Cambridge University Press 978-1-107-61503-8 – Cambridge IGCSE® Chemistry Richard Harwood and Ian Lodge Excerpt <u>More information</u>

Planet Earth

In this chapter, you will find out about:

- the water cycle
- S ◆ the carbon cycle
- ▲ the nitrogen cycle
 - the composition and uses of the gases in the air
- 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.

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. It is the chemicals which make up the Earth and the ways in which they interact with each other that make life on Earth possible.

At the start, the Earth was a ball of molten rock. The surface solidified to a solid crust as it cooled and contracted, and cracks appeared. Volcanoes shot molten rock and gases from this surface and the first atmosphere (mainly carbon dioxide and water vapour) was formed.

Condensing water vapour fell back to the surface and, over many millions of years, plant life developed in these warm, shallow seas. The plants used carbon dioxide in **photosynthesis** and, crucially, put oxygen into the atmosphere. Once sufficient oxygen was present, animal life began to evolve. Nitrogen entered the atmosphere from bacteria. Because nitrogen is an unreactive gas, it was not removed and it has built up to a large percentage of the atmosphere.

The development of plant and animal life over many millions of years has led to the Earth's present balance of chemicals. The activity of humans is now altering this chemical balance and we are rapidly using up many of the Earth's natural resources.

Chapter 1: Planet Earth

Study tip

This chapter provides 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 the chapter that is contained in the syllabus and that can therefore be examined.

1.1 Natural cycles and resources

There are a number of crucial cycles built into the nature of the resources of our planet.

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 1.2).

- 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.

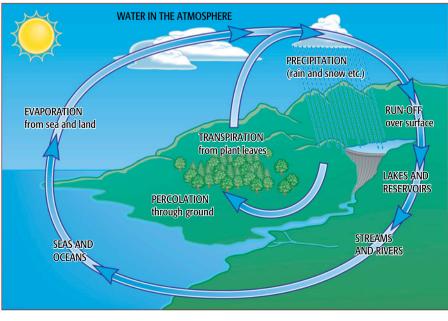
- As it cools, it changes back into liquid water and forms clouds (tiny water droplets).
- As the water droplets stick together, rain clouds are formed and the water falls back to the surface as rain, snow or hail.
- Water then either flows back to the sea or is taken in by plants, which put it back into the atmosphere through their leaves.
- We use the water by trapping it on its way back to the sea.

The carbon cycle

Carbon is only the twelfth most common element in the Earth, making up less than 1% of the crust. It is, 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 **1.3**). 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 \rightarrow glucose + oxygen

Figure 1.2 The water cycle.

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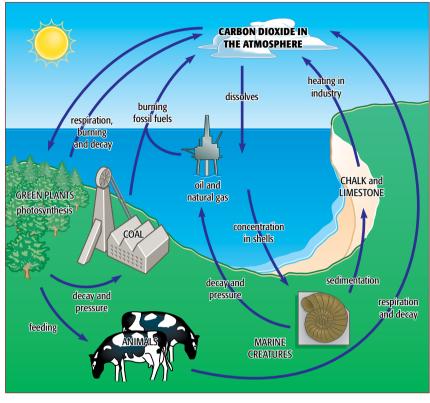


Figure 1.3 The carbon cycle.

 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 they 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. The process of respiration uses oxygen from the air and releases carbon dioxide:

glucose + oxygen \rightarrow carbon dioxide + water

• When plants and animals decay after death, carbon dioxide is produced.

 Wood can be burnt. This combustion produces carbon dioxide:

 $\operatorname{carbon} + \operatorname{oxygen} \rightarrow \operatorname{carbon} \operatorname{dioxide}$

- 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 1.4, overleaf).

The nitrogen cycle

Nitrogen is essential for plant growth and therefore for the life of animals (Figure 1.5, overleaf). There is plenty of nitrogen in the atmosphere (78%) but it is unreactive and so it is difficult to get it into the soil for plants to use.

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

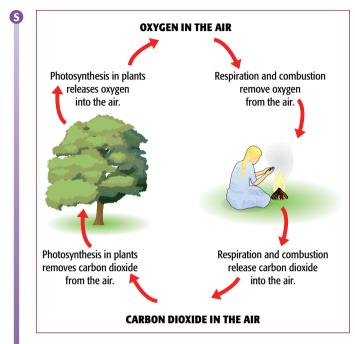


Figure 1.4 Maintaining the levels of oxygen and carbon dioxide in the air.

