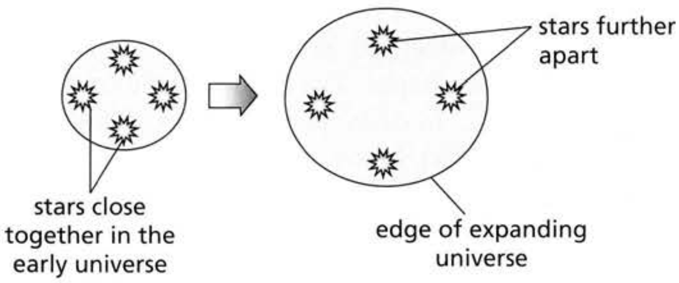
THE BIG BANG

The universe and global systems

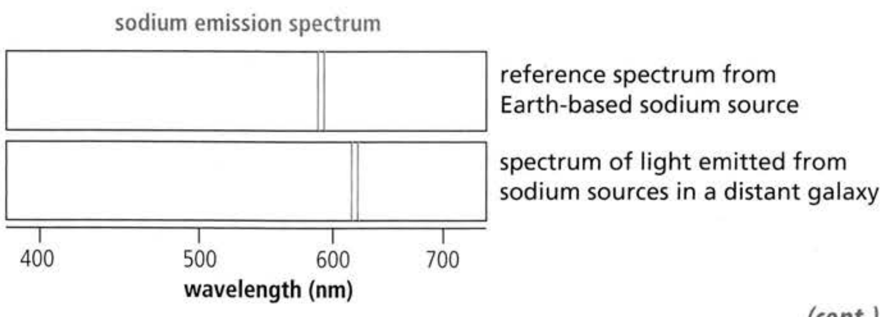
REVISION SUMMARIES

1 The Big Bang theory is an explanation of the origin of the universe and its subsequent changes over time. This theory was first proposed in 1948 by George Gamow. According to this theory the universe formed 13.7 billion years ago. Time and space came into existence at the Big Bang. Space began a rapid period of **inflation** in the first billionth of a second. This was followed by cooling as space started to **expand**, and the first matter particles (**electrons** and **quarks**) began to form. Within a second after the Big Bang more complex particles, such as protons and neutrons, had formed along with a type of material called **anti-matter**. Anti-matter has the opposite properties to matter. If matter and anti-matter come together they destroy each other and form radiant energy. For example, the anti-matter particle called the **positron** is the opposite of an electron. A positron has a positive charge whereas an electron has a negative charge, but they both have the same mass. In the first 10 seconds after the Big Bang most of the matter and anti-matter particles collided and destroyed one another, but some matter particles remained to form the universe. The first composite particles were protons and neutrons which formed from combinations of three quarks. Atomic **nuclei** formed from protons and neutrons within the first 10 minutes. As electrons combined with the atomic nuclei, **atoms** formed. The universe continued to cool as space expanded over the next 13.7 billion years. During that time **gravitational forces** led to the formation of stars and **galaxies**. Planets eventually formed around various stars, as was the case with our own Sun. Overall the universe has cooled from 100 billion degrees moments after the Big Bang to –270 °C in space today. The following diagram shows a simple model of the expansion of space after the Big Bang. In this diagram the distance between stars and galaxies increases because of the expansion of space itself.



2 Various pieces of evidence support the Big Bang theory, including the following.

- **Cosmic background radiation.** Microwave radiation emanating from deep space has been detected by various instruments. This radiation is consistent with matter having cooled to –270 °C as the universe expanded after the Big Bang.
- **Red shift of stars and galaxies.** Hot atoms of different elements emit **electromagnetic radiation** of various wavelengths. The radiation emitted is characteristic of each element. The following diagram shows the emission **spectra** of sodium. The first spectrum is measured in a laboratory from a stationary hot sodium source. This spectrum shows two spectral lines that are very close together. The second spectrum is of the same element emitting light from a distant galaxy. Comparison of these spectra shows that the wavelength lines in the second spectrum have shifted towards longer wavelengths (i.e. towards the red

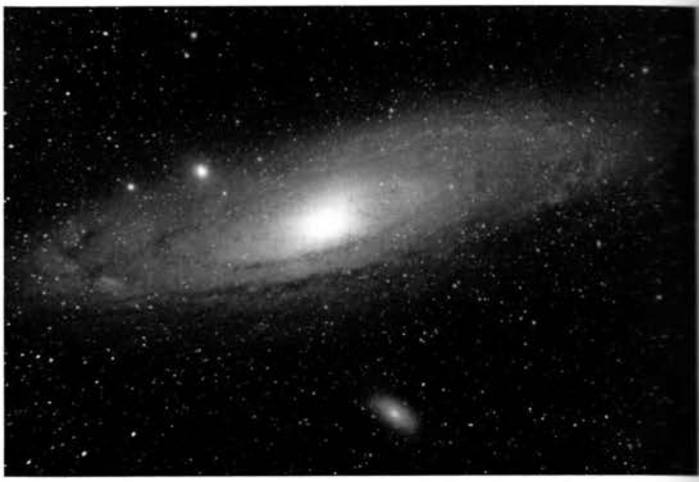


(cont.)

end of the spectrum). This red shift of spectral lines is evidence of an **expanding universe**. As space expands and galaxies and stars move further apart the wavelengths of emitted radiation also become longer. The more distant the galaxy the greater the red shift of spectral lines.

3 Since the Big Bang the universe has evolved. Various bodies exist in space as a result of that evolution. These include the following.

- Stars. Our Sun is a star. Stars started to form about 100 to 200 million years after the Big Bang. Stars formed when clouds of hydrogen gas collapsed under **gravitational forces**. This collapse and compression led to intense heating that finally produced a **nuclear fusion** reaction. In this reaction hydrogen nuclei combined to form helium, producing vast amounts of energy. The universe started to light up as stars formed and emitted electromagnetic radiation.
- Galaxies. Galaxies consist of clusters of stars together with interstellar dust. Our Sun is part of the Milky Way **galaxy**. The next closest galaxy is Andromeda which is over two million light-years away. A light-year (ly) is the distance light travels in one Earth year (1 ly = 9 500 000 000 000 km). Distances in space are measured using light-years as distances such as kilometres are too small. Our Milky Way is a spiral galaxy that is disc shaped with two major spiral arms and two or three smaller arms. It has a diameter of about 100 000 ly and our Sun is located about 27 000 ly from the galactic centre. The galactic centre has a **black hole** around which the galaxy rotates. Some galaxies are elliptical or globular, while others have irregular shapes. The following photo shows Andromeda which is a spiral galaxy.
- Nebulae. In deep space there are many clouds of dust and gas called **nebulae** (one cloud is a nebula). Many astronomers believe new stars have their beginnings in nebulae. Bright nebulae are visible objects. Dark nebulae are not visible. Dark nebulae block or dim the light from stars and other bright objects far behind them. The Coal Sack nebula is a dark nebula near the Southern Cross constellation.



- Novae. Occasionally a star in deep space might shine thousands of times brighter than normal. This is known as a **nova**, and normally happens when huge explosions shear an outer layer off the star and hot gases are blown outwards. Another, much rarer, phenomenon is a **supernova**. The explosions here are much greater and the star is torn apart. The remains of the star form a dense pulsar with a nebula surrounding it.
- Pulsars. A **pulsar**, or **neutron star**, emits extremely regular pulses of radio waves along an axis at right angles to the rotating magnetic field around the pulsar (the word *pulsar* comes from **puls**ating st**ar**). Some pulsars also give off short bursts of visible light, X-rays and gamma rays. Pulsars are rapidly spinning and extremely dense stars composed almost entirely of neutrons. They have a diameter of approximately 20 km. The beam of radio waves can only be observed if it points towards the Earth.

- Quasars and black holes. **Quasars** are not stars, but the glaring centres of remote and turbulent young galaxies. The brilliant light is thought to come from a disc of gas spiralling under intense gravity into a **black hole**. The speed of the orbiting stars allows astronomers to calculate the mass of the black hole. Some of the largest have a mass equal to 100 billion Suns. The average quasar is about the size of our solar system, but it emits more energy than 1000 billion Suns. The word *quasar* comes from **quasi-stellar** radio source. Quasars were first noticed because of the very strong radio waves they emit. The following drawing shows an artist's impression of a quasar. Jets of **luminous** X-rays are shown streaming out of its centre.

4 The **solar system** consists of our Sun and the various bodies orbiting around it. These bodies include eight planets, some minor planets (such as Pluto), **asteroids** and **comets**. The solar system formed from a **planetary nebula**. This process began about five billion years ago with the formation of a red, spinning **protosun.** Nuclear fusion began in the protosun as gravitational forces compressed gas and interstellar dust, and it evolved into a yellow-white star. By about 4.6 billion years ago the Earth and other orbiting bodies had formed.

The early Earth had no structure. **Gravitational compression** led to internal heating. In addition, **radioactive** elements generated heat as they decayed. Eventually parts of the Earth's interior started to melt. Iron and nickel sank down to form a central core and lighter minerals rose towards the surface to form the **mantle** and solid **crust**. Various elements and compounds formed the early **atmosphere**. These included nitrogen (N_2), carbon dioxide (CO_2), water (H_2O), methane (CH_4) and ammonia (NH_3). This primitive atmosphere had no oxygen. Over several billion years the composition of the atmosphere changed due to the action of **ultraviolet light** on various molecules such as ammonia and water vapour. As the Earth cooled, water vapour condensed to liquid water which ultimately created the oceans and rivers. **Oxygen** (O_2) formed in the atmosphere once photosynthetic protists had evolved in the oceans. Much of this early oxygen oxidised various mineral ions in the oceans (e.g. iron ions) to form metal oxides that precipitated. These precipitated minerals ultimately turned into sedimentary mineral ores. Iron ore is such an example. Eventually the oxygen started to enter the atmosphere and this in turn led to the evolution of new life forms.

Checklist
Can you:

1 *Describe the major events of the Big Bang?* ☐
2 *Provide evidence for the Big Bang theory?* ☐
3 *Identify various astronomical bodies and explain how they formed?* ☐
4 *Describe the stages in the formation of the solar system and the Earth?* ☐

THE BIG BANG

The universe and global systems

QUICK REVISION

1 In 1948, George Gamow proposed a theory to explain the __________ of the universe. This theory later became known as the Big Bang theory. Prior to the Big Bang, space and __________ did not exist. They came into existence about 13.7 __________ years ago. It is wrong to ask what happened before the Big Bang as the universe did not __________ and therefore there was no *before*. Physicists call this start of time and space a singularity. Once formed there was a very short period of rapid __________ as the universe expanded and started to cool from an initial temperature of 100 billion degrees. Initially matter did __________ exist. As the expansion of space continued the first matter and anti-matter particles started to form. Anti-matter has the __________ properties to normal matter. For example, the anti-matter equivalent of a positive proton is a __________ anti-proton. The first particles were electrons and __________ and their anti-matter equivalents.

In the first 10 seconds after the Big Bang there were numerous collisions between matter and anti-matter particles. These collisions resulted in the destruction of the particles and the production of __________ radiation.

Following this destructive stage of matter and anti-matter collisions, only matter particles remained. After further cooling, the first composite particles formed when quarks joined together. These particles were __________ and neutrons. Protons and neutrons then combined to form the first atomic nuclei. Eventually __________ formed as atomic nuclei combined with electrons. As the universe continued to expand, gravitational forces led to the formation of astronomical bodies such as stars, galaxies and nebulae. Eventually __________ systems formed from planetary nebulae. The universe has now cooled to a temperature of about –270 °C.

2 Scientists have collected __________ to support the Big Bang theory. The first piece of evidence is the existence of __________ radiation emanating from deep space. This discovery is consistent with the __________ of space and the universe cooling to a temperature of –270 °C. Electromagnetic waves with wavelengths of microwaves are consistent with this temperature. Another important piece of evidence is the observed __________-shift of light waves emitted by distant galaxies. Light from sources that are moving __________ from the observer have their wavelengths increased. In the visible spectrum this increase in wavelength moves the spectral lines closer to the __________ end of the electromagnetic spectrum. As space expands and the universe grows larger, wavelengths of the emitted light also __________.

3 After atoms had formed the force of __________ started to act upon matter and form the various astronomical bodies we see in space today. The first __________ started to form about 100 to 200 million years after the Big Bang. Stars are formed when clouds of __________ gas become compressed by __________ forces. This compression leads to rapid heating. Eventually a certain high temperature is reached at which the hydrogen __________ fuse together to form helium. This process is called nuclear __________, and it releases vast amounts of energy. Some of this energy is emitted as light and the star begins to __________.

Gravitational forces lead to the formation of vast clusters of __________ that are called galaxies. Our galaxy is called the Milky __________. It is an example of a spiral galaxy with a diameter of about 100 000 light-years. The galaxy rotates around its centre as it moves through space. Other galaxies have different shapes including elliptical and __________ galaxies.

New stars are continually forming in deep space. Scientists believe they form in bodies called __________ which are made of gases and dust. Some nebulae are bright and others are dark.

(cont.)

Large stars have a brief lifetime. As they come to the ends of their lives they explode and throw out vast amounts of matter and energy into space. These explosions can be seen on Earth and are called ________. Very large stars produce very large explosions called supernovae. Our Sun is too ________ a star to evolve in this way.

Astronomers have discovered other strange objects in deep space. These are called pulsars and quasars. A pulsar is also called a ________ star. Pulsars are rapidly spinning stars whose nucleus is extremely dense and composed of highly compressed neutrons. They emit pulses of ________ waves as well as X-rays and gamma rays. Quasars are not stars but the centres of highly turbulent ________ galaxies. They emit vast amounts of light and radio waves as gas swirls around a ________ hole. A black hole has intense gravity and matter that gets too close is drawn into it. Quasars also eject luminous X-rays.

4 Our solar system formed from a planetary nebula. This process began about ________ billion years ago with the formation of the Sun. The primitive sun was a ________ protosun which evolved into a yellow-white star. The planets and other bodies orbiting around the Sun had formed by 4.6 billion years ago. Initially the Earth had ________ structure. Gravitational compression and the energy released from the ________ of radioactive elements increased the Earth's temperature to a point where some minerals, such as ________ and nickel, melted and sank to the Earth's centre to form a metallic core. Other lighter elements moved upwards to form the mantle and the ________. The early atmosphere had no oxygen and consisted mainly of ________, methane, ammonia and water vapour. As the planet cooled the water vapour condensed to form liquid water. The liquid water ultimately formed the ________, rivers and lakes. Chemical reactions induced by ultraviolet (UV) light from the Sun led to changes in the atmosphere. The evolution of early life forms also led to changes in the atmosphere and the hydrosphere. Photosynthetic protists produced ________ that initially reacted with metal ions in the oceans to produce insoluble oxides. Later on the oxygen entered the ________ and started to accumulate there. The oxygenated atmosphere was then able to support new life forms as evolution continued.

