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What matter is made of

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Catalyst

The front cover shows a platinum crystal, highly magnified to reveal the arrangement of atoms (Erwin Mueller/SPL).

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Editorial

Working at the limits

Several of the articles in this issue of Catalyst illustrate an important aspect of the work of scientists. Think about the Wright brothers. Their first powered flight was 100 years ago, in 1903. Could they have achieved this earlier?

Their test flights with gliders didn't match up to the published data, so they had to devise their own experimental techniques, using a wind tunnel to measure the lift on model wings. They needed a suitable engine — internal combustion engines were just becoming common as the motor car was developed. They knew about the latest lightweight materials, used in racing bicycles. By pushing things to the limits — the latest technologies, plus new experimental techniques — they became the first people to fly a heavier-than-air powered craft.

Scientists are always working at the limits. Think about Galileo. The telescope was a new technology, invented in Holland. But Galileo turned it to the night sky, and made discoveries which changed our view of the universe itself. In the same way, the scientists of ESA's Mars Express project have pushed technology to its limits to send sensitive instruments to Mars which should tell us more than we know now about our neighbouring planet.

Even when scientists turn their attention to what may seem the most mundane of problems — the slugs that are a pest to farmers, for example — they are working at the limits of our understanding of ecosystems.

When you make observations in your laboratory work, think about what limits you are facing. How can you get the most out of your measurements? How can you push back those limits?

David Sang

DAVID SANG

First flight

The Wright brothers

Orville Wright makes the first powered flight at Kitty Hawk, USA, 17 December 1903

US Library of Congress/SPL

It's 100 years since the Wright brothers made the first powered flight. Unlike the try-it-and-see methods which had been used by many of the previous attempts, the Wrights approached the problem of flight in a scientific way and beat the competition.

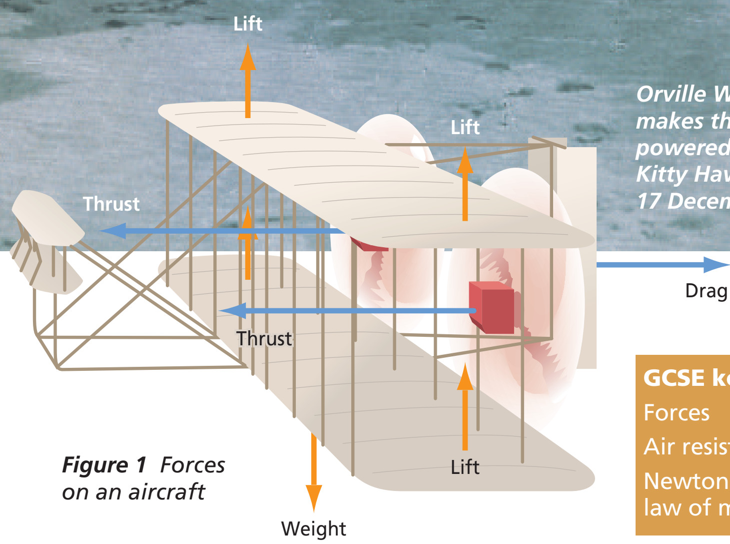


Figure 1 *Forces on an aircraft*

GCSE key words
Forces
Air resistance
Newton's third law of motion

People had flown before 1903, in balloons and gliders, but Wilbur and Orville Wright were the first to travel in a powered, heavier-than-air craft. They did it on 17 December 1903.

The Wrights lived in Dayton, Ohio. They were a relatively uneducated pair, and didn't finish high school, but they were clever technically. The two young men set up a printing shop, having built their own printing press by recycling broken parts. In 1893, when Wilbur was 26 and Orville was 22, they switched to making and repairing bicycles, calling themselves the Wright Cycle Company. Bicycles were a highly-developed technology in the late nineteenth century, making good use of lightweight but strong materials, just the stuff you need to know about to make an aircraft.

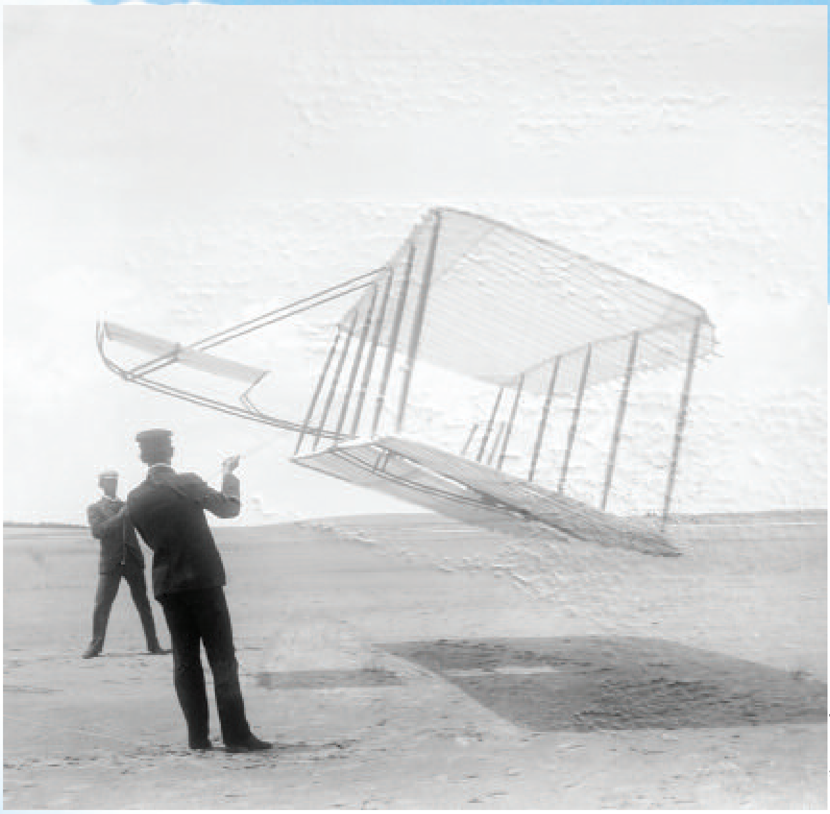
BOX 1 FORCES ON AN AIRCRAFT

Figure 1 shows the forces acting on an aircraft.

- The forward **thrust** is provided by the engine, turning the propeller, which pushes air backwards.
- The backward force of **drag** is another name for air resistance, or friction with the air.
- The downward force, the aircraft's **weight**, is caused by gravity.
- The upward force of **lift**, which acts on the aircraft's wings, balances its weight.

As an aircraft accelerates down the runway, the lift gradually increases, until it is enough to overcome the weight. At top speed, the aircraft cannot go any faster because the drag force is so great that it equals the forward thrust of the engine.

To change direction, the pilot can tilt the aircraft. The lift force on the wings then has a sideways component, and this pushes the plane round.



US Library of Congress/SPL

Above: *Orville (foreground) and Wilbur Wright testing a glider as a kite in 1901*

Imperial units have been given for measurements because that is what the Wright brothers used.

Wind tunnels are still used today, for testing whole aircraft. Cars are also tested, to minimise drag on them.

STUDYING FLIGHT

Like many people at the time, the brothers were fascinated by the possibility of flying. In 1899, they built their first model aircraft, with a wingspan of 5 feet (1.5 m). This helped them to understand the forces which act on a flying machine (see Box 1). The vital thing is to be able to produce an upwards force, **lift**, to counter the aircraft's weight.

The Wrights wanted to make a kite capable of lifting a man off the ground, but they realised that their home town was no good as a trial ground. Strong winds were rare and the ground was hard, so in the summer of 1900 they moved to Kitty Hawk, on the Atlantic coast of North Carolina. Here they had reliable winds and sandy beaches for soft landings.

They built a double-winged glider with a wingspan of 17 feet (5.2 m). For lightness, the wings consisted of a skeleton of bent ash wood covered with fine fabric. Its total weight, including the pilot, was just 85 kg. Using existing data, they calculated the lift which would be provided by the glider's wings, and they achieved some glides up to 120 m, but the lift was much less than they had calculated. It was clear to them that a complete re-think was needed if they were to lift a heavy engine into the air. They went home to Dayton.

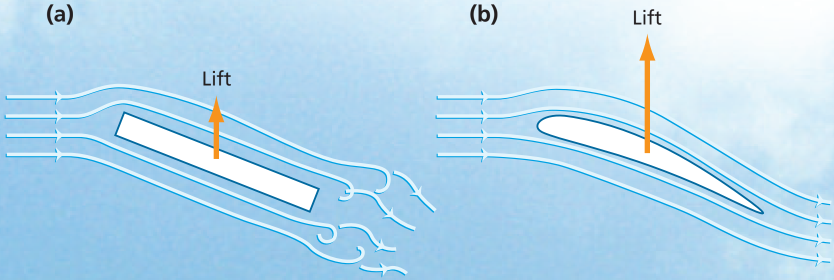


Figure 2 *How air flows over an aircraft wing. (a) Rectangular. (b) Aerofoil*

WILBUR BECOMES A SCIENTIST

The Wrights had been using data and formulae published in scientific journals, but they no longer trusted them. They set about finding out the best way to produce lift for themselves. First, they built a wind tunnel. This was a chamber with a fan at one end to blow air through it. Inside the tunnel, they positioned model aircraft wings in the flow of air, attached to balances to measure the forces acting on them. They changed a lot of variables — the air speed, the angle and area of the wings, and their shape. From this, they drew graphs to show the relationship between lift and air speed, and deduced the best shape and angle for their wings (see Box 2).

The Wrights then built a new glider, which proved excellent. In October 1902, Orville wrote, 'We now hold all the records! The largest machine, the longest time in the air, the smallest angle of descent, and the highest wind!' Wilbur had glided a distance of 190 m in 26 s.

DEVELOPING POWER

The next step was to find a suitable petrol engine for a powered aircraft. There wasn't one, so the brothers set about making one. It had to be both powerful and lightweight. They produced an engine which weighed 80 kg (almost as much as their first glider), and which had a power of 9 kilowatts (12 horsepower).

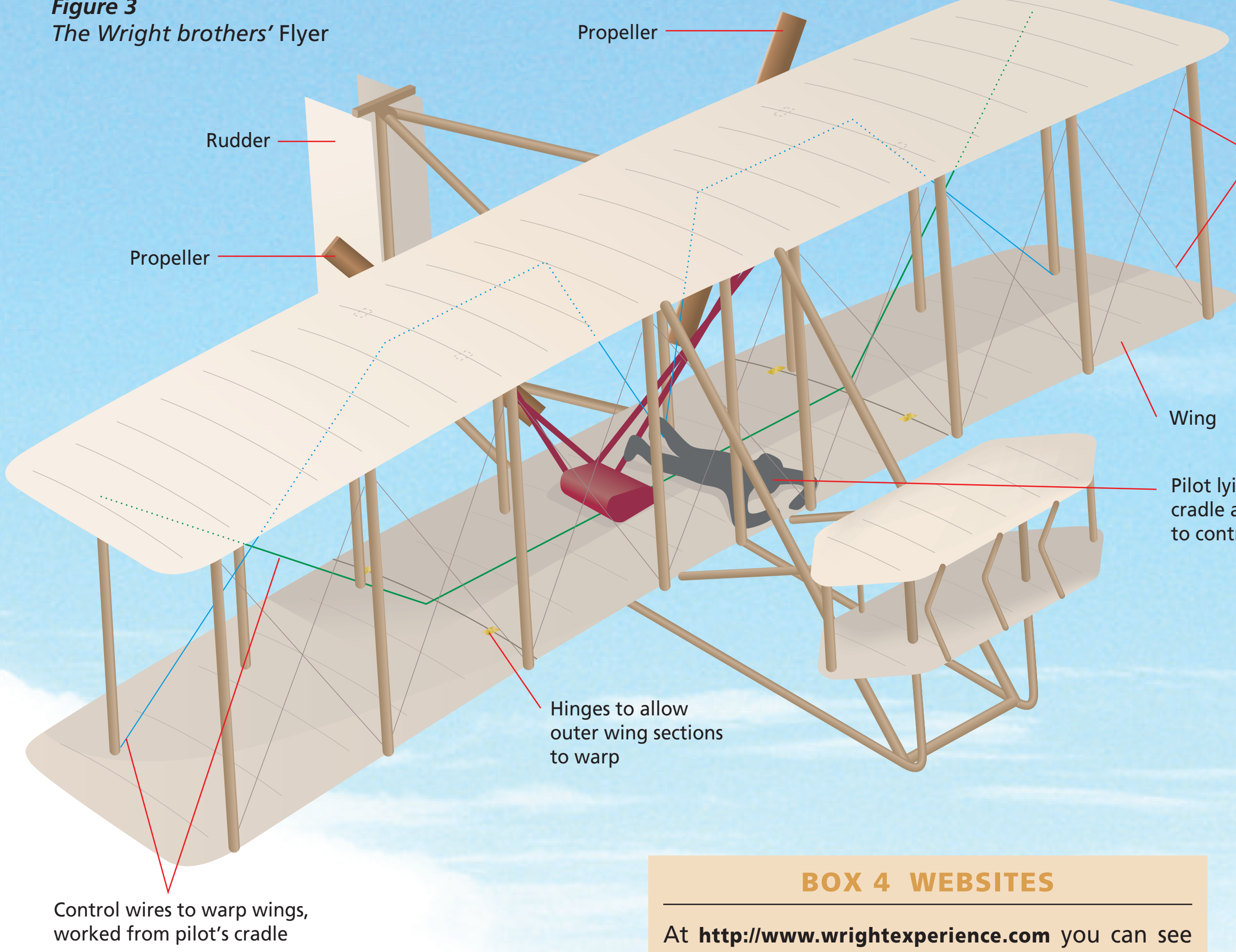
Finally, they had to make a propeller. A well-designed propeller is vital, because this is what pushes the air backwards, providing the thrust to move the aircraft forwards. They carved their propeller out of wood.

