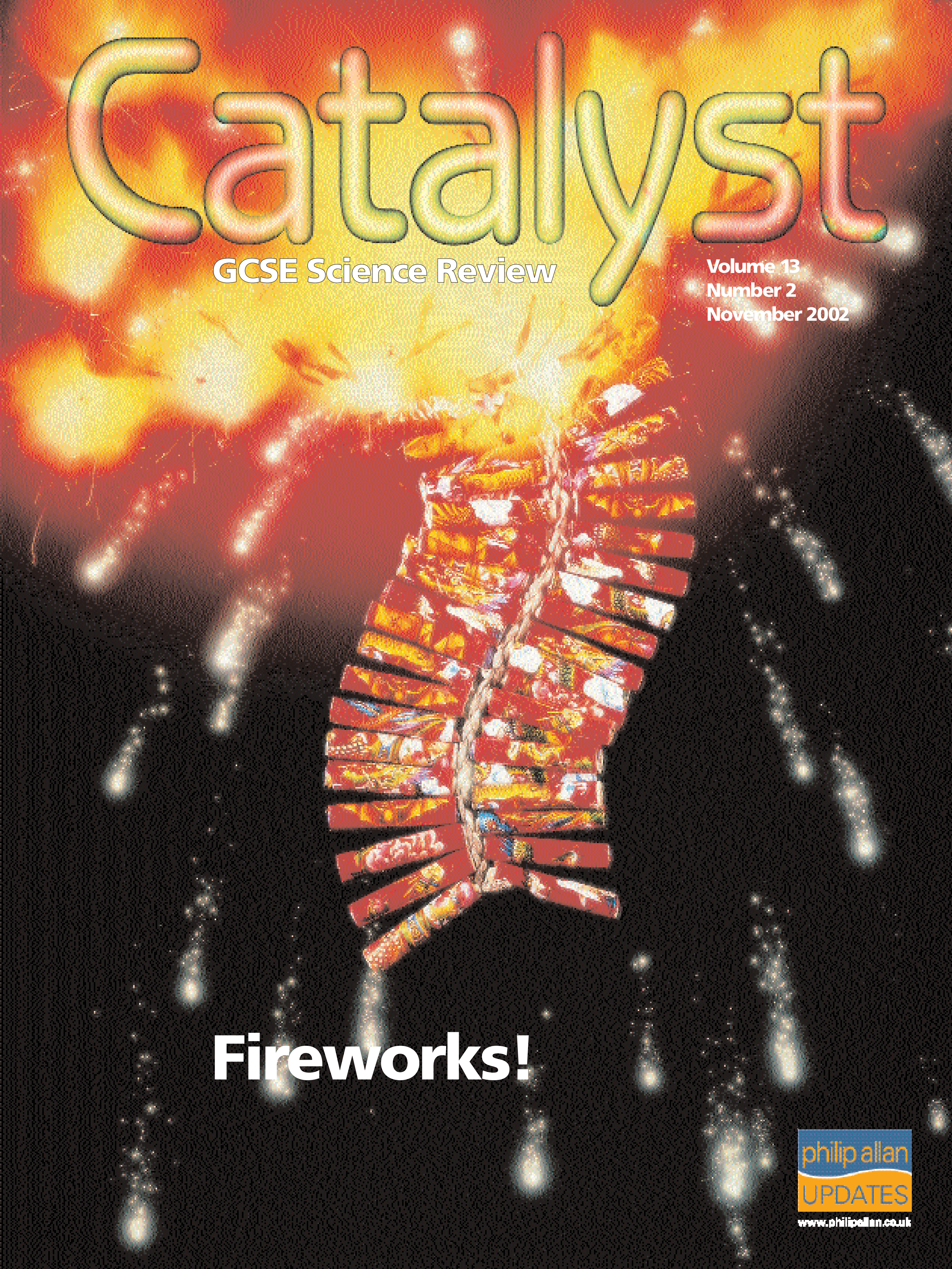

Catalyst

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Fireworks!

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The front cover shows a firecracker exploding (Erich Schrempp/SPL).

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Editorial

Don't be a damp squib!

Exams are a bit like fireworks. You wait all year for them to happen. Then suddenly there is a very busy spell, after which they are all over and you can look forward to the next time they come round. But why are we thinking about exams now — surely they are not until next June? Well, just as a good firework display needs good preparation, so do exams. It's no good just turning up on the day and expecting things to go well.

All exams — whether they are mocks or GCSEs — need preparation. CATALYST can help you with this. With this issue you receive your useful *GCSE Science Essential Word Dictionary*, written by editors of this magazine. The entries are topical and up-to-date. Use your dictionary as part of your reference material and to help when answering tests and questions.

In this issue of CATALYST there are useful articles in all three sciences as well as a section on examination technique. Read the articles well — they will help you to understand a topic better, or give you another way of looking at a particular subject.

Newton's third law underpins many of the articles in this issue — whether it be in forces for propelling rockets and fireworks, the movement of satellites, or the explosive force of dynamite. Even the movement of animals involves this law. Don't become narrow-minded and think that the three sciences exist on their own — they are all interconnected and what you read in one article may help you understand what is mentioned in another on a quite different subject.

Don't be like a damp squib — work at things and go out in a blaze of glory!

David Moore

RONALD LANCASTER

Fireworks

An explosive business

GCSE key words
Combustion
Oxidation
Compounds
Flame tests

Kimbolton Fireworks

Above: *Kimbolton Fireworks gained first prize at an international fireworks and music competition in Cannes in 2001. Displays on three barges 300 m out to sea were synchronised by a computer on the promenade.*

Fireworks have been known for many hundreds of years. What gives them their particular colour or effect? How are they made and how are they set off? This article includes some basic chemistry relevant to your GCSE science course — with an explosive twist.

Fireworks are an explosive combination of colour and noise. Whistles, bangs and humming noises combined with many different kinds of light effects give pleasure and delight to thousands of people all over the world. Although fireworks were invented hundreds of years ago they have developed as science has progressed, particularly over the last 200 years.

Mary Evans Picture Library

Left: *The Gunpowder Plot in 1605 was a famous but unsuccessful attempt to blow up the king and parliament, still celebrated with fireworks made from gunpowder.*

IN THE BEGINNING

Many people think that fireworks came from the Far East, but this is only part of the story. It was the West which taught the East how to make modern fireworks.

Gunpowder was, undoubtedly, discovered in China. The people who made it were not looking for gunpowder but for the 'elixir of life'. They mixed together various salts, some of which must have been nitrates, with charcoal, honey and eventually sulphur, and found that this mixture caught fire readily.

By AD 800 gunpowder had been produced in a form similar to that we use today. It is pretty certain that Arabs brought it to Europe in the thirteenth century. This mixture of potassium nitrate, charcoal and sulphur has a long history, but the Chinese did not use it in weapons, instead they made it into firecrackers. The powder was packed into bamboo tubes and thrown on to the fire so that it exploded and scared away evil spirits. Such crackers are still made today, and are traditionally covered in red paper, which has a spiritual significance.

Nitrates contain the group (NO_3^-).

12 g of charcoal (about 6 cm^3) when completely burnt produces 24 000 cm^3 of gas. If this expansion occurs quickly enough it can be used to propel shells or to cause an explosion.

INTRODUCING COLOURS

Potassium chlorate is $KClO_3$, potassium perchlorate is $KClO_4$.

Fireworks as we know them today are a comparatively recent invention. Some were made with gunpowder before 1800, but they could only burn gold or white and consisted mainly of rockets, bangers and gold or white fountains. The charcoal and the sulphur burn in the oxygen provided by the potassium nitrate (an oxidising agent) to provide golden flames. By-products include gases such as carbon dioxide and sulphur dioxide and some solid potassium compounds. It is mainly the charcoal which produces the gold colour.

The best blue 'stars' were originally made with an easily-decomposed pigment called Paris green. It was made by boiling arsenic oxide with copper sulphate and then precipitating the pigment with ethanoic acid. It is impossible to buy this pigment today because of its toxicity.

Nitrates of barium and strontium provided some other colours, but the discovery of potassium chlorate (another oxidising agent) by Berthollet in 1794 changed everything. By 1820 European firework makers were producing fine coloured fireworks, but they were very dangerous because potassium chlorate is an unstable compound and, when mixed with sulphur, can spontaneously combust. It did this many times, causing serious accidents, before the more stable potassium perchlorate came into use to supply the oxygen.

BOX 1 FLAME TESTS

Flame tests are used to show whether certain metal ions are present in a compound. A tiny sample of compound on a piece of platinum (or nichrome) wire is placed in a non-luminous bunsen flame. The energy of the flame causes electrons in the metal ion to rise to higher energy levels, and as they fall back to their original level they give out specific frequencies of light.

Metal ion	Colour
Lithium	Deep red
Sodium	Persistent yellow-orange
Potassium	Lilac
Rubidium	Red
Caesium	Blue
Calcium	Orange-red
Barium	Pale green
Copper(II)	Blue-green

Deliquescence is when a chemical absorbs water from the atmosphere.

Many street lights contain sodium — hence their colour.

Kimbolton Fireworks

BOX 2 CONGREVE ROCKETS

Around the end of the eighteenth century rockets experienced a brief revival as a weapon of war. Indian rocket barrages were used against the British in 1792 and again in 1799. These caught the interest of an artillery expert, Colonel William Congreve, who set out to design rockets for use by the British military.

Congreve rockets were highly successful in battle. They were used by British ships to pound Fort McHenry in the 1812 war against the USA, and this inspired Francis Scott Key to write the line 'the rockets' red glare,' in his poem that later became 'The Star-Spangled Banner' — the US national anthem.

It was not long before the isolation of magnesium and aluminium (due to the development of electrochemistry) allowed manufacturers to produce brilliant silver fireworks. More recently titanium has become available and has the same effect.

The range of colours used to be restricted to red, blue, green, yellow and white. High temperature flames have now been developed with the addition of either magnesium or magnesium–aluminium alloy, known as magnalium alloy, which corrodes much less easily than magnesium alone. These have made possible intermediate colours such as citron (between green and yellow), turquoise (between green and blue) and rich oranges and violets.

