Catalyst

GCSE Science Review

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Radiation and life

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Catalyst

Volume 15 Number 1 September 2004

The front cover shows a nuclear bomb test near Bikini Atoll in 1954 (US Department of Energy/SPL).

Contents

A new year

CATALYST has plenty of interesting articles in store for you this year. We are anticipating that *Cassini* will reach Saturn and should send back fantastic pictures. Recycling, inherited diseases and the physics of computer games are just a taster of other subjects to come. Each of the articles will help you with your GCSE topics but will also take you out of the classroom and into science in the real world.

New developments in science open doors to new opportunities — the people who developed the first lasers could not have imagined the uses we have for CDs. At the same time they also create new problems and risks. We will look at some of the issues raised by scientific developments, but you will have to make up your own mind about the pros and cons.

As well as our usual features, such as Puzzles and interesting Places to Visit we have a new feature — Reviews. Yes, even CATALYST editors get some time off to read books, see films, and play electronic games. If we think you would like any of them we'll let you know.

Jane Taylor

Free book for every subscriber!

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Jill Sutcliffe

Bryan and Cherry Alexander Photography

A reindeer digging through snow to graze on lichen. But is it radioactive?

Radioactivity and wildlife

Early in 2003, researchers in the Arctic reported that radioactivity was being spread among wildlife species in ways that no one had detected before. Where does this radioactive contamination come from?

Radioactive contamination in the Arctic was discovered by researchers collecting samples of seabird guano (droppings). The team, from the Norwegian Radiation Protection Authority, found that some samples contained ten times as much radioactive material as other samples from the area. From this they worked out that the seabirds must be eating radioactive fish and crustaceans. There was a chance that plants growing in the fertile guano might concentrate the radioactivity it contained, and become a hazard to plant-eating animals.

Where does it come from?

In the 1950s and early 1960s, nuclear weapons were regularly tested in the air at island sites in the Pacific Ocean and in the Russian Arctic. It was soon shown that, as a result of the testing, places far away from the test sites had become contaminated. Radioactive substances were carried high into the atmosphere, and spread by the jet-stream winds. This information contributed to the political pressures which led to the Partial Nuclear Test Ban Treaty, signed in 1963. It also led to the setting up of groups which measure information about radioactivity in the environment.

In 1986 the Chernobyl accident occurred. A fire which got out of control at a nuclear power station in Ukraine resulted in radioactivity getting into the air. Wind movements in the upper atmosphere transported this radioactive material over much of Europe.

Radioactive materials have also sometimes been released into or dumped at sea, where they can move around unpredictably.

What happens to it?

Nuclear testing, Chernobyl and radioactive dumping at sea have all contributed to the spread of radioactive

Even now some sheep movements in the UK are restricted because of the Chernobyl accident in 1986. Rain brought radioactive materials to ground in the uplands of Wales and Cumbria where the sheep were feeding.

GCSE key words
Half-life
Isotope
Ecosystem
Mutation
Food web
Bioaccumulation

Pascal Goetgheluck/SPL

This scientist is using a Geiger counter to check moss samples collected from a mountainside

Box 1 Radioactive detectives

It is relatively easy to detect radioactive materials. As they decay they give off radiation which can be detected using a Geiger counter or other detector. When an individual atom decays, it emits either an alpha particle or a beta particle. It may also emit a gamma ray. Each click of a Geiger counter records the decay of a single atom. There are few techniques which are as sensitive as that!

In addition it is possible to determine which radioactive isotopes are present by studying the gamma radiation. Each isotope gives out gamma rays with a particular energy or wavelength. The Norwegian researchers used this to show that their seabird guano samples contained unusually high concentrations of uranium-238 and radium-226, two naturally-occurring isotopes. They also found a lot of caesium-137, which does not occur naturally. They guessed that it came from nuclear weapons tests 40 or 50 years ago.

A total of 520 atmospheric nuclear explosions were set off in the years up to 1980.

- **Find out more about nuclear weapons testing using a search engine.**

materials in the environment. In the Arctic, algae in the sea take up radioactive ions, fish eat the algae, and birds eat the fish. On land, lichens take in radioactive substances from the air and are then eaten by reindeer. The reindeer eat a lot of lichen and therefore accumulate radioactive substances in their bodies. High levels also build up in other arctic animals as radioactive substances are passed up the food chain — an example of **bioaccumulation**.