BOX 2 WING SHAPES

An aircraft moves forward because the propeller pushes air backwards. This is an example of Newton's third law. The force on the aircraft is equal and opposite to the force it exerts on the air.

We can understand lift in a similar way. An aircraft's wing is tilted slightly, so that as it moves forwards it pushes air downwards. The result is an equal and opposite upward force on the wing. A wing with a rectangular cross section will work, but not very well, because it produces a lot of turbulence (Figure 2). An aerofoil shape is better, as it moves smoothly through the air.

Figure 3
The Wright brothers' Flyer



The Wrights' work was financed by the profits from their bicycle business. Aircraft technology has a lot in common with cycles: an understanding of forces is vital, as well as materials which are lightweight, stiff and strong.

BOX 3 DIMENSIONS OF THE WRIGHT *FLYER*

Wingspan = 40 feet 4 inches (12.3 m)
Chord (front to back of wing) = 6 feet 6 inches (2 m)
Wing camber = 1:20
Total wing area = 510 square feet (47 m^2)
Two propellers, each 8.5 feet (2.6 m) in diameter
Propeller made of three layers of 3 cm spruce, glued together, shaped with hatchet and drawshave
Horizontal forward rudder = 48 square feet (4.5 m^2)
Distance from nose to tail = 21 feet 1 inch (6.4 m)
Unmanned weight = 605 pounds (274 kg) including engine, propellers and chain drive
Wing skeleton covered with white French sateen fabric
Propeller shafts made of steel

Now they were ready to complete their first *Flyer*, and they set off back to Kitty Hawk. On 17 December, at 10.35, Orville made the first flight. It lasted just 20 s and covered 61 m. Then Wilbur went a little further, and by the fourth flight of the day, they began to understand how to control their plane. The pilot lay on his stomach on the lower wing. With his hands he controlled the front elevator, which made the plane move up or down. By twisting his body, he pulled on cords which warped (twisted) the wings, causing the plane to turn right or left. (Nowadays, most aircraft have flaps on the wings to do this.)

Later, Orville emphasised the part that scientific investigation had played in their achievement:

> I look with amazement upon our audacity in attempting flights with a new and untried machine...Yet faith in our calculations and the design of the first machine, based upon our tables of air pressures, secured by months of careful laboratory work, and confidence in our system of control developed by three years of actual experiences in balancing gliders in the air had convinced us that the machine was capable of lifting and maintaining itself in the air, and that, with a little practice, it could be safely flown.

BOX 4 WEBSITES

At **http://www.wrightexperience.com** you can see how a group of engineers has been recreating the Wright brothers' experiments to make accurate replicas of their aircraft. Watch out for reports of these planes flying on the centenary of the first flight. The site includes detailed plans and lets you see how the wings were warped to provide control of the plane's balance.

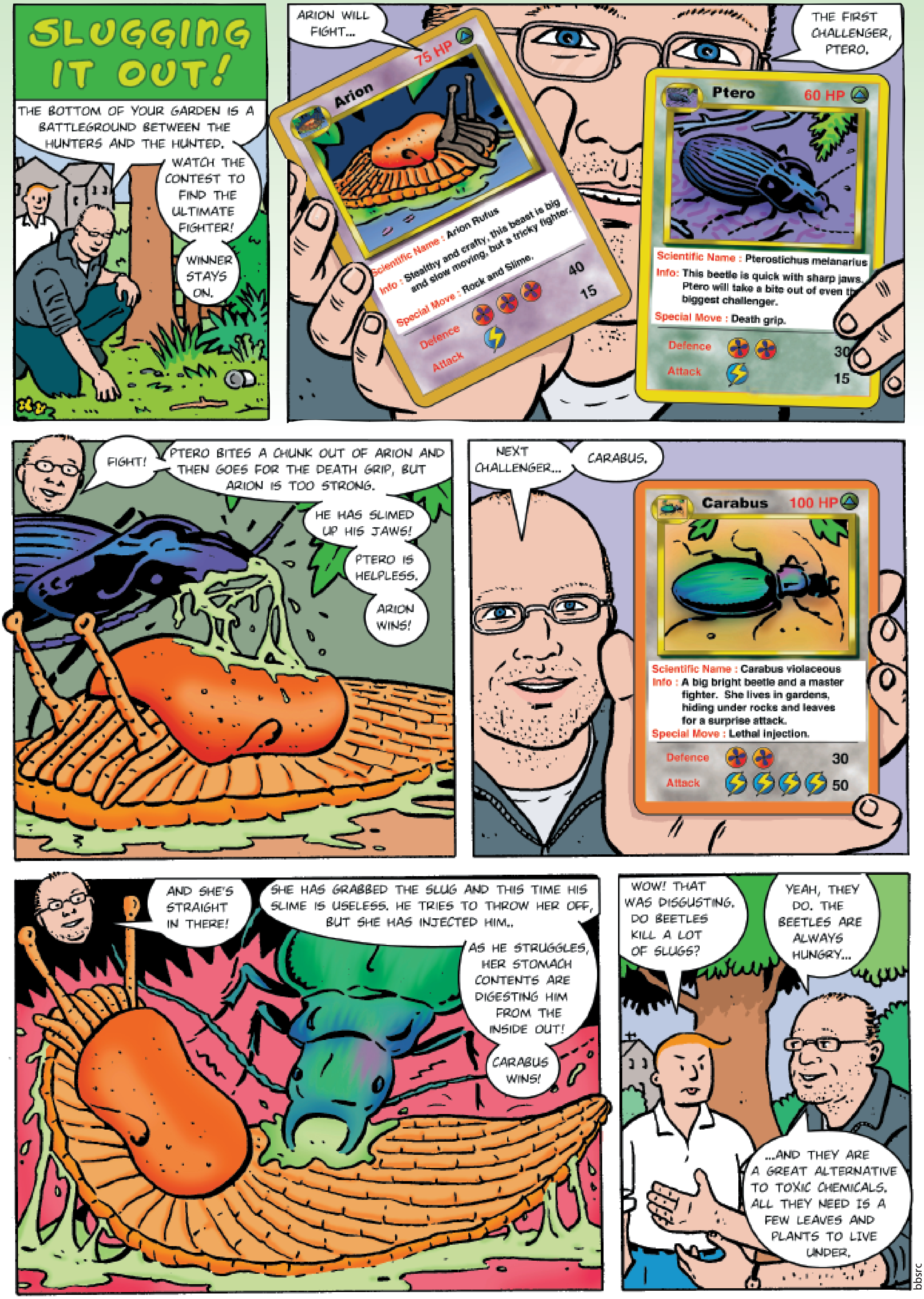
The Science Museum in London has a replica of the Wright *Flyer*. Take a look at their online exhibition on flight at

http://www.sciencemuseum.org.uk

David Sang writes textbooks and is an editor of CATALYST.

● Why did Sir George Cayley's coachman hand in his notice in 1853? Find out about the first manned glider flight. The Wrights were influenced by Cayley's design, including vertical and horizontal control surfaces.

Ingram


SLUGGING IT OUT!
THE BOTTOM OF YOUR GARDEN IS A BATTLEGROUND BETWEEN THE HUNTERS AND THE HUNTED.
WATCH THE CONTEST TO FIND THE ULTIMATE FIGHTER!
WINNER STAYS ON.
ARION WILL FIGHT...
Arion 75 HP
Scientific Name : Arion Rufus
Info : Stealthy and crafty, this beast is big and slow moving, but a tricky fighter.
Special Move : Rock and Slime.
Defence 40
Attack 15
THE FIRST CHALLENGER, PTERO.
Ptero 60 HP
Scientific Name : Pterostichus melanarius
Info: This beetle is quick with sharp jaws. Ptero will take a bite out of even the biggest challenger.
Special Move : Death grip.
Defence 30
Attack 15
FIGHT!
PTERO BITES A CHUNK OUT OF ARION AND THEN GOES FOR THE DEATH GRIP, BUT ARION IS TOO STRONG.
HE HAS SLIMED UP HIS JAWS!
PTERO IS HELPLESS.
ARION WINS!
NEXT CHALLENGER...
CARABUS.
Carabus 100 HP
Scientific Name : Carabus violaceous
Info : A big bright beetle and a master fighter. She lives in gardens, hiding under rocks and leaves for a surprise attack.
Special Move : Lethal injection.
Defence 30
Attack 50
AND SHE'S STRAIGHT IN THERE!
SHE HAS GRABBED THE SLUG AND THIS TIME HIS SLIME IS USELESS. HE TRIES TO THROW HER OFF, BUT SHE HAS INJECTED HIM..
AS HE STRUGGLES, HER STOMACH CONTENTS ARE DIGESTING HIM FROM THE INSIDE OUT!
CARABUS WINS!
WOW! THAT WAS DISGUSTING. DO BEETLES KILL A LOT OF SLUGS?
YEAH, THEY DO. THE BEETLES ARE ALWAYS HUNGRY...
...AND THEY ARE A GREAT ALTERNATIVE TO TOXIC CHEMICALS. ALL THEY NEED IS A FEW LEAVES AND PLANTS TO LIVE UNDER.
bbsrc

Slugging it out

Chantelle Jay asked Dave Bohan to explain the science behind the cartoon in which he features.

Dr Dave Bohan is a research scientist at Rothamsted Research. He studies the ecology of invertebrates and their interactions with plants. Much of Dave's work is concerned with understanding the population dynamics of slugs in agricultural situations: 'In essence I look at how many slugs there are, where they occur and when they cause damage to farmers' fields.' Dave uses computer models to predict the numbers of slugs at some point in the future and the damage they are likely to cause, so that farmers can decide whether to apply poisonous slug pellets. He also studies the beetle predators of slugs (see the cartoon opposite) and slug population genetics.

SLUG DAMAGE

Slugs are serious pests for farmers. Not only do they kill seeds and seedlings, they also feed on leaves, reducing leaf area which may slow down crop growth. Slug feeding can cause cosmetic damage; would you want to share your lettuce with a slug?

There are many species of slugs (including *Arion rufus* in the cartoon), but most slug damage is caused by two species: *Arion intermedius* and *Deroceras reticulatum*. Although these two cause similar damage, their biology and ecology are very different. *D. reticulatum* is a mobile slug, whereas *A. intermedius* prefers to remain close to the stones and crevices where it hatched.

SLUG PREDATORS

Predicting the distribution of slugs is important for control: are you likely to have an area with high, medium or low numbers? The distribution of individuals across a field is determined mainly by a balance of births, deaths and migration. However, recent work by Dave and his colleagues has shown that predation can also affect the distribution of slugs.

