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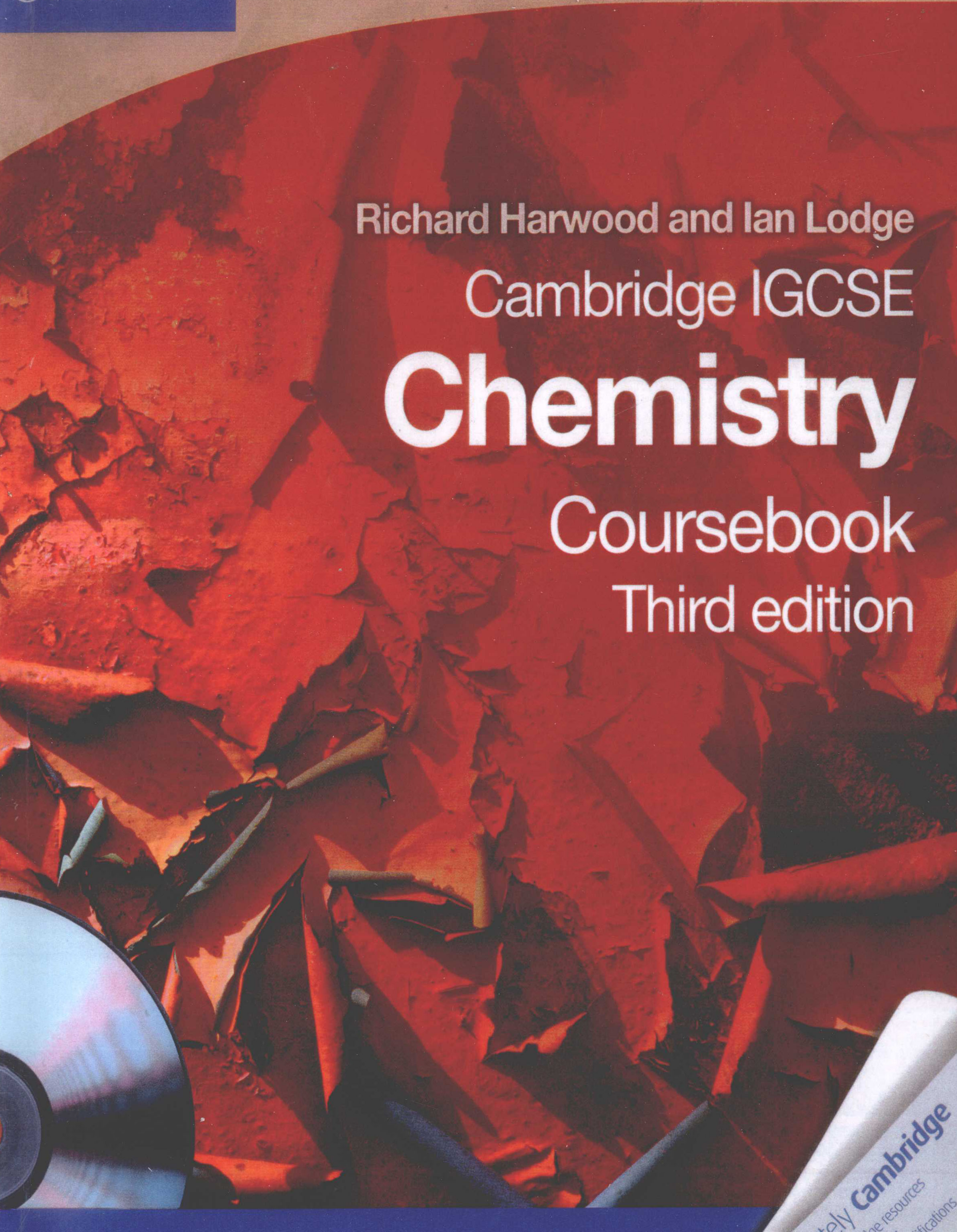

Richard Harwood and Ian Lodge

Cambridge IGCSE

Chemistry

Coursebook

Third edition

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Completely Cambridge
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Cambridge qualifications

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Introduction

Chemistry is a laboratory science: its subject material and theories are based on experimental observation. However, its scope reaches out beyond the laboratory into every aspect of our lives – to our understanding of the nature of our planet, the environment we live in, the resources available to us and the factors that affect our health.

This book thoroughly covers the Cambridge International Examinations (CIE) Chemistry syllabus and includes features which are aimed at helping you grasp the concepts and detail involved. The areas that cover the **Core** and **Supplement** material of the syllabus are clearly marked (the **Supplement** material having a purple dotted line like the one here in the margin) so that you can see which topics will be tested on each exam paper that you will take. The topic summaries, 'quick-check' questions and 'exam-style' questions are also clearly marked so that you can pick out, study and revise the material relevant to the 'core' and 'extended' papers.

The first chapter of the book serves to set chemistry in its broader context and as such contains material that 'sets the scene' as well as syllabus material. At various points in this and other chapters there is material that provides and develops some of the context in which chemical ideas are important. These are areas such as:

- the importance of chemistry to life, and the nature of the universe (Chapter **1**)
- health issues (Chapter **10**)
- our need to develop alternative energy sources (Chapter **11**).

This additional material is included to provide context. It also links together the ideas covered by the syllabus in a way that will help you gain an overall picture of the relevance of chemistry and aid your understanding of the subject. The additional material is clearly marked by being set in a green-bordered box with an E icon.