Answers 1 origin; time; billion; exist; inflation; not; opposite; negative; quarks; electromagnetic; protons; atoms; solar 2 evidence; microwave; expansion; red; away; red; increase 3 gravity; stars; hydrogen; gravitational; nuclei; fusion; shine; stars; Way; globular; nebulae; novae; small; neutron; radio; young; black 4 five; red; no; decay; iron; crust; nitrogen; oceans; oxygen; atmosphere

THE BIG BANG

The universe and global systems

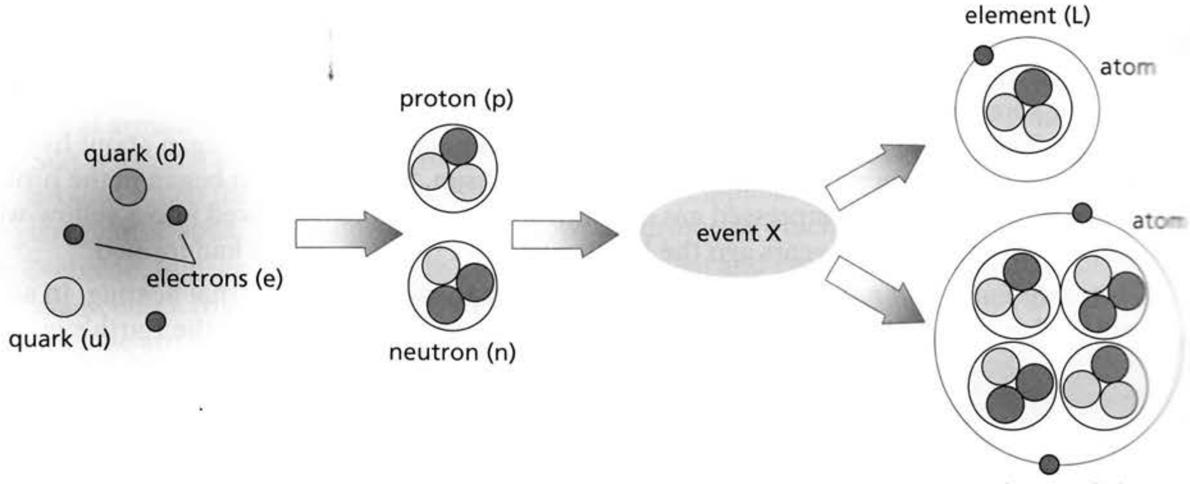
30 MINUTES

REVISION TEST

1 The following table lists some of the events in the Big Bang but they are not in the correct order. Use the code letters to place them in the correct order. (5 marks)

Event	Information
A	Atoms (mainly hydrogen and helium) have formed as nuclei combine with electrons. Light waves have escaped to fill the expanding universe.
B	The universe continues to cool as it expands. Protons and neutrons form.
C	Gravitational forces lead to the formation of stars and galaxies.
D	Space inflates and becomes filled with radiation.
E	Most of the matter and anti-matter particles annihilate each other leaving an excess of matter particles.

2 The following diagram shows the formation of two elements (labelled L and M) following the Big Bang. The atoms are not drawn to scale.



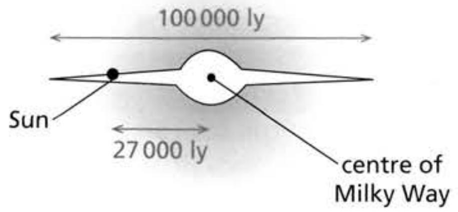
a Two types of fundamental particles were the first to form as the expanding universe cooled. Name these two types of particles. (2 marks)

b Using the symbols for the fundamental particles that are on the diagram, explain how a proton differs from a neutron. (2 marks)

c Identify the type of particle formed during event X. *Hint 1* (1 mark)

d Name elements L and M. (2 marks)

3 The following diagram shows a side view of the Milky Way.



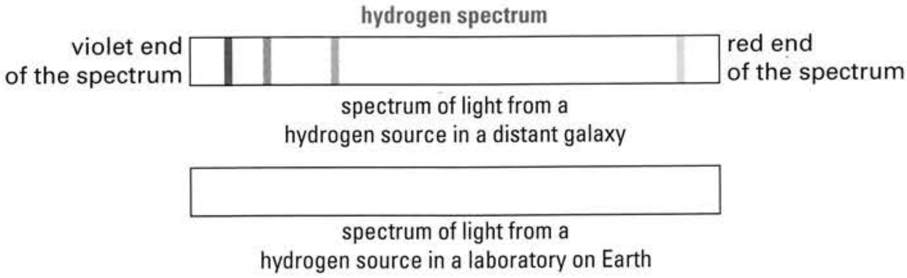
a What type of galaxy is the Milky Way? (1 mark)

b What type of astronomical body is at the centre of the Milky Way? (1 mark) c What type of astronomical body is the Sun? (1 mark)

d The diameter of the Milky Way is 100 000 ly. What does the unit ly stand for? (1 mark)

e Express the distance of the Sun from the galactic centre as a decimal fraction of the radius of the Milky Way. (2 marks)

4 The following diagram is incomplete. It shows the spectrum of hydrogen from a hot source in a distant galaxy. Four spectral lines are shown.



a Copy this diagram and sketch in the four spectral lines from a hydrogen source on Earth. *Hint 2* (1 mark)

b Explain how such spectral observations support the Big Bang theory. (2 marks)

5 The following photograph is a composite of the night sky taken in the Kalahari Desert in Namibia on a clear dark night. A dense band of stars is seen stretching from horizon to horizon.

a Identify this dense band of stars. *Hint 3* (1 mark)

b Suggest a reason why this dense band of stars is not visible from cities in Australia. (1 mark)

6 True or false?

a Some large black holes have masses equal to 1000 billion suns. (1 mark)

b A pulsar forms following a supernova explosion of a star. (1 mark)

c Andromeda is the closest galaxy to the Milky Way. (1 mark)

d The light arriving from distant galaxies shows a decrease in wavelength. (1 mark)

e The first composite particles formed after the Big Bang were electrons and quarks. (1 mark)

f Prior to the Big Bang space was empty. (1 mark)

g A positron is the anti-matter particle of an electron. (1 mark)

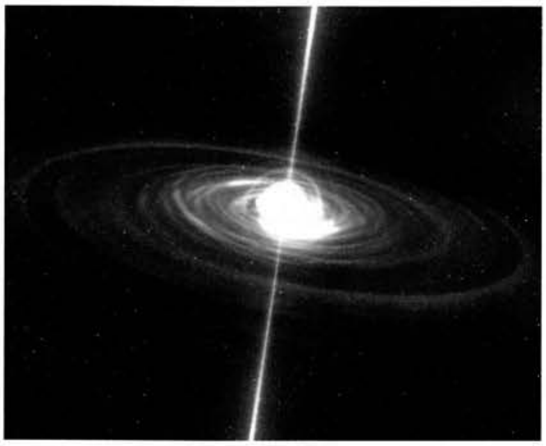
h In the first billionth of a second after the Big Bang there was a rapid inflation of space. (1 mark)

i The Big Bang was the loudest explosion that has ever occurred. (1 mark)

j Microwave radiation emanating from deep space is used as evidence for the Big Bang theory. (1 mark)

(cont.)

7 The following drawing depicts a pulsar in deep space.



a What is the pulsar composed of? (1 mark)

b Two pulsating beams are shown in the drawing. What type of electromagnetic radiation is present in these beams? (1 mark)

c Explain why some pulsars cannot be observed from Earth. (1 mark)

8 a Identify the astronomical body from which the solar system formed. (1 mark)

b The Sun evolved from a protosun. What colour was this protosun? (1 mark)

c Explain how heavy metals such as iron and nickel formed the core of the Earth. (1 mark)

d Name the five common gases present in the early atmosphere of the Earth. (5 marks)

e Explain how oxygen gas started to accumulate in the atmosphere of the Earth. (1 mark)

Hint 1: What is formed when protons and neutrons join together?
Hint 2: Distant sources of light show red-shifting of spectral lines.
Hint 3: In which galaxy is the Sun?

Your Feedback

$\frac{\square}{45} \times 100\% = \square\%$

PAGES 262–263
PAGE 331

d 150 g ✓
e around 22 minutes ✓; this is where the curve flattens out ✓
f Change in mass = 150 – 68 = 82 g ✓; change in time = 20 minutes
Rate of CO_2 production = 82 ÷ 20
= 4.1 g/min ✓

9 Barium is a reactive metal, so it will react with each of these.
a $Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2$ ✓
b $Ba + 2HCl \rightarrow BaCl_2 + H_2$ ✓
c $2Ba + O_2 \rightarrow 2BaO$ ✓

10 a lithium, sodium, potassium ✓
b It will react with dilute acid but not as vigorously. ✓
c It is fairly unreactive. ✓ (Gold was one of the first discovered metals, simply because it occurs natively in nature.)

11 a Sodium is less dense than water. ✓
b Where the sodium comes into contact with the water a reaction occurs and hydrogen gas forms. The sodium metal floats on this gas which, as it's escaping from under the sodium, pushes the sodium in the process. ✓
c Heat is released in this reaction, and hydrogen is flammable. If enough heat is generated and enough hydrogen is close by, it bursts into flames. ✓

Earth and space sciences

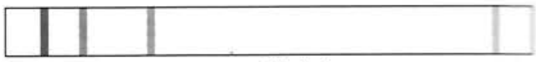
THE BIG BANG
The universe and global systems Pages 132–134

1 D ✓; E ✓; B ✓; A ✓; C ✓

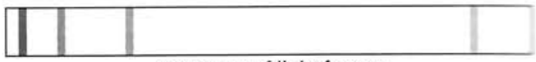
2 a quarks ✓; electrons ✓
b A proton is composed of two *u* quarks and one *d* quark ✓; a neutron is composed of two *d* quarks and one *u* quark. ✓
c atomic nuclei ✓
d L = hydrogen ✓; M = helium ✓

3 a spiral galaxy ✓
b black hole ✓
c star ✓
d light-year ✓
e 27 000 ÷ 50 000 ✓ = 0.54 ✓

4 a The four lines formed by the lab source should be moved to the left. ✓



spectrum of light from a hydrogen source in a distant galaxy



spectrum of light from a hydrogen source in a laboratory on Earth

b As space expands and galaxies and stars move further apart the wavelengths of emitted radiation also become longer. The more distant the galaxy the greater the red shift of spectral lines. ✓ This is consistent with the Big Bang theory in which the universe expands over time. ✓

5 a Milky Way ✓
b There is too much light pollution and the sky is not dark enough. ✓

6 a true ✓; **b** true ✓; **c** true ✓; **d** false ✓;
e false ✓; **f** false ✓; **g** true ✓; **h** true ✓;
i false ✓; **j** true ✓

7 a neutrons ✓
b radio waves ✓
c Unless the radio beam is directed at the Earth then the radio waves cannot be detected. ✓

8 a planetary nebula ✓
b red ✓
c The heat from gravitational compression and radioactive decay melted these metals and they sank into the centre of the Earth to form the core. ✓
d nitrogen ✓; ammonia ✓; water vapour ✓; carbon dioxide ✓; methane ✓
e Oxygen gas formed in the atmosphere once photosynthetic protists had

evolved in the oceans. ✓ Oxygen was produced as a by-product of their photosynthesis.

STARS AND ASTRONOMY
The universe and global systems Pages 141–144

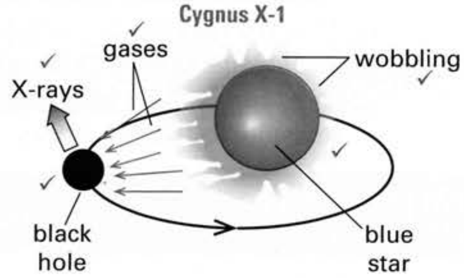
1 a 1 ✓
b 2 ✓
c increases from 1 to 2 ✓
d increases from zero to 2 ✓
e The protons repel each other strongly and therefore great pressures and temperatures are required to compress the nuclei so they combine to form a helium nucleus. ✓

2 a refraction ✓
b Light (electromagnetic radiation) that comes from a distant source is affected by the gravity of the lensing star. ✓ The orbit of the exoplanet interferes with the light that is lensed and these disturbances are recorded by Earth-based astronomers. ✓
c The X-ray light from the quasar must be in a straight line with the lensing star and the Earth observers. ✓ The jets of X-rays must be pointing towards the Earth so they can be observed. ✓

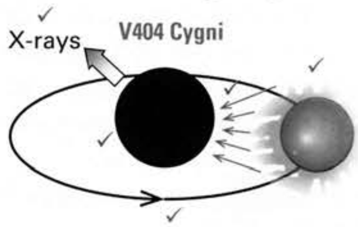
3 a Relative luminosity = 2.6. Thus the star is 2.6 times more luminous than the Sun. ✓
b 0.81 relative solar mass ✓
c relative solar mass = 1.00, relative luminosity = 1.00 ✓

4 a The gravity of Jupiter attracts Cassini and this leads to a change in direction and speed. ✓
b The Cassini craft needed to avoid colliding with Jupiter's moons OR if the craft came too close it might not be able to escape from Jupiter's gravity. ✓
c In order to relay data and images back to Earth and receive communications from Earth. ✓
d infra-red space telescope ✓

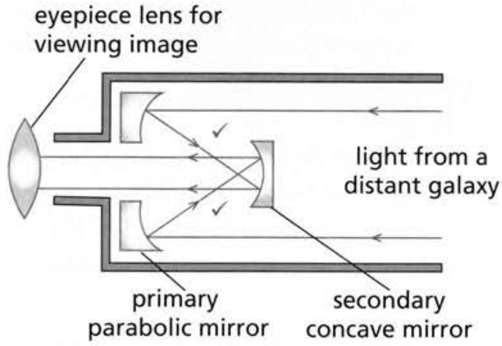
5 a i See the following diagram.



ii An X-ray space telescope in orbit around the Earth can detect the X-rays. ✓
b See the following diagram.



6 a See the following diagram.



b Refracting telescopes can produce image distortions as the light is refracted. This does not happen with a reflecting telescope. ✓
c Galileo ✓

7 a The greater the mass of a red dwarf star, the shorter its lifetime. ✓
b i about 5700 billion years ✓
ii The current age of the universe is 13.7 billion years. ✓ This is a very small fraction of the 5600 billion year lifetime of this red dwarf. ✓

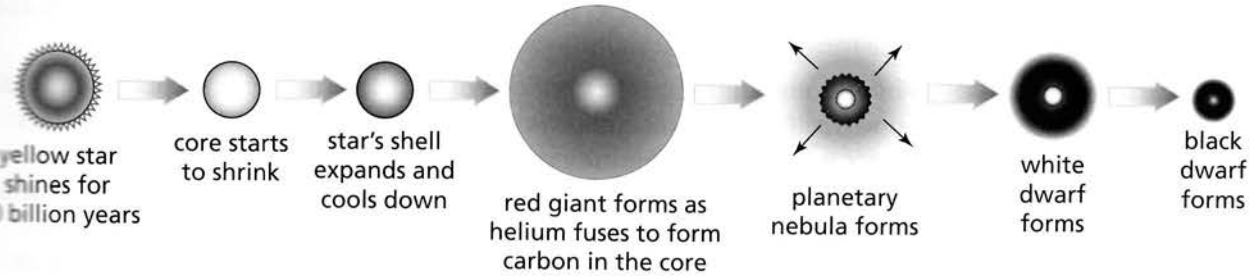
STARS AND ASTRONOMY

The universe and global systems

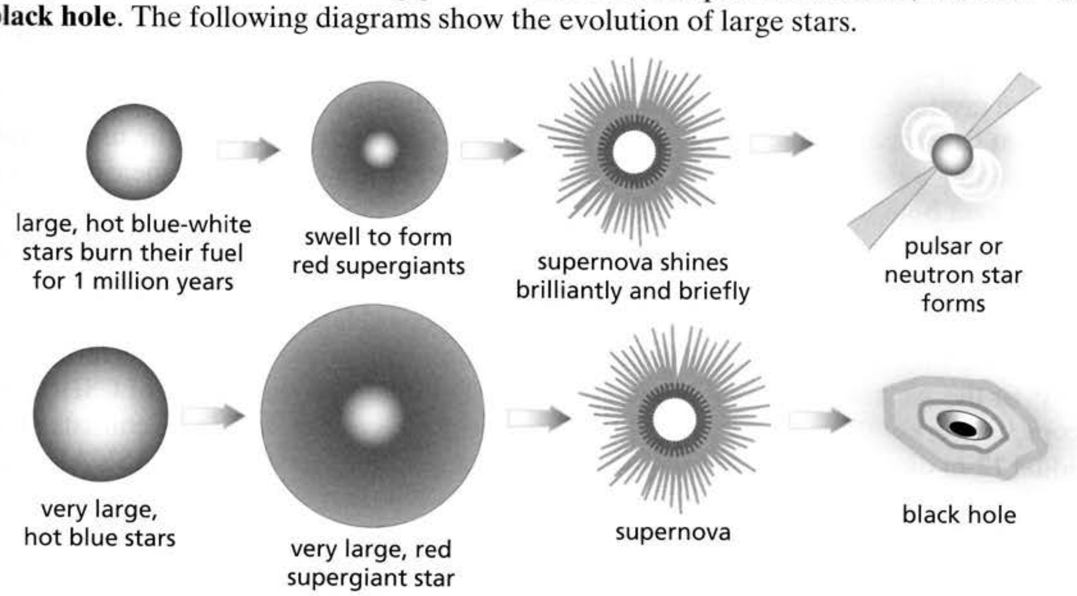
1 Stars are quite variable in their size and mass. Our own Sun is about 1.4 million km in diameter. The Sun is, however, only a medium-sized star. Its mass is about 2×10^{30} kg. The masses of other stars can be compared to our Sun using a comparative scale. On this scale the Sun has a mass of 1 (or 1 **solar mass**). The largest stars have solar masses of about 200. Such stars are very rare in the universe and are located thousands of light-years from Earth. The smallest stars, known as brown or black dwarfs, have solar masses less than 0.1.