Carabid beetles like *Carabus violaceous* and *Pterostichus melanarius* are important predators, but the latter may have to join forces to overcome their prey. Much as lions aggregate to prey upon large herbivores, so the small carabid beetles *P. melanarius* gather in areas of high slug numbers.

Left: *Arion ater — the black variety*

Dave used pitfall traps to sample the beetles, and through molecular techniques found out which beetles had been eating slugs. These beetles were found in the same places as the medium-sized slugs (25–50 mg). The beetles can dramatically change the distribution of slugs found, 'In June, where there were slugs there were sometimes beetles. One month later, in July, where there were beetles, there were no slugs,' says Dave.

LOOK AT A SLUG

Dave's work on the genetics, predators and population dynamics of slugs will lead to the better control of these pests, but Dave believes slugs are much more interesting than you might think. His advice is, 'Go out and look at some slugs — you may be surprised!'

If you do, you won't be alone! This summer, people recorded the colour of the large slug *Arion ater* (which has black or brown/orange varieties) for a BBCi survey. The website **http://www.bbc.co.uk/cbbc/wild/sluk** shows what they found and how that tied in with Dave's theory that more black slugs may be found where temperatures are colder.

Rothamsted Research is an institute researching arable crops. Much of its work is sponsored by the Biotechnology and Biological Sciences Research Council.

BOX 1 SCIENCE STORIES

Science stories are real research stories from Rothamsted Research. Five scientists were turned into cartoon characters by artist Phil Elliott, when Emma Napper and Elspeth Bartlet received a grant from the Biotechnology and Biological Sciences Research Council. You may have already seen 'Down in the Dirt' published in the April 2003 edition of Catalyst. The full set of cartoons is at **http://www.bbsrc.ac.uk/life/comic/index.html**. You can e-mail the scientists, including Dave Bohan, directly at **rothamsted.science@bbsrc.ac.uk**

Dave Bohan and Chantelle Jay

Graphs and charts in science

Plotting graphs can help a great deal in the interpretation of data. Improve your Grade in CATALYST Vol. 13, No. 4 (April 2003) looked at bar charts and graphs, which are useful for presenting data that are in categories. In this issue we investigate the use of best-fit smooth curves and straight-line graphs to present data which are continuous and can take any value within the range of the experiment.

RATES OF REACTION CURVES

The progress curve shown in Figure 1 is the sort often plotted for reactions which give off a gas. A smooth curve is obviously appropriate for the data.

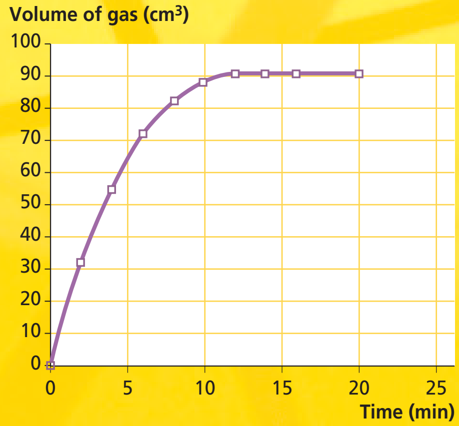


Figure 1 Graph showing the reaction of marble chips with dilute hydrochloric acid

Table 1 Results of the rolling-ball experiment

Time after release (s)	Square of time after release (s^2)	Distance rolled down slope (cm)
0		0
2		2.1
4		8.5
6		19
10		48
15		115
20		200

We can use it to give us a little more information about the reaction by drawing tangents to the curve at various points to work out the gradient. The gradient of the curve tells us the rate of the reaction as cubic centimetres of gas released per minute (cm^3/min). It is clear that the gradient decreases as the reaction proceeds: it is about 24 cm^3/min at the start, and after 7 minutes it is only about 3.5 cm^3/min. This is what we would expect, since the hydrochloric acid is gradually being used up and therefore becoming more dilute.

INTERPOLATION, EXTRAPOLATION AND DOTTED LINES

Smooth curves can be used to infer data which we did not actually measure in the experiment. Figure 2 plots the results in Table 1 from an experiment involving rolling a ball down a (straight) slope. A smooth curve through, or as close as possible to, all the points is allowed here, because the distances and times are both continuous. In fact, the smooth curve looks very convincing. We can use it to estimate how far the ball would have travelled at times other than those we actually recorded. After 17 s, for example, it seems that the ball would have travelled between 140 cm and 150 cm.

This way of using a best-fit curve (or straight line) is called **interpolation**. (The 'inter-' prefix implies that the estimate is *within* the range of measured values.)

Note that you do not 'plot' an extra point on the curve when interpolating, because you did not measure this distance and time, but you use the **dotted line method** to show how you arrived at your value. In this case, draw a straight dotted line (using a ruler) *vertically* from 17 s on the x-axis until it just touches the best-fit curve. From the point where it touches the curve, draw a straight dotted line *horizontally* until it intersects the y-axis. You can now read off the distance travelled in 17 s.

We might try extending the curve on Figure 2 to estimate how far the ball would have rolled in 25 s.

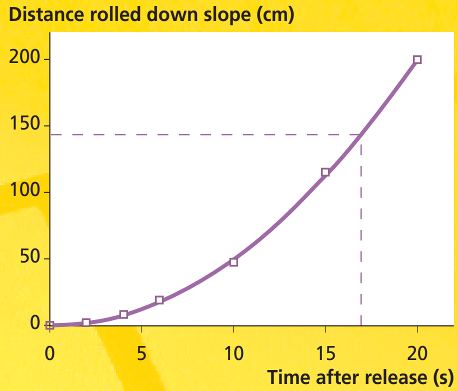


Figure 2 *Graph showing the results of rolling a ball down a slope*

This means going *outside* the range of experimental measurements and is called **extrapolation.** Because we can only guess where the curve will go beyond the measurement range, extrapolation is *less reliable* and *less accurate* than interpolation.

STRAIGHT LINES

The 'smooth curve' graphs above show the information clearly and allow us to understand the experiment better than we might if simply presented with a table of numbers, but it is not very easy to get much further. Drawing tangents to curves is not easy to do accurately, for example.

In the rolling ball experiment you might predict from the results in Figure 2 that the distance travelled each second would become greater and greater, because the ball is obviously speeding up (accelerating) as it rolls down the slope. This is sometimes known as the 'inclined plane' experiment and was a classic experiment of Galileo. He showed that the distance rolled by the ball increased by the square of the time it had been rolling. (For example, if it rolled 1 cm in the first second, then it would have rolled 4 cm after 2 s, since 2^2 is 4.)

It is easier to test whether the results of our experiment agree with Galileo's findings by plotting the data in such a way that a straight line is expected. Straight lines are easy to draw accurately and the errors are more obvious than on a curve. The first step is to complete the extra column in Table 1 for the squares of the times. You can then plot a graph of these figures against distance rolled.

You should get a straight-line graph which shows clearly that the data fit the law very closely (see the answer on page 19). This graph is also useful because interpolating and extrapolating from a straight line is more accurate than from a curve.

John Tucker teaches chemistry at St Edward's School, Oxford and is in charge of ICT training at the school.

Ingram

Web quiz

Use the Visual Elements Periodic Table web pages at **http://www.chemsoc.org/viselements/pages/periodic_table.html** to find out the years in which the following elements were discovered. When you have done this you will be left with one date from the list on the right of the table. This is the year when one of the halogens was isolated. Who by? (Answer on page 19.)

Element	Name	Date
Pt		
Rh		
Cs		
In		
Ga		
Ni		
Mn		
W		
Na		
Si		

Dates:
1803,
1886,
1863,
1751,
1774,
1750,
1824,
1807,
1783,
1875,
1860

MIKE FOLLOWS

Snooker balls, plum and solar systems

GCSE key words
Atomic structure
Atomic particles

People have long wondered about what matter is made of. Snooker balls, plum puddings and solar systems have all featured in descriptive models of atoms. This article describes how people's ideas about atomic structure have changed over the years.

Before anyone knew what they were, electrons were called cathode rays because they came out of the negative terminal, the cathode.

Most ancient civilisations tried to explain the nature of matter, or substance. One explanation offered by the Greek Democritus, who lived four centuries before Christ, was that everything was made of solid particles like snooker balls, called **atoms**. Atoms are too small to see so his ideas were theoretical and not based on experimental evidence. For example, he believed that food tasted sweet because it was made of 'large' round atoms but that small, sharp atoms made things taste sour.

The word 'atom' comes from the Greek word for 'cannot be divided' and this idea was echoed by the British chemist John Dalton in 1808. Dalton proposed that matter could not be subdivided indefinitely. Each element was made up of indivisible particles — atoms — that could not be made or destroyed. All atoms of an element were exactly alike — with the same mass, volume and chemical properties.

It is almost impossible to imagine how small an atom is. Millions of carbon atoms would fit side by side on the full stop at the end of this sentence. Atoms are impossible to see with visible light but a picture of them can be built up using electrons in place of light. The photograph above right is a scanning electron micrograph of some gold and carbon atoms and they certainly look a bit like hard snooker balls.

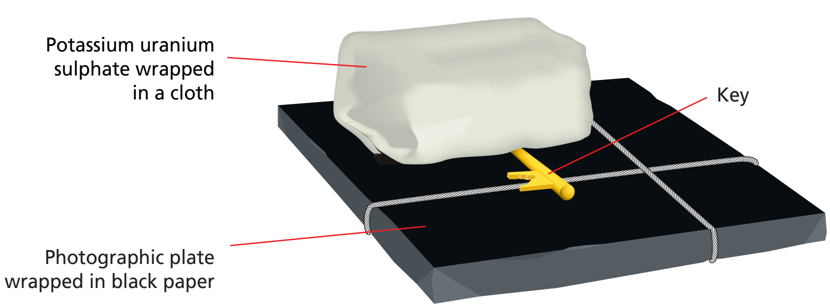
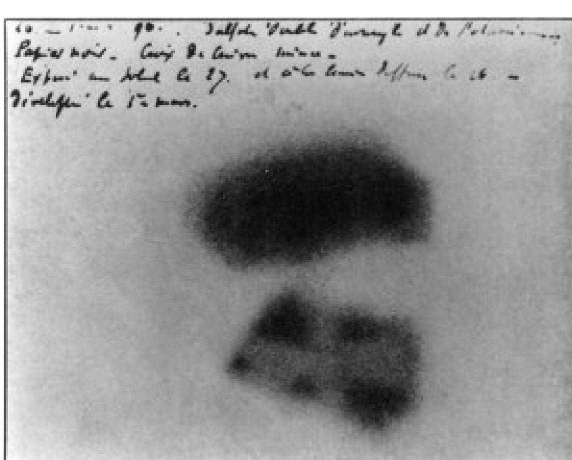


***Figure 1** Becquerel's experiment with uranium salts*



The photograph produced by Becquerel's experiment with uranium salts

SPL

Fluorescent and phosphorescent materials both glow when they absorb radiation. A fluorescent material instantly re-emits the absorbed energy as light while phosphorescent materials glow for several hours.

BECQUEREL TURNED THE KEY

Wilhelm Röntgen discovered X-rays in 1895 (see the September 2003 issue of CATALYST). They appeared to be produced by fluorescence. Henri Becquerel wanted to know whether **phosphorescence** would also produce X-rays. He had some potassium uranium sulphate crystals. These crystals phosphoresce (glow) after they have been exposed to sunlight. He sandwiched some coins and other metal shapes between these crystals and a photographic plate that had been double wrapped in black paper to prevent it being exposed to light (see Figure 1). As he expected, when he developed the plate, he saw the shadow made by the metal shapes just in the same way that bones cast a shadow in X-rays.

He tried repeating the experiment but the sun did not come out for several days which meant that his crystals did not phosphoresce. He decided to develop the plates anyway. To his surprise the metal shapes showed up just as well as before. He deduced that uranium was a source of invisible radiation.

puddings

THOMPSON'S PLUM PUDDING

In 1897 the British scientist J. J. Thompson discovered the **electron**, confirming that the atom was not the hard snooker ball that everyone had previously thought. Electrons could leak out of atoms.

