of the star depends on the original mass of the interstellar gas and dust cloud. Larger clouds will produce massive stars.

Birth of a star

The gas is mainly hydrogen, with tiny amounts of helium. The internal gravitational attraction of the gas and dust particles collapses the cloud and makes it spin, and also increases its temperature. The gas cloud eventually spins faster, heats up and becomes a protostar.

The temperature within the core of a protostar can be about 15 million °C and fusion reactions between hydrogen nuclei occur to make helium nuclei. Fusion reactions release enormous energy, which further increases the temperature of the protostar. The protostar glows brightly. It becomes a stable star when the inward force of gravitational attraction is balanced by the outward force due to the high temperature in the centre of the star. The star will keep shining for millions to billions of years. This is the stage of our Sun right now.

Fate of the star

The final fate of the star depends on its mass.

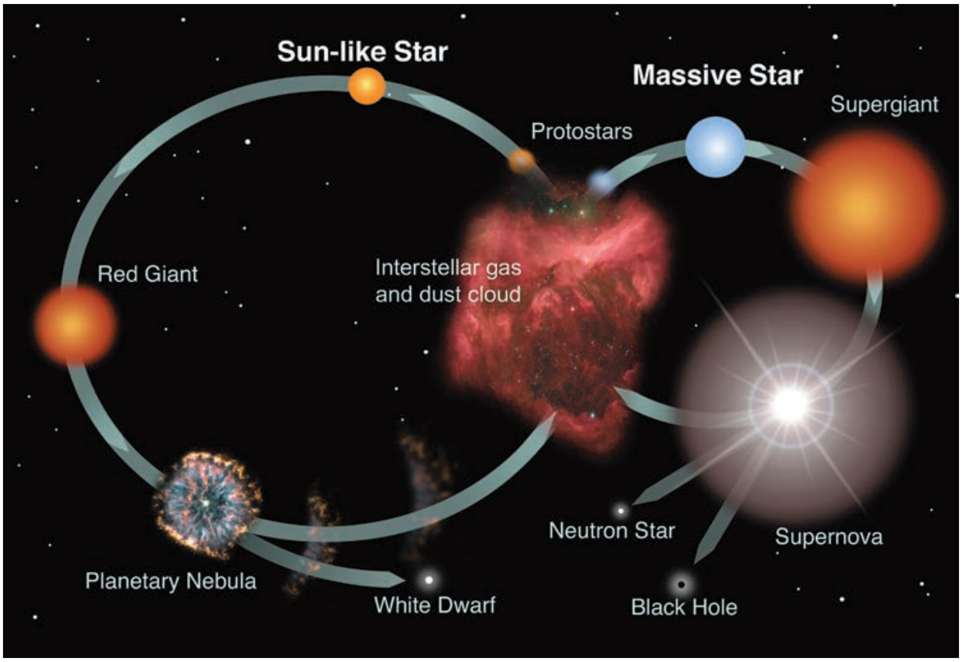
When a star with a similar mass to our Sun starts to run out of hydrogen in the core, it can no longer generate energy by fusion reactions to form helium. The core of the star becomes unstable and starts to contract. The outer layer of the star, which is mostly hydrogen, starts to expand. As it swells up, it cools and glows red in colour. The star has now become a red giant. Within the core of a red giant, helium starts to fuse into carbon. When the helium runs out, the core collapses again. The outer layers of the star are pushed away forming a planetary nebula (see Fig. 6.18) and the core collapses to become a white dwarf.

When a star more massive than the Sun runs low on hydrogen (the fuel for nuclear reactions) it starts to fuse helium into carbon. The star gets hotter and hotter and expands. It becomes a supergiant. Eventually this massive star explodes as a supernova. The explosion ejects into space a nebula containing hydrogen, and new heavier elements such as iron, gold and uranium are formed during this explosion. The remaining core of the star contracts and may form an extremely dense neutron star or, if the original star was extremely massive, a black hole. Black holes are even denser than neutron stars. Their gravitational pull is so huge that even light cannot escape from it.

The nebula from a supernova may, over billions of years, form new stars with orbiting planets, like our Solar System.