When plants and animals die and decay, bacteria help the decomposition and nitrogen is returned to the soil.

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

During thunderstorms, the very high temperature of the lightning provides enough energy to cause atmospheric nitrogen and oxygen to react 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 1.5).

These three major cycles – of water, carbon and nitrogen – together with the rock cycle interlink and, between them, provide us with the resources we need.

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.

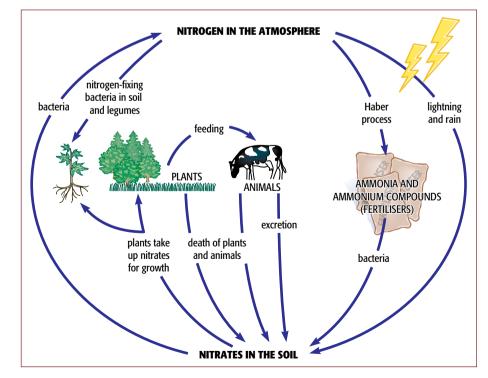


Figure 1.5 The nitrogen cycle.

Material resources can be broadly subdivided into renewable, potentially renewable and non-renewable resources, based on our short human timescale.

- Non-renewable resources are those that exist in a fixed quantity in the Earth's crust – for example, metallic and non-metallic minerals and fossil fuels. They were formed over millions of years and are being used up much faster than they are being formed.
- Renewable resources are those that essentially will never run out (are inexhaustible) – for example, wind, tides and direct solar energy.
- Potentially renewable resources can be renewed, but they will run out if we use them more quickly than they can be renewed. Examples include fresh water and air, fertile soil, and plant and animal biomass.

The biggest environmental concern is the depletion of non-renewable resources. Once they are used up, we will have to manage without them. Metal ores, especially those of iron, aluminium and copper, are becoming scarcer. The ores that still exist are often of low quality, making the process of extraction 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. A time will come when all the oil, and eventually all the coal, will run out. Phosphate minerals, essential for the manufacture of fertilisers, are also becoming scarcer.

A number of these problems can be reduced by recycling some of the substances we use: recycling metals helps conserve metal ores and recycling plastics helps conserve the petroleum from which they are made. All recycling helps save energy, which comes mainly from fossil fuels.

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 overuse and pollution. The next three sections give more detail on these problems.

Questions

- **1.1** Coal is a fossil fuel produced from plant material underground over very long geological periods of time. What are petroleum and natural gas originally formed from?
- **1.2** How does the Sun keep the carbon cycle working?
- **1.3** Why are metallic and non-metallic minerals and fossil fuels thought of as non-renewable resources?
- **1.4** 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 the following approximate composition: nitrogen 78%, oxygen 21%, argon 0.9% and 'other gases' (including carbon dioxide, water vapour, neon and other **noble gases**) 0.1% (Figure **1.6**, overleaf).

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 do not get crushed or go rancid as a result of contact with oxygen in the air.

The biggest single use of oxygen is in the production of steel from cast iron. It is also used in oxyacetylene torches to produce the high-temperature flames needed to cut and weld metals. In hospitals, oxygen in cylinders is used to help the breathing of sick people.

Activity 1.1

Estimating the amount of oxygen in air This is a demonstration of the reduction in volume when air is passed over heated copper.

A worksheet is included on the CD-ROM.

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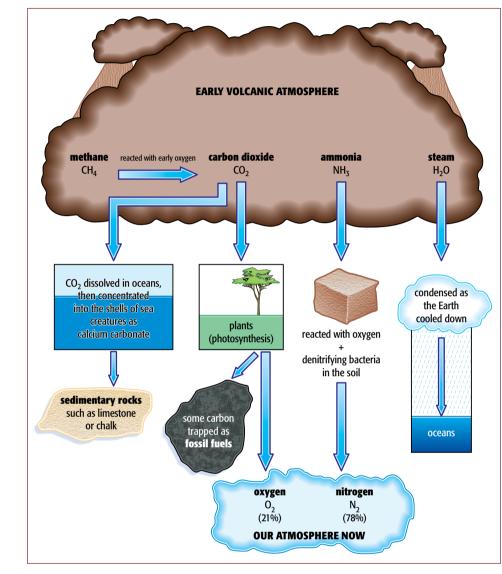


Figure 1.6 The development of the Earth's atmosphere.