Stars also vary in their **brightness**. The closest and brightest star to us is Sirius which is 8.6 ly away. It is bluish-white in colour and is located in the Canis Major constellation. Another bright star is the red supergiant star Betelgeuse. It is about 640 ly away and is in the Orion constellation. Also in the Orion constellation is a very bright, blue-white supergiant star called Rigel. Its solar mass is approximately 18 and it is about 860 ly away.

Stars like our Sun shine for about 10 billion years before they run out of **hydrogen**. The successive events are summarised in the following diagram. The star evolves into a red giant and subsequently it sheds its outer layers to form a planetary **nebula**. The core of the nebula cools to form a white dwarf star and finally a cold **black dwarf**.



Very heavy stars (2 to 6 solar masses) burn their fuel for about one million years. Their cores are so hot that they glow a bright blue. Eventually, these massive stars run out of nuclear fuel and swell to form **red supergiants**. The star gets much hotter as it collapses in on itself in a **supernova**. A **pulsar** (or neutron star) is left behind. Very massive stars eventually expand to form very large red supergiants before they explode to create a supernova. The remaining core collapses in on itself under strong gravitational forces to produce a dense, dark star called a **black hole**. The following diagrams show the evolution of large stars.



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The most common stars in our local group of galaxies are **red dwarfs**. They are smaller than our Sun (about 0.5 solar masses) and the closest is Proxima Centauri which is about 4.2 ly away. These stars evolve very slowly and have estimated lifetimes of about 100 billion years. As they cool they turn into black dwarfs.

2 **Optical telescopes** use visible light to observe the night sky. In 1609 to 1610 **Galileo** used a simple telescope to observe the craters on the Moon and he discovered some of the moons of Jupiter. His first telescope only magnified objects by nine times (9×) but he made further improvements to increase the magnification to 30×. Galileo's telescope used **glass lenses** to refract light but glass lenses do produce some image distortions. **Isaac Newton** developed the reflecting telescope which uses curved mirrors rather than lenses to collect light. Newton used a 15-cm concave mirror in his telescope. Modern telescopes have curved mirrors with much larger diameters to collect more light from distant and fainter objects in space. The Keck telescope in Hawaii has a curved mirror of 10 m diameter. This telescope can observe objects that are 10 billion light-years away. Earth-based telescopes suffer from **distortion effects** caused by the atmosphere and pollution. They also suffer from light pollution from nearby cities. **Space telescopes**, such as the Hubble space telescope, orbit the Earth and therefore do not suffer the effects of atmospheric distortion and light pollution from cities.

Various astronomical bodies emit light in other regions of the electromagnetic spectrum. **Radio telescopes** collect radio waves from distant radio wave sources such as galactic centres, black holes, supernova remnants and pulsars. The radio waves are collected and focused by huge parabolic dishes. The Chandra space telescope was launched into orbit in 1999. It collects and analyses **X-rays** from sources in deep space. Black holes, supernova remnants and neutron stars, for example, emit X-radiation. Infra-red radiation from space can be analysed using an infra-red telescope. Interstellar dust often obscures distant astronomical bodies when viewed using optical telescopes. **Infra-red** space telescopes can observe astronomical bodies that emit infra-red radiation. All bodies emit infra-red radiation, even cool bodies, such as brown dwarfs and various nebulae. This means that infra-red telescopes can detect faint objects where optical telescopes often cannot.

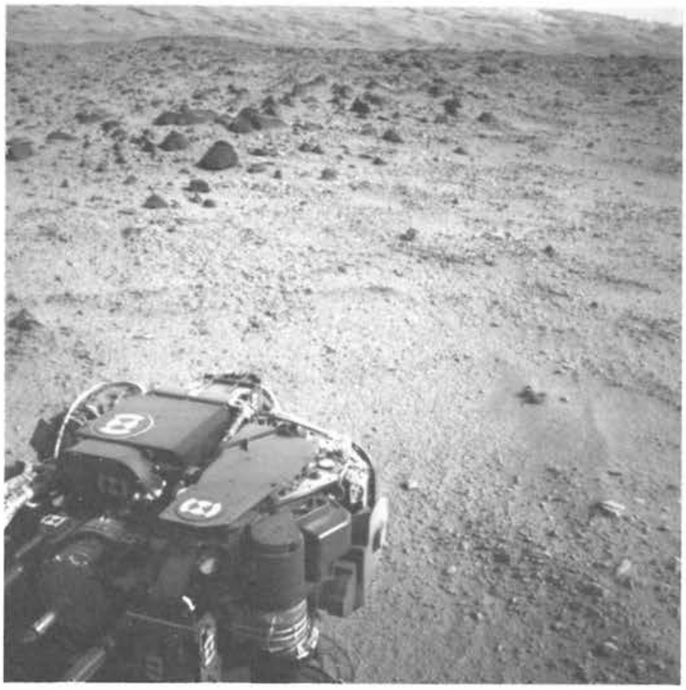
3 For many years Australia has made valuable contributions in optical and **radio astronomy**. The Siding Spring optical telescope in New South Wales has undertaken a project, called SkyMapper, to produce the first digital map of the southern sky. These maps may help to identify the mysterious dark matter in space. The Australian Astronomical Observatory (AAO) is located at Coonabarabran in New South Wales. It has pioneered work on the use of **optical fibres** in feeding light from the telescope for analysis. Other projects include measuring **red shifts** of distant blue star-forming galaxies and determining the mass density of the universe.

Australia is a world leader in radio astronomy. Radio telescopes at Tidbinbilla (near Canberra) are part of NASA's Deep Space Network. The Australia Telescope Compact Array (ATCA) is an array of six 22-m antennas used for radio astronomy near Narrabri in New South Wales. This system of antennas, which are 6 km apart, work together by a process called interferometry. ASKAP, or the Australian Square Kilometre Array Pathfinder, is the newest of CSIRO's radio telescope networks. This system, in the Murchison area of Western Australia, consists of 36 individual 12-m diameter antennas that work together as a single instrument. ASKAP, together with similar systems in New Zealand and South Africa, will then form the Square Kilometre Array (SKA) which will be completed in 2024. The SKA will be the most sensitive telescope in the world and it will investigate the first stars and galaxies that formed after the Big Bang.

Many astronomers working in Australia are at the forefront of astronomical research. **Brian Schmidt**, who works at the Mount Stromlo Observatory in Canberra, shared the 2011 Nobel Prize in Physics for the discovery that the rate of expansion of the universe is increasing. His current interest is investigating the brightness of supernovae as a function of distance. He is also involved in the SkyMapper project and the search for dark matter. **Penny Sackett** is a scientist who works at the Australian National University. Her studies involve the discovery of **exoplanets** using the technique of gravitational **microlensing**. Exoplanets are planets that orbit stars other than our Sun. As these exoplanets orbit their star they interfere with the light rays from a distant light source (such as a quasar). The light from the source is refracted by the large gravity of the star. These changes in light refraction are detected by astronomical observers on Earth. Astronomers discovered the first exoplanet orbiting a Sun-like star in 1995 and since then have spotted more than 800 worlds (as of December 2012) beyond our own solar system of which seven are considered habitable. There are many more exoplanets awaiting discovery.

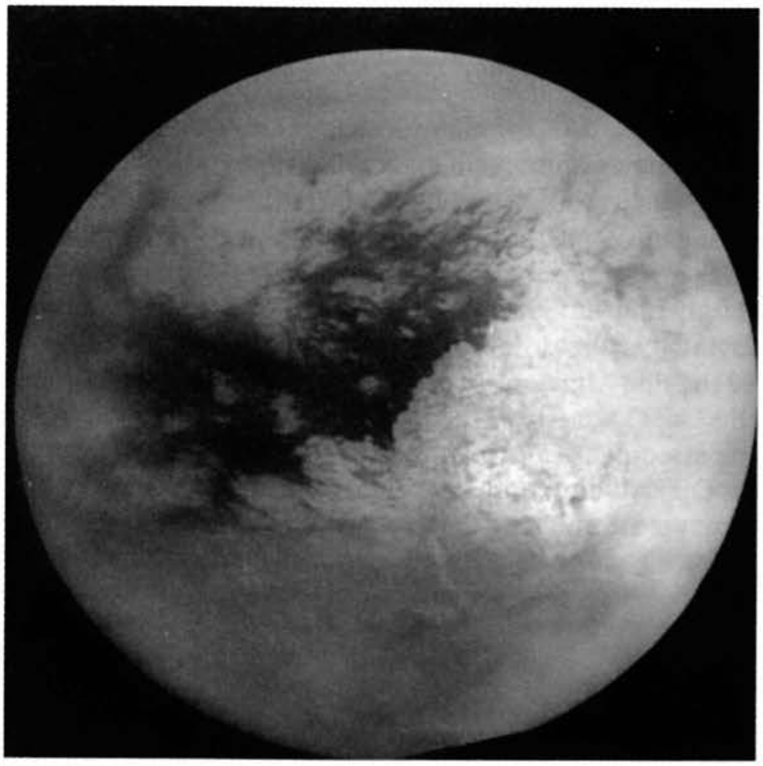
4 Robotic probes have been used for many decades to investigate planets in our solar system. Some examples of these missions include the following.

- **Venus.** Since the early 1960s, Russia and the United States have launched a series of robotic probes to investigate Venus. Orbiting probes have used **radar** to map the surface of the planet as well as measure features of the atmosphere. Some probes landed on the surface of Venus but only transmitted data for up to two hours before failing because of extreme temperatures and the corrosive acidic environment.
- **Mars.** In 1997 the first Mars rover successfully landed on the Martian surface. In 2001 an orbiter called Mars Odyssey was successfully placed in orbit by NASA. It continues to investigate the atmosphere and it currently relays information back to Earth from surface rovers such as Opportunity (mission commenced 2004) and Curiosity (mission commenced 2012). These rovers are studying the geology of Mars and looking for signs of **ancient life** forms. The following photo shows the Curiosity rover on Mars.



(cont.)

- **Jupiter.** NASA and the European Space Agency have launched a number of probes to Jupiter since 1973. The Voyager space probes (1979) flew past the planet and took many photos before continuing on to Saturn, Uranus and Neptune. These missions are called flybys as they do not involve orbiting or landing. The gravitational field of the planet attracts the probe and causes it to change its direction of flight. The Galileo probe (1995 to 2003) orbited Jupiter and investigated that planet's atmosphere as well as some of its moons.
- **Saturn.** NASA launched the Cassini probe in 2004. It went into orbit around Saturn to study the planet and its moons. The Huygens probe was deployed from Cassini and it landed safely on Titan (Saturn's largest moon, shown in the photo below). Radar images of Titan showed lakes of liquid **hydrocarbons** as well as solid ground strewn with rocks.



Checklist
Can you:

1. *Describe the evolution of stars of different masses?* ☐
2. *Describe how astronomers use different wavelengths of light to investigate the universe?* ☐
3. *Describe the work of Australian astronomers?* ☐
4. *Describe the discoveries made by robotic probes in our solar system?* ☐

STARS AND ASTRONOMY

The universe and global systems

QUICK REVISION

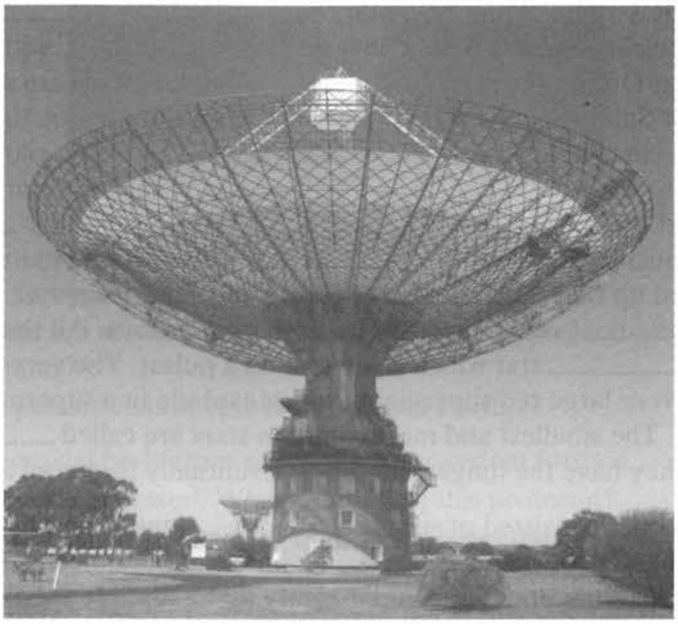
1 Our Sun is a medium-sized __________-white star. Other stars can be compared in size and mass to our Sun. The Sun is assigned a relative __________ mass of 1. The largest stars are found at very great distances from the Sun and have relative solar masses of 200. The smallest stars, called __________ dwarfs, are as small as 0.1 solar masses. Stars vary in their __________ or luminosity. Rigel is a blue-white star that is very bright and Betelgeuse is a bright __________ star. Both are in the Orion constellation. The closest and brightest star is __________ which is a blue-white star. Stars use hydrogen as a __________ fuel. The hydrogen atoms undergo nuclear fusion and are converted into __________ with the release of vast amounts of energy. During the evolution of a star other elements are also formed. Medium-sized stars like our Sun will convert hydrogen into helium for about 10 million years before they undergo dramatic changes which convert them into a __________ giant star. After this stage the star explodes to form a nebula. Following the nebula stage the star cools and shrinks into a __________ dwarf and then a cold black dwarf. The larger a star the __________ is its lifetime. Larger stars are much hotter than our Sun and they shine with a blue-white light. When their nuclear fuel is used up they __________ to form a red supergiant star. Following this stage a gravitational __________ occurs and this leads to a supernova. All that remains following the supernova is a __________ star which is also called a pulsar. The very large stars evolve very rapidly and form very large red supergiants which explode in a supernova that leaves behind a __________ hole. The smallest and most common stars are called __________ dwarfs. Due to their small mass they have the longest lifetimes. Eventually they cool and turn into black dwarfs.

2 The earliest telescopes consisted of simple __________ lenses mounted in a tube. These lenses refracted the light and produced a __________ image of the object. In 1610 __________ constructed a simple telescope that could magnify up to 30×. He used this telescope to observe the Moon and the planets Venus, Jupiter and Saturn. He saw that Venus had phases like our own Moon and that Jupiter had __________ orbiting around it. Isaac Newton developed a reflecting telescope using concave mirrors. This telescope produced greater magnification and image clarity. Some very large __________ telescopes have been constructed in modern times that have mirrors with diameters up to 10 m. These telescopes can detect objects that are 10 billion light-years from our Sun. Space telescopes, such as the Hubble, have also been developed. They __________ the Earth and because they are above the atmosphere they do not suffer image __________ due to movements in the atmosphere. All these optical telescopes use __________ light to observe astronomical objects. Other regions of the electromagnetic __________ can be used for astronomical observations. Ground-based __________ telescopes and X-ray space telescopes are used to investigate various radio wave and X-ray sources such as neutron stars, black holes and supernova remnants. Infra-red telescopes are used to observe interstellar dust as well as cool, faint bodies such as black __________.

3 Australia contributes to our knowledge of the universe using optical and radio telescopes. Optical telescopes at Siding Spring (near Coonabarabran) and Canberra have undertaken pioneering work involving digitally __________ the southern sky as well as determining the mass density of the universe and searching for __________ matter. Scientists such as Brian Schmidt and Penny Sackett have made valuable contributions to astronomy. Professor Schmidt shared the 2011 Nobel Prize for Physics for the discovery that the rate of __________ of the universe is increasing. Professor Sackett has used the technique of gravitational lensing to discover __________ that orbit around distant stars.

(cont.)