Fig. 6.19 shows that the life cycle of a star depends on its original mass.

Δ Fig. 6.18 A planetary nebula in the constellation Aquarius.



Δ Fig. 6.19 Life cycle of stars. The fate of the star depends on its original mass.

QUESTIONS

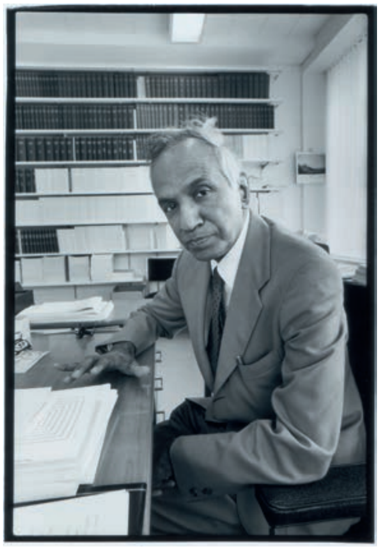
1. **SUPPLEMENT** State why a star starts to expand into a red giant.
2. **SUPPLEMENT** Name two objects created at the end of the life cycle of a star that is much more massive than our Sun.
3. **SUPPLEMENT** Explain the conditions required for a stable star.

SCIENCE IN CONTEXT

WHITE DWARFS

To the naked eye, one of the brightest stars in the night sky is Sirius. Powerful telescopes however show that Sirius is not one but two stars orbiting around each other. The main star, Sirius A, is large and bright, and its smaller companion, Sirius B, is a dim white dwarf.

The surface of Sirius B has a temperature of about 25 000 °C. It is much hotter than our Sun. What makes it dim in the night sky is its physical size. It has a diameter the same as our Earth, yet its mass is almost that of our Sun. Sirius B, like many other white dwarfs, is extremely dense.



Δ Fig. 6.20 Subrahmanyan Chandrasekhar was awarded the 1983 Nobel Prize in Physics for working out the maximum mass of a white dwarf.

Here are some amazing facts about white dwarfs like Sirius B.

- The material of a white dwarf can be 200 000 times denser than water.
- The surface gravitational field strength can be 3500 000 N/kg. As a comparison, the surface field strength of the Sun is 290 N/kg and for the Earth it is only 10 N/kg.
- The mass of a white dwarf cannot exceed 1.44 times the mass of the Sun. This limit is known as Chandrasekhar limit, after Subrahmanyan Chandrasekhar, the Indian-born physicist.
- A white dwarf does not generate any energy from fusion reactions. It steadily cools down by radiating energy from its surface for a couple of billion years.
- A white dwarf can steal material from a neighbouring star and eventually become a supernova, releasing about 10^{44} J of energy in a short period of time.

Challenge Question: The majority of the stars in our Milky Way will evolve into white dwarfs. Why is it that we do not see the night skies full of these mysterious white dwarfs?

THE UNIVERSE

The Universe is everything we can see and detect around us. Our Sun is part of the Milky Way. The Milky Way is about 100 000 light-years in diameter. The Milky Way is one of about 100 billion galaxies that make up the Universe. Some galaxies, like the Andromeda galaxy, are close to us, but some are so far away that light from them has yet to reach us. The space between galaxies is mostly vacuum. The Universe is huge – it could have a diameter of about 90 billion light-years.

Big Bang Theory

The Big Bang Theory is a model used to explain how the Universe came into existence, and also its subsequent evolution. The Universe began from a single point, then for some unknown reason it began to expand from a hot explosion. This event, known as the Big Bang, was the birth of the Universe. Before the birth of the Universe, there was no space, no matter, and no time.