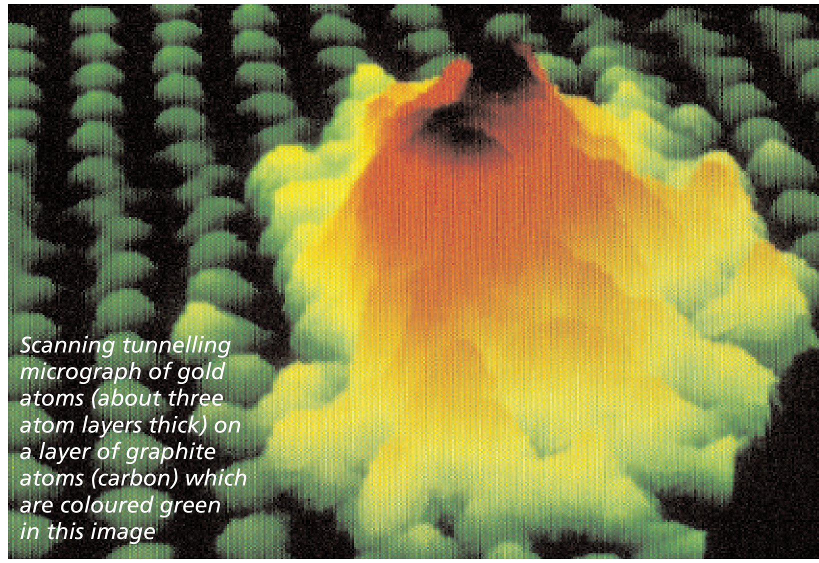
Atoms are usually electrically neutral. This means they contain the same number of positive and negative charges. To reflect this, Thompson believed that the negatively charged electrons were contained inside a 'sphere of positive charge' — like the plums in plum pudding, which was popular at the time (see Figure 2).

In the meantime Becquerel had shown that his radiation from uranium salts was charged, and so could not be X-rays. Ernest Rutherford went on to label this radiation alpha, beta and gamma. Apparently atoms could fall apart or decay in the process called **radioactivity**.

When atoms decay, they also give off energy that ends up as heat. Radioactivity deep inside the Earth provides half the heat energy that drives the convection currents moving the tectonic plates around the Earth's surface.

FIRING ALPHA PARTICLES

Along with a couple of assistants, Ernest Rutherford decided to use alpha particles as 'bullets' and fired them at a thin gold foil 'target' (see Box 1). Why did Rutherford do this experiment? He was the world expert on alpha particles and this was a good way of providing more evidence to support the 'plum pudding' model. An alpha particle is deflected when repelled by another positive charge. If the atom was



Scanning tunnelling micrograph of gold atoms (about three atom layers thick) on a layer of graphite atoms (carbon) which are coloured green in this image

Philippe Plailly/SPL

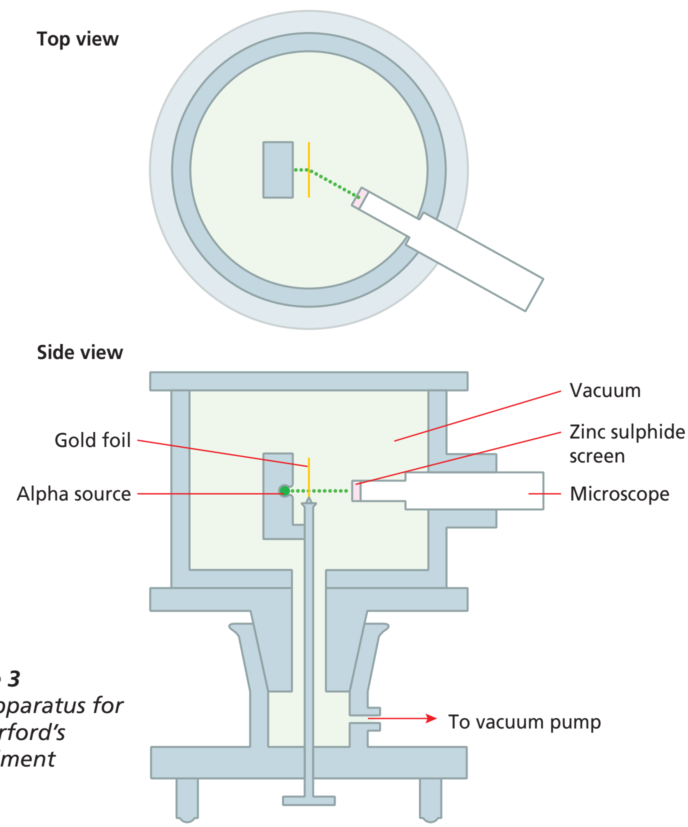


Figure 3 *The apparatus for Rutherford's experiment*

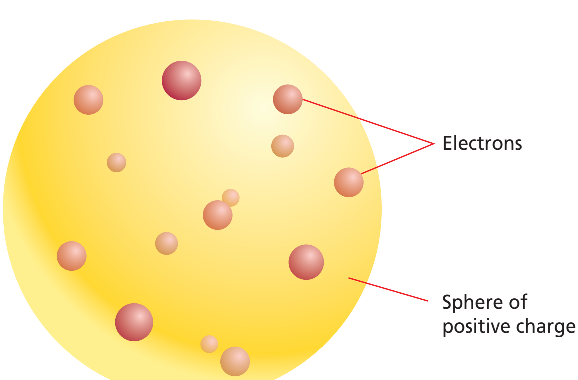


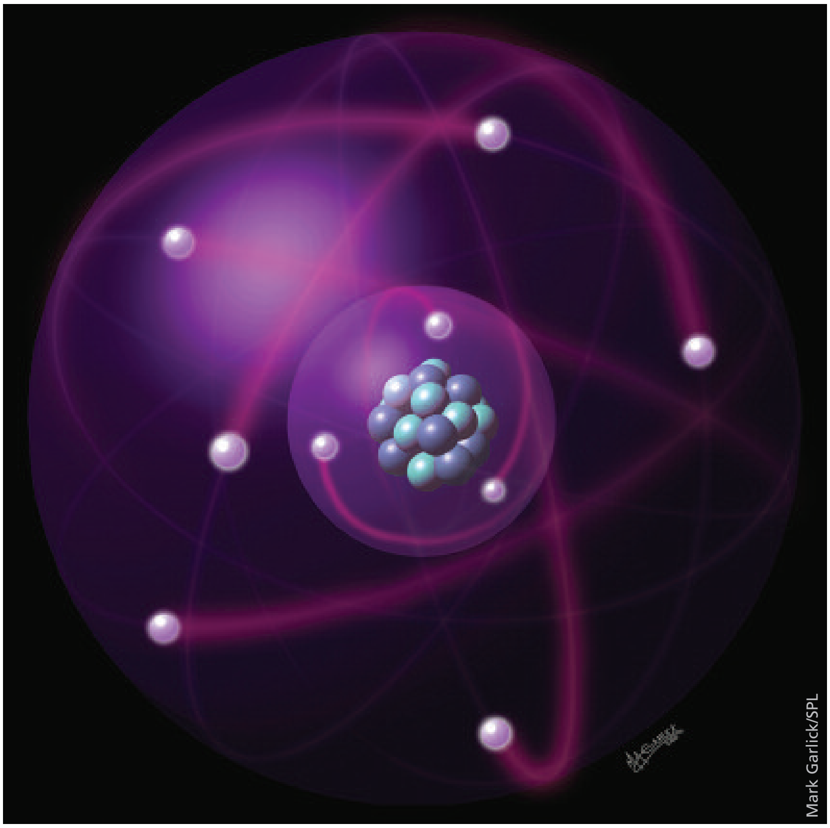
Figure 2 *J. J. Thompson's 'plum pudding' model of the atom. The electrons are like the fruit spread through a Christmas pudding*

BOX 1 TARGET PRACTICE

The apparatus for Rutherford's experiment is shown in Figure 3. Gold was chosen because it could be beaten into a very thin leaf about 400 atoms thick. This would ensure that the alpha particles would be scattered by a single gold atom.

Had the air not been pumped out of the apparatus, the alpha particles would not have reached the foil. Their kinetic energy would have been used up ionising the air, knocking electrons out of the air molecules. It is because they are so ionising that alpha particles only travel a few centimetres in air.

A microscope was fitted to a pivoted arm in order to measure the angle through which the alpha particles were deflected. The microscope was focused on a zinc sulphide screen that would fluoresce when struck by an alpha particle.



Artist's impression of atomic structure. The central nucleus is orbited by electrons — three in an inner shell and six in an outer shell. The sizes of the particles are not to scale — they would be much smaller in an actual atom

If the electrons really did orbit the nucleus in the same way that planets orbit the Sun then they would rapidly lose energy and spiral into the nucleus. The atom would collapse in a ten billionth of a second.

The nucleons themselves are believed to be made of even smaller particles called quarks.

really like a 'plum pudding' then the alpha particles should not have been deflected by more than 4° (see Figure 4). However, about 1 in 8000 alpha particles was deflected by more than 90°. This shocked Rutherford, 'It was quite the most incredible event that ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.'

A 'SOLAR SYSTEM' IN THE ATOM

Rutherford developed a theory and predicted what would happen if gold was replaced by a different metal, or if the thickness of the foil was changed.

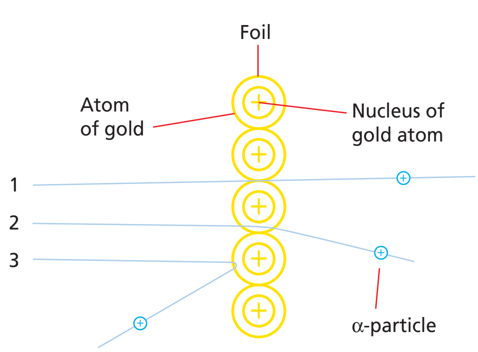


Figure 4 *What happened in Rutherford's experiment*

Table 1 *The properties of the particles inside the atom*

Sub-atomic particle	Relative mass	Relative charge
Proton	1	+1
Neutron	1	0
Electron	$\frac{1}{1840}$	–1

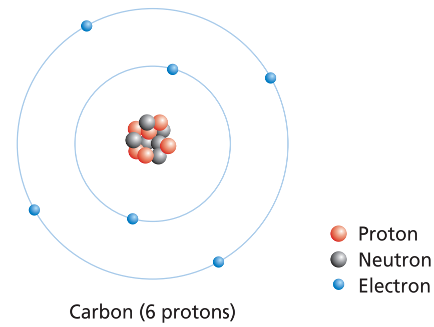


Figure 5 *The 'solar system' model for the atom*

The experiments performed by his assistants confirmed his theory that most of the atom is empty space. A new model of the atom was born, with negatively charged electrons orbiting a positive **nucleus**. The nucleus contains positive **protons** and neutral **neutrons**. If an atom were the size of a football stadium then the nucleus would be roughly the size of a pea placed in the centre circle and electrons would be like crisp packets being blown by the wind around the stands.

Table 1 summarises the properties of the particles inside the atom. It shows that the protons and neutrons carry all the mass. These particles, known collectively as nucleons, live inside the nucleus. Figure 5 shows Rutherford's model of a carbon atom.

Models of the atom are useful because they help us visualise something that is too small to see. Thompson's 'plum pudding' model explained how atoms could remain neutral even though they contained negatively-charged electrons. This model is rarely used now because Rutherford's 'solar system' model explains this and much more. It also shows that the atom is mostly empty space, with electrons orbiting the tiny nucleus in shells. Because all the positive charges are concentrated in the nucleus, where they are desperately repelling each other, it also hints at why nuclei fall apart or decay.

Bohr, a Danish physicist, modified Rutherford's model of the atom to explain how atoms absorb and emit light. In order to do this he treated electrons as waves instead of particles…but that is another story.

Mike Follows *teaches science at Sutton Coldfield Grammar School for Girls, and is a part-time science writer.*

NIGEL COLLINS

Photosynthesis

GCSE key words
Photosynthesis
Diffusion
Phloem
Xylem
Respiration

Plants are all around us. You know that most living things depend on plants, either directly or indirectly. But how much do you know about photosynthesis, beyond the basic equation? In this article we explore some of the basics but also take a detailed look at the intimate workings of the structures upon which life on Earth depends — green leaves.

The process of photosynthesis, by which plants make a range of biochemical compounds, is represented in Figure 1. It is important to realise that plants don't stop at making sugar (and starch). Almost all biochemical compounds are produced either directly or indirectly as a result of the activities of plants. The production of these compounds underpins growth.

