RS•C

Chemistry NOW

This is a series of four leaflets which present modern aspects of chemistry in a way accessible to school students and directly usable by teachers. Each leaflet consists of four pages of information interspersed with questions to test student's understanding of what they are reading, to help them to link what they have read to the chemistry they already know and to help them to understand the text.

The leaflets could be used to support existing workschemes, to develop comprehension skills or as meaningful exercises to be used in the case of teacher absences (planned or unplanned).

The leaflets are:

•Chemistry and sport

This is aimed at 14–16 year olds and deals with the chemistry of aerobic and anaerboic respiration in the context of athletics and looks at a number of ways in which athletes can manipulate (legally!) the chemistry of this process to their advantage by monitoring the concentration of lactic acid in their blood.

•Chemistry of the atmosphere

This is aimed at 14–16 year olds. This looks at the way that the Earth's present atmosphere has evolved from possible earlier atmospheres. Some of the available evidence for different scenarios is presented and critically discussed.

•Computational chemistry

This is aimed at the post-16 age group. It presents a case study of the development of derivatives of cinnamic acid as a repellent to dissuade birds from eating crops treated with it. It explains how chemists develop relationships between structural features and particular types of activity and how computer modelling programmes are used in this work.

•Combinatorial chemistry

This is also aimed at the post-16 age group. Combinatorial chemistry is a group of techniques for synthesising large arrays of related chemicals. These can be easily automated by the use of robot syringes controlled by computers to carry out repetitive processes. The resulting arrays of chemicals called 'libraries' can then be screened for potential drug activities. Combinatorial chemistry is increasingly being used by pharmaceutical companies in their search for new drugs.

Answers

For the use of teachers, answers to the questions on the leaflets are presented overleaf.

Electron distribution of cinnamamide

Chemistry of the atmosphere

We take for granted the air that we breathe, but over the past few years the atmosphere has been in the news with concerns about:

- increasing carbon dioxide levels, a possible cause of global warming;
- decreased ozone levels in the stratosphere;
- increased ozone concentrations at ground level; and
- acidic gases such as the sulfur oxides and nitrogen oxides.

Although important, these changes are relatively small – the concentration of carbon dioxide has only gone up from about 0.0315 per cent to about 0.0350 per cent in the past 30 years. This article looks at greater changes over a longer timescale – in fact how the Earth got an atmosphere at all and how it reached its present composition (Table 1).

There are two main possibilities.

1. **The Earth was formed with an atmosphere – the primary atmosphere - that evolved to its present composition.**
2. **The Earth's atmosphere came from gases escaping from the Earth's interior.**

A third idea, that the Earth's atmosphere was brought by meteorites or debris from comets which bombarded the Earth, is difficult to prove one way or another, although Earth acquires an estimated 500 tonnes of material every day in this way.

We cannot know for certain which of these possibilities is true because the atmosphere has evolved over several billion years. However, there is evidence from several sources.

We know the present composition of:

- the Earth's atmosphere;
- the Earth's oceans;
- the Sun;
- gases trapped in meteorites;
- gases emitted from volcanoes; and
- the rocks on the Earth and other planets.

Table 1
The present composition of the Earth's atmosphere.

Gas	Per cent
Nitrogen	78.08
Oxygen	20.94
Argon	0.93
Carbon dioxide	0.0335
Other noble gases	0.00244
Methane	0.00017
Hydrogen	0.00005
Dinitrogen monoxide	0.00003
Water vapour	Variable, < 1
Hydrogen sulfide, sulfur oxides, carbon monoxide, ammonia	Variable trace amounts

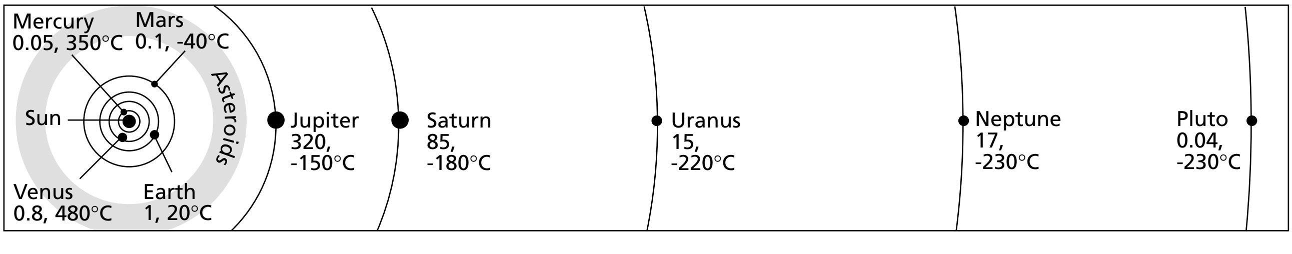
We also know something about the chemistry and physics of the above components and processes, and the structures and biochemistry of living things past and present.