Why should we worry about what's going on up in the Arctic? Environments in the Arctic are fragile because their ecology is highly specialised. There are relatively few species of plants and animals, and when one species in a food web is harmed, the others are also likely to suffer. This means that damage to the environment shows up quickly, and it can be an early indicator of what is going on elsewhere in the world.

Long-lived isotopes

It is only just over 100 years since Henri Becquerel discovered the phenomenon of radioactivity and Marie Curie named it. However, radioactive materials, such as uranium, thorium and the isotope potassium-40, have been present since the formation of the Earth some 4500 million years ago. They have very long half-lives and are known as **primordial elements** (Table 1).

Effects of radioactivity on human health were seen soon after its discovery. People using radioactive materials were exposed to a lot of radiation. There was no means of measuring these invisible rays, and so radiographers (people working with X-rays) measured the standard dose by putting their hands in the path of the rays until they went red.

Table 1 *Many radioactive elements were present in the Earth when it formed, 4500 million years ago. Those with long half-lives are still present, as they decay very slowly*

Radioactive isotope	Half-life
Uranium-238	4500 million years
Thorium-232	14 000 million years
Potassium-40	1300 million years

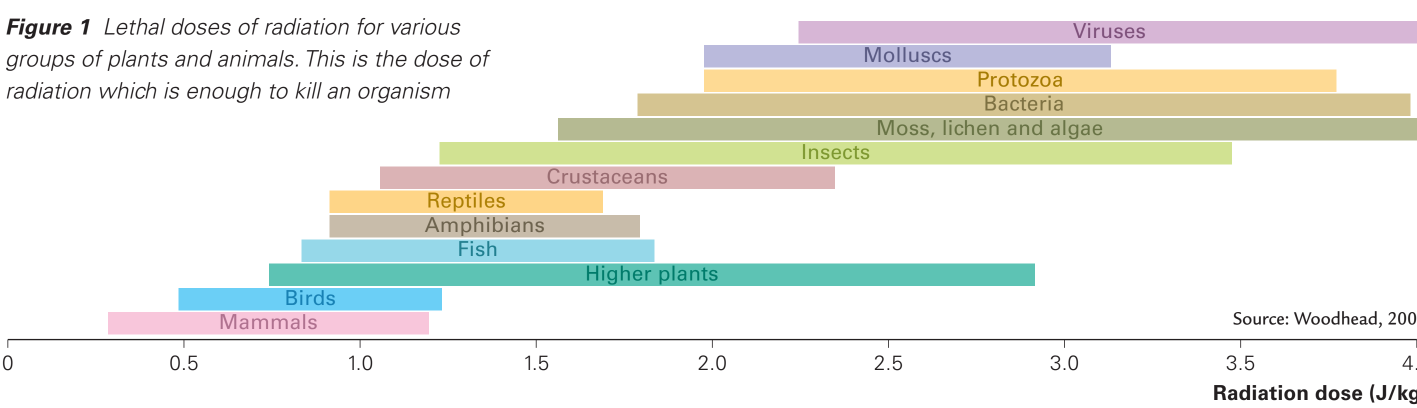


Figure 1 *Lethal doses of radiation for various groups of plants and animals. This is the dose of radiation which is enough to kill an organism*

What's the damage?

Once it was clear that radiation harmed human beings, research was carried out on plants and animals to learn more about the damage it caused. In 1904 researchers working in Russia and Pierre Curie working in Paris looked at the effects of the natural radioactive gas, radon. They found that frogs and white mice died when they had to breathe an atmosphere of radon (the amount of radon present was not given).

Radiation carries energy. When it is absorbed by a cell, it may cause so much damage to the DNA that the cell's normal function is disrupted and it dies. In 1906 research showed that cells that were actively dividing by mitosis — such as cells in the skin, colon or bone marrow — were more sensitive to radiation. In plants the most sensitive cells are in the roots and shoots.

Some species are also more sensitive to radiation damage than others. Research shows that mammals are the most sensitive. Figure 1 illustrates the radiation dose needed to kill different groups of organisms.

Work on the fruit fly (*Drosophila melanogaster*) led to an understanding of the **mutagenic effect** of radiation. Radiation damages the DNA which makes up the chromosomes in the nucleus of a cell. If the coding of the DNA is altered, a mutation has been produced. When the DNA code is read to synthesise proteins such as enzymes, mistakes will result. Crucial enzymes will no longer work properly within cells.

Radiation protection

There are regulations which seek to protect people from exposure to too much radiation in the environment. It has sometimes been assumed that, by limiting our own exposure to radiation, we are also protecting other species. But is this true?