HOW IT WORKS

Colour occurs in the flame due to the formation of halides, but these are unstable and only exist in the flame itself. The best colour emitters are strontium(I) chloride (SrCl) which produces red, copper(I) chloride (CuCl) for blue and barium(I) chloride (BaCl) for green. Sodium atoms produce yellow quite powerfully, and traces of sodium can overwhelm any other colour present. Blue has always been the most difficult colour to produce because the copper chloride molecule is easily destroyed in high-temperature flames.

Most coloured fireworks consist of four main components with a number of additives. The oxidising agent potassium perchlorate provides the oxygen, the fuel is normally a gum resin such as shellac from India or gum yacca (acaroid resin) from Australia. The colouring agent is the insoluble salt of the appropriate metal. Insoluble salts are chosen to avoid chemical reactions which produce deliquescence. In addition there is the halogen donor and sometimes starches to slow down the burning rate or to act as an adhesive for making pellets which burst as stars.

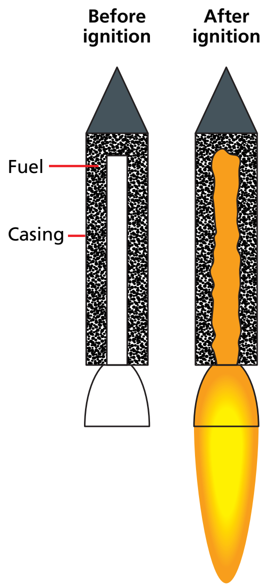


Figure 1 How a rocket works.

Above: *Kimbolton Fireworks setting up a display on the Thames.*

INTO THE AIR

There are four main kinds of fireworks: rockets, roman candles, fountains and shells, but there are literally hundreds of variations of each type.

Rockets have been made for a few hundred years, not only for pleasure but also as weapons (Box 2). The gas produced in the rocket motor issues from the end with great force and the flight of the rocket is guided with a stick, fins or additional stabilising jets (see Figure 1). The payload of stars is ejected at the apex of their flight, but rockets cannot carry large payloads.

Shells are packages of paper — either compressed papier-mâché spheres or paper cylinders bound with cord (see Figure 2). They are propelled into the air by a lifting charge of gunpowder. The mortars from which shells are fired can be made of paper, polyethene or fibreglass. In earlier times steel was used, but this is dangerous if the mortar bursts. In about 1926, Aoki in Japan developed the modern chrysanthemum shell which has produced some of the most innovative shell patterns in recent years.

The roman candle is a very English kind of firework and consists of a long narrow tube. Stars or small bombettes are fired out of the tube at intervals, using some form of delay mechanism between each shot.

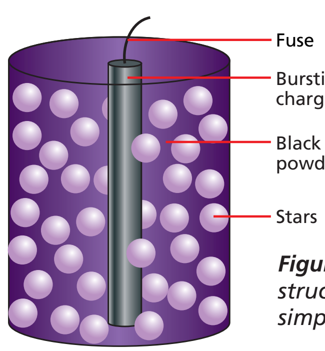


Figure 2 The structure of a simple shell.

BOX 3 SAFETY

All fireworks are potentially dangerous. They must be handled only as instructed on the packaging. No attempt should be made to 'investigate' or dismantle any firework. Do not attempt to make your own fireworks — it is dangerous and illegal.

SETTING OFF

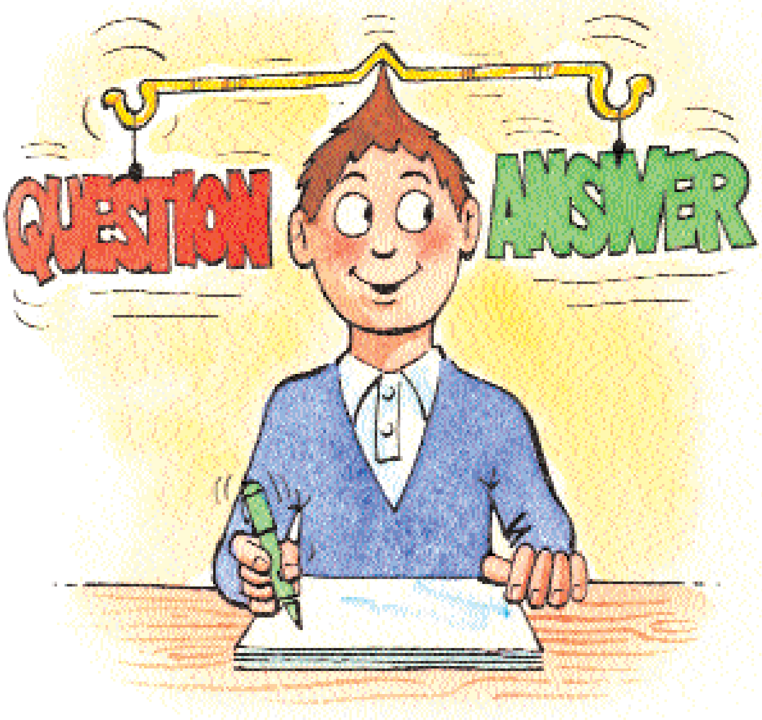
Large firework displays require a lot of skill and time to set up. Many displays are now fired with electric matches which are expensive, but allow multiple firing alongside pyrotechnic delay systems. Computer-fired systems are also available at considerable expense but they do not always work well in poor weather conditions. A good, experienced operator can fire perfectly well by hand without electricity.

Fireworks continue to give pleasure to many people, whether in large public displays or your own back garden. As they are partly based on good old blackpowder it is doubtful whether modern science will be able to enhance them further — but only time will tell.

Below: *The Reverend Ronald Lancaster, with some of his products.*

The Reverend ***Ronald Lancaster*** *taught chemistry and religious studies for many years and is now managing director of Kimbolton Fireworks, the UK's principal manufacturer of display fireworks.*

I knew the answer
so why did I only get 1 mark?



In the last Improve Your Grade we looked at revision. Once you have learned your work thoroughly the battle is half won. This time we deal with how to get maximum marks for the answers you write. Exam technique is all about understanding what is required in an answer. The examination paper itself gives you clues about what, and how much, you should write.

TIMING

Examiners don't just sling together the first 20 questions they come across. They construct a paper with the right number and length of questions. This should allow you a few minutes to read the paper carefully before beginning, time to write appropriate answers to all the questions on the paper and a little time left over to check your answers.

If you often *run out of time* in exams you need to ask yourself if you are trying to put too much into your answers. You may need to be more selective. Instead of 'carpet-bombing' the examiner with every fact you know, choose just the information that is pertinent to the question. You may be penalised if you include irrelevant material — and you haven't the time to write it. *Don't* make the same point in two different ways, and *don't* rewrite the question.

If you *finish your paper* a good while before the end of the exam:

- you are very knowledgeable and write concisely — and there are a lot of very good students around; or
- you haven't written enough in your answers — read the advice in the next section; or
- you haven't learnt enough to write a proper answer — in which case get on with it now!

HOW MUCH SHOULD YOU WRITE?

Questions carry between 1 and 4 marks. The number of marks is a good guide to the number of points you should make in your answer, and whether you should be writing a sentence or a paragraph.

WHY ISN'T THERE ENOUGH SPACE FOR MY ANSWER?

The space given for answers is enough for someone with average handwriting to write a full answer — and have a little bit of space left. Bigger handwriting will just about fit. If you have to write in the space underneath or in the margin then you are going wrong. Students often waste time and space by repeating or rephrasing the question. You are encouraged to do this when answering homework questions because it gives you more information when you look back through your exercise book. However you don't have the space or time to do this in the exam — just go straight into the answer. Example 1 shows a better start to an answer.

EXAMPLE 1

Q **Bile is a juice that helps to digest food in the small intestine. Explain how. (3 marks)**

A1 *Bile helps digest food in the small intestine because…*

A better start would be:

A2 *Bile breaks down the food to give it a larger surface area.*

SHORT ANSWERS

Some questions are very straightforward and require just one word or a phrase as an answer, for example:

Q **Name one organism in this food web which is both a primary consumer and a secondary consumer.** **(1 mark)**

A *Water fleas.*

But if the question includes words such as 'describe' or 'explain' you must answer in whole sentences. Example 2 shows you how.

EXAMPLE 2

Q **Describe one way in which the dolphin is adapted for life in the water.** **(1 mark)**

A1 *Its shape.* (0 marks)

A2 *A dolphin has a smooth streamlined shape that allows it to move rapidly through the water with least resistance.* (1 mark)

Notice that in answers like these it's not enough to say 'it has a streamlined shape'; you need to add the *reason why* this makes it better.

YOUR ANSWER DIDN'T QUITE MAKE IT

Each exam paper has questions that require you to give fuller answers with reasons. To get the marks you may need to make two points and give explanations for both, for example:

Q **Explain how walls made of concrete blocks help to keep a room warm.** **(2 marks)**

Your answer should explain that concrete blocks have trapped air bubbles and that air is a good insulator that reduces heat transfer through the block, or that the air is trapped and that this reduces heat lost by convection.

A lot of students write factually-correct information but fail to get full marks because their answers are too general, include irrelevant material or miss out a crucial phrase.

For example, in a question about changes in the rate of reaction and production of gas when a fixed amount of acid reacts with plenty of limestone, your answer must refer to changes in the frequency of *collisions*, because this is what the rate is. Example 3 illustrates this. Example 4 looks like a great answer from a good student — but it only gets 2 out of 3 marks. Read the commentary on the answer.

Don't forget, when you are asked to do a calculation *always write down your workings*, even if you are using a calculator. You can get a mark for correct procedure even if you make an arithmetical error.

Finally, 3 and 4 mark questions require you to write a paragraph making several points. With these sorts of questions you may be able to make five or six points, but it is better to cover four properly than just to list things. These questions cover broad topics such as the effects of acid rain on the environment, the nitrogen cycle, the effects of pesticide use on food webs or insulation in a house.

Though you may be tempted to write an essay, don't. You have several lines so you need to make each point in one and a half lines.

EXAMPLE 3

Q (refers to a graph of amount of gas produced as limestone reacts with acid) **Explain why the rate of reaction changes during the experiment.** **(3 marks)**

A1 *It slows because there is less acid.*
(1 mark for 'slows')

A2 *The rate slows down because the concentration of acid decreases during the reaction and there are fewer collisions per second.*
(3 marks for 'slows', 'acid concentration decreases', 'fewer collisions per second')

EXAMPLE 4

Q **Bile is a juice that helps to digest food in the small intestine. Explain how.** **(3 marks)**

A *Bile breaks down the food so it has a larger surface area. It is easily digested then. It breaks down fat. It is made in the liver and is stored in the gall bladder. Enzymes break down large molecules to smaller molecules.*

Let's look at this answer from the examiner's view point.