PHOTOSYNTHETIC BASICS

Let us look at how photosynthesis actually ties in with growth. We must remember that respiration is happening all the time in all cells in all living things. Taken on its own, photosynthesis adds materials to the structure of a plant. By contrast, respiration causes a loss of materials. Neither process occurs at a fixed rate.

Plants need light for photosynthesis to take place. The rate at which they carry it out depends in part on light intensity. At low light intensities photosynthesis is slow. As the light intensity increases, so does the rate of photosynthesis. Often a limit is reached at which the plant cannot photosynthesise any faster — this is because there are other factors limiting photosynthesis — perhaps the supply of carbon dioxide or the temperature.

When plants are photosynthesising faster than they are respiring they are *adding* chemicals to their overall structure. When they are respiring faster than they are photosynthesising, there is an overall *loss* of chemicals from the structure of the plant. If you think carefully about this it means that the plant can shrink…well, sort of! Much of the structure of a plant is water, so the loss of biochemical compounds from the dry matter in a plant is neither noticeable to the naked eye nor easily detected, but it happens, nevertheless. Figure 2 summarises the relationship between photosynthesis and respiration in leaves as light intensity varies over 24 hours.

It is thought that the most common protein on Earth is the enzyme ribulose bisphosphate carboxylase-oxidase (RuBisCO for short) which is involved with trapping carbon dioxide during photosynthesis inside mesophyll cells.

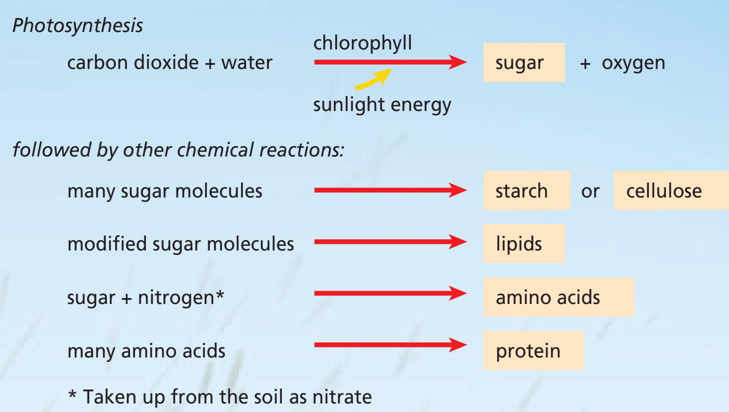


***Figure 1** Products of photosynthesis*

Right: *Coloured scanning electron micrograph of a fractured turnip leaf. The epidermis, palisade and spongy mesophyll cells can clearly be seen*

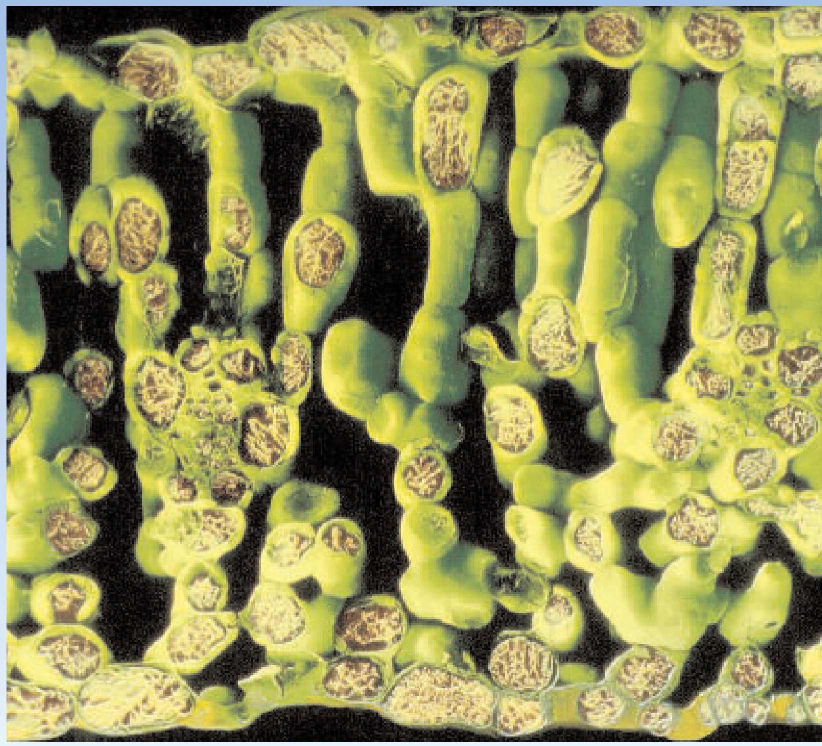
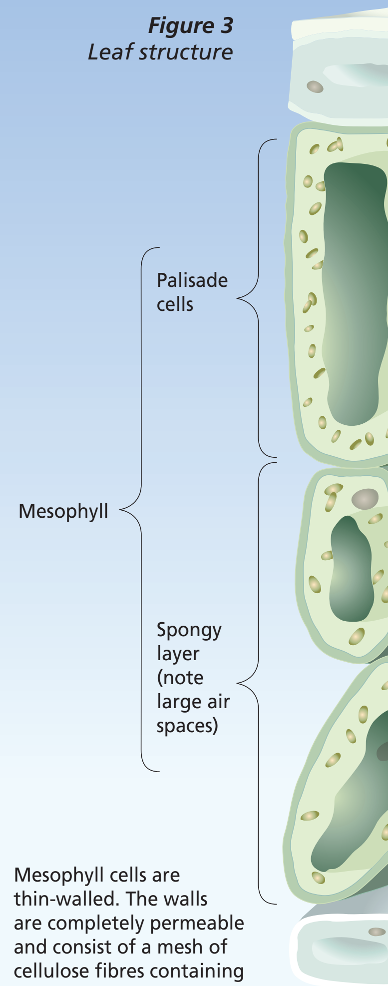

Dr Jeremy Burgess/SPL

Figure 3
Leaf structure



Mesophyll cells are thin-walled. The walls are completely permeable and consist of a mesh of cellulose fibres containing water, which evaporates into the air spaces. Oxygen and carbon dioxide can be dissolved in or released from this water without hindrance. The cell wall is tough, like a string bag or vest

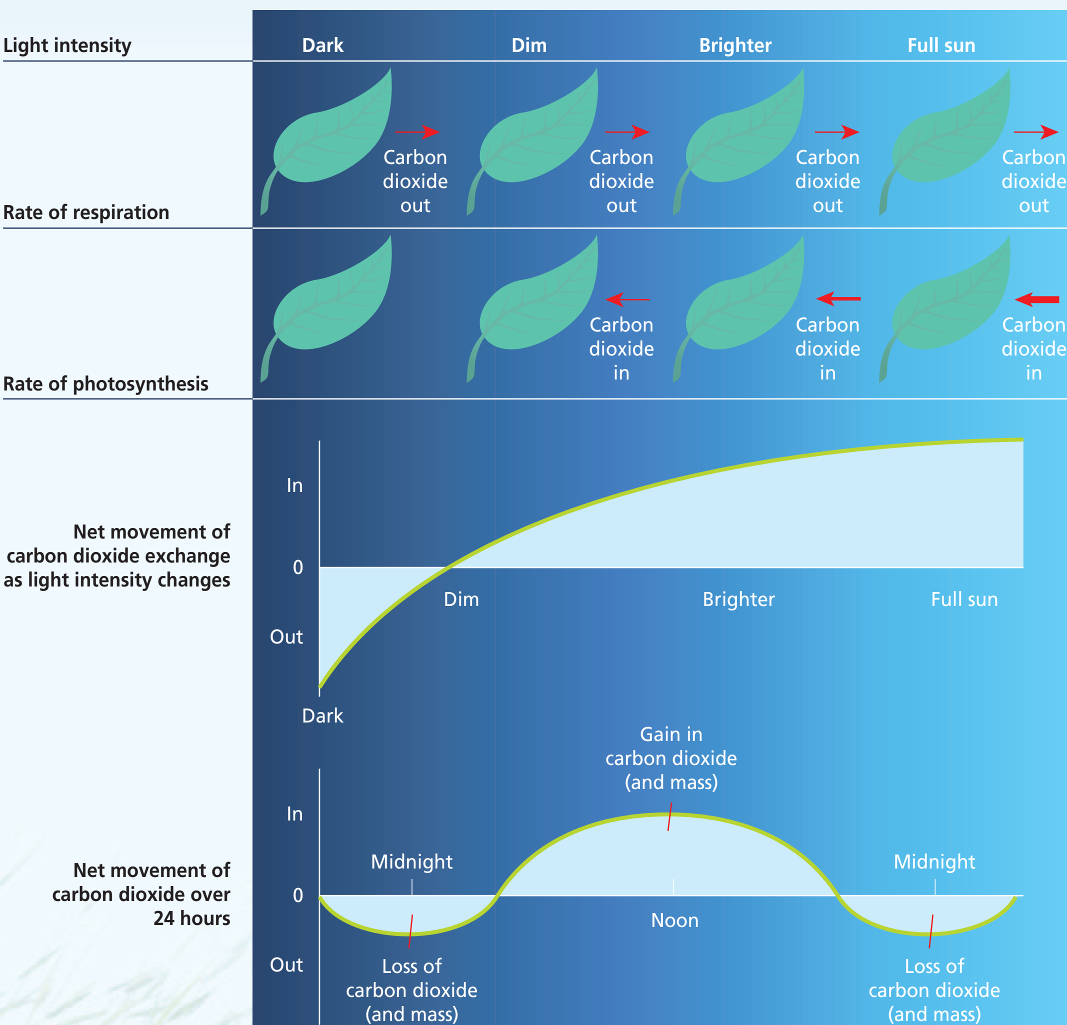
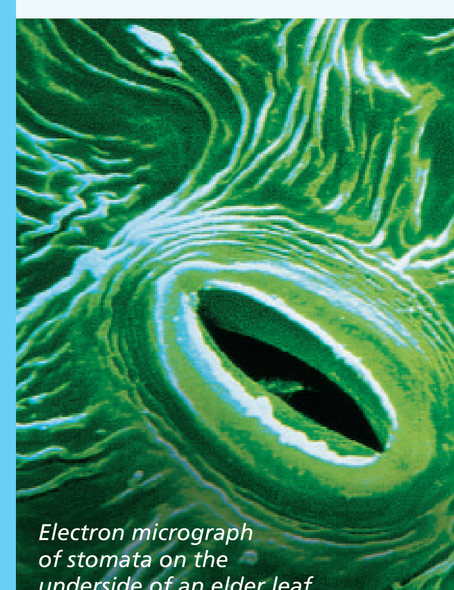
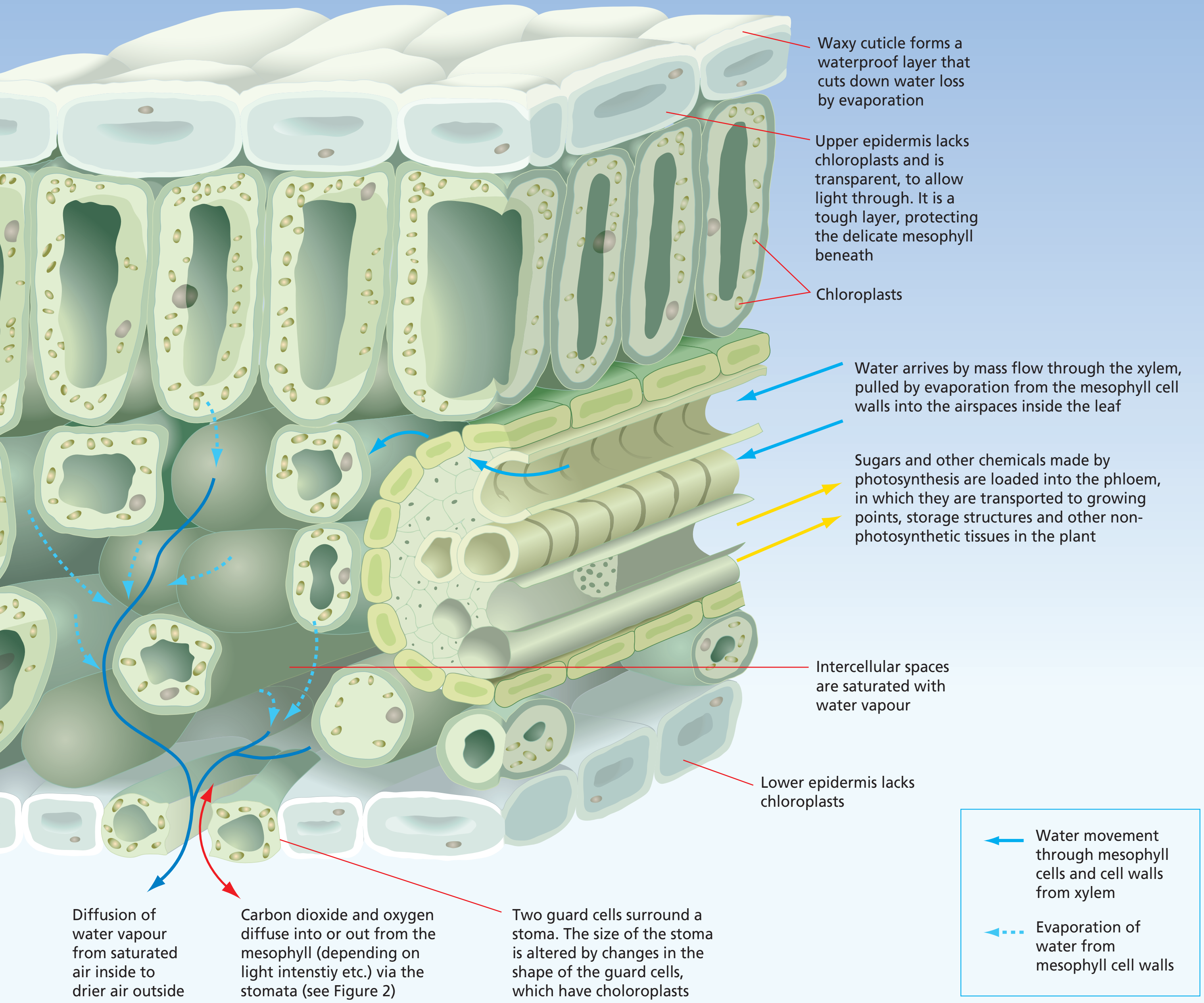
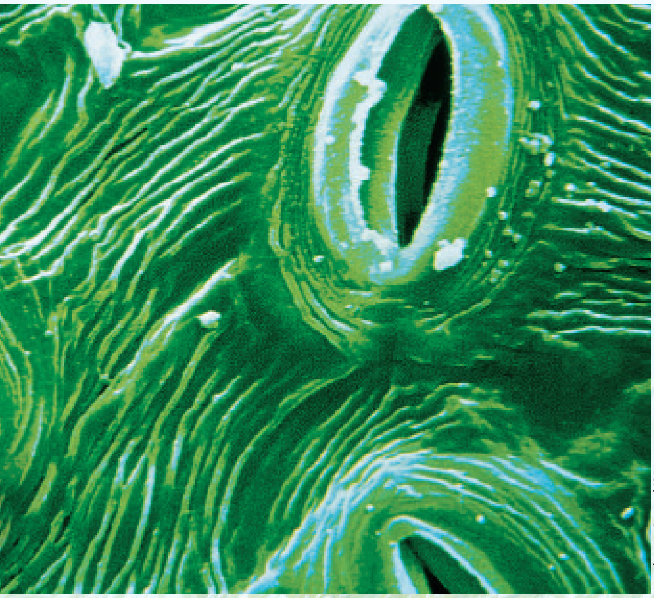