English Nature, the organisation which advises the government on wildlife, commissioned a report to find out. The report showed that there had been two main types of study:

- Research had been done using species such as the mouse as a model for the effects of radiation on humans. The mouse has a genome similar to that of human beings but reproduces quickly and has a shorter lifespan than humans, which allows faster research results.
- Work had also been done on food chains leading back to humans. Farm crops were studied, as was grass where milk-producing cows feed. This was thought important because in 1957 there was a fire at the nuclear power station at Windscale (now called Sellafield). Surrounding farmland was contaminated and millions of litres of milk were thrown away so that there was no chance of radioactivity reaching human beings.

Little work had been done on either **ecosystems** or key species. In 1992, the European Union published a Habitats and Species Directive to protect habitats and species of international importance. Wildlife conservation agencies and the organisations which enforce environmental legislation were faced with the question of whether or not radiation damaged wildlife.

There is little evidence so far of damage to wildlife populations in the UK from exposure to either naturally-occurring or **anthropogenically derived** radiation, but there is evidence that some radioactive materials build up to unacceptable levels in some marine organisms such as mussels and lobsters. The National Radiological Protection Board issues guidelines about the consumption of shellfish gathered close to Sellafield. Concerned organisations are only now developing a framework to assess and evaluate possible risks to wildlife from environmental radioactivity.

Dr Jill Sutcliffe *works for English Nature. She has a particular interest in the effects of radiation from radioactive substances in the environment.*

Topfoto

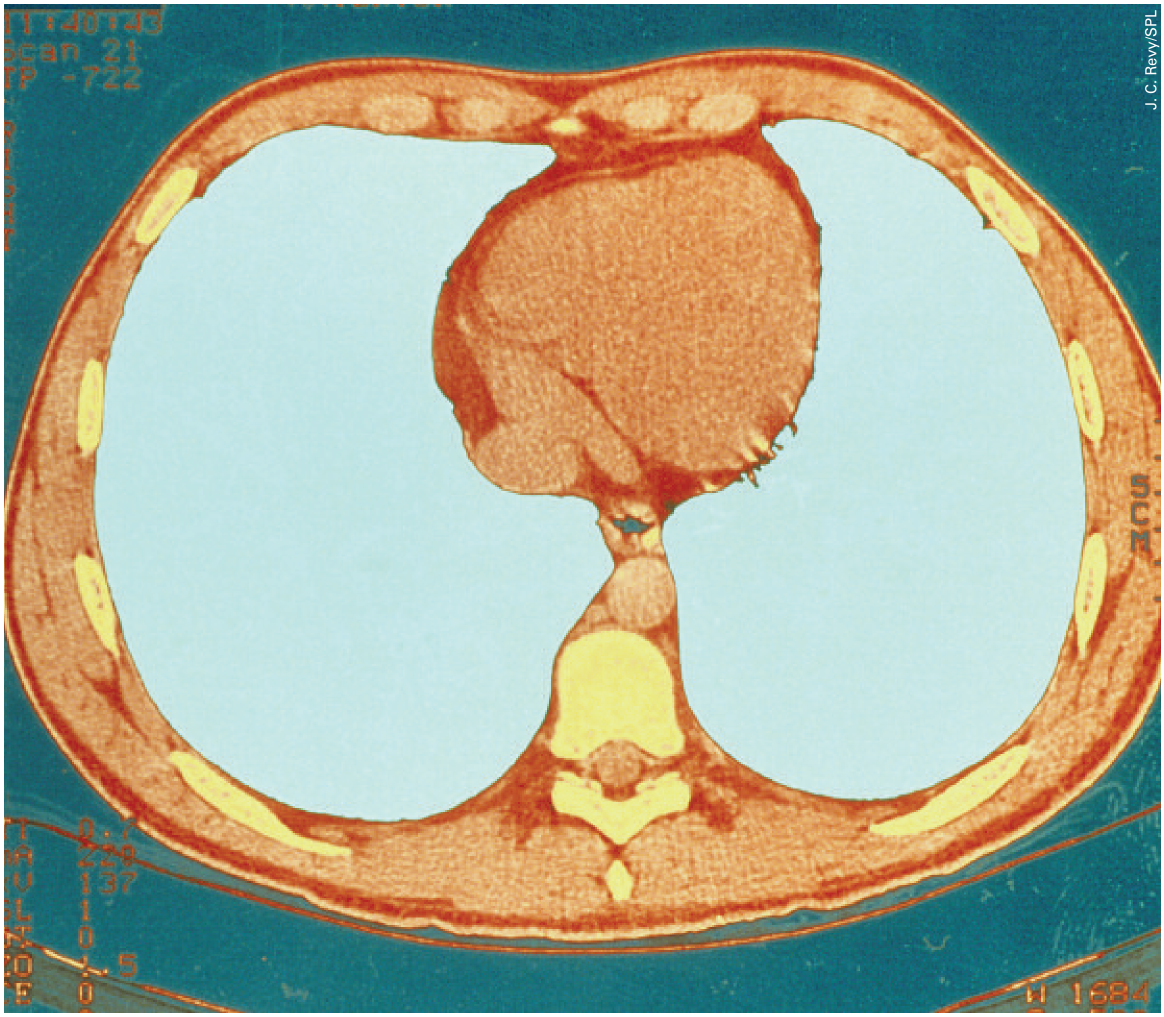
Above: *Chernobyl, 3 days after the disaster*