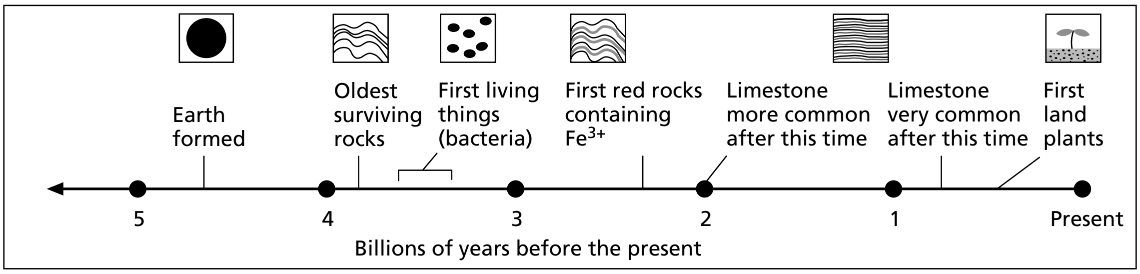
This knowledge enables us to work out some reasonable possibilities as to how the Earth's atmosphere came about.

•The timescale

No one knows for certain when and how the Earth itself was formed. Somehow, gases (mostly hydrogen and helium) and dust collected together in orbit around the Sun. This process occurred about 5 billion (5 000 000 000) years ago and formed the planets of the solar system (*Fig 1*). The Earth's oldest known rocks formed over 4 billion years ago, while the first primitive life – types of bacteria – appeared around 3.5 billion years ago. Plants appeared much later, first in the seas and then on land (*Fig 2*).

***Figure 1** The solar system. The figures show the mass of each planet compared with Earth and their average surface temperatures.* ▼





▲ *Figure 2 Time line showing the Earth's history*

The first (primary) atmosphere

The Earth's first atmosphere probably had the same composition as the gases found in interplanetary space – hydrogen and helium. These are the gases which make up the the atmospheres of the outer planets and from which the Sun is made. However, these gases are too light to have been retained – their small particles move rapidly and can easily escape the Earth's relatively weak gravity.

Q1. a) Use the values of relative atomic mass (A_r) He = 4, C = 12, N = 14, O = 16, to work out the relative molecular masses, M_r, (formula masses) of the following gases: O_2, N_2, CO_2.

b) How many times heavier is a molecule of each gas than an atom of helium?

The heavier planets of the solar system – *ie* Jupiter, Saturn, Uranus and Neptune – have retained this sort of atmosphere for two reasons. First, their greater masses give them stronger gravitational fields so that the lighter gases are more strongly attracted. Secondly, the lower temperatures further from the Sun mean that gas particles move more slowly.

Another reason why Earth, and the other planets close to the Sun have lost their primary atmospheres is the solar wind. This is a stream of ions and subatomic particles which flows out from the Sun and which was particularly strong in the Sun's early period. This would have 'blown away' the primary atmosphere.

So, it seems unlikely that the present atmosphere evolved from the primary one.

The second (secondary) atmosphere

When the Earth was formed by gravitational attraction of material from space, it is likely that gases became trapped and that these were released later to form an early atmosphere. This escape of gases still happens in volcanic eruptions. Table 2 shows the composition of gases from a typical Hawaiian volcano. It contains all the components of the modern atmosphere (see Table 1), except oxygen. So this seems to be a possible starting point for today's atmosphere.

Hawaiian volcano

Table 2
The typical composition of volcanic gases

Gas	Per cent
Nitrogen	4.7
Oxygen	0
Argon	0.2
Carbon dioxide	11.8
Hydrogen	0.4
Sulfur oxides	8.9
Water vapour	73.5
Other, including noble gases	0.5

Q2. Use Tables 1 and 2 to state the main differences in composition between the modern atmosphere and volcanic gases.

•Where did the oxygen come from?