Features of the book and the Student CD-ROM

The book is divided into broad **chapters** covering important areas of the syllabus. These chapters are then divided into different **sections** to help you manage your understanding of the ideas involved. At the end of each section there is a list of **key ideas** and short **quick-check questions** to help you check that you have followed the ideas covered. The answers to these short questions are provided at the end of the book to help you with this.

Each chapter finishes with a **summary** of Core and Supplement material to help you particularly with your revision. This is followed by selection of **exam-style questions** which are there to help you become familiar with the style of question set in each examination.

Answering questions is a great way to get to grips with each of the topics. However, it is not the only way! The **Student CD-ROM** provides information on revision skills and resources available on the internet to help with your study of chemistry. A copy of the syllabus is provided on the CD-ROM, which shows where the different topics are covered in the book – and you can use this interactively as a checklist during revision. 'Mind-mapping' ideas and other revision strategies are discussed on the CD-ROM, and we hope that you can find ideas that will help you study in the most personally effective way.

An important feature which appears both in the book and on the Student CD-ROM is the **glossary**. The terms included in the glossary are highlighted in the text in **dark red bold**. Do use this resource in addition to the text in order to help you understand the meaning of chemical terms. But more than that, it is important that you can express your ideas clearly in an exam – that is why we have included so many practice questions in the book and in the **practice tests** that appear on the CD-ROM. It is also why we have tried to cover the ideas in each chapter thoroughly in our wording. Chemistry, and science in general, can often use certain words in a very precise way, so it is important to read carefully and get used to writing down your answers clearly.

Practical work

We began by saying that chemistry was a practical science and we have aimed to help your preparation for the practical element of the exam in various ways:

- Chapter 12 of the book gives a summary of the different ways that practical work is assessed and some exemplar questions.
- There is a practice 'alternative to practical' paper (Paper 6) on the Student CD-ROM.
- The separate **Student Workbook** contains exercises involving practice at the key skills of writing up your observations and making deductions from your results. Included there are methods that you can use to assess (by yourself, and with your teacher) how well you are developing your data handling and presentation skills.

Chemistry is an important, exciting and challenging subject that impacts on every aspect of our lives. As we face the challenges of the future, the chemical 'angle' on things will figure in our thinking, whatever future course we personally take in our careers. We hope that this book will help you enjoy chemistry, give you some understanding of the ideas involved and help you be successful in the IGCSE course.

Richard Harwood
Ian Lodge

Contents

1 Planet Earth

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A brief history of the Earth

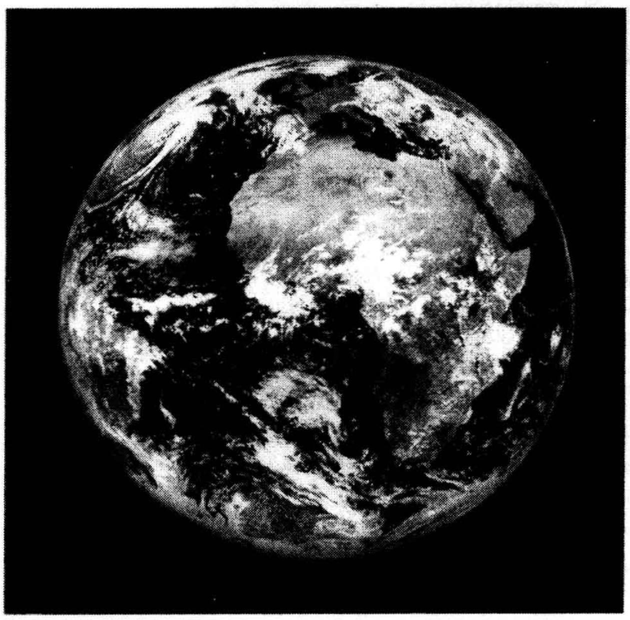

Figure 1.1 A satellite image over Africa: one view of the 'blue marble'.

The Earth is a ball of rock orbiting a star along with a group of other planets (Figure 1.1). The star is one of many billions of stars in a galaxy which, in turn, is one of many billion galaxies in a constantly expanding Universe. As such the Earth is unremarkable. However, a view of the Earth from space shows it to be a very beautiful ball of rock, and it is also the ball of rock upon which we are totally dependent for our existence. It is the chemicals which make up the Earth and the ways in which they interact with each other that make life in general, and human life in particular, possible.

- At the start, the Earth was a ball of molten rock.
- The surface solidified to a solid crust as it cooled and contracted; cracks appeared.
- Volcanoes shot molten rock and gases from this surface.
- The first atmosphere (mainly carbon dioxide and water vapour) was formed in this way (Figure **1.2**, overleaf).
- The water vapour condensed and fell back to the surface, forming the first seas.
- Over many millions of years, plant life developed in these warm shallow seas. These used carbon dioxide and, crucially, put oxygen into the atmosphere. The atmosphere of the Earth is different from that of its neighbours because 'life' happened on this planet.
- Plants gradually used the carbon dioxide in **photosynthesis** and produced oxygen.
- Once sufficient oxygen was present, animal life developed.
- Nitrogen entered the atmosphere from bacteria. It is unreactive and so was not removed. It has built up to a large percentage of the atmosphere.
- Plant and animal life continued to develop over millions of years until the Earth reached its present balance of chemicals.
- The activity of humans is now altering this chemical balance.