Novosti/SPL

Left: *Monitoring radioactivity levels on farmland near Chernobyl following the 1986 accident*

Anthropogenically derived radiation is radiation that occurs in the environment as a result of human activities.

Improve your grade



J. C. Revy/SPL

Right: *Coloured CT scan showing a cross-section through the chest of a healthy person. The lungs are blue, the heart red and the bones yellow*

Using diagrams

Diagrams are used to help describe a structure, a process or how some apparatus works. It pays to study them, and it is sometimes a good idea to look at more than one version of a diagram to deepen your understanding.

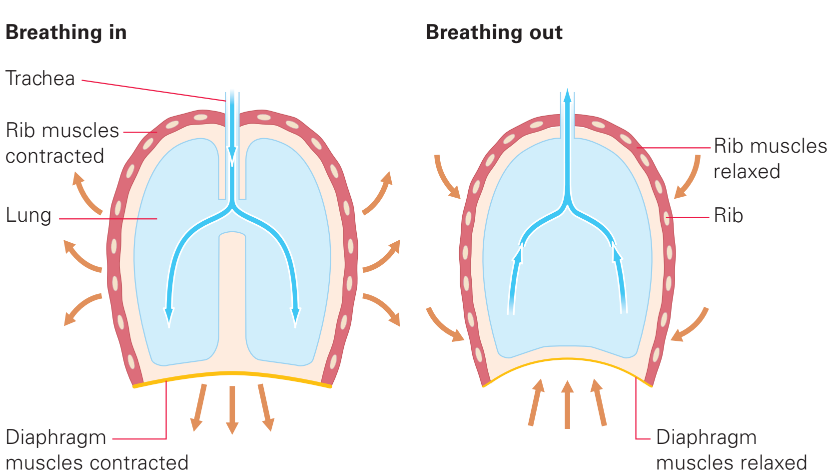


Figure 1 *A simplified diagram of breathing showing a cross-section of the lungs from the front*

School science textbooks contain lots of diagrams. These show us at a glance something that may be quite complex. Research into how people use books shows that many readers do not look at diagrams or realise what they show. Make sure you look at them. Some textbooks have high-quality diagrams and drawings over which much care has been taken. Others are poor and may even be inaccurate. This happens when things are simplified, but sometimes the diagrams are just badly drawn.

Your school may have some recent textbooks, matching the specification for your particular course. These textbooks have been written with your examination in mind — most likely a Double Award in science at GCSE. They contain exactly what the specification says you need to know and nothing more. This means they are of limited use if you want

Box 1 Breathing

Breathing involves:

- movement of the ribs, caused by muscles and by gravity
- movement of the diaphragm, caused by muscles and by pressure from the abdomen below

Foundation tier

In Foundation tier GCSE a simple description of breathing is required. When you breathe in the ribs lift up and forwards, moved by muscles. Muscles in the diaphragm contract, causing it to flatten. The volume of the chest increases, so air is forced in from outside. Exhaling involves the ribs sinking down and inwards, as the muscles relax. The diaphragm muscles relax, so that the diaphragm rises into a dome shape, forcing air out.