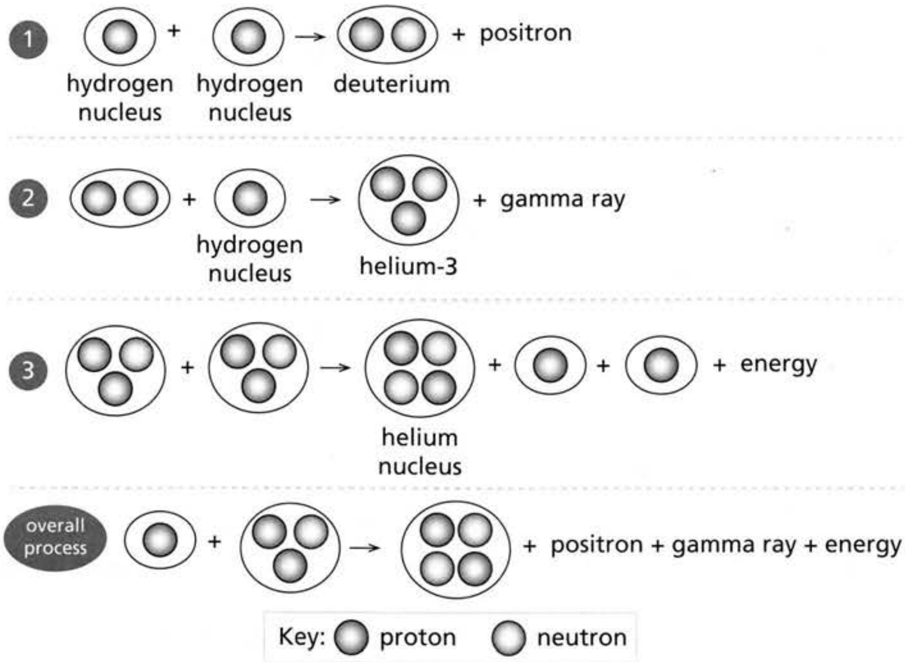
Australia continues to make important contributions to radio astronomy. The latest projects involve the construction of the Australian Square Kilometre Array Pathfinder (ASKAP) of 36 __________ telescopes in Western Australia. These telescopes will be linked with others in New Zealand and South Africa to become the most __________ telescope in the world by 2024. This array will be able to investigate the earliest stars that formed after the Big Bang. The following photograph shows a radio telescope near Parkes, New South Wales.



4 Over the past 50 years robotic probes have been launched to investigate the planets in our solar system. Some of these missions have involved __________ in which the probe comes close to a planet and takes photographs for transmission back to Earth. Other probes have gone into __________ around a planet and taken various measurements. In some missions the probe has landed on the surface for a close-up study of the planet. Venus has been studied in this way and was found to be a very inhospitable planet. It is extremely __________ and the thick atmosphere is very acidic. Probes have survived only several hours on the surface before being destroyed. Many missions have been launched to Mars. A number of these have involved the deployment of robot __________ that can travel over the Martian surface and examine its geology and chemistry. Jupiter has been studied using flyby and __________ probes. The Cassini probe to Saturn achieved orbit in 2008. Since then, considerable scientific data has been collected. The orbiter also released a smaller robotic craft called Huygens that descended and landed on Saturn's largest __________ called Titan. This moon has a rocky surface and, due to the extreme cold, it also has lakes of liquid __________ such as methane and ethane.

Answers **1** yellow; solar; black; brightness; red; Sirius; nuclear; helium; red; white; shorter; expand; collapse; neutron; black; red **2** glass; magnified; Galileo; moons; reflecting; orbit; distortions; visible; spectrum; radio; dwarfs **3** mapping; dark; expansion; exoplanets; radio; sensitive **4** flybys; orbit; hot; rovers; orbiting; moon; hydrocarbons

1 Hydrogen is converted into helium by a process called nuclear fusion which occurs in the core of stars like our Sun. The following diagram shows how the nuclear fusion of hydrogen happens.



a How many protons are present in the nucleus of a hydrogen atom? (1 mark)

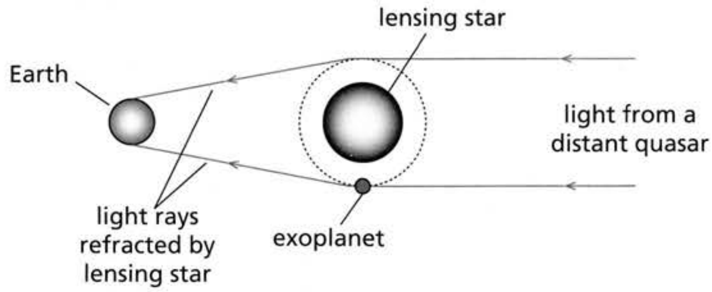
b How many protons are present in the nucleus of a helium atom? (1 mark)

c How does the number of protons change during the nuclear fusion process? (1 mark)

d How does the number of neutrons change? (1 mark)

e Protons are positively charged. Suggest why nuclear fusion only occurs under extremely high pressures and temperatures. (1 mark)

2 Penny Sackett is an astronomer who is interested in discovering exoplanets that orbit distant stars. The following diagram shows the principle used to discover such planets.



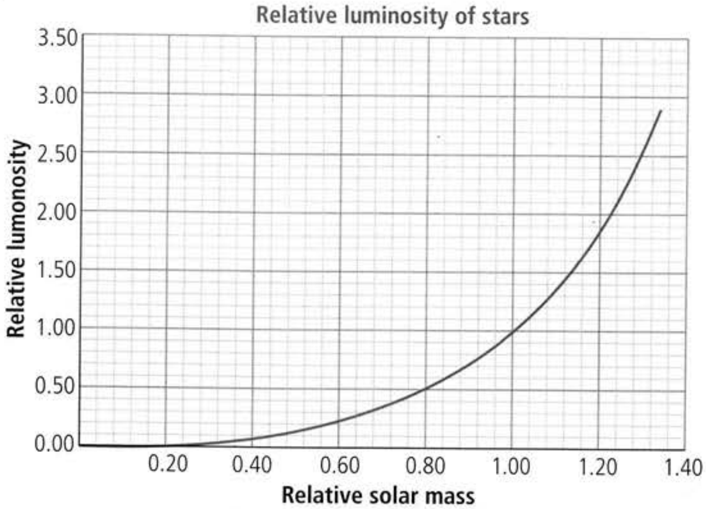
a The gravity of the lensing star causes the light from a distant source, such as a quasar or galaxy, to bend. What term is used to describe the bending of light rays? (1 mark)

b Explain how an astronomer on Earth can detect the presence of an exoplanet orbiting the lensing star. (2 marks)

c If the light is coming from a distant quasar, describe the conditions required to make a positive observation of an exoplanet by an Earth-based observer. *Hint 1* (2 marks)

(cont.)

3 The approximate brightness (or luminosity) of a star is related to its mass. The following diagram shows the relationship between L (the luminosity compared with the Sun) and its relative solar mass.

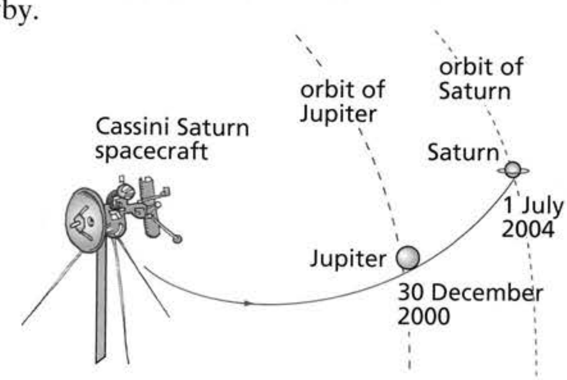


a A star has a mass 1.3 times the mass of the Sun. How many times more luminous than the Sun is it? (1 mark)

b If a star has only half the luminosity of the Sun, what would be the solar mass of this star? (1 mark)

c Where on this graph are the coordinates for the Sun? (1 mark)

4 The Cassini probe made a flyby of Jupiter on its mission to Saturn. The following diagram shows the trajectory of this flyby.



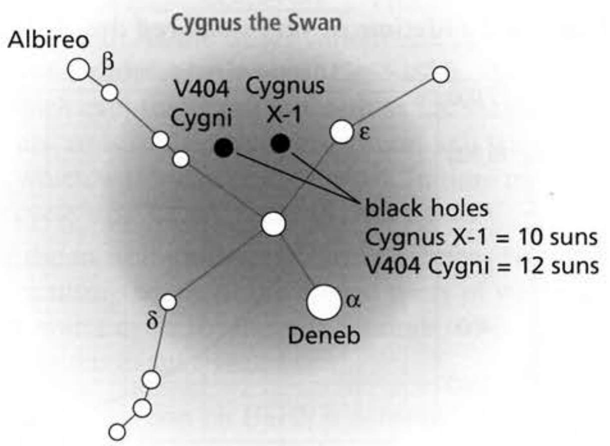
a Explain how the Cassini probe changes direction as it approaches and passes Jupiter if it does not use rocket engines. (1 mark)

b At its closest approach, Cassini was 9.7 million km from Jupiter. The radius of Jupiter is 71.5 thousand km. Suggest one reason why Cassini did not approach too closely to Jupiter. *Hint 2* (1 mark)

c The Cassini probe has several antennas projecting from the body of the craft. What is the purpose of these antennas? (1 mark)

d In 2012, the Cassini probe witnessed a giant storm on Saturn. This storm produced a spike in temperatures at that site. What type of space telescope would be used to record this temperature spike? (1 mark)

5 Deneb is the brightest star in the constellation of Cygnus (the Swan). This constellation probably contains two black holes. These are coded Cygnus X-1 and V404 Cygni. Their locations are shown in the following diagram.



a **i** Use the following description to sketch a labelled diagram showing the features described. (5 marks)

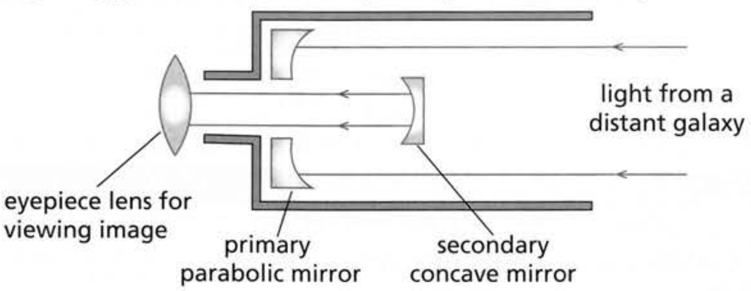
> Cygnus X-1 is part of a double-star (binary) system about 6000 light-years from Earth. The supergiant companion to the black hole is a hot, blue star of about 30 solar masses. Cygnus X-1 is probably only 30 km in diameter. The black hole tears gases away from the blue star. As they funnel down the black hole they become very hot and emit X-rays which can be detected by astronomical observations. Because the blue star is more massive than the black hole, the centre of mass of the double-star system is inside the blue star. The blue supergiant, therefore, only wobbles as the pair rotate.

ii How can astronomers know that X-rays are emitted if our atmosphere absorbs X-rays? *Hint 3* (1 mark)

b Use the following description to draw a labelled diagram showing the features described. (5 marks)

> V404 Cygni is also part of a binary system. The black hole is immensely heavy compared to its small companion star. The centre of mass balance of the binary system lies almost in the black hole. The small star seems to be swinging around the black hole like a ball on a string. As gases are drawn from the star into the black hole whirlpool they emit X-rays.

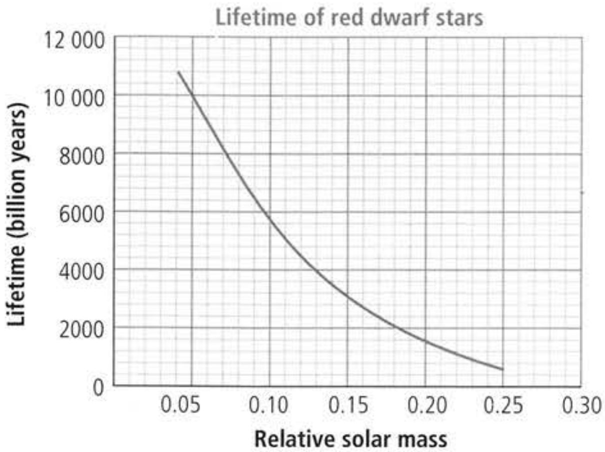
6 The following diagram shows a design for a reflecting telescope. The diagram is incomplete as it does not show the light ray paths between the primary and secondary mirrors.



(cont.)

a Copy and complete the ray diagram to show the pathway of the missing light rays. (2 marks)
b Explain why reflecting telescopes are generally superior to refracting telescopes. (1 mark)
c Name the scientist who first used a refracting telescope to observe Jupiter. (1 mark)

7 The following graph shows the lifetime of very small red dwarf stars.



a State one conclusion that can be made from this graph. (1 mark)
b i A red dwarf star has a relative solar mass of 0.10. Use the graph to predict its lifetime. (1 mark)
ii Compare the predicted lifetime of this red dwarf to the current age of the universe. (2 marks)
c i Use the following table and the graph to compare the relative luminosity (brightness) of a red dwarf with a lifetime of 3500 billion years to the Sun's luminosity. (2 marks)

Relative solar mass	0.08	0.10	0.12	0.14	0.20
Luminosity relative to the Sun (%)	0.03	0.09	0.15	0.22	0.55

ii Use your answer to part i to explain why no red dwarf stars are visible to the naked eye. (1 mark)

Hint 1: Quasars produce jets of X-rays from the centre at right angles to the spiralling disc of gas.
Hint 2: Does Jupiter have moons?
Hint 3: Where can observations be made other than on the Earth's surface?

Your Feedback

$\frac{\square}{39} \times 100\% = \square\%$

PAGES 263–264
PAGE 282

evolved in the oceans. ✓ Oxygen was produced as a by-product of their photosynthesis.

STARS AND ASTRONOMY
The universe and global systems Pages 141–144

1 a 1 ✓

b 2 ✓

c increases from 1 to 2 ✓

d increases from zero to 2 ✓

e The protons repel each other strongly and therefore great pressures and temperatures are required to compress the nuclei so they combine to form a helium nucleus. ✓

2 a refraction ✓

b Light (electromagnetic radiation) that comes from a distant source is affected by the gravity of the lensing star. ✓ The orbit of the exoplanet interferes with the light that is lensed and these disturbances are recorded by Earth-based astronomers. ✓

c The X-ray light from the quasar must be in a straight line with the lensing star and the Earth observers. ✓ The jets of X-rays must be pointing towards the Earth so they can be observed. ✓

3 a Relative luminosity = 2.6. Thus the star is 2.6 times more luminous than the Sun. ✓

b 0.81 relative solar mass ✓

c relative solar mass = 1.00, relative luminosity = 1.00 ✓

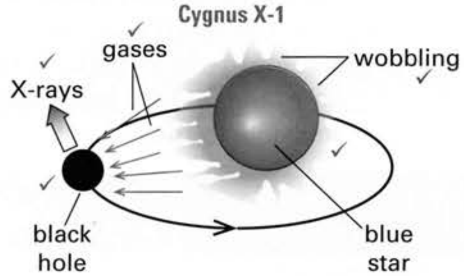
4 a The gravity of Jupiter attracts Cassini and this leads to a change in direction and speed. ✓

b The Cassini craft needed to avoid colliding with Jupiter's moons OR if the craft came too close it might not be able to escape from Jupiter's gravity. ✓

c In order to relay data and images back to Earth and receive communications from Earth. ✓

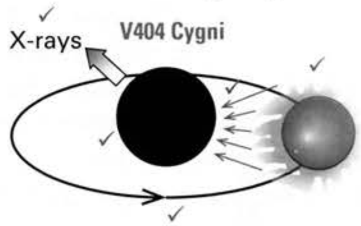
d infra-red space telescope ✓

5 a i See the following diagram.

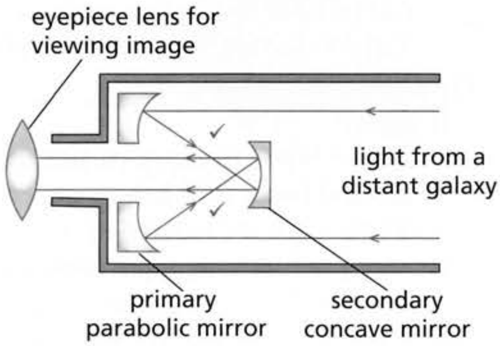


ii An X-ray space telescope in orbit around the Earth can detect the X-rays. ✓

b See the following diagram.