Bile breaks down the food so it has a larger surface area (1 mark given for 'increasing surface area'). *It is easily digested then* (no explanation of why — it allows enzymes to work on the fat molecules — so no mark given). *It breaks down fat* (1 mark given for the idea of helping to break down fats). *It is made in the liver and is stored in the gall bladder* (true but not relevant to the question so no mark). *Enzymes break down large molecules to smaller molecules* (true but bile is not an enzyme — no mark).

This candidate could easily have scored another mark by mentioning that bile emulsifies fats, or that it neutralises acids from the stomach.

EXAMPLE 5

Use what you have learned to decide which is the better answer.

Q **Describe the type of orbit used by weather satellites, and explain why this type is used.** **(3 marks)**

A1 *A polar orbit is used, so that the satellite observes different areas as the Earth rotates. A low orbit is used, so that the satellite can see more detail.*

A2 *The satellite is in a low orbit that takes it over the poles, so it gets a better view of all of the Earth's surface.*

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DAVID SANG

Where on Earth?

GCSE key words
Satellites
Orbits
Electromagnetic waves
Digital signals

Spacecraft move around the Earth in many different orbits, according to their purpose. In this article, we look at one use of satellites — navigation.

An artist's impression of a GPS satellite.

GE Astro Space/SPL

In a flat, rectangular field near Bognor Regis in Sussex, a tractor moves steadily up and down, spreading fertiliser. But this is no ordinary tractor. For a start, there is no driver. The vehicle is controlled by an onboard computer which uses satellite technology to determine its position in the field.

The computer has a detailed record of the crop yield from every square metre of this field last autumn; where the yield was poor, extra fertiliser is added to the soil.

The tractor's onboard computer relies on the **global positioning system** (GPS), a navigation system originally set up by the United States Department of Defense but now more widely available. If you go sailing, you may use a GPS receiver for navigating, an increasing number of mobile phones have GPS built in, and so do many cars.

THE GPS SATELLITES

The GPS 'constellation' is made up of 24 satellites. They occupy six orbits around the Earth, with four satellites spaced around each orbit (Figure 2).

- Orbit radius: 20 190 km — about three times the radius of the Earth.
- Orbital period: about 12 hours, so each satellite orbits the Earth twice a day.
- Orbital tilt: 55° relative to the plane of the equator.

The satellites are spaced out in this way so that, wherever you are on the Earth's surface, you will be in 'line-of-sight' of at least four satellites at any moment; in other words, your GPS receiver will be receiving at least four signals.

GPS SIGNALS

Each of the 24 satellites transmits a signal towards the Earth. This is a digital signal — it consists of a sequence of on–off pulses of different lengths (Figure 1). The signal encodes a range of information, including the identity of the satellite and the time. The receiver can decode this information to work out the user's position on the Earth.

Signals are transmitted at two different frequencies, L1 = 1575.42 MHz, and L2 = 1227.6 MHz.

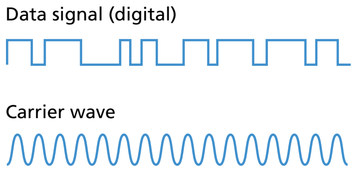


Figure 1 *The digital GPS signal transmits information at a slow rate — about 50 bits per second.*

These frequencies are in the microwave region of the electromagnetic spectrum, with a wavelength of 20 or 30 cm. The wavelength must be as short as this if a position is to be determined to within a metre or so.

Two frequencies are used because microwaves are slowed down as they pass through the ionosphere, a charged region high in the atmosphere, and this introduces an error into the measurements. Different frequencies are slowed down by different amounts, just as violet light is slowed down more than red light as it passes through glass; this is an example of **dispersion**. Expensive GPS systems can compare the two signals and correct for the error. Most civilian receivers use only the L1 frequency.

CALCULATING POSITION

If you have a GPS receiver, how can it use the four or more signals reaching it to work out your precise location? Here is an analogy, using sound.

Imagine that you are in the countryside, surrounded by mountains. Three of the mountains have a cannon on the summit. At midday, each cannon fires a blank. What do you hear?

WAVELENGTH OF L1 WAVES

$$\text{wavelength} = \text{speed of light/frequency}$$
$$= \frac{3 \times 10^8 \text{ m/s}}{1575.42 \times 10^6 \text{ Hz}}$$
$$= 0.19 \text{ m}$$

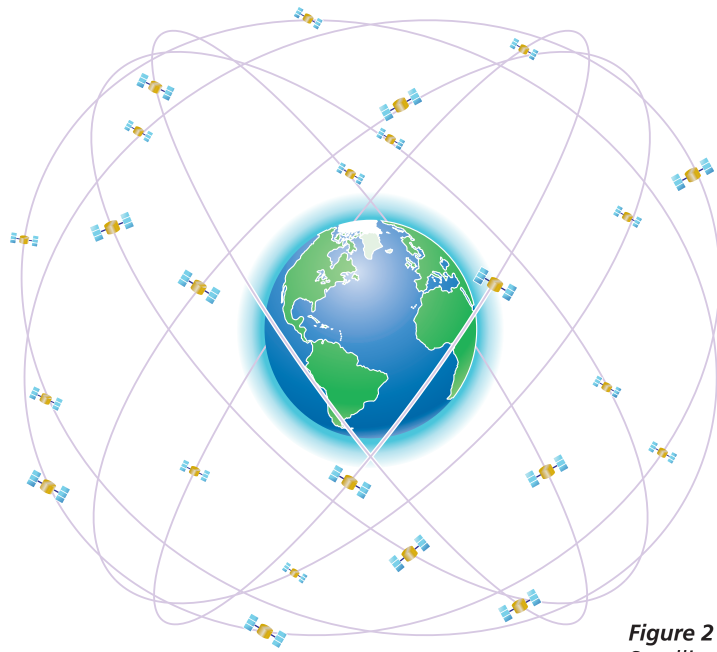


Figure 2
Satellite orbits.

If you are the same distance from all three mountains, all three bangs will reach your ears simultaneously. But elsewhere, you are likely to hear three bangs in succession. If you look at your watch, you will be able to determine how many seconds after midday each bang arrives. Knowing the speed of sound, you can work out your distance from each mountain, and find your position. (This technique is known as **triangulation**; you have probably come across it in geography or maths — see Figure 4.)

The GPS system works in the same way, but using radio waves. The signals are transmitted continuously, not just at midday. Of course, in the sound analogy, you need to know which bang has come from which cannon. In the case of GPS, each signal encodes the details of the satellite which transmits it, together with the time.

The advantage of having signals from at least four satellites is that the receiver's computer can work out four things: latitude, longitude and altitude (equivalent to x, y and z coordinates), and the precise time.

GPS satellites are not positioned in a geostationary orbit, alongside telecommunications and television satellites, because this orbit cannot be seen from polar regions.

The European Space Agency plans to establish a second satellite navigation system.

Today's GPS systems are typically accurate to within a metre or so; for surveying purposes, they can be accurate to within 1 cm.

1 MHz
= 1 megahertz
= 10^6 Hz.

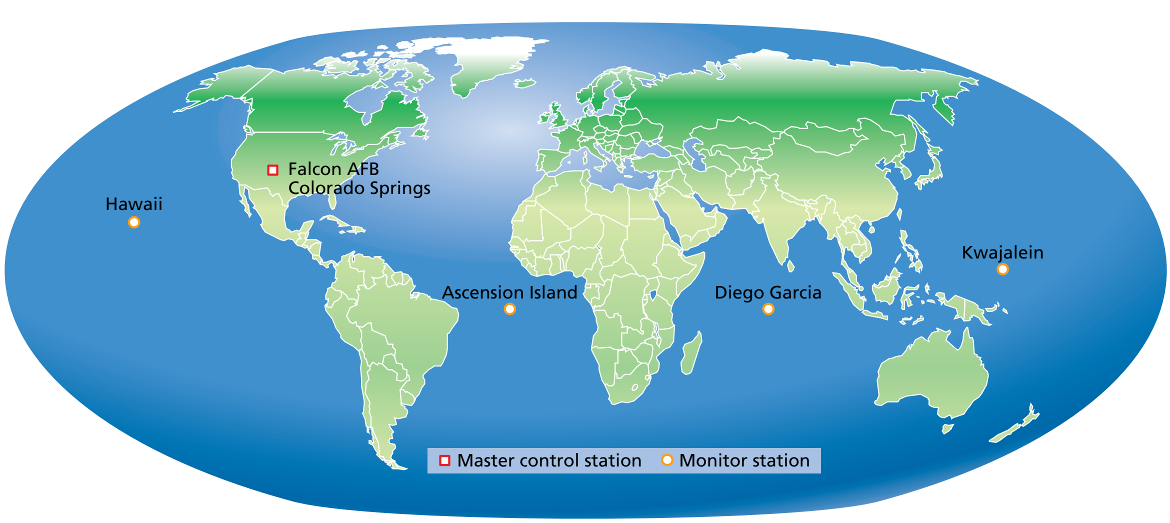


Figure 3 *The central GPS control station is at Falcon Air Force Base, Colorado Springs. The satellites are monitored from four other stations around the world.*

Sailor Ellen MacArthur. GPS is an important aid to navigation.

Rick Tomlinson

Figure 4
How triangulation works.

In addition, your own speed can also be found, using the Doppler effect. This is the change in frequency which occurs when a source of waves and the receiver move relative to one another.

USING GPS

Aircraft and shipping make great use of GPS for navigation. In the past, they used a system called dead-reckoning — by monitoring speed, direction and time taken, they could plot their routes on a map. Usually, they had to travel in this way from one radio beacon to the next. Now, an aircraft using GPS can follow a great circle around the Earth, the shortest distance between two points.

The US government is insisting that all mobile phones should include GPS. This will mean that the rescue services will be able to pinpoint the position of anyone making an emergency phone call. Some people suspect that it will also make it possible to track anyone carrying a phone — this is seen as an invasion of personal privacy.