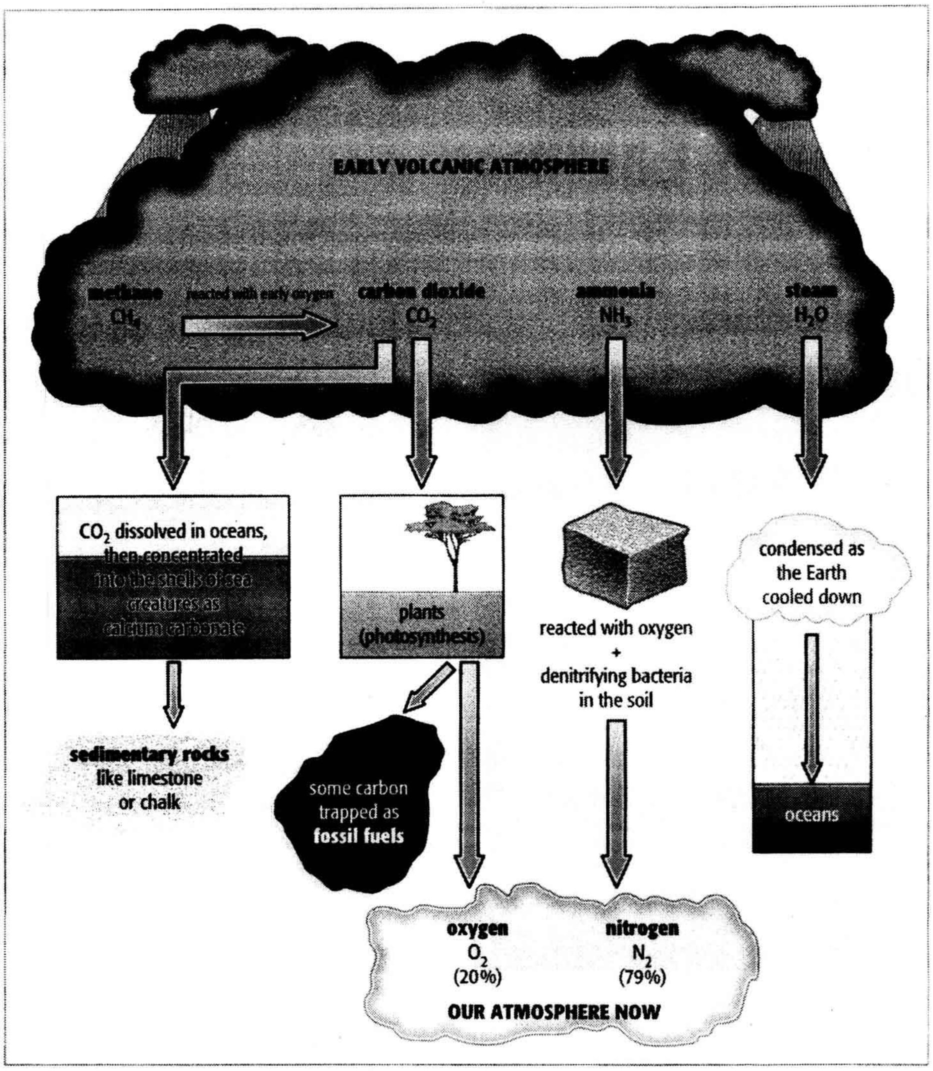

Figure 1.2 The development of the Earth's atmosphere.

This chapter covers the following ideas:

- the water cycle
- (S) the carbon cycle
- the nitrogen cycle
- the composition and uses of the gases in the air
- (S) the separation of air into its components
- the sources of air pollution
- the problems of air pollution, and their solution
- 'greenhouse gases' and climate change
- water treatment and sewage treatment
- the pollution of water
- metal ores and limestone
- fossil fuels and the problems they cause
- alternative sources of energy
- hydrogen as a fuel
- (S) the hydrogen fuel cell

Exam tip

This chapter is aimed at providing a context for the chemistry that you study. As such, it makes some general comments about the origins of the Earth and the nature of the natural resource cycles that occur. The list at the start of this chapter is similar to those given at the beginning of each chapter. It gives you an idea of the material in this chapter that is contained in the syllabus, and can therefore be examined.

1.1 Natural cycles and resources

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The rock cycle

As the Earth's crust moves, rock is constantly being taken down into the molten rock beneath the surface (Figure 1.3):

- This rock is changed and sometimes decomposed before it rises back to the surface and cools.
- These processes give rise to the different types of rock as shown in the diagram. The decomposition also produces gases, mainly carbon dioxide and water vapour. These, together with molten rock, escape from the Earth's **crust** in volcanoes.
- This is a very slow process. The plates of the Earth's crust are moving only a few centimetres each year. This **rock cycle** is powered by energy produced by radioactive decay and heat from the Earth's **core**. We use the rocks that are near the surface by mining and quarrying.

The water cycle

The Earth is sometimes referred to as the 'blue marble' because of the predominance of water on the surface and the swirling cloud formations seen in satellite images. The Earth is distinctive in the solar system in that its surface temperature is such that all three states of water exist on the surface. There is a distinct '**water cycle**' taking place on the Earth's surface (**Figure 1.4, overleaf**).

- The energy to drive this cycle comes from the Sun.
- Water evaporates from the sea and from other areas of water, such as lakes, and enters the atmosphere.
- As it cools, it changes back into liquid water and forms clouds (tiny water droplets).
- As the water droplets stick together, rain clouds are formed and the water falls back to the surface as rain, snow or hail.
- Water then either flows back to the sea or is taken in by plants, which put it back into the atmosphere through their leaves.
- We use the water by trapping it on its way back to the sea.