Figure 2 *The relationship between respiration and photosynthesis in leaves*


Electron micrograph of stomata on the underside of an elder leaf





Andrew Syred/SPL

LEAF STRUCTURE

Plants are multicellular organisms — some of them are huge, dwarfing the largest animals. As in all multicellular organisms with complex structures, there have to be some parts of the structure where they take materials in and give them out. However large the organism may be, these interfaces where exchanges occur with the surroundings are incredibly thin, delicate and potentially vulnerable.

In animals these surfaces occur in lungs, guts and the tubules inside kidneys. In plants they occur in the short-lived root hairs, near root tips that grow through the soil, and inside leaves, where mesophyll cells (literally the middle-leaf cells) are in contact with air spaces inside the leaves.

Nigel Collins teaches biology and is an editor of CATALYST.

Most details of the mechanism of photosynthesis were worked out in the first half of the twentieth century.

Mesophyll means middle leaf.

The plural of stoma is stomata.

Ingram

YOUR future

Geoscience

Above: *A geologist working for the British Antarctic Survey near Mount Jackson on the Antarctic Peninsula*

Geoscientists investigate the processes that have shaped the Earth through its 4600 million year history. They use the rock record to unravel that history. Their work often takes them outside the laboratory and has direct relevance to the needs of society.

Geoscience includes geology, geophysics and geochemistry — anything concerned with the structure, evolution and dynamics of the planet Earth and the natural mineral and energy resources it contains. Some geoscientists are interested in the other planets, working for example on materials from Mars.

Modern geoscience is founded on plate tectonic theory. This states that the outer part of the Earth (the **lithosphere**) is composed of a series of interlocking plates in relative motion. All major geological processes, such as mountain building, earthquakes and volcanic activity, are directly or indirectly caused by the motions of the plates.

The lithosphere consists of the Earth's crust and outer mantle.

WHAT DO GEOSCIENTISTS DO?

Geological survey and mapping

Geoscientists study and map the distribution of rocks exposed at the Earth's surface. They look at how the rocks are folded, fractured and altered by geological processes, and determine their ages. Geological maps and databases can then be produced. These are the basic tools needed for using all geological resources.

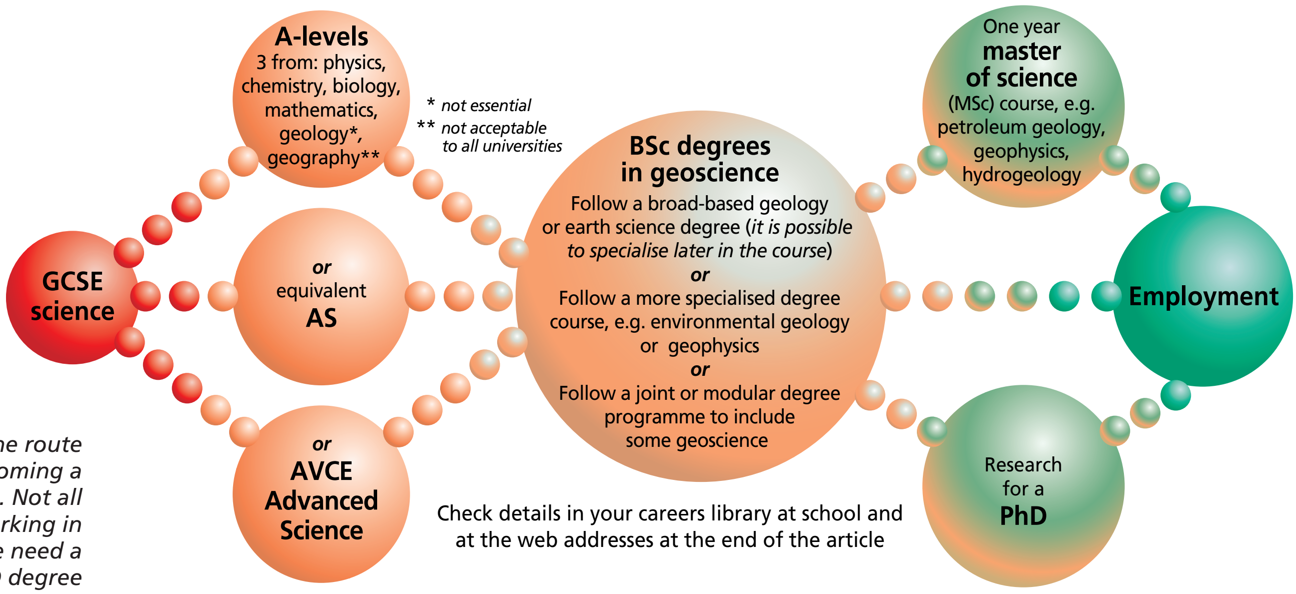


Figure 1 *The route to becoming a geoscientist. Not all people working in geoscience need a PhD degree*

Above left:
A geologist at work in the laboratory

Above right:
A palaeontologist sorting fossil teeth in a tent on Seymour Island, Antarctica

Energy supplies
Geoscience provides knowledge and understanding of how energy resources such as oil and gas, coal and uranium are formed and where they may be found. This is essential information when planning expensive exploration programmes. Geoscience is also involved in the search for sources of geothermal energy. Several types of rock act as heat reservoirs and in many parts of the world this heat is used as an energy resource.

Rocks as a natural resource
Rock itself is a raw material of immense importance. Its uses include:

- slates for roofing
- ornamental stone for facing buildings
- rock chippings for roads
- limestone for cement
- sand and gravel for aggregate
- clays for brick-making and pottery
- silica for furnace-linings
- gypsum for plaster
- rock salt for icy roads and, purified, for the table
- phosphorites for fertiliser
- metallic ores

The discovery, extraction and production of all these raw materials depend on the expertise of geoscientists.

Engineering geology
Major construction projects such as dams and tunnels depend on geoscientific investigation of local ground conditions. Geoscientists also advise on the design and safety of landfill sites and other environmentally sensitive developments. Seepage from landfill sites may pose a serious problem for the local water supply. Old mine workings may present a threat to buildings or may cause pollution, especially during floods, when solutions of heavy metals may be flushed into rivers. Underground storage sites for nuclear waste raise special environmental concerns because of the very long time period for which such waste must remain sealed and undisturbed. Geoscientists can offer expert advice on whether selected sites will be sufficiently safe.

Geology of water supplies
Water is the most important natural resource of all and much of the world's water comes from underground supplies. Geoscientists study the movement, behaviour and quality of groundwater, and potential sources of pollution. They design exploration programmes for new water supplies, especially in developing countries.

SOURCES OF INFORMATION

In your school's careers library:
CRAC Degree Course Guide: Geography and Geological Sciences, Hobsons Publishing.
Write off for:
Careers in Geoscience (leaflet), The Geological Society, Burlington House, Piccadilly, London W1V 0JU.
Visit these websites:
The Geological Society at: **http://www.geolsoc.org.uk**
British Geological Survey at: **http://www.bgs.ac.uk**
A link to all university courses in geoscience at **http://www.geolsoc.org.uk/template.cfm?name=university_links**

This article first appeared in C*ATALYST Vol. 8, No. 3 and has been updated for this issue. It is written by* ***Professor Mike Brooks****, Education Officer, The Geological Society, and is now part of the society's website.*

VALERIE
DRAKE

GCSE key words
Radioactivity
Isotopes
Half life

Decommissioning

As the first generation of nuclear power stations reaches the end of its useful life this article looks at what is involved in decommissioning them and how the process is affected by the properties of radioactive elements.

Above: *Cutting up components from a disused reactor to pack into a waste container*

The name magnox comes from the magnesium oxide casing of the uranium metal fuel.

The world's first use of nuclear energy to produce electricity on a commercial scale was in 1956 at Calder Hall in Cumbria. This paved the way for the magnox series of power reactors. These first-generation gas cooled reactors are now reaching the end of their useful life and a staged programme to close and decommission them has already begun.

WHAT IS DECOMMISSIONING?

Decommissioning is the series of activities through which a nuclear reactor is taken out of service. It may include operations such as decontamination of equipment and buildings, dismantling and demolition, management of the resulting wastes and restoration of the land under and around the reactor.

The processes involved in decommissioning are all complicated by hazards due to radiation. In the case of a magnox reactor the process is more difficult because there were a number of different designs and because, unlike modern reactors, they were not designed with decommissioning in mind.

WHEN DOES IT HAPPEN?

Decommissioning is generally carried out in a series of stages (see Figure 1). When a nuclear reactor reaches the end of its operating life, the nuclear fuel, any mobile nuclear material in the plant and the radioactive waste produced by the plant are usually removed immediately.