Cars may combine a GPS receiver with an on-board **geographical information system** (GIS). The GIS is a computer with details of road networks, tourist information and so on, which can alert drivers to useful information as they drive around. A specialised GPS device can warn drivers of high-sided vehicles when they are approaching low bridges; another can warn drivers when they are nearing a speed camera, so that they will slow down. Is this a form of cheating?

David Sang *writes textbooks and is an editor of* C*ATALYST*.

JANE TAYLOR

Steve Hopkin/Ardea

Energy transfer

GCSE key words
Efficiency of energy transfer
Heat
Respiration
Egestion
Trophic level

You may have wondered why the real-life food chains you have studied aren't very long. In this article we show how the loss of energy from food chains limits the number of animals that can survive on the energy fixed by a patch of vegetation.

The Earth's outer atmosphere is irradiated by huge amounts of energy from the Sun. The atmosphere reflects and absorbs some of this energy, but most reaches the Earth's surface. Energy enters food chains only when sunlight is used in photosynthesis.

Over 3 million kilojoules of visible light energy reaches each square metre of ground in the UK in a year. Relatively little of this kick-starts food chains through the process of photosynthesis. Some is reflected by bare soil and some is absorbed, heating the soil — think of walking barefoot on a dry sandy beach on a sunny day. Plants can benefit from the warming of soil because it makes them grow faster. About half of the light energy is used evaporating water from moist soil; this is what dries the ground out after rain.

Plant leaves reflect and transmit green and yellow light — which is why they look green — so this energy is lost too. They absorb red and blue wavelengths of light and use them for photosynthesis. Of each thousand kilojoules reaching the Earth's surface less than 25 kJ/m^2 is used for photosynthesis. This small amount is what ecosystems are built on.

PLANTS AS FIXERS

Only a portion of the sugar made in photosynthesis contributes to the increase in biomass. Some of it is used in *respiration* as a source of energy to drive the synthesis of other substances the plant needs in its growth. The energy transformations involved are not 100% efficient so energy is also lost to the environment as *heat* (Figure 1). Only the molecules used in tissues, for example sugars used to make cellulose for new cell walls, proteins for cytoplasm and lipids for waterproofing the leaves, contribute to the biomass of plants. This biomass amounts to 1–5% of the light energy received per square metre and is the source of energy for **primary consumers**.

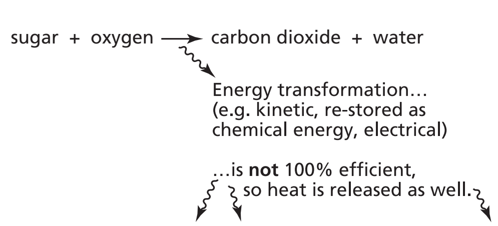
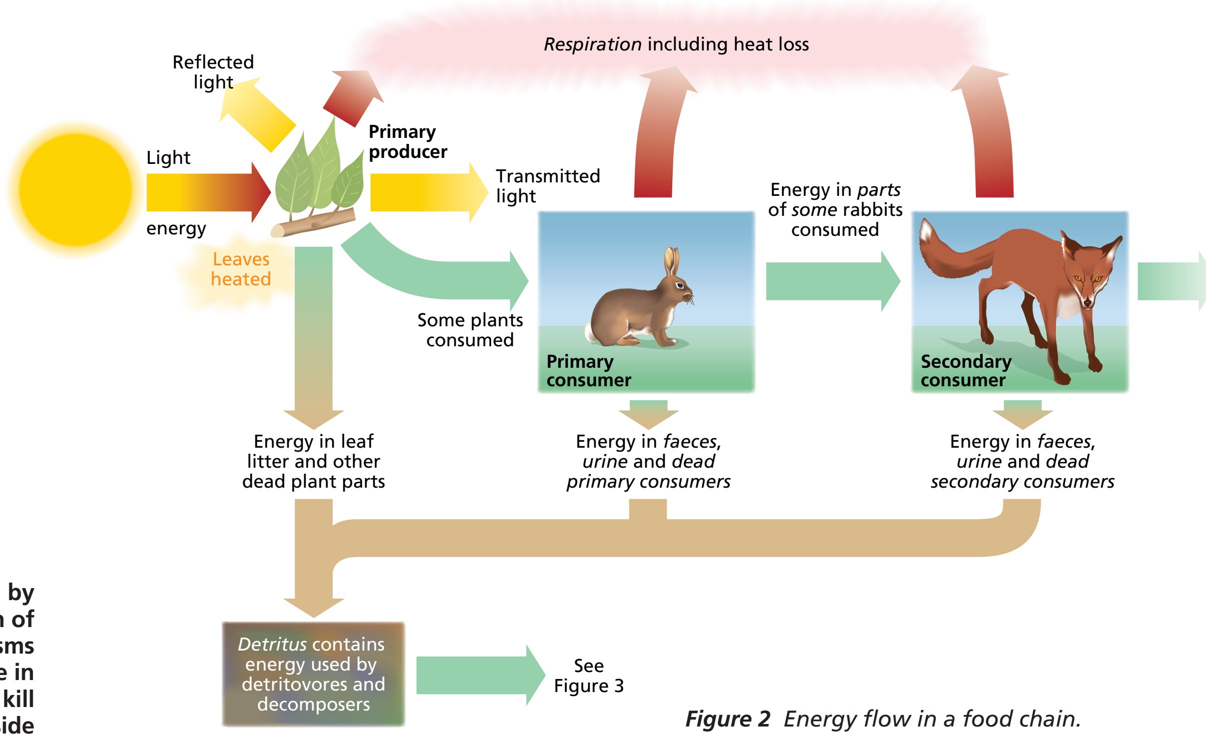


Figure 1 *Energy is mostly lost as a result of respiration.*

Above: *Food webs are very complex. It is not only large herbivores that eat plants.*

● **Why do plants grow faster in warmer ground? Hint: think about rates of chemical reactions.**



Heat generated by the respiration of microorganisms can cause a fire in a haystack or kill weed seeds inside a compost heap.

Figure 2 *Energy flow in a food chain.*

CONSUMING EXPERIENCES

A herbivore — a primary consumer — browses on vegetation. Of course the energy in the parts of the plant it does not eat is lost to that food chain, but it may enter another. The roots or remnants of leaves damaged by large herbivores may be eaten by other small herbivores such as slugs or millipedes.

Detritus includes all fragments of living things, such as dead leaves, fur, remnants of carcass and solid waste — the food of detritovores.

Food webs are very complex. Ecologists often consider energy transfer between trophic levels rather than energy passing down a food chain. They measure the energy per square metre fixed by **primary producers**, how much energy passes to the primary consumers grazing on that area of vegetation, how much then passes on to **secondary consumers**, and so on. It is very difficult to accurately measure and portray energy transfer because animals' feeding habits can be complex (see Box 2).

Quite a lot of the energy in the biomass an animal consumes is not available for growth. For example, cellulose, the polymer of glucose making up plant cell walls, is by far the commonest substance in vegetation, but few herbivores can digest it and use its energy. Even animals that have microbes in their gut to digest cellulose, such as cows, cannot make use of all of it. Most cellulose is egested as *faeces*. However

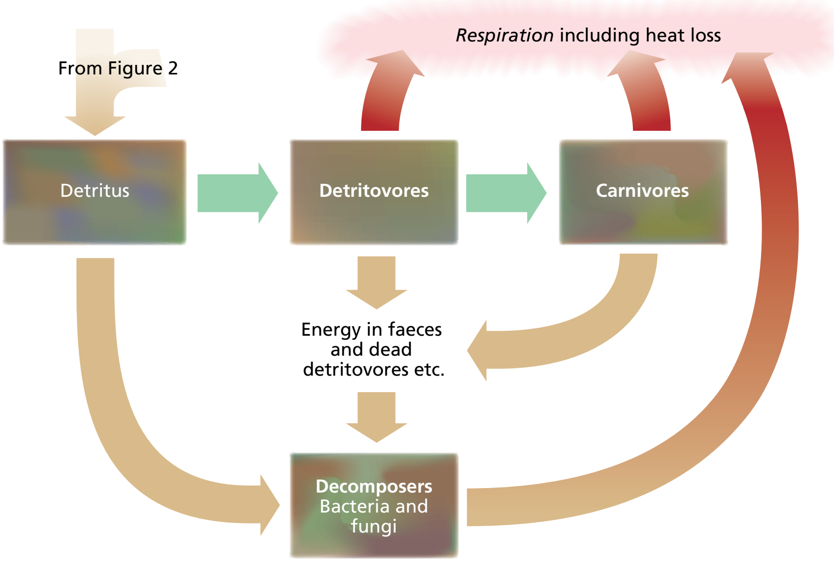


Figure 3 *What happens to the energy in detritus.*

BOX 1 DIFFICULTIES MEASURING ENERGY TRANSFER

It is difficult to measure how much of the energy present in 1 m^2 of grassland passes into each trophic level above it. We can quantify the energy transfer in only the simplest systems with a few organisms and few levels. Such simple systems are rare, and so there are few fully-investigated examples.

Food chains are simplified versions of the real-life situation in which predators such as starlings eat several prey organisms and so link several food chains — which change as they migrate across Europe each year. Field mice fall victim to many different predators, herbivores browse on different food plants in different places. It does not get easier if scientists attempt to quantify energy transfer in a food web, as many predators and scavengers such as foxes feed on primary and secondary consumers as well as taking the occasional fruit meal.

BOX 2 FORAGING STRATEGY

Animals make life complicated for ecologists trying to estimate who eats how much. Errors creep in because animals do not forage evenly within a habitat, they are choosy about what and where they eat. They have to make important decisions when foraging, and choosing the wrong strategy may impair their chances of survival.

Howler monkeys eat leaves but may completely ignore those of nearby trees and search for the rare trees whose leaves contain less of a toxic chemical. They eat just the youngest leaves with the least toxin and fibre. They will select individual mature leaves but only if they have a high protein content. A 'snapshot' visit by an ecologist estimating leaves consumed may not accurately reflect the situation.

Animals forage away from their usual territory from time to time if it makes sense in terms of energy lost and gained. A starling will ignore small soil invertebrates where it usually feeds and use slightly more energy to travel further for larger energy-rich leatherjackets. Again this upsets the energy figures.

How does a howler monkey choose which leaves to eat?

M. Watson/Ardea

How many elephants can a game park support?