The carbon cycle

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Carbon is only the twelfth most common element in the Earth, making up less than 1% of the crust. It is,

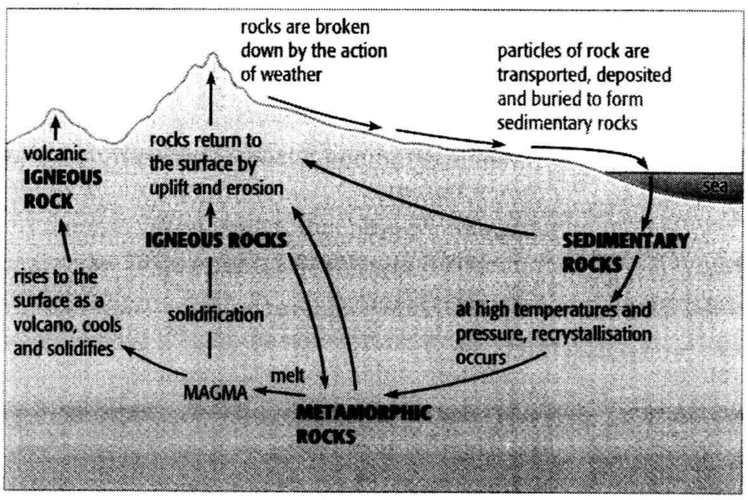

Figure 1.3 The rock cycle.

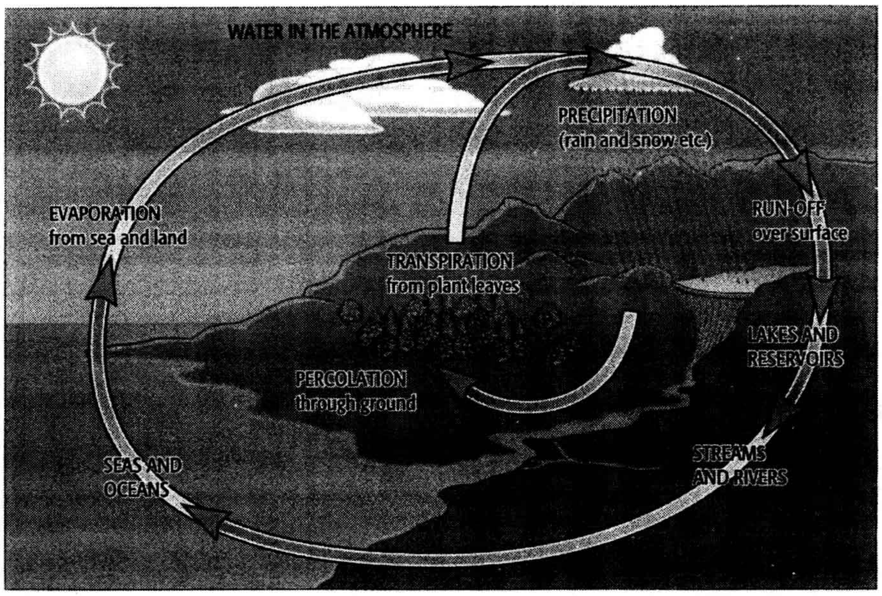

Figure 1.4 The water cycle.

however, very important to us. Without carbon, life would not exist. The way in which carbon moves around in the **carbon cycle** is vital to all life (Figure 1.5). The source of the carbon in the cycle is carbon dioxide in the atmosphere. Only about 0.04% of the atmosphere is carbon dioxide.

Carbon dioxide leaves the atmosphere in the following ways:

- Green plants take carbon dioxide and water, combining them together to form glucose and oxygen. This process uses energy from the Sun and is called **photosynthesis**. The word equation for the reaction is:

  carbon dioxide + water → glucose + oxygen

- Carbon dioxide dissolves in water (mainly seawater), where it is used by animals and plants. Plants use it in photosynthesis; animals use it to make their shells.

This is what happens to the carbon once it has been captured from the atmosphere:

- The plants are eaten by animals.
- Animals and plants die and rot away, or are buried, and slowly (over millions of years) are fossilised.
- Tiny sea creatures die and their bodies fall to the bottom of the sea, where they slowly (over millions of years) change to limestone.

These are the ways in which carbon dioxide is put back into the atmosphere:

- Animals and plants 'breathe out' carbon dioxide when they respire food. The process of **respiration** uses oxygen from the air, and releases carbon dioxide:

  glucose + oxygen → carbon dioxide + water

- When plants and animals decay after death, carbon dioxide is produced.
- Wood can be burnt. This **combustion** produces carbon dioxide:

  carbon + oxygen → carbon dioxide

- Fossilised plants and animals form **fossil fuels** (coal, oil and gas); these produce carbon dioxide when they are burnt.
- Limestone produces carbon dioxide when it is heated in industry and when it moves back below the Earth's crust.

The problem we face is balancing the amount of carbon dioxide being added to the atmosphere with the amount being taken out by plants and the oceans (Figure 1.6).