Study tip

If you are asked for a use of oxygen, 'breathing' is not considered to be a correct answer because it is air rather than oxygen that we breathe. You need to give a use of pure oxygen.

Argon and other noble gases are used in different types of lighting. Argon is used to 'fill' light bulbs to prevent the tungsten filament burning away (Figure 1.7). It does not react with tungsten even at very high temperatures. The other noble gases are used in advertising signs because they glow with different colours when electricity flows through them.

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).

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Study 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).



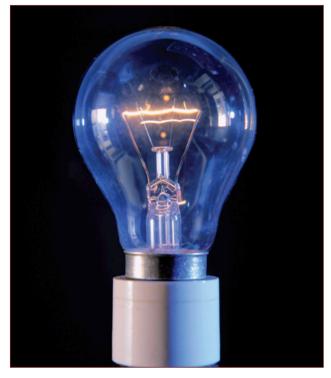
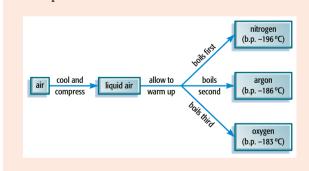


Figure 1.7 Filament light bulbs contain argon which does not react with the hot tungsten filament.

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

- First the air must be cooled until it turns into a liquid (liquefies).
- 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.

Gas	Boiling point/°C	Proportion in mixture / %	
carbon dioxide (sublimes)	-32	0.04	
xenon	-108	(a)	
krypton	-153	(a)	
oxygen	-183	21	
argon	-186	0.9	
nitrogen	-196	78	
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.

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	\rightarrow	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 rainwater to produce 'acid rain' (Figure 1.8, overleaf).

There are numerous effects of acid rain.

- Limestone buildings, statues, etc., are worn away.
- Lakes are acidified, and metal ions (for example, Al³⁺ 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, which damages 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.

One way to remedy the effects of acid rain is to add lime to lakes and the surrounding land to decrease the acidity. The best solution, however, is to prevent

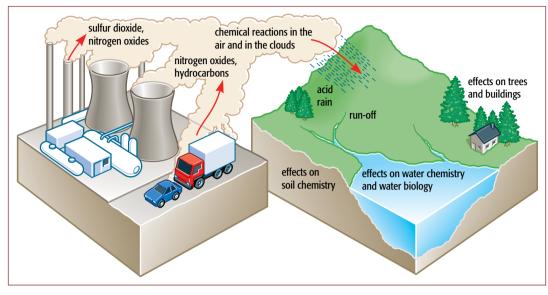


Figure 1.8 The formation of acid rain.

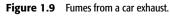
the acidic gases from being released in the first place. 'Scrubbers' are fitted to power station furnaces. In these devices, the acidic gases are passed through an alkaline substance such as lime. This removes the acids, making the escaping gases much less harmful. In many countries, though, acidic gases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

Petrol (gasoline) and diesel for use in road transport have most of their sulfur removed when they are refined. Sulfur dioxide is not a serious problem with motor vehicles but the other contents of vehicle exhaust fumes (Figure 1.9) can cause problems. Nitrogen dioxide, for example, is still produced. The high temperature inside the engine's cylinders causes the nitrogen and oxygen in the air to react together:

nitrogen	+	oxygen	\rightarrow	nitrogen dioxide
N_2	+	$2O_2$	\rightarrow	$2NO_2$

Because of the lack of oxygen in the enclosed space of an engine, the fuel does not usually burn completely and carbon monoxide (CO) is formed.





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Another pollution problem arising from motor vehicles is caused by tetraethyl lead in petrol (leaded petrol). Burning this type of petrol releases the toxic metal lead into the environment (Figure **1.9**). The use of lead in petrol has decreased significantly over the last 20 years. In 2011, the United Nations announced the successful, worldwide, phasing out of leaded petrol for road vehicles. There are only a handful of countries where it is still available.