Ferrero/Labat/Ardea

BOX 3 CARRYING CAPACITY

The productivity of an area of vegetation (that is energy fixed per square metre per year) limits how many animals can live there. The total energy fixed each year in plant biomass in an area can feed many different herbivores, but there is a limit to the total animal mass it can support. If there are too many herbivores the vegetation will be grazed faster than it grows and will not be able to flower, set seed and replace itself.

The number, or biomass, of herbivores that can be maintained in an area is called its **carrying capacity**. There are also limits to the number of predators that can live on the herbivores.

This information is important to people managing areas of land. Farmers need to know, for example, how many sheep can be satisfactorily grazed on a given size of farm. Similarly, game park managers have to know how many elephants can graze in the park. A growing population risks damaging the vegetation so badly that the whole system becomes unbalanced.

It has been estimated that a human needs eight times as much energy as a crocodile of the same size. This is because humans need to maintain a constant body temperature, normally above that of their surroundings.

microbes in the soil — fungi and bacteria — can degrade cellulose in dead plant material and herbivore faeces to release organic compounds. They can absorb and use these for their own respiration and growth. In addition, animals do not use all the nutrients absorbed from the gut, and some energy is lost as urea in *urine*.

RESPIRATION LOSSES

Animals use sugars in respiration to provide energy for movement and metabolism; again, the energy transformations are not 100% efficient so energy is lost to the environment as heat (Figure 1). Mammals and birds use most of their energy intake to maintain a steady body temperature.

Less than 10% of the energy taken in ends up in new biomass. This biomass is the source of energy for organisms at the *next* trophic level in the chain.

As Figures 2 and 3 show, the diminishing proportion of the energy originally stored in plants that is transferred on through the chain severely reduces the quantity of energy available for the animals in the next level.

As the animals at the next level use energy in similar ways, there is a similar reduction in the energy fixed as biomass. Predators take the most easily accessible energy-rich parts of their prey, such as the liver, and leave less digestible parts such as fur, bone and feathers. However these are a food source for scavengers or **detritovores** (Figure 3).

By the time energy has been passed from plants to secondary consumers there is very little left for top carnivores. A family of carnivores needs a huge territory of vegetation to support it (see Box 3).

***Jane Taylor** teaches biology, writes textbooks and edits* CATALYST.

● **Try to work out the size of territory a domestic cat would need if it had to fend for itself.**

PLACES to visit

The International LIFE™ Centre

Visit the LIFE centre's website http://www.centre-for-life.co.uk

PCR stands for polymerase chain reaction, a process used to make lots of extra copies of pieces of DNA. It is used in research on DNA and by forensic scientists.

Current exhibitions: weirdscience@life (November 2002) and skating@life (December–January).

Teachers' contact for education visits 0191 243 8211.

From time to time, CATALYST brings you news about scientific places to visit. Here's news of an attraction in the north of England, at Newcastle-upon-Tyne.

The LIFE visitor attraction gives you a chance to find out more about evolution, cells, genetics and neuroscience. These are the sciences which are likely to have the same impact in the early twenty-first century as computers had at the end of the last century.

LIFE builds on our fascination as human beings with ourselves — our origins, our makeup, our relationships and our capabilities. It has three themes:

- What is life and how does it work?
- What makes life for you and me?
- Celebrating life.

DNA is the thread that holds this all together. It connects us with our ancestors and with each other. At the same time, it makes each one of us different — unless you are identical twins!

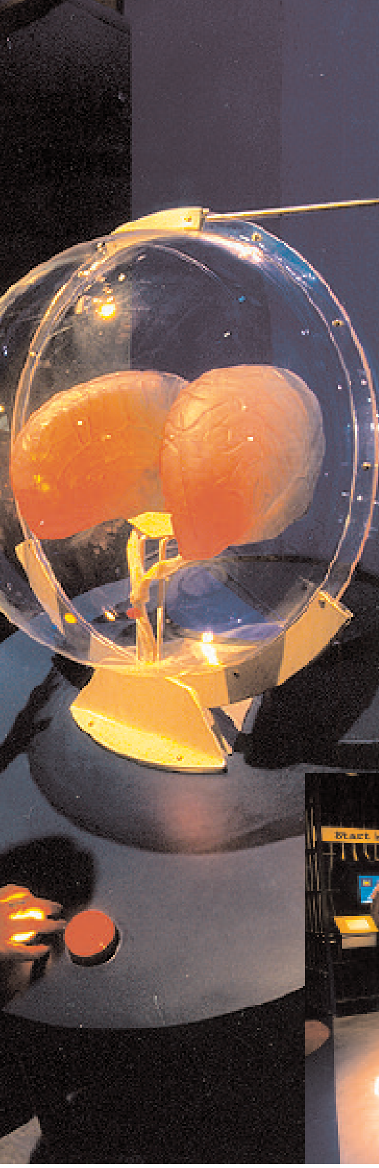
Visits start with a journey along the River of Life, back through 4 billion years of evolutionary history. Then there are theatre shows including a motion simulator, and interactive exhibits devoted to sport, diet, creativity and the workings of the brain.

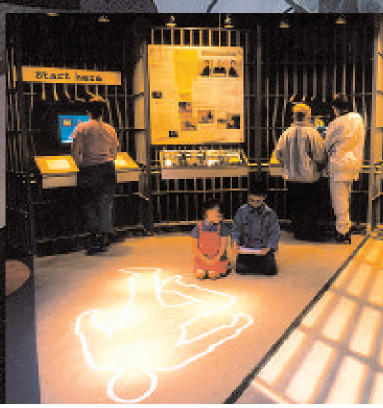
HANDS-ON IN THE LAB

Ever looked at some DNA — your own, even? If you visit the LIFE centre with a school party, you will have the chance to work in the Senior LIFElab alongside students, researchers and professional scientists. You might try such things as using DNA analysis to identify species collected from the rainforests and find out if they are new to science. You might also try DNA photocopying, in which you can collect, extract, 'amplify' and visualise your own DNA using the latest techniques of PCR and electrophoresis.

FAST FORWARD — TOO FAST?

Perhaps you think that the science and technology of genetics are getting out of hand. Well, the LIFE centre is also home to a research institute looking at the ethics of life sciences. Workers look at the ethical issues raised by developments in genetics and human biology, and they find ways to involve members of





Life

the public in debating these issues. At the same time, they make sure that scientific researchers are aware of public concerns.

Through the LIFE visitor attraction, you can add your voice to this work.

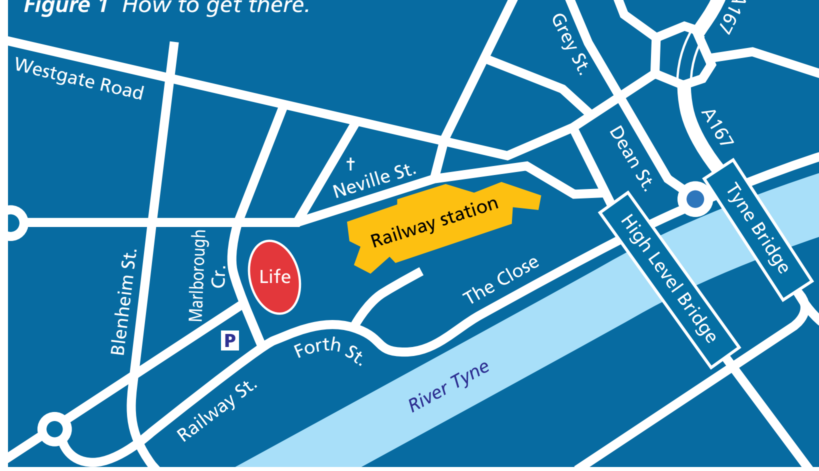
REGENERATION

The International Centre for Life is a dramatic development in the heart of Newcastle-upon-Tyne. A run-down site which was previously a bowling green, army barracks, hospital, air raid bunker, livestock market, abattoir and timber mills has been transformed. As well as the visitor centre, hands-on labs and ethics centre, it houses the Institute of Human Genetics (part of Newcastle University) and the Bioscience Centre, a specialist space for small biotechnology companies. Come and take a look.

GETTING THERE

The International Centre for Life is in Newcastle City Centre, next to the city's mainline railway station and 2 minutes from Newcastle Arena. See Figure 1.

Figure 1 *How to get there.*



MAX DE BOO

Margaret Barton/The Woodland Trust

Above: *The first horse chestnut leaves, bluebells, and wood anemone flowers are all signs of spring — but are they appearing earlier?*

Effects of climate change

GCSE key skills and concepts

- Considering ideas and evidence
- The power and limitations of science, uncertainties in scientific knowledge
- Patterns and relationships in data
- The impact of humans on the environment
- Interrelationships of organisms

Do your grandparents ever complain, 'You don't have to suffer the really cold winters we had when we were young'? If so, they are right. Records began 350 years ago, and nine of the warmest years recorded have been since 1990. You might think warmer temperatures are a good thing, but climate change has far-reaching implications. You need to know about the impacts we have on our global environment for your GCSE course. This article explores climate change in detail.

Climate is defined as the prevailing conditions of factors such as temperature, humidity, rainfall and wind in a region. The UK is in the **temperate** zone, one that does not exhibit extremes of heat or cold.

Animals and plants have annual cycles of growth and reproduction. **Phenology** is the study of the times each year that certain life-cycle events occur. It involves recording things like when you heard the first cuckoo or saw the first frogspawn, hawthorn trees in blossom, blackberries fruiting or leaves changing colour. If the climate is changing, the timing of these events might change as well.

CLIMATE IS CHANGING

The debate among scientists now is not *whether* climate change will happen but *how fast* it will occur. The United Nations' IPCC (Intergovernmental Panel for Climate Change) predicts warming of 2.4–5.8°C over the next century. Nine of the ten warmest years since temperature records began in Britain, in 1659, occurred in the 1990s. The warmest year on record was 1998, the second warmest was 2001 and the Meteorological Office predicts a 75% probability that 2002 will be warmer than 2001. January 2002 was the warmest January for 9 years (the average temperature of 5.8°C was even warmer than the average of 5.2°C in 1998), February 2002 was 3.2°C warmer than the 30-year average, and March was 1.8°C above the average.