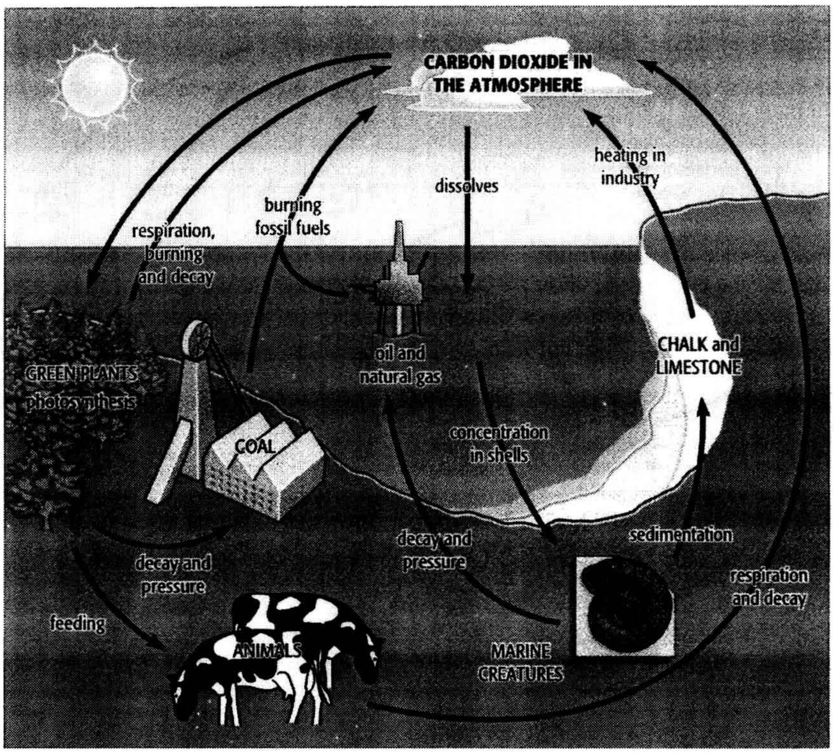

Figure 1.5 The carbon cycle.

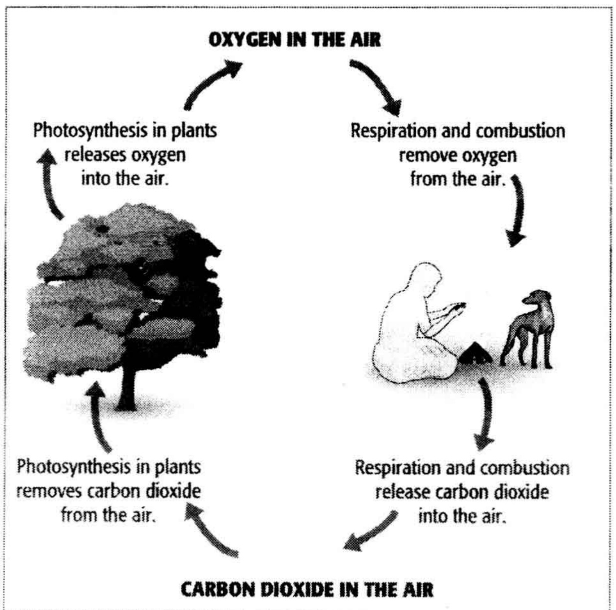

Figure 1.6 Maintaining the levels of oxygen and carbon dioxide in the air.

The nitrogen cycle

Nitrogen is essential for plant growth and, therefore, for the life of animals (Figure 1.7, overleaf). There is plenty (78%) of nitrogen in the atmosphere but it is unreactive and so it is difficult to get it into the soil for plants to use.

Plants get their nitrogen from nitrates in the soil and animals get theirs from plants.

When plants and animals die and decay, their nitrogen returns to the soil as bacteria help their bodies to decay.

There are also bacteria that live in the roots of some plants (e.g. beans and clover) which can 'fix' nitrogen from the atmosphere which the plants can then use.

During thunderstorms, the very high temperature of the lightning provides enough energy to cause nitrogen and oxygen in the atmosphere to react. This reacts with water in the atmosphere to form nitric acid. When this falls with rain, it forms nitrates in the soil. Nitrogen is also taken from the air by the chemical industry when fertiliser is made by the Haber process.

Taken together these processes form the **nitrogen cycle** (Figure 1.7).

These four major cycles – of water, carbon, nitrogen and rocks – interlink and, between them, provide us with the resources we need.

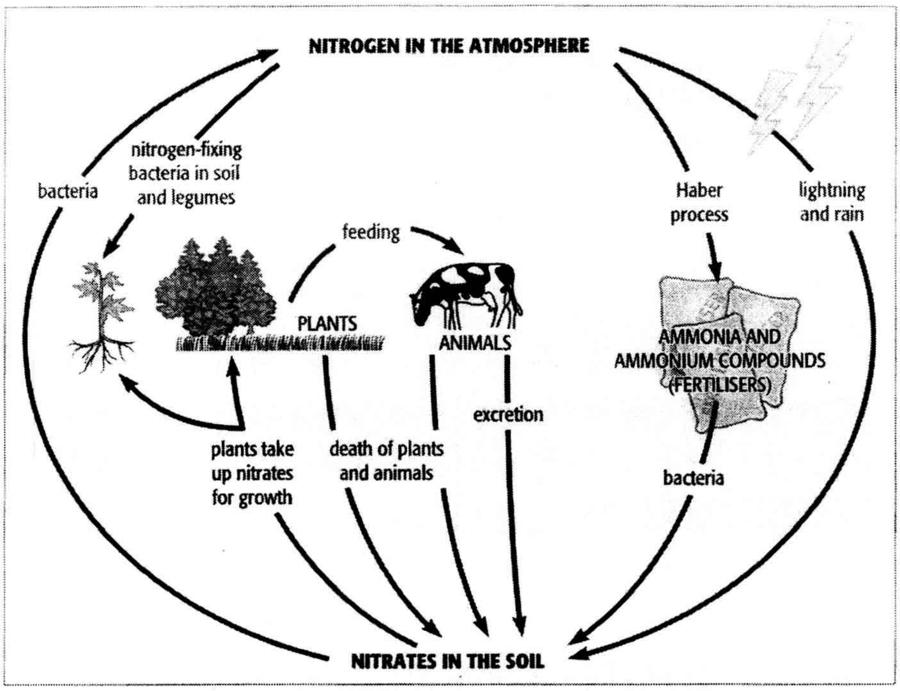

Figure 1.7 The nitrogen cycle.