6 a See the following diagram.



b Refracting telescopes can produce image distortions as the light is refracted. This does not happen with a reflecting telescope. ✓

c Galileo ✓

7 a The greater the mass of a red dwarf star, the shorter its lifetime. ✓

b i about 5700 billion years ✓

ii The current age of the universe is 13.7 billion years. ✓ This is a very small fraction of the 5600 billion year lifetime of this red dwarf. ✓

c i The relative solar mass is 0.14. ✓ Thus, the relative luminosity is 0.22% of the Sun's luminosity. ✓
ii This red dwarf has a very low luminosity or brightness and so would be very faint and thus invisible to the naked eye. ✓

NATURAL CYCLES
The universe and global systems Pages 152–154

1 a true ✓
b true ✓
c false ✓ The main substance released is carbon dioxide.
d false ✓ It is called nitrogen fixing.
e true ✓ Carbon can be locked away in fossil fuels and other forms and not be part of the cycle for many millions of years.
f true ✓ This is a waste product from cellular respiration.
g false ✓ Green plants also need to carry out cellular respiration and so release carbon dioxide, but they take in more than they release.
h false ✓
i true ✓ Some forms of carbon may go around faster than others depending on where they are located in the cycle.
j true ✓ The atmosphere consists of around 78% nitrogen gas (N_2).
k false ✓ Infiltration is water entering the ground; transpiration is the movement of water out of plant leaves.
l true ✓
m true ✓
n false ✓ While the atmosphere contains a lot of N_2, most plants cannot use nitrogen in that form.
o false ✓ It comes from the air, as carbon dioxide. Animals take in carbon by eating plants and/or other animals.
p true ✓
q false ✓ They get it by feeding. Animals cannot make their own proteins so they need protein as part of their diet.
r false ✓ There is increasing evidence to suggest that it has, but to what extent is still debated.
s true ✓
t true ✓
u false ✓ Minerals from agricultural fertilisers can enter waterways causing harmful algal blooms.
v false ✓ It is used to produce amino acids and proteins.
w false ✓ It is precipitation.
x false ✓ It stays the same.
y true ✓ The phosphate ion is PO_4^{3-}
z false ✓ They are found as salts in ocean sediments or in rocks.

2 i/R ✓; ii/T ✓; iii/S ✓; iv/P ✓; v/Q ✓; vi/U ✓

3 a Unlike carbon, oxygen and nitrogen the atmosphere is not a reservoir for phosphorus. ✓ The cycle of phosphorus occurs between the organism and the ground. ✓
b No. Microorganisms do not fix phosphorus as they do nitrogen. ✓

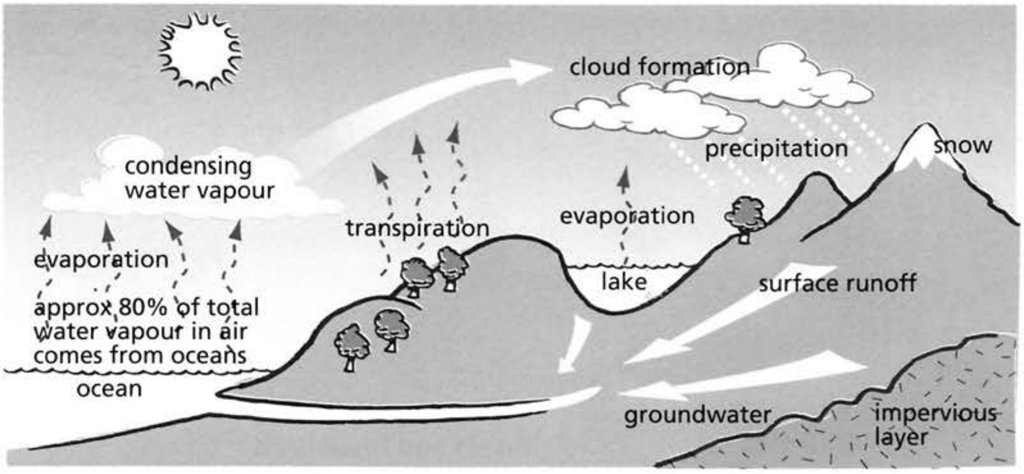
4 a 18.25% ✓
b $(18.25 \div 100) \times 500 = 91.25$ tonnes ✓

5 a X = ammonia ✓; Y = nitrite ✓; Z = nitrate ✓
b One type changes poisonous ammonia into nitrites ✓; the other type changes poisonous nitrites into nitrates ✓.
c Too many fish and not enough plants for natural biological cycling to occur. ✓
d Replacing the water, or filtering it for nitrates and other wastes, will prevent it from building up nitrates to the point where it becomes a problem. ✓
e sunlight ✓ Energy from the Sun is necessary for the plants to carry out photosynthesis.

1 Our planet is continuously changing but there is only a constant amount of material (oxygen, nitrogen, water, etc.) on it. **Natural cycles** of these materials balance and regulate the Earth and its atmosphere, and allow this material to be used over and over again. Life on Earth is well adapted to these cycles, four of which will be discussed in the following sections.

The **water cycle**. The water on Earth has been around for millions of years. Over this time the amount of water has not changed very much. It moves around the world in a large, continuous cycle called the water cycle or the hydrological cycle. In some parts of this cycle water is a liquid (rain, rivers, ocean) while in other parts it is gaseous (vapour, steam) or a solid (ice, snow).

The Sun's heat drives this cycle, **evaporating** water from seas, rivers and lakes, and from soil and plants on land. Plants lose water to the air through **transpiration**. The water vapour cools as it rises into the atmosphere forming tiny water droplets in clouds. Cool air cannot hold as much water vapour as warm air. Some droplets combine, forming larger droplets and eventually falling to the ground as rain, hail or snow (**precipitation**). Some soaks into the ground, perhaps remaining there for thousands of years, and some remains as ice. Much of the water on land eventually flows in streams and rivers to the sea, and the water cycle continues.



Water is not evenly distributed over the Earth. Some places can be very dry (such as Antarctica and the Atacama Desert in Chile) and others very wet (such as north-eastern India). A problem in many parts of the world is not the lack of water, but the lack of clean drinking water.

2 The **carbon–oxygen cycle**. This is a complex series of processes through which all carbon atoms cycle. It is often linked with oxygen as the two follow similar paths. All living things are made of carbon, and it is the most abundant element in living matter. In the carbon cycle, plants absorb carbon dioxide from the atmosphere, combine it with water they get from the soil and use it to make the matter they need for growth. In the process of **photosynthesis** carbon atoms from this carbon dioxide are turned into **sugars** and **carbohydrates**, and the remaining oxygen is released to the atmosphere. Plant-eating animals then eat (some of) the plants and use the carbon in the plants to construct their own tissues. Other animals eat these plant-eaters, so acquiring and using the carbon in them for their own requirements. **Respiration** is going on all the time in all living things and produces carbon dioxide. All these animals return some carbon dioxide into the atmosphere when they breathe. When they die the carbon is returned to the soil during decay and **decomposition**. The carbon atoms present in the soil may be taken up by other small

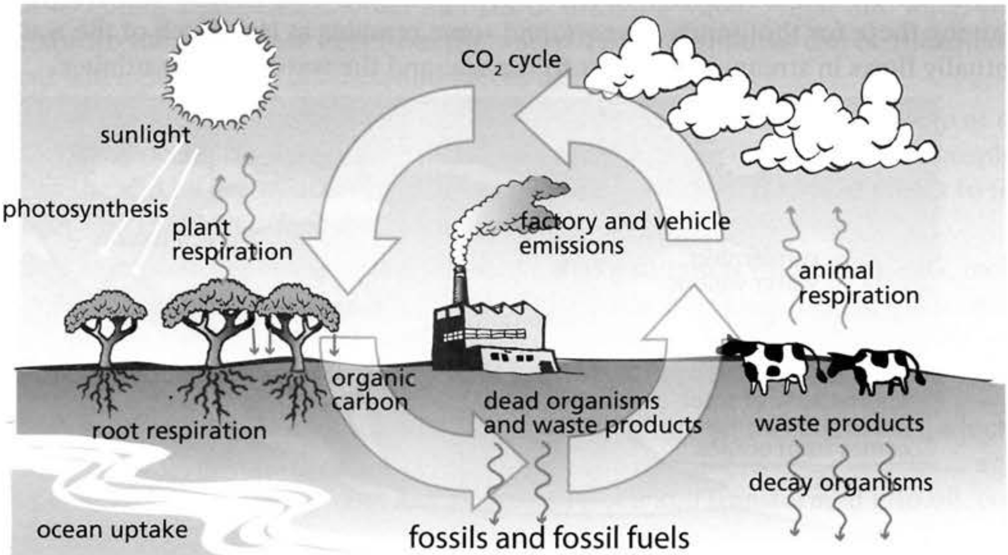
(cont.)

microorganisms. These, too, carry on respiration and will also release carbon when they die and decay. So the carbon dioxide in the atmosphere is replenished.

Millions of years ago many energy-rich plants were covered over in swamps and slowly turned into **coal**. Similarly, many microorganisms in the seas fell to the bottom when they died, were covered by mud and slowly formed **petroleum**. These **fossil fuels** contain carbon and are used by humans as energy sources for transport, generating electricity and to operate factories. When fossil fuels are burned, most of the carbon quickly re-enters the atmosphere as carbon dioxide.

Small amounts of carbon dioxide enter the atmosphere through volcanoes and from the weathering of limestone.

As carbon dioxide is slightly soluble in water, it dissolves in oceans providing carbon for plants and animals living there. Both the carbon and the oxygen in the oceans are cycled from the atmosphere and back to the atmosphere through living organisms.

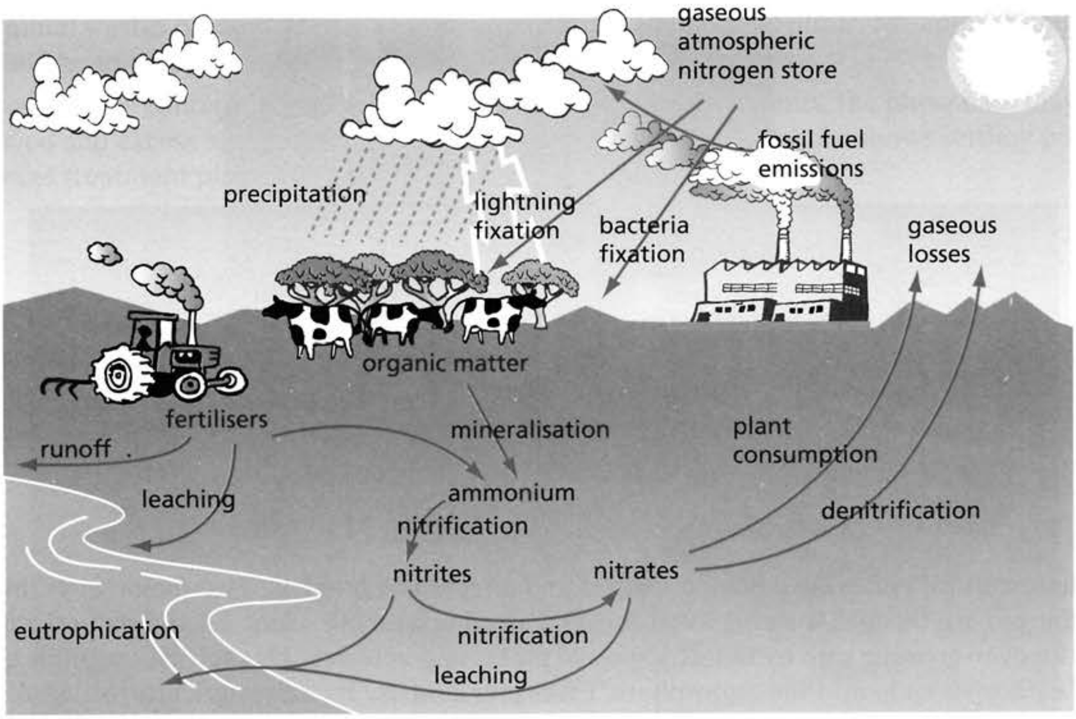


3 The **nitrogen cycle**. Nitrogen is used by living organisms to manufacture different types of organic molecules, such as **amino acids** and **nucleic acids**. Atmospheric nitrogen is very abundant, existing mainly as the gas N_2, although most living things can't use it in this form. Other major sources of nitrogen include organic matter in soil and the oceans. Most plants can only absorb nitrogen in two solid forms: **ammonium ions** (NH_4^+) and **nitrate ions** (NO_3^-). Inorganic nitrates enter plants dissolved in water in the soil. The plants are eaten by animals and the nitrogen becomes available to them. Other animals, too, receive the nitrogen they need for **metabolism**, growth and reproduction by eating living or dead organic matter containing these nitrogen compounds.

This organic nitrogen is changed into inorganic forms when plants and animals die and are decomposed. **Decomposers** (a number of species of bacteria and fungi) found in the upper soil layer chemically modify the nitrogen found in organic matter into ammonium salts. Various **nitrifying bacteria** alter these ammonium salts to nitrite (NO_2^-) and then on to nitrate (NO_3^-).

Nitrates are very soluble and are easily lost from the soil by leaching. Some of the leached nitrates flow through the water system until they reach lakes or oceans, where the nitrogen can be returned to the atmosphere by **denitrifying bacteria**. Denitrification is also widespread in anaerobic soils (soils where there is little oxygen).

Almost all of the nitrogen found in the ecosystem originally came from the atmosphere. Some enters the soil during rainfall or through the effects of lightning. However, most is fixed within the soil by specialised **nitrogen-fixing bacteria**. Certain plants, called **legumes**, form symbiotic relationships with nitrogen-fixing bacteria. These bacteria live in special structures (nodules) in roots where they can survive in a moist environment. This relationship allows those plants to grow in soils that are deficient in nitrates and, in return, the bacteria obtain carbohydrates from the plant. Farmers often grow legumes in their pastures to increase the nitrogen content of their soils.



4 The **phosphorus cycle**. Phosphorus is an essential nutrient for living things in the form of phosphate (PO_4^{3-}) and hydrogen phosphate (HPO_4^{2-}) ions. It forms part of DNA molecules, it is in molecules that store energy and is found in the fats of cell membranes. It is also an important component of bones and teeth.

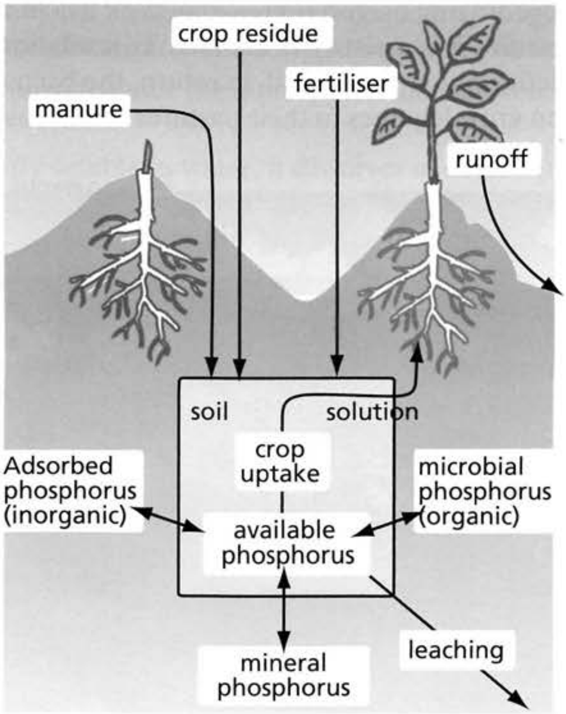
Phosphorus is found mainly cycling through water, soil and sediments, but is not found in the atmosphere in the gaseous state (as other recycled elements are). The phosphorus cycle is the slowest of the matter cycles described here.

Phosphorus enters the environment from the weathering and erosion of rocks or other deposits. Fossilised bones or bird droppings (**guano**) are other sources. The phosphate ions that are released are soluble in water. Land plants need phosphate as a fertiliser or nutrient. Animals absorb phosphates by eating plants or plant-eating animals. Eventually when plants and animals die and waste products decay, the phosphate is released and returned to the environment to be recycled.

(cont.)

Erosion *and* ***leaching*** *washes much of the phosphate into* water courses. Water plants and algae use the phosphate as a nutrient, but a significant amount is precipitated from water as insoluble iron phosphate. In shallow sediments it may be easily recycled into the water to be used again.