Certain other parts of the reactor can be taken out but this is not done straight away because it would

Figure 1 *Stages of decommissioning*

Operational phase	Stage 1	Stage 2	Stage 3
	Remove fuel and coolant Post-operational clean out Manage mobile radioactivity Remove non-fixed plant	Dismantle plant outside of biological shielding	Remove remainder of plant Return site to condition where no significant radioactive hazard remains

Plant shutdown → Time

Topham/PA

The queen in the turbine hall at the opening of Calder Hall, the world's first nuclear power station, 1956

UKAEA

Removing the heat exchanger through the dome of Windscale's advanced gas cooled reactor using the world's largest crane. The metal could not be decontaminated so the entire exchanger has been buried in low-level waste disposal (an engineered trench lined with concrete)

a nuclear reactor

UKAEA

BOX 1 TYPES OF RADIATION

Gamma rays are electromagnetic radiation with the speed of light. They have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used to stop them.

Beta particles are fast-moving electrons which travel at about 90% of the speed of light. They can penetrate up to 2 cm of human flesh. A sheet of aluminium a few millimetres thick can stop them.

Alpha particles consist of two neutrons and two protons and travel at about 10% of the speed of light. They have little penetrating power and can be stopped by a sheet of paper. However, if alpha emitting radionuclides are inhaled or ingested, the alpha particles can cause damage to the body's cells as they lose their energy quickly over relatively short distances.

Neutron radiation is very penetrating and requires thick barriers of concrete to stop it.

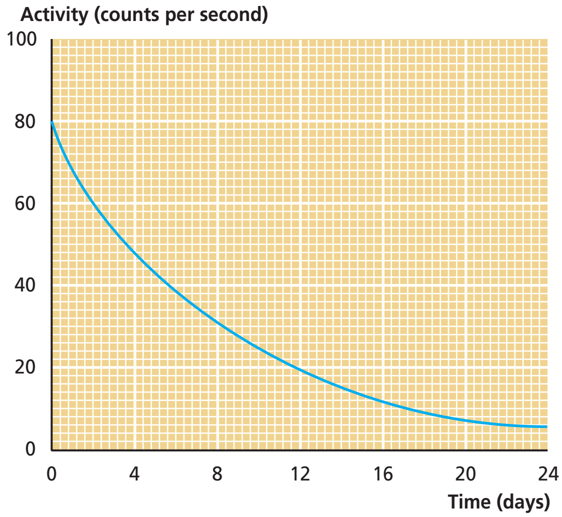


Figure 2 *Graph to show how radioactive decay changes over time*

Activation occurs when elements in structural components such as steels are changed to radioactive isotopes by neutron bombardment, e.g. natural Co-59 in steel can absorb a neutron to produce radioactive Co-60.

expose workers to unnecessarily high levels of radiation. These high levels result mainly from gamma-emitting radionuclides produced by **activation** of the construction materials of the reactor, especially the core, shielding and pressure vessels.

In magnox reactors the most dominant radionuclide is typically Co-60 in the activated steelwork. Co-60 has a half life of 5.27 years, so it will decay naturally in a few decades and there will then be a much smaller radiation dose to decommissioning workers (but see Box 3). If decommissioning had to be done immediately, robots could be used, but this would be more difficult and costly.

Radioactive decay is not the only factor to take into account when working out the time scale for decommissioning. Other safety factors are also important. **Conventional safety** includes assessing the structural stability of the reactor containment and support structures over the time period proposed. **Environmental factors** include consideration of the impact of radionuclides leaching into the environment and possible ways in which accidental releases of radioactive elements could occur.

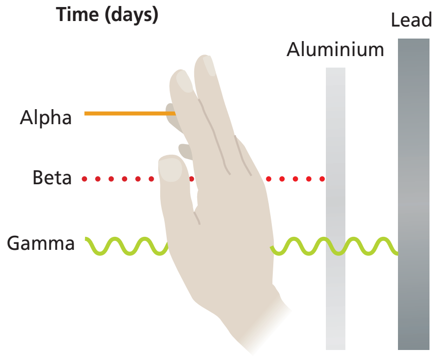


Figure 3 *The penetration of different types of radiation*

	Element	Half-life
	uranium-238	4.5×10^9 years
α		
	thorium-234	24.5 days
β		
	protactinium-234	1.14 minutes
β		
	uranium-234	2.33×10^5 years
α		
	thorium-230	8.3×10^4 years
α		
	radium-226	1590 years
α		
	radon-222	3.825 days
α		
	polonium-218	3.05 minutes
α		
	lead-214	26.8 minutes
β		
	bismuth-214	19.7 minutes
β		
	polonium-214	1.5×10^{-4} seconds
α		
	lead-210	22 years
β		
	bismuth-210	5 days
β		
	polonium-210	140 days
α		
	lead-206	stable

Figure 4 *Decay chain for uranium-238*

BOX 2 RADIOACTIVE DECAY

Radioactive decay is the process by which an unstable isotope changes into another isotope of a different element, or into a less energetic form of the same isotope by emitting alpha, beta or gamma radiation. If the decay product is also unstable, decay continues until a stable product is reached.

The rate of decay of a particular radionuclide is constant. The time taken for a quantity of a radionuclide to decay to half its original mass is called the **half-life** and is characteristic of that particular radionuclide. For example, the half-life of radium is about 1600 years, so 1 g of radium decays to 0.5 g in 1600 years and to 0.25 g in 3200 years. Of course the radium does not disappear — it changes into its daughter products. The total mass does not change appreciably, for the loss in mass in the form of alpha and beta particles is negligible.

Figure 4 shows the radioactive series for uranium and the way it changes to eventually become stable lead. Throughout the decay process, all the products remain in equilibrium with each other. The half-lives of the radioactive elements vary over a wide range: some are only fractions of a second while others are thousands of years.

BOX 3 IT'S NOT ALWAYS BEST TO WAIT

Radioactive decay may not always work to the decommissioners' advantage. Decommissioning a plutonium-contaminated laboratory, for example, is best carried out as soon as possible after the facility is shut down. This is because the plutonium decay chain (Pu-241 has a half life of 13.2 years) proceeds via a long-lived high-energy gamma emitter called americium-241 (which has a half life of 458 years). Over time this will build up, making decommissioning a more hazardous operation the longer it is left.

Table 1 *Advantages and disadvantages of deferring decommissioning*

Advantages	Disadvantages
Radiation doses to decommissioning workers are reduced	Need to retain knowledge of the plant over a long period
Opportunity to develop better or improved dismantling technologies	Need to maintain the facility in a safe and secure condition
The cost is deferred	Need to keep money available for a long time

An unstable isotope is called a radionuclide.

UKAEA

Workers underneath the main part of the Windscale advanced gas cooled reactor removing parts that might be contaminated

● **Find out about radioactivity on the BBC Bitesize website at: http://www.bbc.co.uk/schools/gcsebitesize/physics/radioactivity/index.shtml**

Some advantages and disadvantages of deferring decommissioning are shown in Table 1.

ACCELERATING THE DECAY PROCESS

Imagine if, instead of it taking hundreds or thousands of years for long-lived radionuclides to decay naturally, the decay process could be accelerated. Scientists, particularly in France and the US, are attempting to do just that using linear accelerators to bombard the radionuclides with neutrons and transmute them into non-radioactive elements. For example, long-lived technetium-99 will absorb a neutron to become technetium-100 which undergoes complete radioactive decay to stable ruthenium within minutes.

$$_{43}Tc^{99} \longrightarrow {}_{43}Tc^{100} \longrightarrow Ru$$

$t_{1/2} = 5.12 \times 10^5$ years $t_{1/2} = 17$ s   stable

Making the transmutation process work is technically very challenging and requires difficult chemical separations of the nuclides before it can begin. However, the goal of eliminating the radiological hazard from nuclear waste, just like the original alchemist's dream of transmuting base metals to gold, continues to spur on this type of research.

Valerie Drake is a Decommissioning Project Support Manager at UKAEA.

Flight control

To stay up in the air, an aircraft must be continuously pushing air downwards. This provides it with lift. But how can an aircraft be made to change direction?

WARPING

There are two ways of doing this. The first, called **warping**, was the method used by the Wright brothers and other early aviators. They pulled on cables to twist the wings of their aircraft. One wing was twisted downwards, the other upwards, and the craft turned gently to one side.

You can see this effect using a paper aeroplane (a paper dart). Make a dart, and fly it. Now pull one wing between two of your fingers, bending the wing so it curves *downwards*. Repeat with the other wing, but make it curve *upwards*. Use your understanding of forces to predict how the dart will fly; then test your prediction.

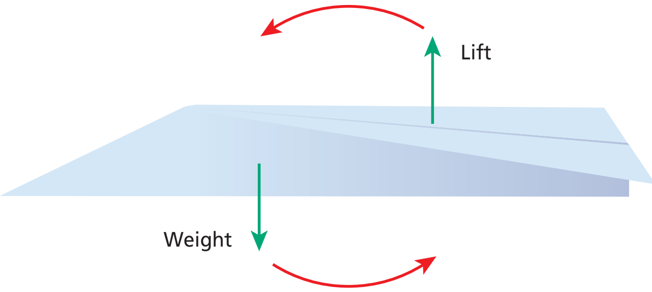


Figure 1 *Aircraft designers have to think about where the forces act on a plane. Here you can see that the forces of lift and weight will have a turning effect, causing the dart to tip forwards*

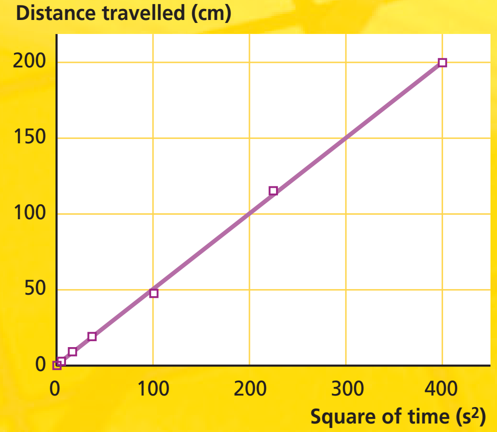
WING FLAPS

The other method, found in most modern aircraft, uses flaps ('**control surfaces**') on the wings. Tear or cut the back edge of each wing of your dart, so that you have flaps which you can bend up or down. How can you make the dart veer towards the right? What happens if you bend both flaps upwards?

David Sang

Answer to Improve your Grade, page 7

Graph of time squared against distance rolled for a ball rolling down a slope



Answer to web quiz, page 7

Henri Moissan (fluorine)

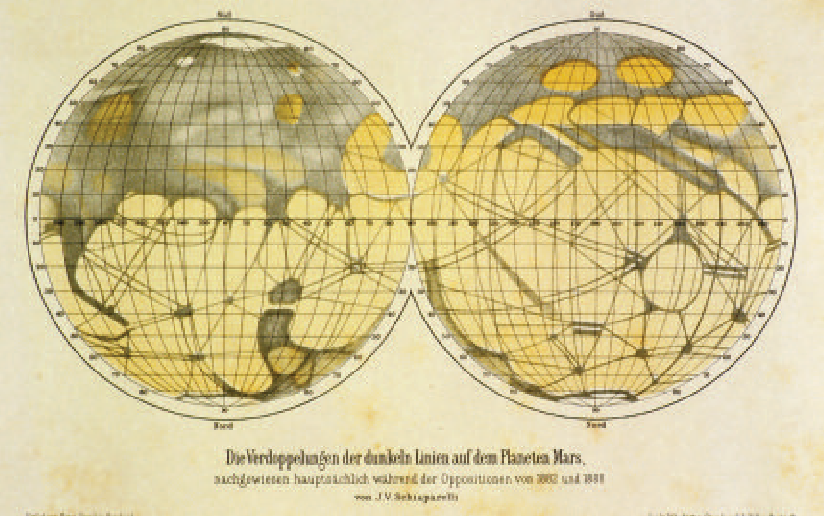
DAVID SANG

http://beagle2.open.ac.uk

Mars Express

GCSE key words
Ideas and evidence

The idea of life on Mars has intrigued scientists for centuries. The Mars Express mission aims to find out more.