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 in people with asthma.
- Carbon monoxide is a highly 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 neurotoxic 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 1.10). 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

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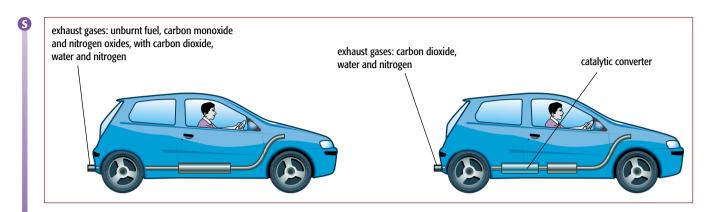


Figure 1.10 A catalytic converter changes harmful exhaust gases into safer gases.

where leaded petrol is still being used, catalytic converters cannot be used either.

Study 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 each have distinct causes and clear consequences.

Figure 1.11 summarises the effects of the main pollutants of the air.

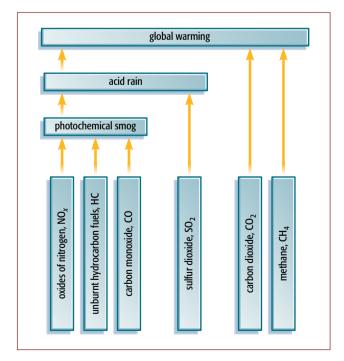


Figure 1.11 A summary of various atmospheric pollution problems caused by human activity.

Global warming and the 'greenhouse effect'

There are two gases in Figure 1.11, carbon dioxide and methane, which are not in the list of pollutants given so far. These, together with water vapour and oxides of nitrogen, are causing **global warming** due to the '**greenhouse effect**'. The Earth is warmed by the Sun but this heat would quickly escape if it were not for our atmosphere. It is always colder on a clear night because there are no clouds to keep the heat in. Some gases are better at keeping heat in than others; if there is too much of these gases in the atmosphere, the Earth gets warmer and this causes problems (Figure 1.12).

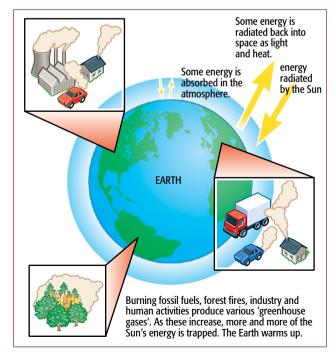


Figure 1.12 The greenhouse effect.



Some of the problems global warming will cause are listed below.

- Glaciers and polar ice will melt. This will cause a rise in sea level, and low-lying land will be flooded.
- The surface temperature of the Earth will increase. Deserts will spread and millions of people will have less water.
- Severe weather events will increase in frequency, and hurricanes and flooding will become more common.
- In some areas it may become easier to grow food crops but in others it will certainly become more difficult.

Carbon dioxide and methane are the two main problem gases; methane is around 20 times more effective at stopping heat escaping than carbon dioxide is.

Carbon dioxide enters the air through respiration and burning and it is removed by plants during photosynthesis. Burning more fuel and cutting down the forests increase the problem. Burning less fossil fuel and planting more trees would help to solve it.

Methane is produced by animals such as cows: it is a by-product of digesting their food. It emerges from both ends of the cow (but mostly from the mouth). Intriguingly, termites are also significant contributors to the methane in the atmosphere (Figure 1.13a). In addition, it is produced by the decay of food and other dead organic matter. It is produced in large quantities by rice paddy fields (Figure 1.13b) and landfill sites. Treating organic waste so that the methane could be collected and burnt as fuel would help solve the problem.

The warming of the Arctic region in recent years has heightened our awareness of a further source of methane, known to scientists as 'fire ice' because it can ignite spontaneously. Melting of the Arctic ice and the consequent release of the large amount of the gas stored in the permafrost could have a huge economic and damaging environmental impact.

🚯 Questions 🤞

- **1.5** Which gases contribute most significantly to acid rain?
- **1.6** How do the gases responsible for acid rain get into the atmosphere?
- **1.7** What are the problems caused by acid rain?
- **1.8** What is photochemical smog and why is it a problem?
- **1.9** How does carbon monoxide stop the blood from carrying oxygen?
- **1.10** Why are light bulbs filled with argon?
- **1.11** How does methane get into the air?
- **1.12** What is the 'greenhouse effect'?
- **1.13** What does a catalytic converter do to the exhaust gases from a car?
- **1.14** Why is it possible to separate the gases in the air by fractional distillation?



Figure 1.13 a A termite mound in Northern Territory, Australia – termites produce methane from digestion in their guts. b Terraced rice fields in Bali, Indonesia. Rice is the staple diet of about half the world's population.