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The Earth's resources

In human terms, **resources** are materials we get from the environment to meet our needs. Some are the basic material resources we and other organisms need to keep alive. Others are materials from which we obtain energy, or substances useful for our civilised way of life. Chemistry helps us to understand how the basic resources sustain our life. It also provides the methods of extraction and use of other resources. Figure **1.8** summarises the major types of material resources. It subdivides them into **renewable,** potentially renewable and **non-renewable** resources, based on our short human timescale.

The biggest concern is the depletion of non-renewable resources. Once they are used up, then we will have to manage without them. Metal ores, especially those of iron, aluminium and copper, are becoming more scarce. The ores that still exist are often of lower quality, making the process of extraction more costly. Fossil fuels are another concern. New deposits of oil are being discovered but the speed at which we are using the oil we have is increasing. There will be a time when all the oil, and eventually all the coal, will run out.

- **Non-renewable resources** are those which exist in a fixed quantity in the Earth's crust. They were formed over geological periods of time (millions of years) and, over a shorter timescale, are being used up faster than they are formed.
- **Renewable resources** are those which essentially will never run out (are inexhaustible).
- **Potentially renewable resources** can be renewed, but they can become used up if we use them more quickly than they can be renewed.

Phosphate minerals, essential for the manufacture of fertilisers, are also beginning to become scarcer.

Some of these problems can be helped by recycling some of the substances we use. Recycling metals helps conserve metal ores. Recycling plastics helps conserve the petroleum from which they are made. All recycling helps save energy, which is mainly produced from fossil fuels.

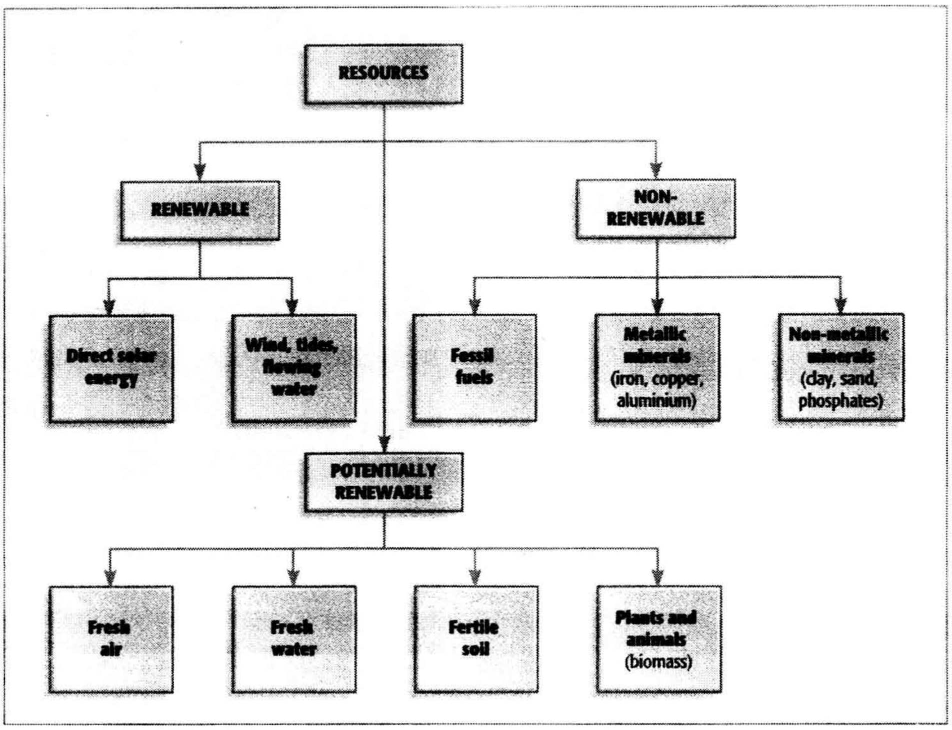

Figure 1.8 Renewable and non-renewable resources.

Fossil fuels are a bigger problem. We will always need energy. A partial solution is to make more use of our renewable resources. Wind power, solar power and water power from rivers, tides and waves can all be used to generate electricity.

An increasing problem is the way in which our 'potentially renewable resources' are being affected by over-use and pollution. More detail on these problems will appear in the next three sections.

Key ideas so far

- The Earth is our only source of the chemical and other resources which we need.
- The balance of chemicals in our environment is maintained by a number of natural cycles.
- Some of the Earth's resources are finite and non-renewable.
- Renewable sources of energy can be used to generate electricity.
- The carbon cycle moves carbon in and out of the atmosphere by the processes of respiration, combustion and photosynthesis.

Quick-check questions

1. How does the Sun keep the water cycle working?
2. How does the Sun keep the carbon cycle working?
3. How could the Sun be the source of our energy in the future?
4. Write the word equations for:
   - **a** photosynthesis
   - **b** the complete combustion of carbon in air
   - **c** respiration.

1.2 The atmosphere

Uses of the gases of the air

Clean air has, approximately, the following composition: nitrogen 79%, oxygen 20%, argon 0.9%, and 'other gases' (including carbon dioxide, water vapour, neon and other noble gases) 0.1%.

Carbon dioxide is an important part of the air but makes up only about 0.04% of it. The carbon dioxide which is used by humans is not usually obtained from the air.

Nitrogen is used in the manufacture of ammonia and fertilisers in the Haber process. Liquid nitrogen is used in cryogenics (the storing of embryos and other types of living tissue at very low temperatures). Nitrogen is also sometimes used where an unreactive gas is needed to keep air away from certain products; for example, it is used to fill bags of crisps (chips) to ensure that the crisps neither get crushed nor go rancid by contact with oxygen in the air.