We need to explain the fact that our present atmosphere contains about 20 per cent free oxygen. *Figure 3* shows how the percentage of oxygen in the atmosphere has changed over time. Oxygen is a reactive gas and combines with most elements to form oxides, so this level of oxygen is quite surprising. If the Earth's atmosphere came from volcanic gases, oxygen would be present combined in carbon dioxide and in water. How could these release free oxygen? Why has the percentage of oxygen in the atmosphere changed in the way shown in the graph?

The most probable way in which oxygen

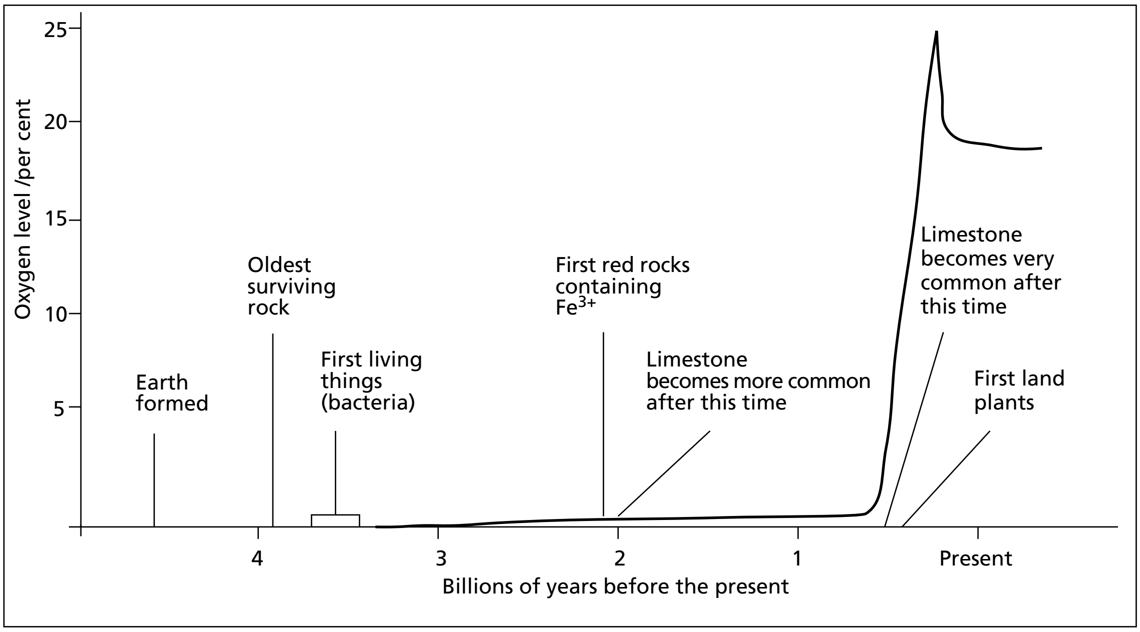


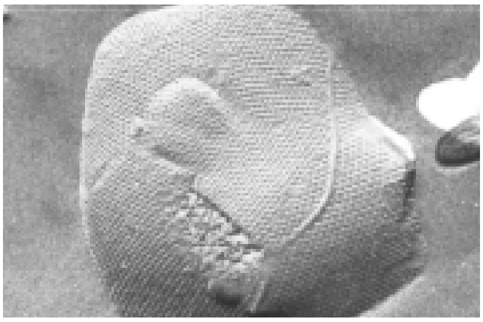
***Figure 3* Changes in oxygen levels in the Earth's atmosphere**

was released is biochemical. The earliest living organisms that we know about from the fossil record are called *Archaea*, very simple organisms which appeared over 3.5 billion years ago. About 3 billion years ago they evolved the ability to photosynthesise - that is to use sunlight to convert water and carbon dioxide (both present in volcanic gases) into carbohydrates and oxygen.

Photosynthesis

$$6H_2O + 6CO_2 \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Water + Carbon dioxide ⟶ Glucose + Oxygen
(a carbohydrate)



***A freeze-etched electron-micrograph of the archaea Methanoculleus marisnigri* ▶**

Today, life on the surface of the Earth is possible because the ozone layer in the upper atmosphere protects living things from damaging ultraviolet radiation from the Sun. There was no ozone when life first appeared and so life probably started underwater in the seas. A few metres of water is enough to absorb harmful ultraviolet radiation, but allows enough visible light to make photosynthesis possible. The formation of ozone, a gas with formula O_3, was not possible until oxygen was present in the atmosphere.