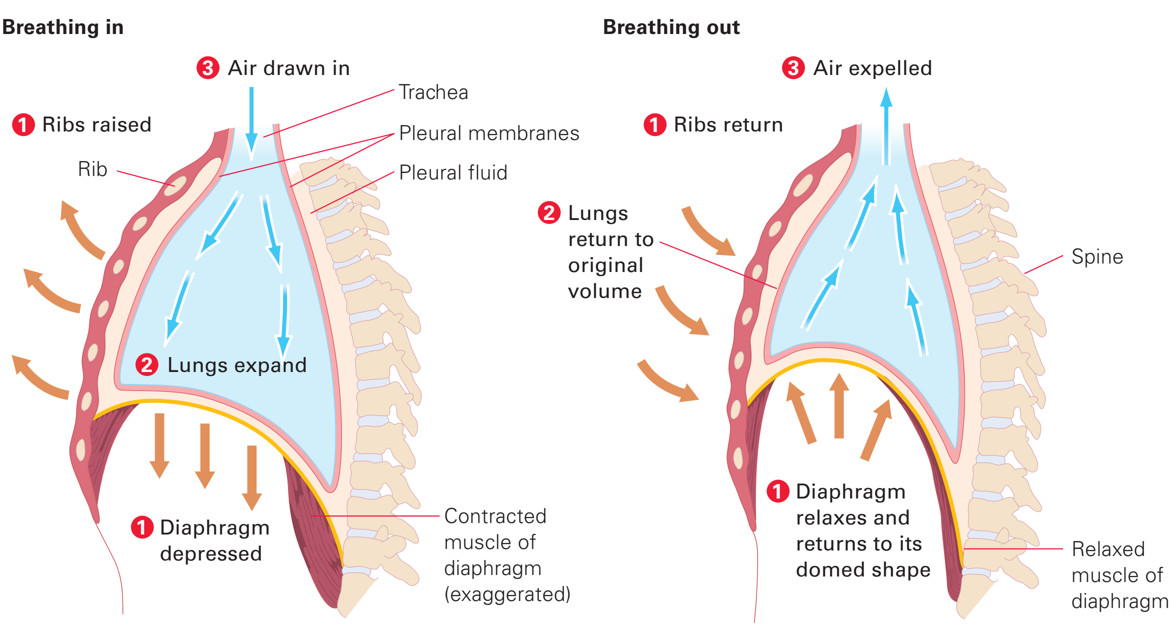
Higher tier

If you are entering the Higher tier, you will know that increasing the volume inside the chest causes the pressure in the lungs to drop. Atmospheric pressure is higher and forces air into the lungs. When the ribs fall and the diaphragm moves up into a dome shape, the volume in the chest falls and the pressure increases. This forces air out.

The paragraphs above summarise what you need to know and read a bit like the specification. Figure 1 gives this basic information — but a lot more is missed out.

Figure 2 shows much more:

- The chest cavity is lined by the pleural membrane, which also covers the lungs, leaving a gap in between — the pleural cavity. It contains a fluid which sticks the lungs to the rib cage, so they move with it.
- There are in fact two **antagonistic** sets of intercostal (between-rib) muscles — interior and exterior ones. The exterior muscles contract to pull the rib cage up and forwards. The interior ones can pull the rib cage down and inwards, but most of this movement happens because of the force of gravity on the raised up chest. We also use them when we cough, talk or sing.
- Where is the antagonistic muscle which operates against the muscle which causes the diaphragm to flatten? Antagonism is provided from below, by the abdomen — its contents and the muscles that make up its wall.
- Our ribs are angled downwards as well as forwards from the spine to join the breast bone (sternum). This geometrical arrangement allows the ribs to swing up and down, forward and back, changing chest volume. If the ribs stuck more or less straight forward we would produce inadequate changes in volume and pressure. It is possible to breathe after a fashion by making your rib cage stay still and moving your abdomen wall in and out. Most mammals are quadrupeds — walk on four legs — and so breathe this way. Their rib cages move very little; their ribs hang straight down, so they cannot get gravity to assist.



Source: Mackean, D. *GCSE Biology*.

- **Why do new babies breathe mainly with their abdomens?**

Figure 2 *A more complex diagram of breathing, showing a cross-section of the lungs viewed from the side*

to read around the subject to improve your understanding.

Older textbooks, from the time when each component science was worth one GCSE, often contain much more information, with longer explanations of things. They are often very useful sources of information, with lots of detailed diagrams. You can find amazing things on the web to help you improve your grade, but don't ignore these older resources. In Box 1 we take a look at one particular topic to see how you can pull together information to gain a fuller understanding and improve your grade.

Pay attention to what the specification for your exam board demands (see CATALYST Vol. 14, No. 4) but do not be afraid to explore some topics in greater depth than specification-based textbooks allow. This will certainly improve your grade!

Nigel Collins *teaches biology and is an editor of CATALYST.*

It is better to say 'lung volume increases' than 'lungs expand'.