RECORDING CHANGE

Over the centuries both scientists and non-scientists have kept records of natural events. In 1736, Robert Marsham began recording 27 indications of spring in the UK and we have recently found a few even older records dating back to 1703. When correlated with temperature these phenological records show how nature is responding to a changing climate. The Marsham family continued recording until 1958. A nationally coordinated scheme ran from 1875 to 1947 and the UK Phenology Network (UKPN) began in 1998.

In autumn 2000 UKPN had 350 recorders. Two years on there are more than 14,000 recorders spread across the UK, mostly working over the internet. Although recordings of natural events by the public are sometimes dismissed as unscientific, the UKPN records are producing some important results which are statistically significant. When a large number of people are recording, the data as a whole become credible because anomalous records can be spotted.

Phenology is taken very seriously. The IPCC sees it as legitimate research into climate change and phenological events are now part of the UK government's Climate Change Indicators.

INDICATORS OF CHANGE

Chemical reactions, including those of respiration and growth, speed up with increased temperature. The UK Phenology Network has found that for each 1°C rise in temperature, events happen on average 6–8 days earlier in spring!

Earlier this year we predicted, based on temperatures and phenological data, that spring 2002 would be 2–2.5 weeks earlier than the norm and that seasonal changes in autumn 2002 would be delayed or prolonged.

IMPLICATIONS FOR WILDLIFE

Let's consider a woodland. Organisms in woodland communities are interdependent, not only in the way represented in food webs, but also in the timings of their life cycles. For example, herbivorous insects need to hatch from eggs when their food plant is available. If this breaks down as climate patterns change, feeding relationships will be disrupted.

At present, insects seem to be responding to temperature changes at the same rate as their food plants. Orange tip butterflies are active and egg-laying earlier; but garlic mustard, their food plant, is growing sooner. The same is happening with winter moths and oak trees. However, there is evidence that the hatching of blue tits may no longer coincide with the peak of caterpillar numbers in a wood in Oxfordshire, and the arrival dates of some summer migrant birds are already lagging behind the rest of the woodland community.

Climate change may also affect woodland composition. Trees such as sycamore and oak are responding more quickly to climate change than, for example, beech and ash. Bluebells and snowdrops may lose the competitive advantage gained by starting growth

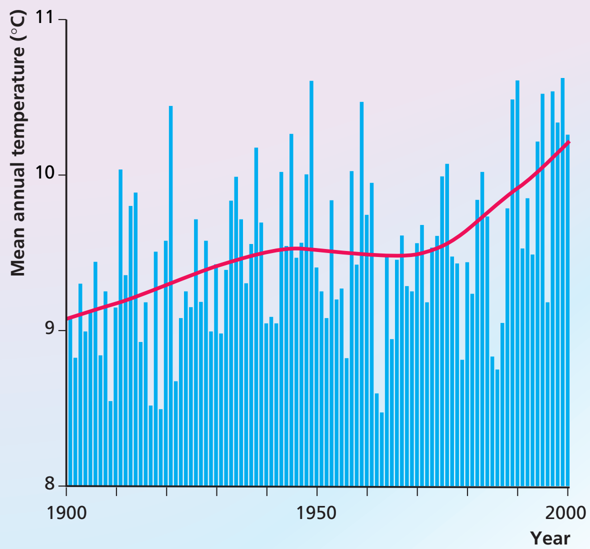


Figure 1 *Graph showing temperature change over the last 100 years. Predict the rise in temperature over the next 20 years if the same trend continues.*

At the end of 2001, observers noted very intense autumn colours on trees. Warmer weather and a longer growing season increase the concentration of sugars in the leaves. At the end of the season, the chlorophyll breaks down, revealing the other pigments, particularly carotene and anthocyanin, both of which are more intense with increased sugar concentrations.

BOX 1 REGISTERING AS A RECORDER

Wherever you live in the UK you can join the Woodland Trust's network of recorders. Connect to Nature's Calendar at **http://www.phenology.org.uk**. You will get help online and offline to identify species for observation. It is easy to record some natural events — for example the first snowdrops, the first leaves on oak trees, and autumn events such as blackberry fruits and leaf fall.

BOX 2 CAUSES OF CLIMATE CHANGE

Some variation in climate is natural, but the primary cause of climate change is the increase in carbon dioxide concentration in the atmosphere. Levels of this gas were relatively stable for thousands of years but have increased by 31% since 1750. Burning of fossil fuels (industry, domestic use, vehicles on the road) has contributed 75% of this increase, while deforestation accounts for most of the remainder.

Carbon dioxide is quantitatively the most significant contributor to global warming but some other gases play a part. These include methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (SF_6).

The USA releases most of the global carbon dioxide (85% of all emissions).

Ian Beamer/Ardea

Above: *First sightings of frogspawn around the British Isles are recorded by the UK Phenology Network each year.*

in the previous autumn, as leaf growth of many other plants now begins earlier in the spring.

Ancient woodland is by far the richest habitat for wildlife in the UK. Such woods are often small and isolated — surrounded by intensively-managed land. A rise in annual temperatures will mean that those species that can will spread north to a more suitable climate. Many of the species found in ancient woodland, such as lichens, fungi and invertebrates, are very immobile, rare and threatened. Effectively they will be locked into these small wildlife 'islands'.

IMPLICATIONS FOR PEOPLE

Winters will be warmer, wetter and increasingly frost-free. A longer growing season can be useful for farmers, although other factors, such as flooding, the survival of pests through the winter and the chance for them to produce more generations in one year, might counteract these benefits. Temperate plants often rely on winter chills to break dormancy. Research is being done on this at the moment, for example investigating the potential impact on yields of fruits such as blackcurrants. Longer growing seasons might even mean longer pollen seasons and more hay fever.

BOX 3 ACTIVITIES

(1) Try this at home. Can you find out how much electricity is used per week by:
- a computer used for 6 hours per day?
- all the LEDs (cooker, VCR, televison) left on permanently in your home?

(2) Predict the increases/decreases in the animal and plant populations if blue tits hatch later than caterpillars:
- to the caterpillars.
- to the birds.
- to green plants.
- to other wildlife.

(3) Can you find out which country abandoned its commitment to the Kyoto Protocol? Clue: It is the country producing the most carbon dioxide emissions.

WHAT CAN WE DO?

All the major carbon dioxide emitting countries (EU states, Japan and the US), signed the Kyoto Protocol of 1997. This committed them to reducing overall emissions of greenhouse gases by at least 5% of the 1990 levels by 2005. When the protocol was due to be ratified in 2001, one country withdrew its agreement to cut back emissions (see Box 3).

In Britain, from April 2002, businesses will be liable to the Climate Change Levy (adding 15% to typical energy bills) but discounts will be awarded to those who cut their energy use.

There are ways that we as individuals can reduce carbon dioxide emissions:
- use the car less — walk, cycle or use public transport instead;
- make sure our homes are well insulated;
- install energy-saving devices;
- avoid using energy-consuming equipment like air conditioning unnecessarily — open a window instead.

And why not contribute to research on the local effects of global warming by joining the UK Phenology Network (Box 1)?

WEBSITES

The UK Phenology Network **http://www.phenology.org.uk**

Eco Schools **http://www.eco-schools.org.uk** promotes school and community involvement in improving the environment, citizenship and healthy lifestyles.

http://www.greencode.org.uk for schools wishing to include education for sustainable development in the curriculum.

The Met Office **http://www.meto.gov.uk/research/hadleycentre/index.html**

Friends of the Earth **http://www.foe.co.uk**

Green Energy Options **http://www.greenenergy.org.uk**

Government energy projections for the UK **http://www.carboncalculator.org/faq.html**

Max de Boo has taught science for many years, in primary and secondary schools and in teacher education. *She is grateful to Nick Collinson (Conservation Policy Advisor, The Woodland Trust/UK Phenology Network), Tim Sparks (Centre for Ecology and Hydrology/UK Phenology Network) and Jill Attenborough (Phenology Project Manager, The Woodland Trust UK).*

Spheres in space

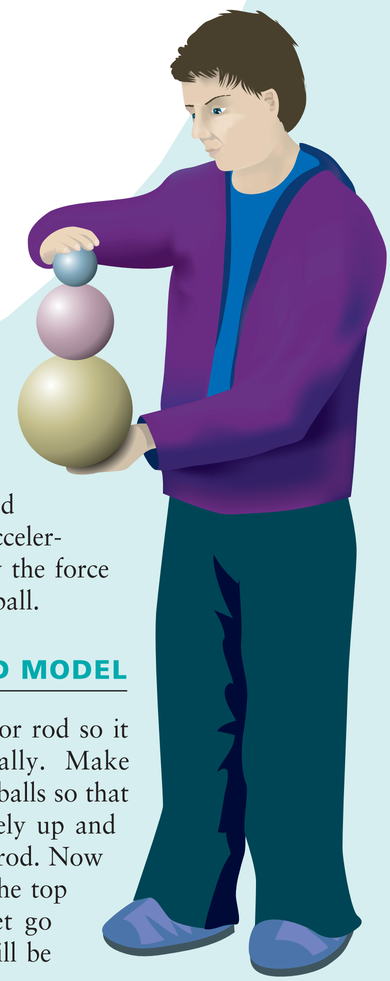


Figure 1 Hold the three balls on top of each other before letting go.

For this spectacular trick, you will need bouncy balls of three different sizes. Hold them at arm's length, with the medium-sized ball on top of the biggest one, and the smallest on top of that. (Like all good tricks, this one is tricky to perform.)

Now, release the balls so that they fall downwards. When they hit the ground, you should find that the smallest ball ricochets upwards and reaches a surprising height.

HOW IT WORKS

All three balls fall together at the same rate — that's something which Galileo explained.

What happens when the big ball strikes the ground? It bounces back upwards, imparting a shock to the medium sized ball, which in turn exerts a force on the small ball.

Think about what happens when a larger object collides with a smaller one — a tennis racket with a tennis ball, for example. Each feels the same force (that's Newton's third law), but the force will have a bigger effect on the object with the smaller mass. So the medium ball is accelerated by the force from the large ball, and the small ball is accelerated even more by the force from the medium ball.

AN IMPROVED MODEL

Try fixing a wire or rod so it stands up vertically. Make holes through the balls so that they will slide freely up and down the wire or rod. Now hold the balls at the top of the rod and let go as before. They will be guided by the rod — you can even try the trick with four balls. The smallest ball should fly at least 10 metres into the air.