Phosphorus can also end up in sediments or rock formations again, and be trapped there for millions of years. Eventually, it is released through weathering and the cycle starts over.



5 These natural cycles have been impacted and affected by humans. Two major ways this has occurred are through **burning fossil fuel** and **altering land use**. Coal, oil and natural gas are used at an ever-growing rate by industry, power plants and vehicles. This releases copious quantities of carbon dioxide into the atmosphere. Changing land use includes agriculture, deforestation and reforestation. Humans have cleared large swathes of natural vegetation for their farms and cities, and this impacts the environment. In the process, humans have altered water courses and built dams, activities that affect flora and fauna that live near and in them.

Human activities have impacted the nitrogen cycle.

- Nitrogen fertilisers applied to crops have caused increased rates of **denitrification** and **leaching** of nitrate into groundwater. Excess nitrates end up in streams, rivers, lakes and estuaries, leading to **eutrophication**.
- Many Australian plants have adapted to living in nitrogen-poor soils, so nitrogen fertilisers that find their way into natural bushland can be harmful for native vegetation and promote the growth of **weeds** and introduced plants.
- Livestock release large quantities of ammonia into the environment from their **urine** and **faeces**. This nitrogen enters the soil system and then gets into the water system through leaching, groundwater flow and run-off.
- Increasing human populations mean increased human wastes. **Sewage** waste and septic tank leaching into soils can alter the nitrogen balance.

Humans have also impacted the phosphorus cycle, mainly through the use of commercial **synthetic fertilisers**. Some other impacts on the phosphorus cycle are as follows.

- **Mining** the mineral apatite, an important phosphorus source, requires using enormous quantities of sulfuric acid to convert the phosphate rock into a fertiliser. If not handled properly there may be detrimental effects on the environment. In order to keep mining practices from permanently destroying wildlife habitats, mining areas need to be contoured and revegetated to return them to their original condition.
- Plants may not be able to make use of all of the phosphate fertiliser that is applied. Consequently, much of it can be washed from the land through water run-off, and can then be a nutrient problem downstream.
- Animal wastes or manure may also be applied to the land as fertiliser. Misapplied, there could be too much run-off of phosphate and nitrate into streams.

Human sewage contains phosphates. Without appropriate treatments, the phosphate may not be removed and excess amounts enter the waterways. The following photo shows settling ponds in a sewage treatment plant.

Checklist
Can you:

1 *Describe the main features of the water cycle?*	☐
2 *Describe the main features of the carbon–oxygen cycle?*	☐
3 *Describe the main features of the nitrogen cycle?*	☐
4 *Describe the main features of the phosphorus cycle?*	☐
5 *Outline the effects of human impact on these cycles?*	☐

NATURAL CYCLES

The universe and global systems

QUICK REVISION

1 No new water is being created and water can't ______ from the Earth. The water we use is ______ again and again. The water cycle is one of the simplest natural cycles on Earth. Solar ______ evaporates water from the ocean, lakes and rivers, which rises into the atmosphere as an invisible gas (water ______). This process is called evaporation. Winds push this water vapour over land. As the water vapour ______ over mountains it cools and turns back into tiny water droplets, forming ______. Small water droplets condense to form larger droplets which eventually fall to Earth as ______ (precipitation). The rain runs into streams and rivers, or is soaked into the ground and trapped in ______ (layers of permeable rock through which water can easily move). In time much of this water will flow into lakes or the sea, and the cycle will ______ all over again.

The water cycle is one of the most important natural processes sustaining human life and the natural environment. Agriculture is one of the largest users of water. Farmers depend on clean water moving through the water cycle for their livelihoods, while all living ______ need water and a healthy food source to survive.

2 Like water, the total amount of carbon on Earth is constant. No more can be created, nor is it ______ from the Earth. Carbon can be found in gaseous, ______ and liquid compounds, and is vital to life on Earth. Every living organism needs ______ to maintain life, for its physical composition, as an energy source or to grow. Carbon is found in all parts of the Earth: its atmosphere, oceans, biosphere and ground.

In agriculture, carbon is cycled through the atmosphere, plants and ______, and through the soil. Green plants use carbon dioxide and sunlight to make their own ______ and grow. The carbon becomes part of the plant. Animals that eat plants, and animals that eat other ______, take in this carbon and make it part of their own body systems. Harvesting ______ and animal products removes carbon from the agricultural system.

Carbon is the prime constituent of all ______ fuels (coal, oil and gas) that we burn to create power. These were formed over ______ of years through the partial decay of plants and microscopic organisms. The energy from the ______ remained trapped in these fossil fuels and provides a storehouse of potential energy. Our increased use of energy has increased the volume of carbon ______ in the atmosphere through burning fossil fuels.

3 Nitrogen is present in all parts of the Earth. Around 78% of the ______ is nitrogen; however, atmospheric nitrogen as such is unavailable for biological use. It must first be fixed to make it available for plants to use. Nitrogen is essential to plant growth and reproduction. Most plants get the nitrogen they need from the ______. Often farmers add fertilisers containing nitrogen to the soil to improve plants' growth. Using ______ fertilisers has dramatically increased the productive capacity of soils worldwide. Australian soils are often ______ in nitrogen. Bushfires add huge amounts of nitrogen into the soil, often replenishing it and allowing for ______ and vigorous growth.

There are important ______ concerns to be considered when using nitrogen fertilisers. Excess fertiliser can be washed into nearby waterways, rivers and lakes upsetting aquatic environments. It may also leach into groundwater, eventually acidifying ______.

Too many nitrates in water can cause eutrophication. This is where a high concentration of ______, especially phosphates and nitrates, causes excessive growth of plants and algae. This is particularly apparent in slow-moving rivers and ______ lakes. Plants may die

(cont.)

suddenly when there are too many for the environment to support. As the algae __________ and decompose, high levels of organic matter and the decomposing organisms rob the water of available oxygen, causing the __________ of other organisms, such as fish. Aquatic plants grow on or near the surface, which has the added problem of blocking out __________ and oxygen, and warming the water below. While eutrophication can occur naturally, human activity greatly __________ the process.

4 Most plants contain only about 0.2% phosphorus by weight, but that small amount is vitally important. Phosphorus enters the biosphere almost entirely from the __________ through absorption by plant roots. Rocks containing phosphate minerals __________ and produce a relatively small quantity of inorganic phosphorus available for use by living organisms. In most soils the major amount of phosphorus absorbed by plants comes from inorganic forms.

Phosphorus is built into many organic compounds used in cells. Animals can get their phosphorus by eating __________, other animals or drinking water. Algae and water plants are able to absorb the phosphate ions from the water. That phosphorus can be returned to the environment when plants, __________ and faeces decay.

However, there is a great deal of phosphorus lost. Usable phosphorus often ends up at the __________ of the ocean where the phosphate ions are taken out of circulation. Phosphorus only gets into the soil by the weathering process on rocks, so straightforward places to find phosphorus on the Earth's surface are running out.

By harvesting and removing crops farmers have created a situation where nutrients, including phosphorus, need to be artificially __________. Phosphorus is heavily used in the farming industry and fertilisers crammed with phosphates are used all over the world to assist in __________ growth.

5 Humans impact the carbon cycle during the __________ of any type of fossil fuel, which may include oil, coal or natural gas. Fossil fuels were formed millions of __________ ago from plant or animal remains that were buried, compressed and transformed into oil, coal or natural __________. This carbon is essentially locked out of the natural carbon cycle. Humans intervene by burning the __________ fuels. During combustion in the presence of air (oxygen), __________ dioxide and water molecules are released into the atmosphere. This increases atmospheric carbon dioxide and can lead to __________ warming.

Phosphates and nitrates are used by __________ to grow bigger and better crops as part of intensive farming. Run-off can take some of these nutrients and __________ them into streams, lakes and bays. This causes excessive algal and plant __________ that can have a detrimental impact on the environment.

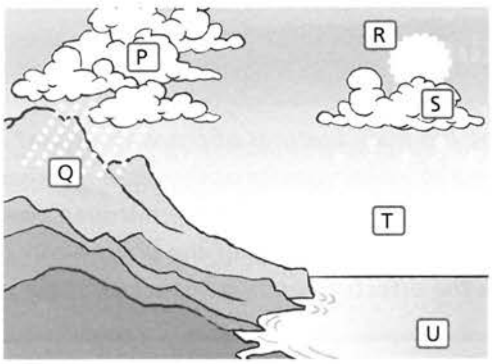
Answers 1 escape (disappear); recycled; energy (radiation); vapour; rises; clouds; rain (hail, snow); aquifers; begin (occur); organisms 2 removed; solid; carbon; animals; food; animals; plant; fossil; millions; Sun; dioxide 3 atmosphere; soil (ground); nitrogen (nitrate); poor (lacking); new; environmental; soils; nutrients (minerals); shallow; die; death; sunlight; accelerates (hastens) 4 soil; weather (break down); plants; animals; bottom; replenished (replaced); plant 5 combustion (burning); years; gas; fossil; carbon; global; farmers; deposit (transfer); growth

1 True or false?

a The flow of water over the land into rivers, lakes and seas is called surface run-off. (1 mark)
b Plants are the main consumers of carbon dioxide. (1 mark)
c When fossil fuels are burned nitrogen is released. (1 mark)
d The conversion of nitrogen gas to nitrates by bacteria is called nitrification. (1 mark)
e The geologic portion of the carbon cycle takes many thousands, if not millions, of years. (1 mark)
f Humans and other animals produce carbon dioxide. (1 mark)
g Green plants only take in carbon dioxide, they do not release it. (1 mark)
h Nitrogen is an important element in carbohydrates. (1 mark)
i All of the carbon in existence is continually recycled in the carbon cycle. (1 mark)
j The largest nitrogen reservoir is the atmosphere. (1 mark)
k The release of water through plant leaves and into the atmosphere is called infiltration. (1 mark)
l The conversion of nitrates to nitrogen gas by bacteria is called denitrification. (1 mark)
m Carbon gets into the soil when plants and animals die. (1 mark)
n Atmospheric nitrogen (N_2 gas) is easily taken up and used by plants and animals. (1 mark)
o The carbon that the plants use come from animals. (1 mark)
p Humans contribute to the carbon cycle through breathing and by burning fossil fuels. (1 mark)
q Animals get their organic nitrogen compounds by breathing. (1 mark)
r Most scientists believe that activities like burning fossil fuel and deforestation have not affected the global carbon cycle. (1 mark)
s Plants absorb phosphates from the soil then bind them into organic compounds. (1 mark)
t A widespread method of nitrogen fixation is by bacteria in the root nodules of some plants. (1 mark)
u Eutrophication in coastal waters can cause an increase in agricultural productivity. (1 mark)
v Once bacteria have fixed nitrogen, it can be taken up by plants and animals where it is used in the production of energy. (1 mark)
w Water that falls to Earth as rain, hail or sleet is called condensation. (1 mark)
x As water passes through the water cycle over again, the amount of water on Earth decreases. (1 mark)
y Phosphorus normally occurs in nature as part of an ion, consisting of a phosphorus atom and several oxygen atoms. (1 mark)
z Most phosphates are found as salts in the atmosphere. (1 mark)

2 The diagram shows the water cycle. (6 marks)
Match the letter with the statement below.

i The never-ending water cycle is driven by the energy from the sun.
ii The sun evaporates water from the land, rivers and oceans.
iii As the moisture rises it cools and the water droplets condense to form clouds.



iv Wind blows clouds over the land.
v When the droplets become too heavy they fall to the ground as rain.
vi This water soaks into the ground or runs across the land to eventually gather in lakes or seas.

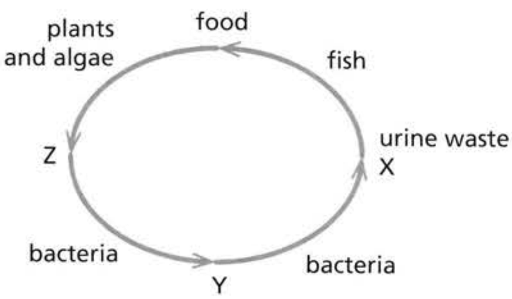
3 a The phosphorus cycle has been described as a sedimentary cycle. Explain what this means. Hint 1 (2 marks)
b Nitrogen can be fixed by bacteria into a form used by plants. Is this true of phosphorus as well? (1 mark)

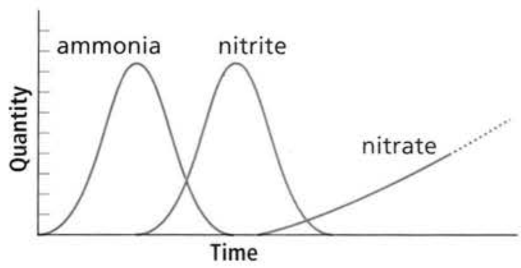
4 Phosphate is commercially available in a form called apatite. This has the formula $Ca_5(PO_4)_3(OH,F,Cl)$. Apatite is a pale green to purple mineral, found in igneous rocks and metamorphosed limestones. It is a source of phosphorus for plants and is used in the manufacture of fertilisers. The table gives an analysis of each of the elements present in apatite.

Element	Percentage
calcium	39.36
phosphorus	
oxygen	38.76
chlorine	2.32
fluorine	1.24
hydrogen	0.07
total	100.00

a Complete the table by calculating the percentage by weight of phosphorus. Hint 2 (1 mark)
b Five hundred tonnes of apatite are mined. What is the theoretical mass of phosphorus that can be obtained? (1 mark)

5 A koi fish enthusiast keeps a large fish pond with fish. He monitors the nitrogen present in the pond in the form of ammonia, nitrite and nitrate. He knows that both ammonia and nitrate in any significant quantities can be harmful to his fish, so he introduces different bacteria to deal with them.





a Identify the nitrogen compounds labelled X, Y and Z. (3 marks)
b Describe the function of the two types of bacteria. (2 marks)
c Suggest a reason for the nitrate concentration to keep on increasing. (1 mark)
d How will regular partial water changes by the fish enthusiast fix the problem of too much nitrate? (1 mark)
e What necessary component has not been shown on the cycle? Hint 3 (1 mark)

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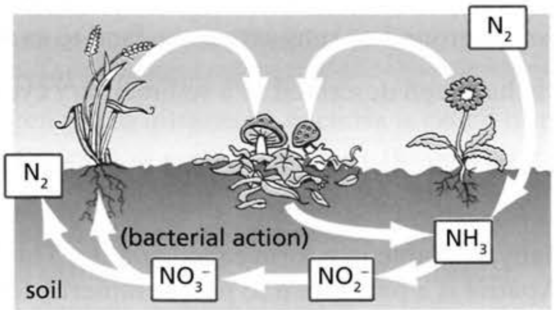
6 The diagram shows part of the nitrogen cycle.



a State two ways atmospheric nitrogen enters the cycle. (2 marks)

b What would happen to the number of plants if bacteria were not able to convert NO_2^- ions into NO_3^- ions? (1 mark)

7 Atmospheric carbon dioxide content has been steadily rising over recent decades. The following table shows carbon dioxide data collected between 1960 and 2010 at the Mauna Loa laboratory in Hawaii. The concentration of carbon dioxide is expressed in the units of parts per million (ppm).

Year	1960	1970	1980	1990	2000	2010	2020
Carbon dioxide concentration (ppm)	320	329	342	357	371	392	

a Plot this data as a line graph. Draw the curved line of best fit. (5 marks)

b Extrapolate your line to 2020. (1 mark)

c Predict the carbon dioxide concentration in 2020. (1 mark)

d In 2013 it was announced that carbon dioxide levels had reached 398 ppm. How does this measurement compare with your extrapolation of data? (1 mark)

Hint 1: Consider where the phosphorus cycle occurs. Do you find any in the atmosphere?
Hint 2: The total for all elements present is 100%.
Hint 3: What do plants need to manufacture their own food?

Your Feedback

$\frac{\square}{56} \times 100\% = \square\%$

PAGES 264–265
PAGE 282

POLLUTION AND CLIMATE CHANGE

The universe and global systems

REVISION SUMMARIES

1 **Air pollution** refers to a variety of chemicals (solid, liquid or gaseous), particulates or biological materials that cause uneasiness, disease or death to humans, harm other living organisms such as animals or food crops or spoil the natural or built environments. There are two major sources.