The biggest single use of oxygen is in the production of steel from cast iron. Oxygen is also used to make the high-temperature flames needed to cut and weld metals (oxy-acetylene torches). In cylinders it is also used in hospitals to aid the breathing of sick people.

Exam tip

If you are asked for a use of oxygen, 'breathing' is not considered to be a correct answer. A use of pure oxygen is needed, and we breathe air.

Argon and other noble gases are used in different types of light. Argon is used to 'fill' light bulbs to prevent the tungsten filament burning away (Figure 1.9). It does not react with tungsten even at very high temperatures. The other noble gases are used in advertising signs, as they glow with different colours when electricity flows through them.

S Before any of the gases in the air can be used separately they have to be separated from the air in the atmosphere. The method used is fractional distillation, which works because the gases have different boiling points (Table 1.1).

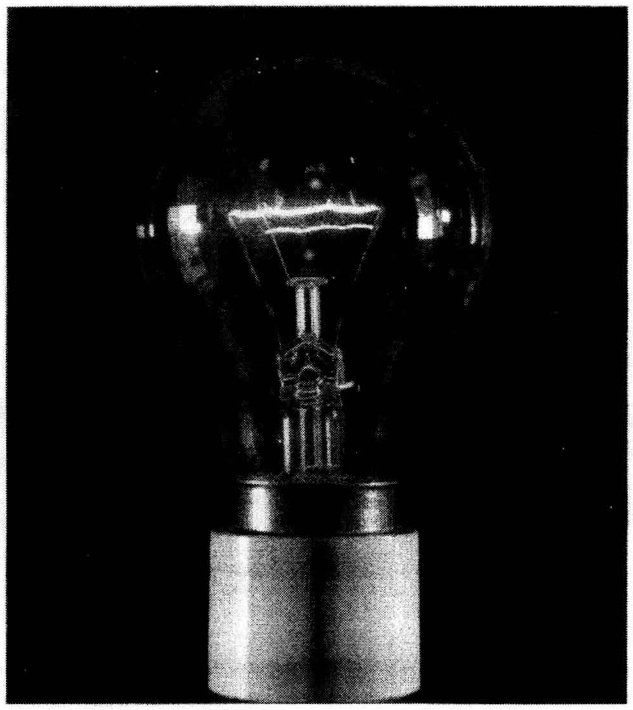

Figure 1.9 Filament light bulbs contain argon, as it does not react with the hot tungsten filament.

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Gas	Boiling point / °C	Proportion in mixture / %
carbon dioxide (sublimes)	−32	0.04
xenon	−108	—[a]
krypton	−153	—[a]
oxygen	−183	20
argon	−186	0.9
nitrogen	−196	79
neon	−246	—[a]
helium	−249	—[a]

[a] *All the other gases in the air make up 0.06% of the total.*

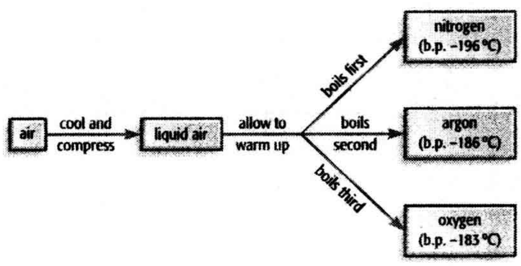
Table 1.1 The boiling points of the gases in air.

Exam tip

Remember to be careful with temperatures below 0 °C (with a negative sign). The boiling point of nitrogen (−196 °C) is a lower temperature than −183 °C (the boiling point of oxygen).

The process of **fractional distillation** involves two stages.

- First the air must be cooled until it turns into a liquid.
- Then the liquid air is allowed to warm up again. The various gases boil off one at a time at different temperatures.



Pollution of the air

Many gases are accidentally or deliberately released into the air. Some are harmless but many create problems for the environment. The main source of 'problem' gases is the burning of fossil fuels.

Most countries produce electricity by burning coal or oil. Both these fuels are contaminated with sulfur, which produces sulfur dioxide when it burns:

sulfur + oxygen → sulfur dioxide

$$S + O_2 \rightarrow SO_2$$

Oxides of nitrogen (NO_x) (for example nitrogen dioxide, NO_2) are also produced when air is heated in furnaces. These gases dissolve in rain water to produce 'acid rain' (Figure 1.10).

There are numerous effects of **acid rain.**

- Limestone buildings, statues, etc., are worn away.
- Lakes are acidified, and metal ions (for example Al^{3+} ions) that are leached (washed) out of the soil damage the gills of fish, which may die.
- Nutrients are leached out of the soil and from leaves. Trees are deprived of these nutrients. Aluminium ions are freed from clays as aluminium sulfate, and damage tree roots. The tree is unable to draw up enough water through the damaged roots, and it dies.

The wind can carry acid rain clouds away from the industrialised areas, causing the **pollution** to fall on other countries.

There are some remedies for the effects of acid rain:

- Lime can be added to lakes and the surrounding land, to decrease the acidity.