This may seem like a trivial experiment, but a scaled-up version was once suggested as a way of sending a simple spacecraft into orbit.

David Sang writes textbooks and is an editor of CATALYST.

Fireworks quiz

Unscramble the following anagrams of substances used in the manufacture of fireworks. All the words can be found in the 'Fireworks' article on pages 1–3.

1 grow up, Den (9)
2 resist amputation (9, 7)
3 arch cola (8)
4 thor spots primulaceae (9, 11)
5 amusing me (9)
6 CRT rush demolition (9, 8)
7 ah, cells (7)
8 miniature Bart (6, 7)
9 precooled chirp (6, 8)
10 go mail manually (9, 5)

Answers on page 21

Corel

Alfred Nobel and the Nobel prizes

The website of the Nobel Foundation is at http://www.nobel.se

The Nobel Foundation was 100 years old last year. Every October it awards prizes for the best workers in the fields of physics, chemistry, medicine, literature, economics and peace. Who was Alfred Nobel — and who won the prizes in 2001?

Alfred Nobel.

Mary Evans Picture Library

● Find out about the thalidomide disaster of the 1960s. Try entering the word in a search engine. What link is there with the Nobel chemistry prize for 2001?

***Below:** Sticks of dynamite, which is made from nitroglycerine ($C_3H_5(NO_3)_3$) and an inert binding substance.*

Charles D. Winters/SPL

Alfred Nobel was born in Stockholm on 21 October 1833. His father was an inventor and engineer, his mother came from a wealthy family. In 1842 the family moved to St Petersburg in Russia, where Alfred was educated by private tutors. By the age of 17 Alfred was fluent in Swedish, Russian, French, English and German as well as being interested in literature and poetry, and chemistry and physics.

EXPLOSIVES

He travelled widely and it was on his travels that he became interested in **nitroglycerine**. This highly explosive liquid was thought to be too dangerous to be of any practical use. Alfred returned to Stockholm and started experimenting. His attempts to make nitroglycerine safer to use resulted in many accidents — in one explosion his brother Emil and several other people were killed. Alfred was soon banned by the authorities from experimenting within the city limits and had to perform all his experiments on a barge anchored in the middle of a lake.

Alfred eventually found that mixing the nitroglycerine with silica made it more stable. He patented the new material under the name of **dynamite**. Together with detonators, which he also invented, this explosive was soon used worldwide in the mining and construction industries. Within a few years there were 90 factories and laboratories in 20 different countries making and experimenting with dynamite. Nobel liked to travel round his laboratories. As well as studying explosives technology he also worked on making synthetic rubber and leather and artificial silk. He soon became immensely wealthy. Many of the companies he founded have prospered and still play a part in the world economy today.

Popperfoto/Reuters

Above: *Sir Paul Nurse and Dr Tim Hunt (right), British winners (with American Leland Hartwell) of the 2001 Nobel prize for medicine (see Box 1).*

BOX 1 NOBEL PRIZE-WINNERS OF 2001

The **chemistry** prize last year was awarded to William Knowles (USA), Ryoji Noyori (Japan) and Barry Sharpless (USA) for their work on chiral molecules. A chiral molecule is one that exists in two different forms — one being a mirror image of the other (think of a pair of gloves). One shape of the molecule may undergo a particular reaction which its mirror image might not. The prize-winning chemists made catalysts which could create molecules of one mirror image and not the other. This is important for some forms of drug synthesis.

The **physics** prize went to Eric Cornell, Wolfgang Ketterle and Carl Weiman (USA). They proved experimentally a new state of matter — one which had been thought of as long ago as 1924 but had never been seen. It is relatively easy to make the particles of light all have the same energy and to vibrate the same way (i.e. a laser), but this had not been shown to be true for matter. The researchers managed to cool 2000 rubidium atoms down to 0.000 000 02 degrees above absolute zero. At this point all the atoms had the lowest energy possible and condensed together to vibrate in unison. The theory had been proved. This may be of use in precision measurement and nano-technology in the future.

The **medicine** prize was won by Leland Hartwell (USA), Paul Nurse and Tim Hunt (UK) for their work on the cell cycle — the stages through which a cell goes from one division to the next. Before the cell can divide it has to duplicate and separate its chromosomes — this is regulated as part of the cell cycle. The researchers were able to identify some of the key molecules which control the cycle. Faults in the cell cycle may result in the abnormalities of chromosomes seen in cancer cells. It is hoped that knowledge of how the cycle works may lead to new ways of treating cancer.

An adult human being has approximately 100 000 billion cells, all originating from a single fertilised egg cell.

NOBEL PRIZES

Alfred Nobel died in San Remo, Italy on 10 December 1896, aged 63. His will decreed that his fortune should be used to award prizes in physics, chemistry, medicine (or physiology), literature, economics and peace. The Nobel Foundation was set up to take care of the finances and to award prizes each year. This work still continues and a Nobel prize is one of the most prestigious awards anyone can win.

David Moore teaches chemistry at St Edward's School in Oxford and is an editor of C*ATALYST*.

- **What do we normally think of as the three states of matter?**

DAVID SANG

Yes, it is rocket

The launch of a space rocket has become a familiar image. But how do rockets work, and what is the future for rocket science?

Take care with the pairs of forces in Newton's third law. They are equal in size and opposite in direction and, most importantly, they act on different objects.

Rocket propulsion works by controlling an explosion. In conventional rockets, the explosion is the result of burning fuel. As the fuel is oxidised, energy is released. The exhaust gases are very hot, and they push out of the back of the rocket. The effect is a forward thrust on the rocket.

One of the problems with space rockets is that they have to take with them their own supply of oxygen — there's no oxygen in space. This adds to the overall load they must carry. One way to overcome this is with the new generation of solar-powered ion-propulsion rockets.

Artist's impression of the launch of an Ariane 5 rocket. Two large solid rocket boosters flank the main liquid fuel rocket in the middle.

David Ducros/SPL

SOLID ROCKET BOOSTERS

● A catherine wheel uses the action-and-reaction principle. Explain how.

Solid rocket boosters (SRBs) are often used as the first propulsion system of a rocket. 'Yes, we have ignition!' — that's the SRBs starting to burn. The rocket is bound to lift off, because there's no way to turn off the SRBs. Within a few minutes, they are burnt out and jettisoned. They are the parts you see falling to Earth shortly after launch.

SRB fuel is often a mixture of nitrocellulose and nitroglycerine, with an added plasticiser to give the fuel a solid, rubbery consistency.

Space shuttle SRB fuel is a mixture of aluminium perchlorate (a source of oxygen) and aluminium powder, which burns.

LIQUID FUEL ROCKETS

For a more controlled thrust, rocket engines use liquid hydrogen and liquid oxygen as their fuel mixture. The two liquids are pumped into a combustion chamber, where they are ignited. The temperature may reach 3000°C. The hot exhaust gases emerge from the back of the rocket at speeds of up to 5 km/s.

Other liquid fuels include kerosene in place of hydrogen, and nitrogen peroxide (N_2O_4) in place of oxygen.

Most rockets have a sequence of engines to lift them into space. The first stages are the most powerful, with engines providing up to 500 000 newtons of thrust. The later stages may provide only 20 000 newtons.

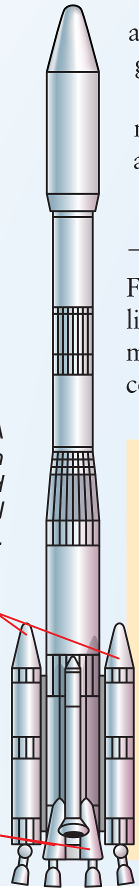


Figure 1 *A rocket with solid and liquid fuel boosters.*

BOX 1 ACTION AND REACTION

Blow up a balloon and let go. It flies around the room as the air rushes out. This is an example of Newton's third law of motion. As the air is pushed in one direction, the balloon is pushed by an equal force in the opposite direction.

A rocket works in the same way. Hot exhaust gases (or high-velocity xenon ions) are pushed out through the nozzles at the rear and the rocket feels an equal and opposite force in the opposite direction. (That's why both types of rocket have to take something with them to push out backwards — fuel and oxygen, or xenon gas.) These forces are often described as an 'action and reaction pair'.

Here's another way to think of it. Inside the rocket's combustion chamber, fuel and oxygen burn. Roughly speaking, half of the resulting molecules fly backwards, and half fly forwards. The molecules that fly forwards bounce off the inside of the combustion chamber, exerting a force on it. That's the physical origin of the force which pushes the rocket forwards.

science

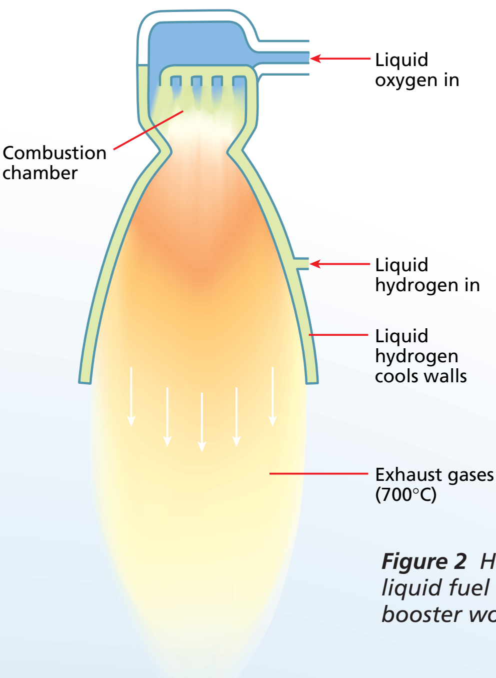
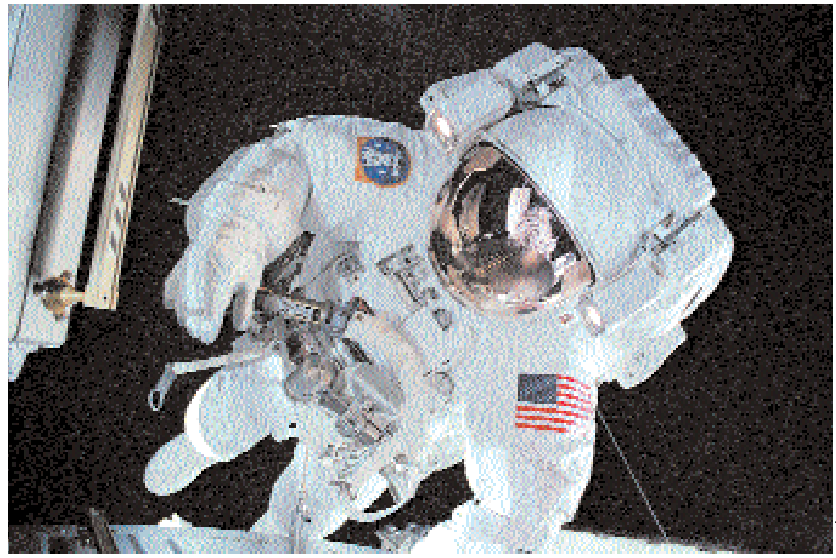


Figure 2 *How a liquid fuel booster works.*



Above: *When walking in space, astronauts use cylinders of compressed nitrogen to push themselves about. The gas is fired through 24 nozzles, and is controlled by a joystick.*

BOX 2 IMPULSE OF A FORCE

A fuel-and-oxygen rocket provides a large force. An ion-propulsion motor provides a much smaller force, but it acts for a long time. A small force acting for a long time can have a greater effect than a large force acting for a short time.