Archaea are still found today and are more resistant to damage by ultraviolet light than other organisms. This tends to support the biochemical theory.

Q3. What is the fossil record, and how does it help to date rocks?

How can we explain the shape of the graph?

Archaea started producing oxygen 3 billion years ago, and yet the graph shows that oxygen levels only started to increase significantly less than 1 billion years ago. The reason for this is that the oxygen was being 'mopped up' by reacting with – *ie* oxidising – substances in the rocks. This is shown by the colours of rocks containing compounds of iron (Fe). Dull, dark-coloured rocks containing compounds of Fe^{2+} ions, can be oxidised to orange-red ones containing compounds of Fe^{3+} ions. The first red beds began to appear about 2.2 billion years ago and gradually became more common. By about 0.6 billion years ago, almost all the iron in the rocks exposed to the atmosphere was in the red (oxidised) form, and significant amounts of free oxygen began to accumulate in the atmosphere.

Q4. a) What is the common name for the reddish iron compound which results when iron reacts with air?

b) Write a balanced symbol equation for the oxidation of iron(II) oxide (FeO) to iron(III) oxide (Fe_2O_3) by oxygen.

What about the 'kink' in the graph?

Figure 3 shows that about 300 million years ago, the oxygen level may have risen to as high as about 27per cent and then fell back to its present 20 per cent. The peak was at the time when the Earth had very luxuriant forests (which later became our coal deposits). The extra photosynthesis of this mass of vegetation caused the high oxygen levels. However, the high percentage of oxygen in the atmosphere led to many forest fires which converted some of the oxygen back to carbon dioxide. Traces of charcoal remain as evidence of these fires.

Q5. How might forest fires have started at this time?

•What happened to the carbon dioxide?

The Earth's original atmosphere is thought to have contained high levels of carbon dioxide. It now contains only about 0.03 per cent. What has happened to the rest?

Some is removed by dissolving in sea water:

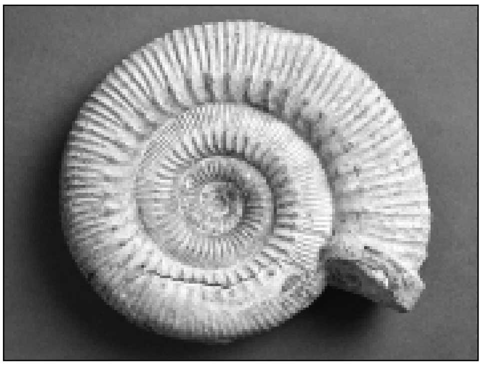
$$CO_2(g) \rightleftharpoons CO_2(aq)$$

Some dissolved carbon dioxide is removed by photosynthesis in land and sea plants and algae. When these die, they may eventually form coal or oil deposits which 'lock up' some of the carbon.

Some of the dissolved carbon dioxide reacts with water to form hydrogencarbonate ions:

$$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

These may then be removed by reaction with calcium ions to form insoluble calcium carbonate ($CaCO_3$) or by sea creatures as they form shells of calcium carbonate. Most of this calcium carbonate eventually forms limestone.



Ammonite stephanoceras humphresianum This has a shell containing calcium carbonate ▶

Limestone became more common from about 2 billion years ago, suggesting that it is living organisms which were responsible for the removal of carbon dioxide. The decrease in carbon dioxide level thus mirrors the increase in oxygen level.

Q6. When we release carbon dioxide into the air by burning coal, we are freeing 'carbon that has been locked away'. Explain this statement.

Q7. Describe a simple test to show that a fossil sea shell contains a carbonate.

•Summary

- The Earth was possibly formed with a primary atmosphere of hydrogen and helium.
- This primary atmosphere was lost into space because the Earth's gravity could not hold it and it was also 'blown away' by the solar wind.
- The present atmosphere probably escaped from the Earth's interior and at first contained a lot of carbon dioxide and no oxygen.
- Carbon dioxide has been converted into oxygen by photosynthesis carried out by living things. This has occurred mainly during the past 2 billion years.

•Acknowledgements

This article was adapted by Ted Lister from an article by Alastair Fleming of Keele University which appeared in *Teaching Earth Sciences*, 1998, **23**, 130.

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