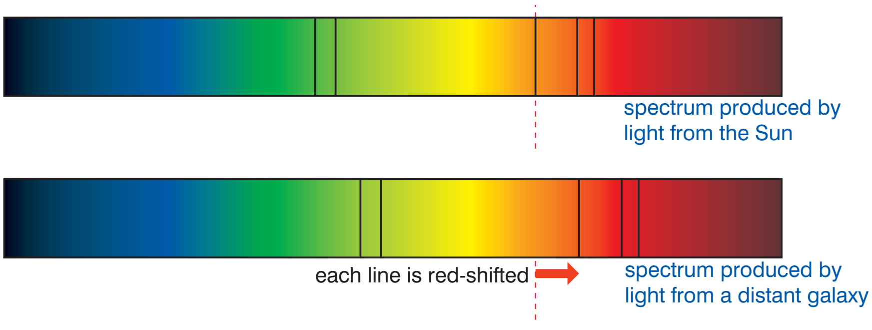
Space has been expanding and stretching ever since the Big Bang. Stars and galaxies created soon after the Big Bang have been carried away by the stretching of space. From the Earth, we see all the galaxies rushing away from us – this is evidence for the Big Bang and the expansion of the Universe.

How do astronomers know that the Big Bang took place some 14 billion years ago? The evidence comes from the redshift of light.

Redshift

The spectrum from the Sun, observed from Earth, shows dark lines set against a continuous spectrum of colours. These dark lines are caused by the Sun's atmosphere absorbing specific colours of light emitted from the Sun. All the galaxies in the Universe are receding from us. The spectrum of light from the stars of a distant receding galaxy is almost identical to that of the Sun, but there is one major difference. All the dark lines observed in the spectrum are shifted towards the longer wavelengths. This is called redshift because the lines are shifted towards the red end of the visible spectrum, see Fig. 6.21. The redshift in the light from distant galaxies is evidence that the Universe is expanding and supports the Big Bang Theory.

There is an equivalent of redshift of light with sound waves. Imagine a police car moving away from us with its siren on. We would hear a lower-pitch sound, or detect sound of longer wavelength than if the police car was stationary.

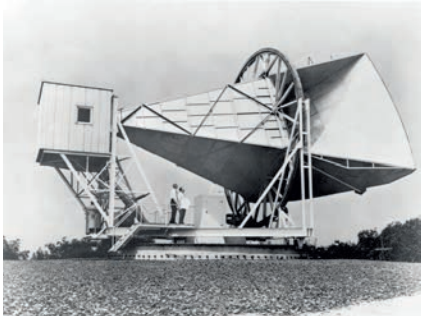


Δ Fig. 6.21 The whole pattern of lines from a distant galaxy has been red-shifted compared with light from the Sun.

SUPPLEMENT

COSMIC MICROWAVE BACKGROUND RADIATION (CMBR)

The Universe began from an extremely hot explosion. At the start of this creation, there was no matter in the Universe but it was full of short-wavelength electromagnetic radiation. As the Universe expanded, the fabric of space itself stretched, and this also stretched out these short-wavelength waves. We now observe these waves in the microwave region of the electromagnetic spectrum. Most of them have a wavelength of about 1 mm. The whole of the Universe is currently filled up with these microwaves. We can detect these microwaves, known as cosmic background radiation (CMBR), coming from all directions of space around us.



Δ Fig. 6.22 Wilson and Penzias with their radio telescope.

The expansion of the Universe led to the cooling of its overall temperature. Its temperature now is about –270 °C.

The first-ever detection of CMBR was a pure accident. Two astrophysicists, Arno Penzias and Robert Wilson, were using a large radio telescope to communicate with orbiting satellites, but had problems because they could not get rid of 'static' noise coming from all directions of space. They even cleaned the bird droppings on their telescope to get rid of this unwanted signal. It was only through a chance conversation with other physicists that they realised that the telescope was picking up CMBR. For their pioneering work, both physicists were awarded the Nobel Prize in Physics in 1978.

AGE OF THE UNIVERSE

The receding speed v of a galaxy from the Earth can be determined from the change in the wavelength of starlight due to redshift. The greater the change in the wavelength, the greater the speed v. Some supernovas are unique – they release the same amount of energy when they explode. The brightness of a supernova in a particular galaxy can be used to determine the distance d of the galaxy.