The quantity force × time is known as the impulse of the force, and tells us how much the rocket's momentum is changed by the force.

SOLAR POWER

Most spacecraft have solar cells to provide electrical power during their mission in space. This normally only powers the on-board instrumentation. However, the first solar-powered craft are now being produced.

The European Space Agency's SMART-1 mission to the Moon will be launched early in 2003, and will make use of the latest ion-propelled motor. This works as follows. Solar panels generate electricity which has two functions. First, it is used to ionise xenon gas. Second, the xenon ions are accelerated by high-voltage electricity, so that they emerge from the back of the motor at a speed of 30 km/s, much faster than the exhaust gases of a conventional rocket.

These motors have the great advantage that they do not require an oxygen supply. They produce only a tiny thrust — perhaps 70 millinewtons, less than a millionth of the thrust of a giant *Ariane* rocket. However, they can operate for months on end, gradually accelerating a spacecraft to speeds approaching 5 km/s (11 000 miles per hour).

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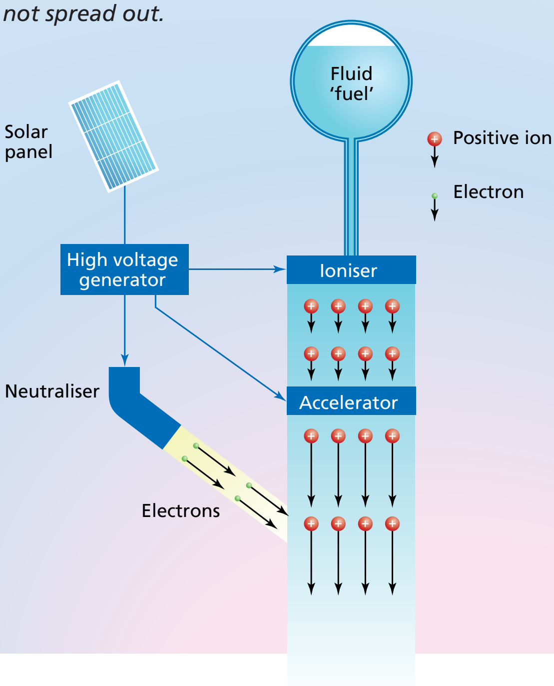
Figure 3 *An ion-propulsion booster. The solar panel is the ultimate source of energy for an ion-propulsion system. Liquid xenon gas is fed to the ioniser, where the atoms are ionised before being accelerated by a high voltage. Electrons are also fed into the beam of ions so that it is neutral and does not spread out.*



Xenon is a noble gas, like helium and argon.

Xenon ions are atoms which have lost one electron, leaving them positively charged.

Ion-propelled motors may be used for the first manned spaceflights to Mars.

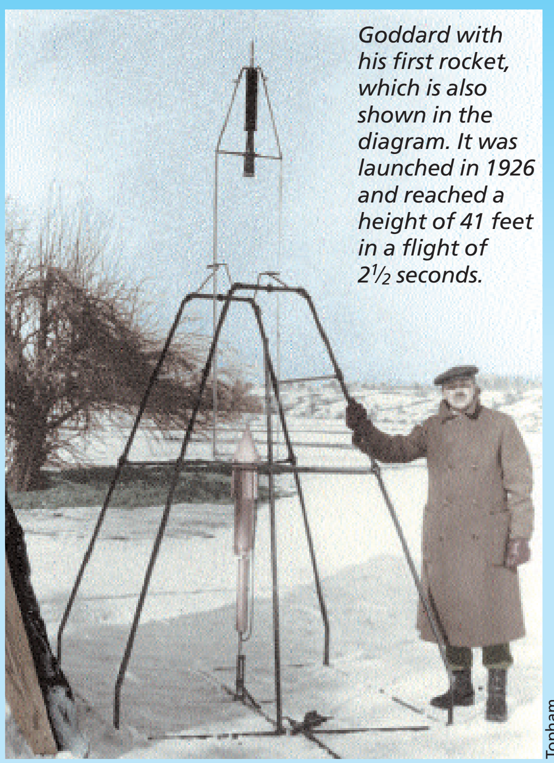
ANSWERS TO FIREWORKS QUIZ, PAGE 17

1. gunpowder
2. potassium nitrate
3. charcoal
4. potassium perchlorate
5. magnesium
6. strontium chloride
7. shellac
8. barium nitrate
9. copper chloride
10. magnalium alloy

Corel

Rocket man

Robert H. Goddard invented the liquid-fuelled rocket. His first rocket flew in 1926, and the technology he developed became the basis for all modern space rockets. He died in 1945, and NASA's Goddard Space Flight centre is named in his honour.



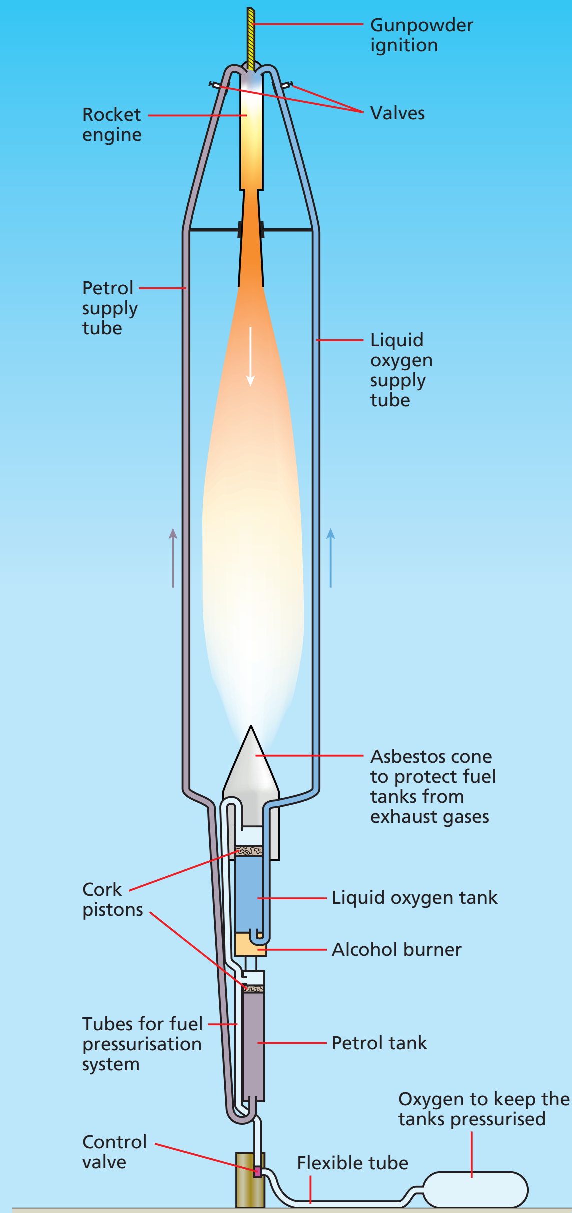
Goddard with his first rocket, which is also shown in the diagram. It was launched in 1926 and reached a height of 41 feet in a flight of $2\frac{1}{2}$ seconds.

Robert Goddard was born in 1882, and grew up in Worcester, Massachusetts, USA. As a child, he was inspired by books such as H. G. Wells' *The War of the Worlds* and Jules Verne's *From the Earth to the Moon*. He wrote, 'They gripped my imagination tremendously. Wells' wonderful true psychology made the thing very vivid, and possible ways and means of accomplishing the physical marvels set forth kept me busy thinking.'

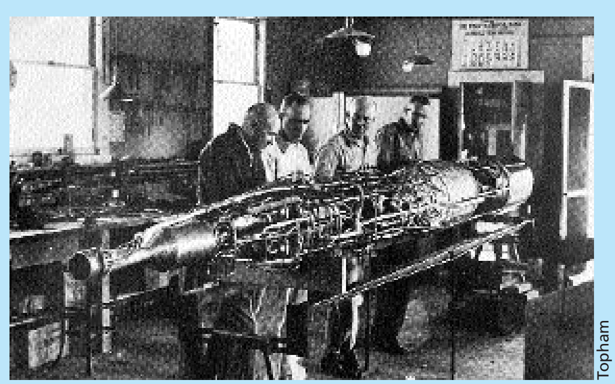
What he was thinking about was how to leave the Earth and navigate space. In his twenties he came to the conclusion that a rocket was the only way to achieve this; the principle of action and reaction would permit people to explore the solar system. He made calculations which showed that, in theory, a liquid-fuelled rocket could carry enough energy to reach the Moon.

Goddard started work as a college physics teacher and soon found funding to work independently on his ideas. He devised systems for multistage rockets, gyroscopic stabilisers and propellant feed systems, and these basic ideas are still in use today. His first liquid-fuelled rocket used liquid hydrogen and liquid oxygen.

For a scientist, Goddard led an unusual life. He worked almost alone, with help from a few assistants and funding from the US army and navy. He set himself up at a ranch in the New Mexico desert, and eventually produced rockets which were capable of reaching a height of 3 km, travelling at speeds of up to 900 km/h.



Goddard's first successful rocket.



Goddard (left) and his team check over one of his most sophisticated rockets in 1940.