- **Human activity** including burning fossil fuels, incinerators and furnaces, fumes from paints and aerosols, waste deposited in landfills generating methane, chemical sprays and controlled burns in agriculture.
- **Natural sources** including dust storms, methane gas released from animals, smoke and carbon monoxide from bushfires, radon gas from natural radioactive decay, volatile organic compounds emitted from plants and volcanic activity.

There are a number of major pollutants generated by humans.

- **Carbon monoxide** (CO) is a colourless, odourless and very poisonous gas. It is formed during incomplete combustion of fuel. A major source is car and truck exhausts.
- **Carbon dioxide** (CO_2) is a colourless, odourless and non-toxic greenhouse gas emitted from processes such as combustion, cement production and respiration. Some argue that carbon dioxide should not be considered a pollutant as it is naturally present in the atmosphere, but excess amounts are linked with global warming and ocean acidification.
- **Oxides of sulfur** are produced in volcanoes; however, coal and petroleum produce appreciable quantities of sulfur dioxide (SO_2) and sulfur trioxide (SO_3) on combustion. In the right conditions sulfur oxides form sulfurous acid (H_2SO_3) which can undergo atmospheric oxidation to form sulfuric acid (H_2SO_4). Acid rain will form when these acids dissolve in rain water.
- **Oxides of nitrogen** occur naturally and are man-made. Nitrogen dioxide (NO_2) occurs naturally during lightning; however, it is also produced during high temperature combustion. Nitrogen dioxide is a reddish-brown toxic gas which has a characteristic sharp odour and accounts for the brown haze over cities.
- **Volatile organic compounds** include methane, an exceptionally efficient greenhouse gas, and other organic compounds such as buta-1,3-diene, benzene, toluene and xylene. Some of these compounds are carcinogens (able to cause cancers).
- **Particulates** are very fine solid or liquid particles suspended in air. While many are natural (e.g. from sea spray, dust storms, volcanoes and bushfires) significant amounts enter the atmosphere by burning fossil fuels. Increased quantities of fine particles in the air are connected to health hazards.
- **Toxic metals** include lead, cadmium and copper, and can find their way into the atmosphere. Lead used to be added to petrol to increase its octane rating, but airborne lead compounds were implicated in nerve problems.
- **Chlorofluorocarbons** (CFCs) were once widely used as refrigerants, propellants (in aerosols) and solvents. They are harmful to the ozone layer and are currently banned from use, but they will still remain in the upper atmosphere for many decades to come.
- **Radioactive pollutants** from nuclear explosions are blown around the world. Some of these radioactive particles are long-lived, and many settle on plants, so entering the food chain.

2 The atmosphere creates a natural blanket of gases to insulate Earth from large temperature fluctuations. This **natural greenhouse effect** maintains a relatively even temperature that allows a wide variety of species, including humans, to survive and prosper. This natural warming makes

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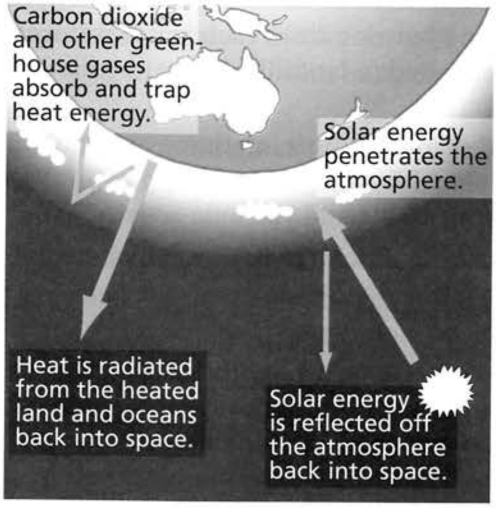
the Earth habitable, keeping it about 33 °C warmer than it would otherwise be. However, that same protecting greenhouse effect can become hazardous if allowed to grow uncontrolled.



Visible light wavelengths and longer ultraviolet bands (e.g. UV-A) from the Sun pass through the atmosphere and are absorbed. This warms both the atmosphere and the Earth's surface, which give off longer-wavelength infra-red radiation. This radiation cannot escape into space because greenhouse gases trap these longer-radiation wavelengths, resulting in more warming.

Water vapour, ozone and carbon dioxide naturally contribute to the greenhouse effect. But humans have pumped out other greenhouse gases that have enhanced this outcome. Burning fossil fuels is a major contributor in increasing atmospheric carbon dioxide concentrations, as are deforestation and agricultural practices that release methane. Other gases, including methane and trace quantities of chlorofluorocarbons (CFCs), can have an excessively large effect. Methane is 20 to 30 times more effective as a greenhouse gas than carbon dioxide but its concentration is around 2 ppm (parts per million). (The atmospheric concentration of carbon dioxide is around 400 ppm.) CFCs are roughly 10 000 times more effective greenhouse gases than carbon dioxide, but their concentrations is only about 10 to 20 parts per trillion! Nitrous oxide (N_2O) is naturally present in the atmosphere as part of the Earth's nitrogen cycle. Human emissions of this gas, mainly from developed countries, account for about 4% of all greenhouse gas emissions.

The **enhanced greenhouse effect** increases the overall average temperature of the Earth, with possibly disastrous outcomes. While most scientists agree that much of the observed warming over the last half-century is mainly due to the increase in greenhouse gas concentrations, there is still debate as to what extent it is a result of human activity.

Climate is the long-term average of weather in a particular region. There are many reasons why climates change and most of these are natural. In the geological past the Earth's climate has changed many times. But increasing temperatures are already having considerable impacts on the world's physical, biological and human systems. It is projected that these impacts will become more severe.

- Warmer temperatures are altering the water cycle both regionally and globally. Many of the world's glaciers, ice sheets and sea ice are melting. There is decreasing snow cover and earlier snow melt as well as changes in rainfall patterns. Warmer temperatures are affecting how severe and how often drought and floods occur, and also the availability of water. Sea level is rising due to thermal expansion and melting ice. This will have an increasing impact on human settlements and infrastructure. It is already impacting on animals that live in Arctic and Antarctic regions.

- As temperatures rise, plant and animal species are shifting their ranges to higher latitudes and altitudes. Changes in the types of species and their abundance and variations in the timing of many life-cycle events such as flowering and migration are occurring.
- Future climate change will affect ecosystems, particularly tundra, mangroves and coral reefs. The following photo shows mangroves in Queensland.

Higher atmospheric carbon dioxide levels, and higher global temperatures, will most likely result in the extinction of many species and reduce the variety of ecosystems. Higher levels of dissolved carbon dioxide in ocean waters are already causing increases in ocean acidity, with harmful effects on corals, foraminifera (protozoa) and other organisms that rely on carbonates for part of their structure.

Many of these impacts, especially when combined, are likely to cause increasing pressure on our resources and industries, and possibly on our social systems and health.

3 Around 10% of atmospheric **ozone** (O_3) is in the **troposphere**, the lowest portion of Earth's atmosphere (0 to 16 km altitude). Here it is toxic and harmful to many living organisms. Ozone pollution in the troposphere is often associated with photochemical smog. It can be formed during electrical discharges, such as lightning and high voltage equipment. Oxygen atoms are split into highly reactive oxygen atoms (called radicals) which can then combine with other oxygen molecules to form ozone. The symbol O• stands for an oxygen radical.

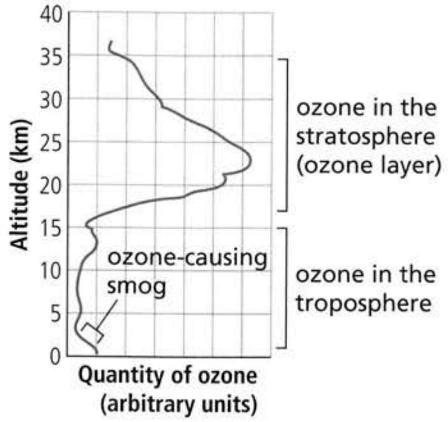
$$O_2 \rightarrow 2O\bullet$$
$$O_2 + O\bullet \rightarrow O_3$$

The remaining 90% of ozone is located in the **stratosphere** (16 to 50 km altitude). Here it functions differently, being the primary ultraviolet (UV) radiation protection. Short-wavelength UV radiation from the Sun (<240 nm) has enough energy to split ozone molecules into oxygen radicals (i.e. it decomposes ozone) and oxygen molecules.

$$O_3 \rightarrow O_2 + O\bullet$$

(cont.)

Again these oxygen radicals react with oxygen molecules to form ozone, but here in the stratosphere the ozone can absorb harmful UV-B and UV-C radiation, stopping them from reaching the surface of the Earth. So UV radiation both forms and destroys ozone and, in doing so, harmful UV doesn't reach the ground.



This cycle progressed quite well until humans disturbed the balance. The release of CFCs (**chlorofluorocarbons**, compounds containing only carbon, chlorine and fluorine) and **halons** (compounds containing only carbon, and one or more of bromine, chlorine and fluorine) into the atmosphere affected ozone. CFCs were commonly used as refrigerants in refrigerators and air conditioners, as foaming agents in the production of certain foam plastics, as a propellant in spray cans and for insulation and packing materials. Halons were commonly used in fire extinguishers.

CFCs are stable and easily reach the stratosphere without breaking down. Once in the stratosphere, however, they are broken down by ultraviolet radiation, freeing chlorine atoms (radicals). This chlorine is able to destroy large amounts of ozone. This has been observed, especially over Antarctica where an ozone hole was first detected in 1985. Consequently, levels of genetically harmful ultraviolet radiation have increased at the Earth's surface.

Halons and CFCs deplete atmospheric ozone and are potent greenhouse gases. Adopting the **Montreal Protocol** agreement, their production and use are being phased out. Alternative compounds that are less harmful to the atmosphere are now being used. But CFCs have a lifetime in the atmosphere of 20 to 100 years, so one free chlorine radical from a CFC molecule can destroy many ozone molecules. One estimate puts it at up to 100 000 ozone atoms before the chlorine is transformed into an unreactive form. Although emissions of CFCs have largely ceased, the damage to the ozone layer will persist well into the 21st century.

Checklist

Can you:

1 *Name and describe some types of atmospheric pollution?* ☐

2 *Describe the enhanced greenhouse effect and climate change?* ☐

3 *Describe the connection between CFCs and ozone depletion?* ☐

POLLUTION AND CLIMATE CHANGE

The universe and global systems

QUICK REVISION

1 Air pollution refers to the contamination of the environment by any chemical, physical or biological means that alters the natural features of the __________. It includes all contaminants found in the atmosphere, which may be gases, __________ or solids. The atmosphere is a complex and dynamic natural gaseous system that is essential to support __________ on this planet.

Air pollution sources are both __________ and human-generated. Humans have been producing __________ amounts of pollution as time has progressed, and human-generated pollutants now account for the majority of pollutants released into the __________.

Household combustion devices, motor __________, industrial facilities and bushfires are common sources of air pollution. While there are many stationary sources of air pollution (e.g. factories, chimneys, agriculture), the majority comes from __________ sources (e.g. cars, trucks, planes).

The effects of air pollution are varied and numerous. While impacting severely on natural ecosystems, air __________ is also a major environmental risk to health. Pollutants of major public health concern include particulate matter, carbon __________, ozone, nitrogen dioxide and sulfur dioxide. Reducing air pollution levels assists to reduce the global burden of disease from respiratory infections, heart disease and lung cancer. The World Health Organization estimates that 4.6 __________ people die each year from causes directly linked to air pollution.

Mandatory air quality standards, enforced by __________, have reduced the presence of some pollutants. Large cities, especially in poorer countries where laws may be lacking or not strictly enforced, often have serious __________ issues with air pollutants.

Because it is located in the atmosphere, air pollution is able to __________ easily. As a result, air pollution is a global problem and has been the subject of both global cooperation and argument.

2 The natural greenhouse effect is what keeps the Earth's climate __________ and fit for humans to live in. Without it the Earth's average __________ would be around –18 °C. The enhanced greenhouse effect (made by humans) is the addition of greenhouse gases to the atmosphere, mainly from the burning of __________ fuels.

Greenhouse gases __________ the rate at which the Earth's surface loses __________ (infra-red radiation) to space. They act like a blanket, keeping the Earth's surface and lower atmosphere layers __________, while the upper layers remain colder. Around 80 to 90% of the natural greenhouse effect results from __________ vapour and clouds. Most of the rest is due to carbon dioxide, methane and a few other minor gases.

Methane is a much more __________ greenhouse gas than carbon dioxide but there is far less of it in the atmosphere. While both have increased in recent years, the majority of global warming is due to __________. Burning of fossil fuels, cement production and clearing rainforests has __________ carbon dioxide levels from around 270 parts per million (ppm) a couple of centuries ago to around 400 ppm today. Scientists believe this is responsible for the global __________ that has occurred over several decades.

While temperature increases seem only small, they can have profound effects.

- Water __________ on warming, and as the water in the oceans warms and expands, sea level rises. It is estimated that during the 21st century sea levels will rise by up to half a metre or

(cont.)

more. If the Greenland ice sheet and the West Antarctic ice sheet were to melt, sea level rises could be far greater.

- The extent of snow cover and sea ice are projected to __________, with the Arctic expected to be largely ice-free in summer by the middle of this century.
- The water __________ is expected to be upset, with more intense droughts and floods in certain parts of the world.
- Climate change will negatively affect hundreds of millions of people through increased coastal flooding, __________ in water supplies, increased malnutrition and increased health problems.
- Crop production in tropical regions is expected to __________ by 10 to 30%.

3 The ozone layer in the stratosphere contains a small concentration of the gas __________ (O_3). This layer protects life on Earth from exposure to __________ levels of ultraviolet (UV) radiation from our Sun by preventing it from reaching the __________. Energetic UV radiation can lead to greater numbers of skin __________, cataracts and weakened immune systems. It also reduces crop yields and __________ the productivity of the oceans.

Over half a __________ ago, chlorofluorocarbons (__________) were invented and they soon found many uses as coolants in refrigeration, air conditioning and other industrial processes. Decades later, scientists discovered that CFCs and other chemicals __________ ozone in the upper atmosphere. This was dramatically confirmed when a large hole appeared in the ozone layer over __________ in 1985. But other ozone decreases have been __________ in various populated regions of the Earth. Efforts are now in place worldwide to scale back and phase out CFC production. Replacement compounds for CFCs have been developed and tested so they do not harm the __________ layer.

CFCs and other ozone-__________ chemicals are very stable and not soluble in water, so __________ won't wash them out of the lower atmosphere. They are not chemically broken down in the lower atmosphere and so survive to reach the stratosphere. Here they are decomposed by intense sunlight, releasing __________ atoms which catalyse the destruction of ozone molecules. This destruction is occurring at a more rapid rate than ozone can be __________ through natural processes. Chlorine can undergo hundreds or even many thousands of catalytic cycles with ozone before being neutralised by other chemicals.