Fig. 6.23 shows a graph of v against d. Although there is considerable scatter of the data, it is clear that v is directly proportional to d. The further the galaxy is from us, the faster it is moving away from us. The gradient of the straight line is equal to the Hubble constant H_0. We can define the Hubble constant as the ratio of the speed at which the galaxy is moving away from the Earth to its distance from the Earth, therefore:

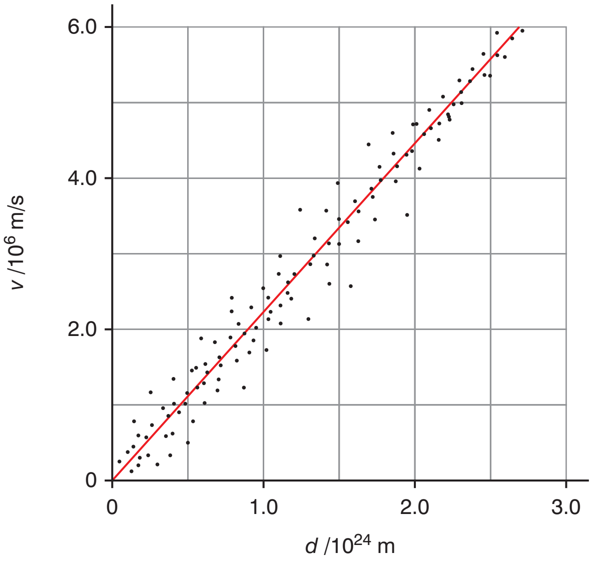
$$H_0 = \frac{v}{d}$$

The current estimate for H_0 is about 2.2×10^{-18} per second.

The Universe is expanding – the galaxies are receding from each other because the space itself is expanding. If we could run time backwards, the Universe would be much smaller, denser, and hotter, and would eventually reach a single point just before its birth.

The age of the Universe in seconds can be estimated from the equation:

$$\text{age of Universe} = \frac{d}{v} = \frac{1}{H_0}$$



Δ Fig. 6.23 Graph of receding speed *v* against distance *d* for galaxies in the Universe.

WORKED EXAMPLE

The Hubble constant is about 2.2×10^{-18} per second. Estimate the age of the Universe in years.

First, determine the age in seconds.

$$\text{age of Universe} = \frac{1}{H_0}$$

$$\text{age of Universe} = \frac{1}{2.2 \times 10^{-18}} = 4.45 \times 10^{17} \text{ seconds}$$

Now convert the age into years.

$1 \text{ year} = 365 \times 24 \times 60 \times 60 = 3.15 \times 10^7 \text{ s}$

$$\text{age of Universe} = \frac{4.45 \times 10^{17}}{3.15 \times 10^7} = 1.4 \times 10^{10} \text{ years}$$

1 billion years = 10^9 years, therefore the age of the Universe is about 14 billion years.

QUESTIONS

1. State what happened to the Universe after the Big Bang.
2. State the significance of redshift in the starlight from a distant galaxy.
3. **SUPPLEMENT** Where would you detect cosmic background radiation (CMBR)?
4. **SUPPLEMENT** State how the distance of a galaxy is determined.
5. **SUPPLEMENT** Describe how spectrum of starlight can be used to determine the speed of a galaxy.
6. **SUPPLEMENT** State the relationship between receding speed v of a galaxy and its distance d from us.
7. **SUPPLEMENT** Estimate the Hubble constant given $v = 11\,000$ km/s and $d = 5.0 \times 10^{24}$ m.

End of topic checklist

Key terms

Big Bang Theory, galaxy, Milky Way, redshift

SUPPLEMENT black hole, cosmic microwave background radiation (CMBR), fusion, Hubble constant H_0, red giant, neutron star, planetary nebula, protostar, supergiant, supernova, white dwarf

During your study of this topic you should have learned:

- ❍ The Sun is a star of medium size, consisting mostly of hydrogen and helium.
- ❍ The Sun radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.
- ❍ **SUPPLEMENT** Stars are powered by nuclear reactions that release energy.
- ❍ A galaxy is made up of many billions of stars.
- ❍ The Sun is a star in the galaxy known as the Milky Way.
- ❍ Stars that make up the Milky Way are much further away from the Earth than the Sun is from the Earth.
- ❍ Astronomical distances can be measured in light-years.
- ❍ **SUPPLEMENT** One light-year is the distance travelled in (the vacuum of) space by light in one year.
- ❍ **SUPPLEMENT** 1 light-year = 9.5×10^{15} m.
- ❍ **SUPPLEMENT** In stable stars the nuclear reactions involve the fusion of hydrogen into helium.
- ❍ **SUPPLEMENT** A star is formed from interstellar clouds of gas and dust that contain hydrogen.
- ❍ **SUPPLEMENT** A protostar is an interstellar cloud collapsing and increasing in temperature as a result of its internal gravitational attraction.
- ❍ **SUPPLEMENT** A protostar becomes a stable star when the inward force of gravitational attraction is balanced by an outward force due to the high temperature in the centre of the star.
- ❍ **SUPPLEMENT** All stars will eventually run out of hydrogen as fuel for the nuclear reaction.
- ❍ **SUPPLEMENT** Most stars expand to form red giants.

- **SUPPLEMENT** More massive stars expand to form red supergiants when most of the hydrogen in the centre of the star has been converted to helium.
- **SUPPLEMENT** A red giant from a less massive star forms a planetary nebula with a white dwarf star at its centre.
- **SUPPLEMENT** A red supergiant explodes as a supernova, forming a nebula containing hydrogen and new heavier elements, leaving behind a neutron star or a black hole at its centre.
- **SUPPLEMENT** The nebula from a supernova may form new stars with orbiting planets.
- The Milky Way is one of many billions of galaxies making up the Universe.
- The diameter of the Milky Way is approximately 100 000 light-years.
- Redshift is an increase in the observed wavelength of electromagnetic radiation emitted from receding stars and galaxies.
- The light emitted from distant galaxies appears redshifted in comparison with light emitted on the Earth.
- Redshift in the light from distant galaxies is evidence that the Universe is expanding, and supports the Big Bang Theory.
- **SUPPLEMENT** Cosmic microwave background radiation (CMBR) is the microwave radiation of a specific frequency and is observed at all points in space around us.
- **SUPPLEMENT** CMBR was produced shortly after the Universe was formed and has been expanded into the microwave region of the electromagnetic spectrum as the Universe expanded.
- **SUPPLEMENT** The speed v at which a galaxy is moving away from the Earth can be found from the change in wavelength of the galaxy's starlight due to redshift.
- **SUPPLEMENT** The distance of a far galaxy d can be determined using the brightness of a supernova in that galaxy.
- **SUPPLEMENT** Hubble constant H_0 is defined as the ratio of the speed v at which the galaxy is moving away from the Earth to its distance d from the Earth; $H_0 = \frac{v}{d}$.
- **SUPPLEMENT** The current estimate for H_0 is 2.2×10^{-18} per second.
- **SUPPLEMENT** Age of the Universe $= \frac{d}{v}$ and age of the Universe $= \frac{1}{H_0}$.
- **SUPPLEMENT** The age of the universe is evidence for the idea that all the matter in the Universe was present at a single point.

End of topic questions

Note: the marks in brackets give an indication of the level of detail you should include in your answers.

1. a) What is the name of the galaxy that contains the Earth and our Sun?

A Andromeda

B Milky Way

C Canis Major

D Virgo (1 mark)

b) State the diameter of our galaxy in light-years. (1 mark)

c) There are about 100 000 000 000 stars in a galaxy.

The mass of a typical star is 2.0×10^{30} kg. Estimate the total mass of our galaxy. (2 marks)

2. The star Tau Ceti is similar to our Sun. It is about 12 light-years from us.

a) State three types of electromagnetic radiation emitted by this star. (3 marks)

b) Explain why Tau Ceti must be in our Milky Way. (2 marks)

c) Define the light-year. (1 mark)

d) **SUPPLEMENT** Calculate the distance of Tau Ceti in metres. (2 marks)

e) **SUPPLEMENT** Explain how hydrogen within its core produces energy. (2 marks)