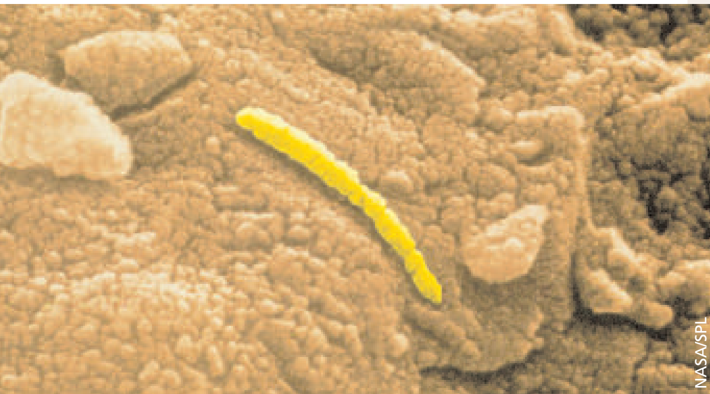
Detlev van Ravenswaay/SPL

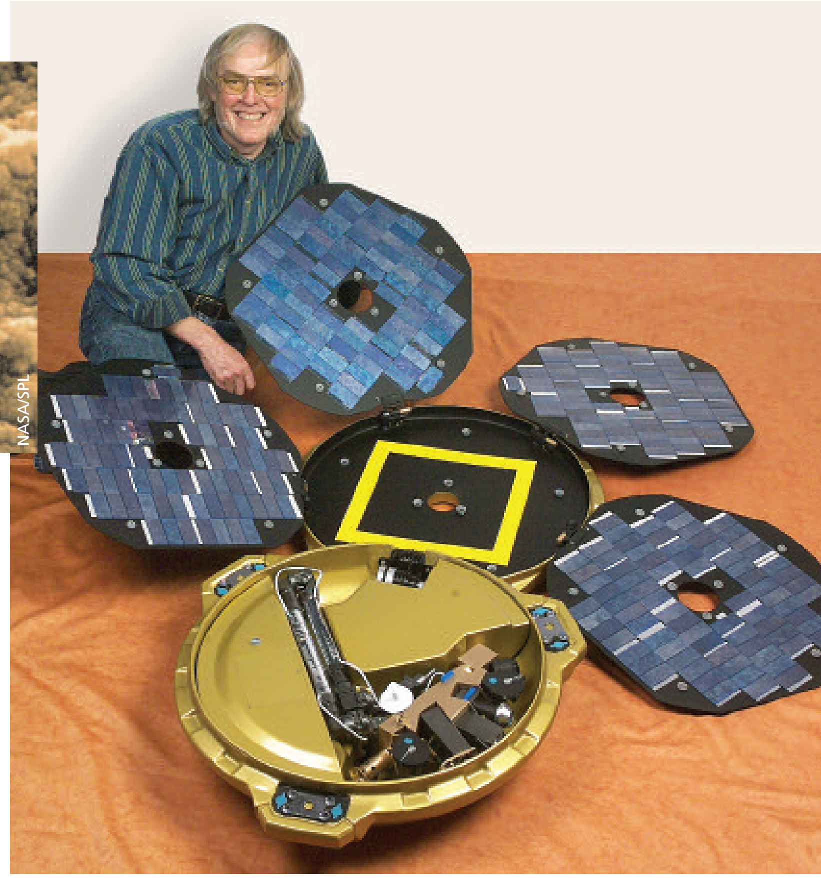
A map of the surface of Mars made by the Italian astronomer Giovanni Schiaparelli between 1882 and 1898. Schiaparelli called the straight surface features canali, *and noticed that the patterns on the surface changed with the Martian seasons. He wrongly assumed this to be due to seasonal changes in vegetation. It is now known that Mars is swept by powerful dust storms which alter the surface features*

On 2 June, at 6.45 p.m., the Mars Express mission blasted off from the Russian launch site at Baikonur in Kazakhstan. This is the first European mission to another planet. It is due to reach Mars on Christmas Day — look out for the nail-biting moments as the UK-built *Beagle* 2 lander descends to the planet's surface!

Nineteenth-century astronomers had telescopes which were good enough to allow them to see some detail on the surface of Mars. In 1877, Giovanni Schiaparelli drew maps showing what he thought were channels — *canali* in Italian. Unfortunately, English-speakers translated this as canals, and decided they were evidence of major engineering works on the planet. They thought that the canals linked major Martian settlements, and that they carried water from the wetter poles to the deserts close to Mars's equator.

Better telescopes showed that this was simply wrong, an incorrect interpretation of limited information. However, even in the 1960s, many scientists believed that Mars might be a lush planet supporting life similar to that on Earth. The first spacecraft to visit the planet, *Vikings* 1 and 2 in 1976, showed that the surface of Mars, at least, is dry and rocky.





Above: Professor Colin Pillinger, the scientist leading the Mars Express project, with a model of *Beagle 2*

Above: *False-colour scanning electron micrograph showing a tube-like structure found on a meteorite which came from Mars. These structures could be fossils of primitive microscopic organisms that lived on Mars more than 3.6 billion years ago*

Left: *A simulation of* Beagle *2 on the surface of Mars*

A SHORT TRIP

Mars Express is called 'express' because it has been designed and built quickly, not because it will be travelling especially quickly. In fact, its cruising speed is about 10 800 km/h. It has been built to catch a window of opportunity, as Mars's orbit brings it close to Earth, something which happens roughly every 22 months. This means that the distance it has to travel is at a minimum. Even so, it will take over 6 months to complete its journey of over 75 million km.

The spacecraft was launched on a large Soyuz rocket. An extra stage, the Fregat ('freight'), was needed to carry the craft, which is about the size of a small car. The craft is in two parts:

- the orbiter, which will travel around Mars
- the lander, *Beagle* 2, which will drop down to the surface

The orbiter carries seven different instruments which will look at such things as the land surface, minerals and the planet's atmosphere. It will also take high-resolution stereo photographs. At the same time, it will upload data from *Beagle* 2 and radio it back to Earth.

MINIATURE DEVICES

Beagle 2, designed by a team based at the Open University, is a remarkable device. The developers were told that there was a limit of 60 kg within which they must work. The instruments they felt they needed would normally occupy a large lab; they have been miniaturised and automated within the limit set by the European Space Agency (ESA).

On Mars *Beagle* 2 will be able to analyse gases and rocks. It carries a range of environmental sensors and a stereo camera, and it will even be able to dig down below the soil surface to collect rocks unaffected by the Martian atmosphere. All this is contained in a package less than 1 m across.

SIGNS OF LIFE

What will *Beagle* 2 be looking for in the materials it samples? Surprisingly, we already have samples of Martian rocks to examine. These arrived in the form of meteorites. It seems that, at some time in the past, a major collision, perhaps with a comet, blasted rocks from the surface of Mars. A few pieces ended up on Earth, attracted by its gravity, and have been collected. These meteorites have a different composition from others, suggesting a different origin.

There was great excitement in 1996 when NASA scientists announced that they had found traces of ancient life, similar to earthly bacteria, in one of these meteorites. There was also great scepticism, and everyone agrees that more evidence is needed to confirm the hypothesis. Hence *Beagle* 2. It will look for oxygen and methane in the atmosphere — since methane is readily oxidised, any free methane would be a sign of an existing source.

It will also measure the proportions of different isotopes of carbon in the soil and rocks. On Earth, living organisms tend to have a higher proportion of the lighter isotope, carbon-12, than is generally found. Rocks formed from living material therefore have more carbon-12. If this is the case in the Martian rocks it will be a sign that Mars once supported life.

Mars Express is a project of ESA, the European Space Agency. ESA has 15 member states, including the UK.

- **Find out more about Mars and the Mars Express mission at http://www.new-media.co.uk/space/**

Stealth technology

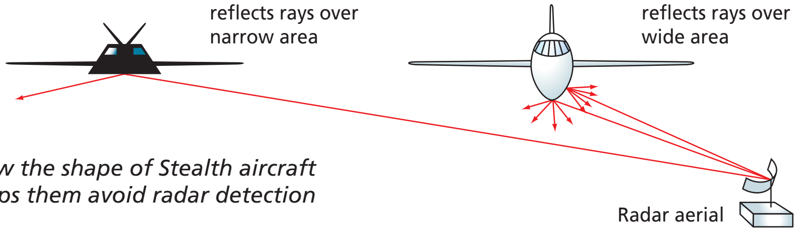
The F117 Stealth Fighter and the B2 Stealth Bomber played a major role in the Iraq War earlier this year. These aircraft can fly undetected into and out of enemy territory. How do they do this?

Radar tracking systems on the ground pick up reflected beams of radio waves. Aircraft can also be spotted by detecting the infrared radiation from their hot engine exhausts. The F117 Stealth Fighter is designed to overcome these problems.

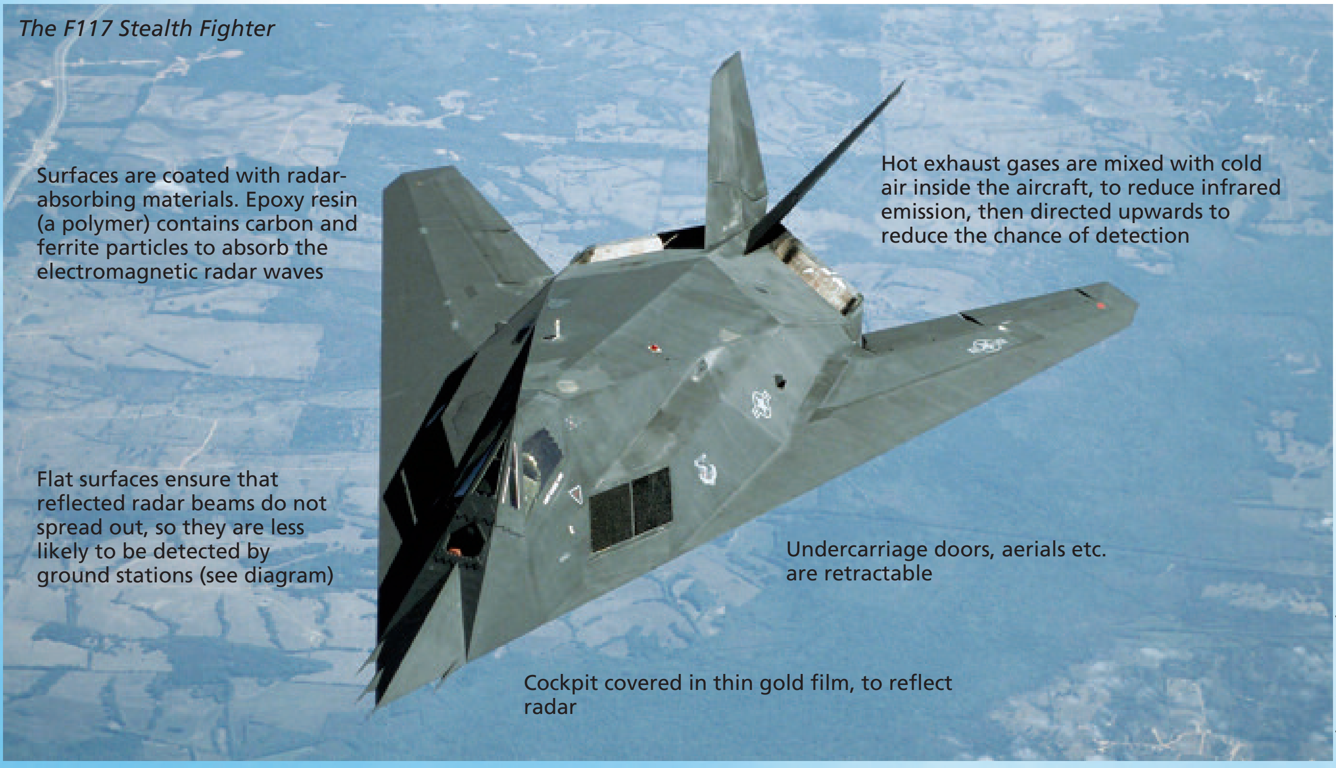
The same technology can be used to design tanks which evade detection by radar or laser beams. The photograph on the right shows an AMX 30 tank, with flat surfaces to limit radar reflections. Also shown is a drone, a type of robotic vehicle which can be sent into dangerous areas to undertake surveillance missions. Its camera can detect visible light and infrared radiation. The cage structure around the drone ensures that, if it topples over, it can right itself automatically.

Stealth technology is not only used on aircraft

Philippe Psalia/SPL



How the shape of Stealth aircraft helps them avoid radar detection



The F117 Stealth Fighter

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