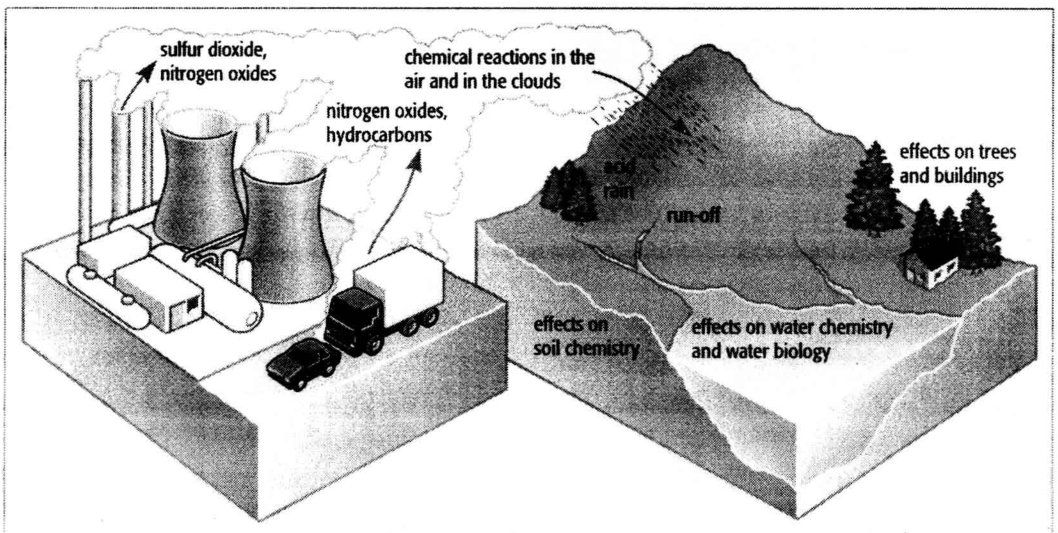


Figure 1.10 The formation of acid rain.

- The best solution is to prevent the acidic gases from being released in the first place. 'Scrubbers' are fitted to power station furnaces. In these devices, the acidic gases are passed through an alkaline substance such as lime. This removes the acids, making the escaping gases much less harmful. In many countries, however, acidic gases from power stations are still a serious problem.

Petrol (gasoline) and diesel for use in road transport has most of its sulfur removed when it is refined. Sulfur dioxide is not a serious problem with motor vehicles. However, the other contents of vehicle exhaust fumes (Figure 1.11) can cause problems. Nitrogen dioxide is still produced though. The high temperature inside the engine's cylinders causes the nitrogen and oxygen in the air to react together:

nitrogen + oxygen → nitrogen dioxide

$$N_2 + 2O_2 \rightarrow 2NO_2$$

In the enclosed space of an engine the fuel does not usually burn completely, owing to lack of oxygen, and carbon monoxide, CO, is formed.

Another pollution problem arising from motor vehicles is due to the use of tetraethyl lead in petrol (leaded petrol). Burning this type of petrol releases the toxic metal lead into the environment (Figure 1.11). The use of lead in petrol has decreased significantly, over the last 20 years, with over 50 countries now banning its use. In 2009 over 80% of petrol sold was unleaded.

The dangers of these pollutants are as follows.

- **Nitrogen dioxide** causes acid rain and can combine with other gases in very hot weather to cause **photochemical smog**. This contains low-level ozone and is likely to cause breathing problems, especially for people with asthma.
- **Carbon monoxide** is a very toxic gas. It combines with the haemoglobin in blood and stops it from carrying oxygen. Even very small amounts of carbon monoxide can cause dizziness and headaches. Larger quantities cause death.
- **Lead** is a toxic metal and can cause learning difficulties in children, even in small quantities. The body cannot easily get rid of lead, so small amounts can build up to dangerous levels over time.

There are solutions to some of these problems. **Catalytic converters** can be attached to the exhaust systems of cars (Figure 1.12). These convert carbon monoxide and nitrogen dioxide into carbon dioxide and nitrogen. Unfortunately, if there is lead in the petrol being used, the **catalyst** becomes poisoned and will no longer work. This means that in countries where leaded petrol is still being used, catalytic converters cannot be used either.

Figure 1.11 Fumes from a car exhaust.

Exam tip

Try to keep these different atmospheric pollution problems clear and distinct in your mind rather than letting them merge together into one (confused?) problem. They have distinctive causes and clear consequences.

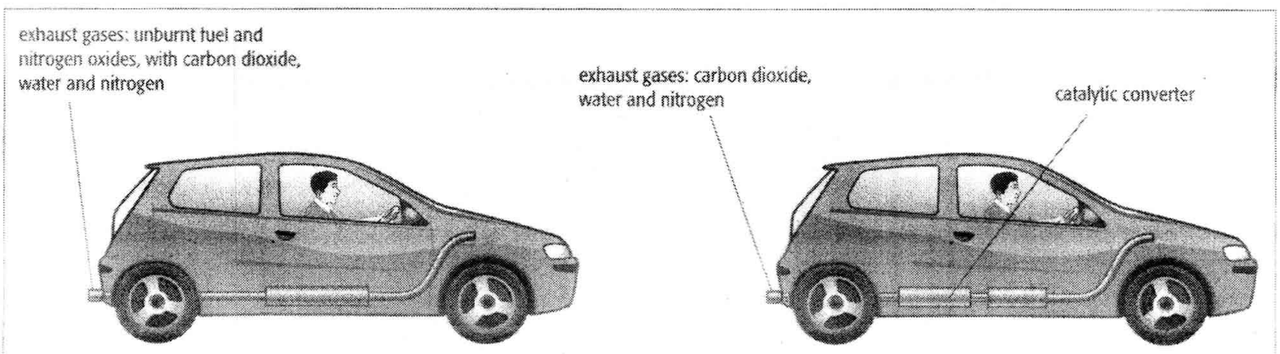


Figure 1.12 A catalytic converter changes harmful exhaust gases into safer gases.