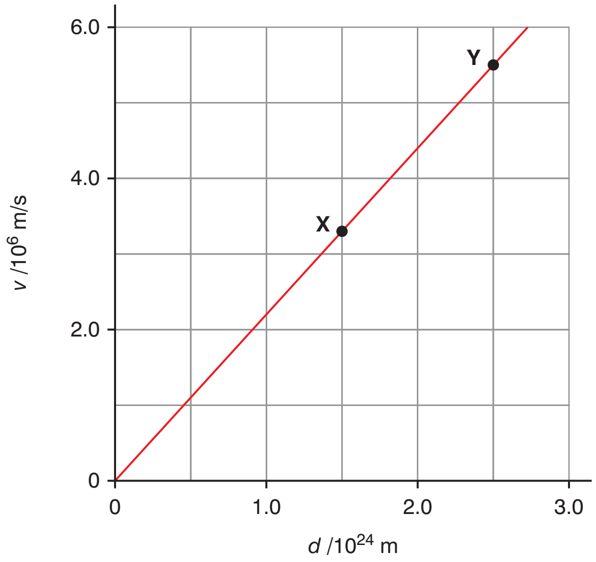
3. **SUPPLEMENT** **a)** An astronomer keeps detecting microwave radiation coming from all directions of space.

i) State what the astronomer is detecting. (1 mark)

ii) Explain the significance of these microwaves. (3 marks)

b) Explain the significance of redshift of starlight from a distant galaxy. (1 mark)

c) The velocity v against distance d is shown for galaxies in the Universe.



Two galaxies X and Y are marked on the graph.

i) State and explain which galaxy will show greater redshift. (2 marks)

ii) For galaxy Y, $v = 5.5 \times 10^6$ m/s and $d = 2.5 \times 10^{24}$ m.

Use this information to determine the age of the Universe in seconds. (3 marks)

COMMENTS

1. a) The key technical term 'phases' of the Moon has been correctly stated.

b) The idea of gravitational attraction is correctly given. Objects, such as planets, orbit the Sun because of its gravitational pull.

To improve the answer, this needed to be expanded to include the idea that the Sun is far more massive than objects orbiting around it. The term 'big' is not equivalent to 'having greater mass'. The Sun being 'hot' has nothing to do with the question.

c) This answer is the inverse of the correct answer – so the rearranging was incorrect. The correct answer is:

$$\text{time} = \frac{5.0 \times 10^{12}}{3.0 \times 10^{8}} = 16700 \text{ s}$$

(4.6 hours)

Exam-style questions

Note: exam-style questions, sample answers and comments have been written by the authors. The marks awarded for these questions indicate the level of detail required in the answers. In examinations, the way marks are awarded may be different. References to assessment and/or assessment preparation are the publisher's interpretation of the syllabus requirements and may not fully reflect the approach of Cambridge Assessment International Education.

Example answer

Question 1

a) State the evidence that the Moon orbits around the Earth. (1)

The Moon shows phases - it must therefore be orbiting the Earth. ✓

b) Explain why the objects in the Solar System orbit around the Sun. (2)

Objects such as planets orbit the Sun because of its gravitational pull. ✓ Planets orbit the Sun because it is big and hot. ✗

c) The dwarf planet Pluto is 5.0×10^{12} m from the Earth.

The speed of light in vacuum is 3.0×10^{8} m/s.

Calculate the time it takes for light from Pluto to reach the Earth. (3)

distance = speed × time ✓

$5.0 \times 10^{12} = 3.0 \times 10^{8} \times \text{time}$ ✓

time = 0.00006 s ✗

(Total 6 marks)

4/6

EXAM-STYLE QUESTIONS

Question 2

a) Describe the Milky Way and state its approximate diameter. (2)

b) Explain redshift of light from distant galaxies and its significance to the Universe. (3)

(Total 5 marks)

Question 3 SUPPLEMENT

a) i) Explain how astronomers determine the distance d and speed v of a distant galaxy. (2)

ii) The figure below shows the Triangulum Galaxy.

For this galaxy, $d = 8.2 \times 10^{22}$ m and $v = 180\,000$ m/s.

Use this information to calculate the age of the Universe in seconds. (3)

b) Explain how the cosmic microwave background radiation (CMBR) provides evidence for the Big Bang Theory. (3)

(Total 8 marks)