Answers 1 atmosphere; liquids; life; natural; increasing (rising); air (atmosphere); vehicles (cars); mobile (moving); pollution; monoxide; million; governments (law); health; travel (move, shift) 2 warm (comfortable, optimal); temperature; fossil; reduce (lessen, slow); heat (warmth); warmer; water; effective (potent, powerful); carbon dioxide; increased; warming; expands; decrease; cycle; reductions (decrease); decline (drop) 3 ozone; dangerous (harmful); ground; cancers; shrinks (lessens, diminishes); century; CFCs; destroy; Antarctica; observed (detected, seen); ozone; depleting (harming, degrading); rain; chlorine; created (produced)

POLLUTION AND CLIMATE CHANGE

The universe and global systems

30 MINUTES

REVISION TEST

1 The following table gives a breakdown of annual world greenhouse gas emissions.

Sector	Percentage
electricity/heat	24.9
industry	19.0
transport	14.3
agriculture	13.8
changing land use	12.2
other fuel combustion	8.6
miscellaneous	
total	100.0

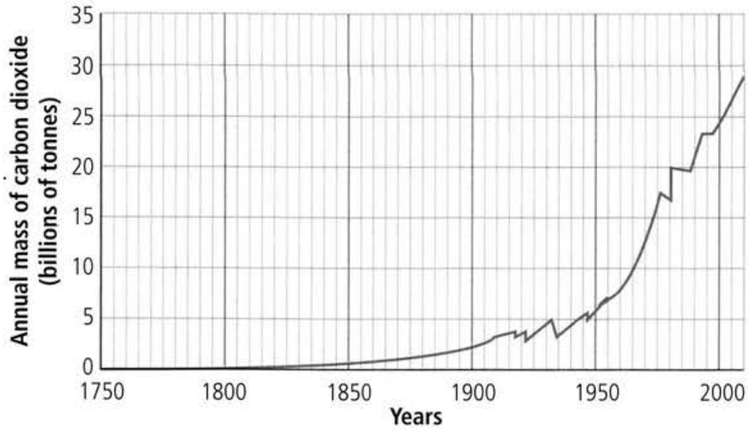
a Calculate the percentage for *miscellaneous*. Hint 1 (1 mark)

b Name something that might be included under *miscellaneous*. (1 mark)

c Use this information to draw a labelled sector (pie) graph of the information. (3 marks)

d Give your graph a title. (1 mark)

2 The graph shows the yearly mass of carbon dioxide released into the atmosphere from human sources.



a Describe, in words, the shape of the graph. (3 marks)

b In which year did annual emissions exceed:

i 5 billion tonnes? (1 mark)

ii 10 billion tonnes? (1 mark)

iii 15 billion tonnes? (1 mark)

c What do you notice about your answer to the previous part? Hint 2 (2 marks)

d Another graph showing the concentration of carbon dioxide in the atmosphere for this time period could be drawn. It would follow a similar trend but only increase from 300 ppm (1750) to 390 ppm (2010). Given the tremendous increase in carbon dioxide emissions by humans, suggest two possible reasons why the atmospheric carbon dioxide concentrations have only increased by 90 ppm. Hint 3 (2 marks)

(cont.)

POLLUTION AND CLIMATE CHANGE *(continued)*

The universe and global systems

REVISION TEST

3 The following table shows the deviation from average global air temperatures. The period between 1961 and 1990 was used to calculate the mean value of 0.00.

Year	Temperature variation (°C)
1850	–0.36
1860	–0.41
1870	–0.31
1880	–0.25
1890	–0.38
1900	–0.37
1910	–0.49
1920	–0.35
1930	–0.22

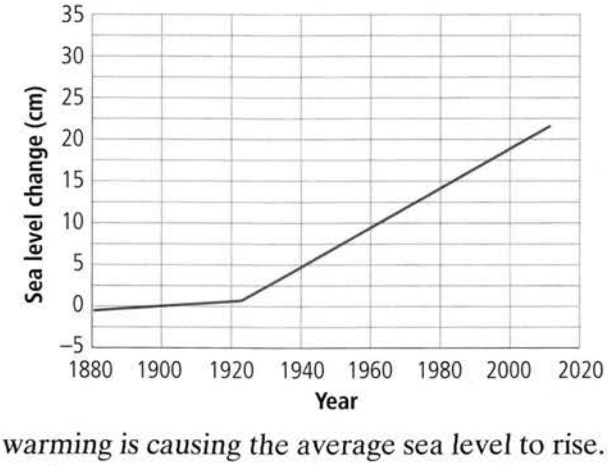
Year	Temperature variation (°C)
1940	–0.02
1950	–0.17
1960	–0.11
1970	–0.11
1980	0.01
1990	0.15
2000	0.37
2010	0.42

a Use the table to draw a line graph of this information. (3 marks)

b What trend is shown by this graph? (2 marks)

c Comment on the following statement.
Most of the observed increase in atmospheric temperatures is very likely due to the observed increase in human-caused greenhouse gas emissions. *Hint 4* (2 marks)

4 The graph shows the average sea level rise due to global warming.



a Explain how global warming is causing the average sea level to rise. (2 marks)

b Which year was adopted to compare sea level changes at other occasions? (1 mark)

c Approximately how fast is sea level rising in the period between 1960 and 2010? Give your answer in mm/year. *Hint 5* (3 marks)

d Assuming the trend continues, in which year will the average sea level have increased by 30 cm? (1 mark)

5 Air pollution has done much damage to marble statues and monuments, such as the Parthenon in Greece, over the past 2500 years. Continuous damage by air pollution has caused substantial harm to monuments on the Acropolis. Name the types of compounds that are largely causing this pollution damage, and explain how. (3 marks)

6 Ozone can be destroyed by several free radicals, including the hydroxyl radical (OH•), the nitric oxide radical (NO•), the atomic chlorine radical (Cl•) and the atomic bromine radical (Br•). (The dot • indicates that the species is a reactive species called a radical.) While these radicals have natural origins, human action has significantly increased chlorine and bromine levels. Chlorofluorocarbons (CFCs) are an important source of chlorine radicals.

a What elements are in CFCs? (1 mark)

b Why are CFCs not broken down, or removed, in the troposphere? (2 marks)

c Explain why $CFCl_3$ is a chlorofluorocarbon. Is CF_2Cl_2 also a chlorofluorocarbon? (2 marks)

d In the stratosphere Cl• can be liberated from $CFCl_3$:
$CFCl_3 \rightarrow CFCl_2 + Cl\bullet$
What causes this reaction? (1 mark)

e Write a similar reaction for CF_2Cl_2. (1 mark)

f Chlorine atoms can break down ozone molecules through a variety of means. Here are two.
i $Cl\bullet + O_3 \rightarrow ClO + O_2$
ii $ClO + O_3 \rightarrow Cl\bullet + 2O_2$
Describe what each reaction is showing. (2 marks)

g Explain how one Cl• radical can destroy many thousands of ozone molecules before it is itself inactivated. (3 marks)

Hint 1: The total of all percentages must equal 100%.
Hint 2: Consider how long it takes for an extra 5 billion tonnes to be emitted.
Hint 3: The question asks for 'possible' reasons. Your reasons may or may not be factors, but make sure you can back your argument up.
Hint 4: Consider what the graph actually shows, and why the commenter is saying 'very likely'.
Hint 5: You will need to calculate the slope of the line.

Your Feedback

$\frac{\square}{45} \times 100\% = \square\%$

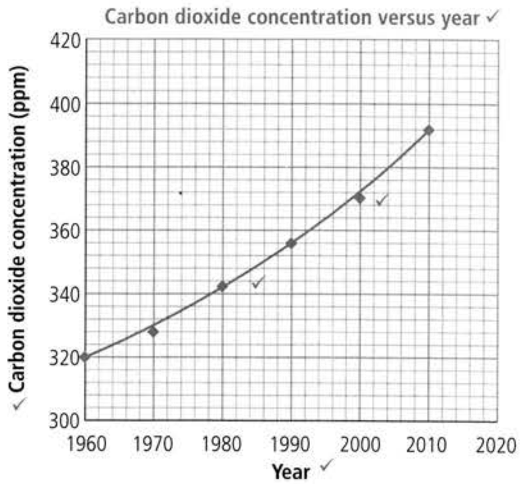
PAGES 265–267

PAGE 282

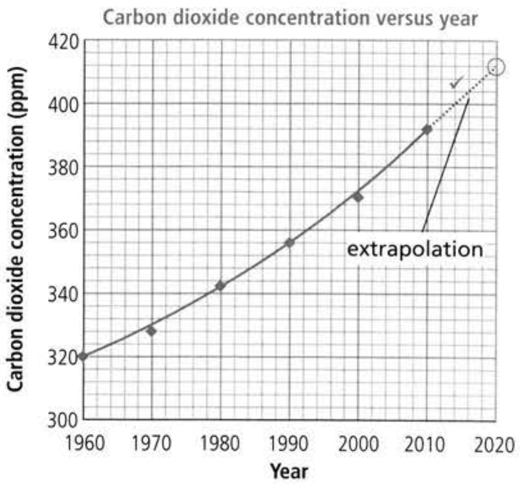
6 **a** Bacteria (of the genus *Rhizobium*) lives in plants, such as legumes (peas, clover and alfalfa), and can fix atmospheric nitrogen. ✓ Some organisms living in soil and water can also do this. Lightning plays a minor role in fixing atmospheric nitrogen. The extreme heat of a lightning flash causes nitrogen to combine with oxygen of the air ✓ to form nitrogen oxides. The oxides then combine with moisture in the air. Eventually the oxides are carried by rain to the ground where, in the form of nitrates, they may be used by plants.

b No nitrates means fewer ✓, stunted or sickly plants.

7 **a** Refer to the following graph.



b Refer to the following graph.



c about 412 ppm ✓

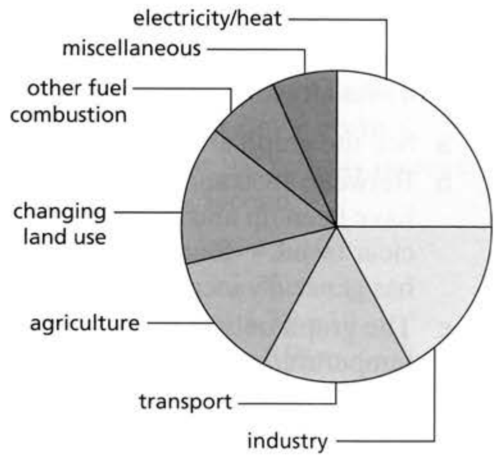
d The 398 ppm in 2013 shows that the extrapolation is reasonably accurate. ✓

POLLUTION AND CLIMATE CHANGE
The universe and global systems Pages 161–163

1 **a** 7.2% ✓

b *(either one)* Methane generated from garbage dumps; inadvertent (accidental) release of greenhouse gases into atmosphere. ✓

c See the following graph. *(1 tick for drawing a pie chart with sequential decreasing sized angles ; 1 tick for correct sector angles; 1 tick for labels present)* ✓✓✓



d annual world greenhouse gas emissions by sector ✓

2 **a** Between 1750 and about 1860 there was very little increase ✓ in carbon dioxide emissions. Then the curve started getting steeper ✓, and even steeper still after the 1950s ✓. This indicates tremendous emissions especially in the last 50 years.

b **i** about 1950 ✓ (years could vary slightly)

ii about 1965 ✓

iii about 1970 ✓

c It took around 25 years for carbon dioxide emissions to increase from

5 billion tonnes to 10 billion tonnes ✓, but only five years to increase from 10 billion tonnes to 15 billion tonnes. ✓ The rate of increase is increasing.

d Plants absorb carbon dioxide in the carbon–oxygen cycle and so take it out of the atmosphere. ✓ (However, given that in this same time large areas of forests have been cut down, this is possibly not the main reason.) The atmosphere is in contact with the oceans, which also absorb carbon dioxide. ✓ (Carbon dioxide combines with water to produce carbonic acid, which is toxic to ocean life in excess.) Another possible reason is that natural sources produce so much more carbon compared to human sources that human-produced carbon dioxide represents only a small fraction of the total.

3 **a** See the graph at the bottom of the page.

b Between 1850 and 1910 fluctuations have been up and down, showing no clear trend. ✓ Since 1910 temperature has generally increased. ✓

c The graph only shows that average temperatures each decade, compared to the 1961 to 1990 average pegged at 0.00, have increased. It does not show what has caused this increase. ✓ But given burning of fossil fuels by humans has rapidly increased in this time, and that greenhouse gas emissions have also hastily increased as well, it is a fair assumption (though by no means certain) that human factors are largely to play. ✓

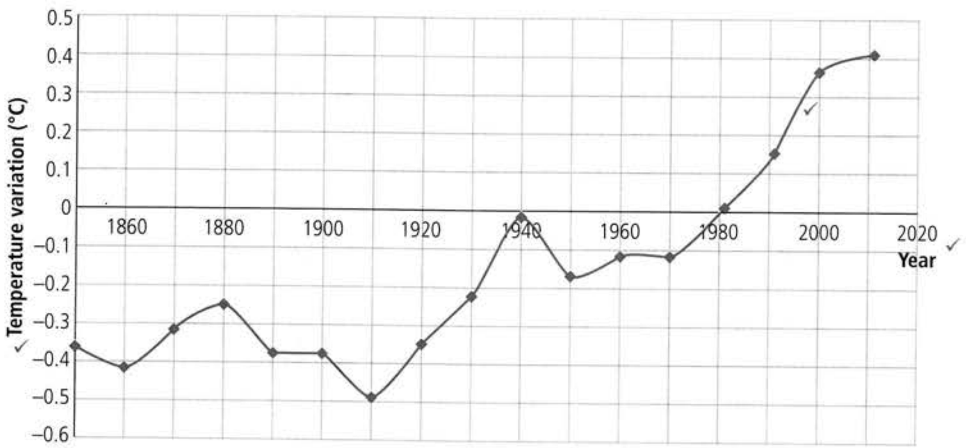
4 **a** Water expands on heating. With so much water in the oceans, a few degrees rise in temperature can alter the sea level by several centimetres. ✓ Also, increased temperatures hasten melting of ice sheets and glaciers thereby adding more water into the sea. ✓

b 1900 ✓ This year was pegged at a sea level change of 0 cm.

c In 1960, sea level rise was 9 cm; in 2010, it was 22 cm. ✓ So the rate of change is (22 – 9) ÷ (2010 – 1960) = 0.26 cm/year = 2.6 mm/year. ✓

d 2050 ✓

5 Oxides of non-metals, such as sulfur oxides and nitrogen oxides, are released into the atmosphere. ✓ This could be largely due to factories and transport sited near these monuments. These non-metal oxides react with water to form acidic rain. ✓ Marble is mostly calcium carbonate and this reacts with the acid rain. ✓ (Acid precipitation affects stone mainly in two ways: dissolution and alteration. When sulfurous, sulfuric and nitric acids in polluted air react with the calcite in marble and limestone, the calcite dissolves. In



exposed areas of buildings and statues, this results in roughened surfaces, removal of material and loss of carved details.)

6 a chlorine, fluorine, carbon ✓
b CFCs are chemically and thermally stable and non-combustible. As they rise in the troposphere there are no substances that can break them down. ✓ And, since they are not soluble, they won't dissolve in moisture to be later removed as rain. ✓
c compound consists of chlorine, fluorine and carbon ✓; yes ✓
d UV radiation has enough energy to tear away a Cl• radical from the molecule. ✓
e $CF_2Cl_2 \rightarrow CF_2Cl + Cl\bullet$ ✓
f i A chlorine atom reacts with an ozone molecule, to form ClO (chlorine monoxide) and a normal oxygen molecule. ✓
ii The chlorine monoxide reacts with another ozone molecule to give up the chlorine radical and two molecules of oxygen. ✓
g The Cl• radical is used up in the first reaction ✓, but is then liberated in the second reaction ✓. In the process it has destroyed two ozone molecules. It is now free to repeat the first reaction and continue destroying ozone. ✓ This cycle can recur many times. The overall effect is a decrease in the amount of ozone.

Physical sciences

MOTION
Motion, force and energy Pages 168–169

1 a i time = 50 ÷ 60 h
= 0.833 h ✓
average speed = $d \div t$
= 45 ÷ 0.833
= 54 km/h ✓
ii time = 50 × 60
= 3000 s ✓
average speed = 45 000 ÷ 3000
= 15 m/s ✓
b d = 15 × 120
= 1800 m ✓
c 50 km/h = 50000 ÷ 3600
= 13.889 m/s ✓
time = 500 ÷ 13.889
= 36 s ✓

2 a She did not label which diagram was for the Earth and which was for Mars. ✓
b Bessie ✓
c Florence has shown the balls falling with a constant velocity. Falling under gravity is an accelerated motion and the distances fallen increase with time as Bessie shows in her diagram. ✓
d Mars has less mass than Earth and therefore its gravity is less. ✓

3 a false ✓ (it was moving at 4 m/s)
b average acceleration = change in velocity ÷ time = (16 – 4) ÷ 6
= 2 m/s² north ✓
c It is uniform, as the velocity increases by 2 m/s every second. ✓

4 a athlete: distance = 7 × 10
= 70 m ✓;
cheetah: distance = 35 × 10
= 350 m ✓
b athlete: time = 150 ÷ 7
= 21.4 s ✓;
cheetah: time = 150 ÷ 35
= 4.3 s ✓

5 a 900 m ✓
b time = 2 × 60 = 120 s ✓
average speed = distance ÷ time
= 900 ÷ 120 = 7.5 m/s ✓
c displacement = 200 m east
average velocity
= displacement ÷ time
= 200 ÷ 120 = 1.67 m/s east ✓

6 a The change in velocity is not constant with time (the graph is non-linear). ✓
b non-uniform ✓
c 1 m/s ✓