Your future

Supporting dentists

Dentists often have assistants working with them, who pass them items in response to cryptic requests and enter mysterious coded data about your teeth on a computer. These dental nurses are part of a team involved in the care of your teeth. What does it take to become a member of the team supporting a dentist?

Nigel Collins

Above: *Dental hygienist Carol Hassall teaching a patient good dental hygiene*
Below: *Dental plaque and tartar on teeth*

CNRI/SPL

The dental team includes dental nurses, hygienists, technicians and therapists. Dentists concentrate on treating tooth and gum conditions, but an important part of a dental team's work lies in educating people to care for their mouths and teeth – preventing problems before they arise.

Dental nurses

A dental nurse supports the dentist in all aspects of patient care. This includes getting the appropriate

Box 1 Teeth at risk

Bacteria in our mouths produce an invisible, sticky film called **plaque** which constantly forms on the teeth. Plaque (which is 90% bacteria) is one of the main causes of tooth decay and gum disease. When bacteria in plaque use sugars in food they produce acids which damage tooth enamel and cause tooth decay and cavities. Plaque can also affect the gums, causing diseases such as **gingivitis**. If this is left untreated it can lead to a more serious gum disease called **periodontitis**.

Gingivitis (gum disease) causes the gums to redden, swell slightly and to bleed easily when the teeth are brushed. Provided patients pay greater care and attention to good oral hygiene this can usually be cleared up.

Periodontitis is an advanced state of gingivitis, in which the plaque spreads below the gums and forms a hard deposit called **tartar**. The bacteria in plaque and tartar produce toxins which irritate and inflame the gums. The disease may progress to break down the tissues and bone which support the teeth. Eventually teeth become loose and may have to be extracted.

instruments ready, mixing materials and ensuring the patient is comfortable. A nurse also take notes dictated by the dentist for the patient's records. Once the patient has left, the nurse tidies the surgery and sterilises all the instruments. A dental nurse may also be involved with administration, working in reception and records, organising suppliers and liaising with specialist laboratories.

You can train to be a dental nurse in several ways. Some dental hospitals and further education colleges run full-time 1 or 2-year courses, leading either to the National Certificate or to the hospital's own exam. If, like most dental nurses, you start your career in general dental practice, you will be able to study in the evenings or on day release. You need no formal academic qualifications to study for the certificate, but some colleges may have their own requirements.

If you want to become a dental hygienist or dental therapist, you may need experience as a dental nurse first.

Dental hygienists

Dental hygienists carry out procedures such as scaling and polishing teeth, and applying topical fluoride and fissure sealants. They also teach patients the necessary skills to carry out their oral hygiene effectively. Most dental hygienists work in community dental services, usually in general dental practice. Hospital-based hygienists also help patients to maintain a healthy mouth when they are having surgery or complicated orthodontic treatment, or if they suffer from particular medical conditions.

Hygienists must be qualified and enrolled with the General Dental Council in order to practise in the UK. To qualify you need to take a full-time 2-year course at a school of dental hygiene. These are based at the dental teaching hospitals and also at the Defence Dental Agency training college. You study anatomy and physiology, preventive dentistry, dental health education, dental pathology and the management and care of patients.

To enter the course you need 5 GCSE subjects graded A–C or equivalent, plus 2 A-levels or a recognised nursing qualification. Competition for places is strong.

Box 2 Useful websites

Further information can be found on these websites:

The British Association of Dental Nurses at http://www.badn.org.uk

The British Dental Hygienists' Association at http://www.bdha.org.uk

The British Association of Dental Therapists at http://www.badt.org.uk

The General Dental Council at http://www.gdc-uk.org

Box 3 Case study: Carol Hassall, dental hygienist

I started my first job at the age of 17 as a dental nurse in my local surgery. The idea of looking into people's mouths was not very appealing but within a week of working alongside a dentist I was enjoying all aspects of the job. It involved taking care of the patients from when they entered the surgery until they left and making them as relaxed as possible by talking to them. There were dental records to keep in order, as well as tasks such as mixing filling materials, preparing and sterilising equipment and instruments, processing X-rays and generally assisting the dentist.

I qualified as a dental surgery assistant and stayed in the job for 6 years, working with dentists, orthodontists and dental hygienists. I did some evening classes and gained more qualifications; then I applied to Birmingham Dental Hospital to train as a dental hygienist.

The training covered all aspects of dentistry and orthodontics, dealing with dental problems caused by anything from cancer to car crashes. We learnt how to work with disabled patients and how to communicate with different age groups, spending time in playgroups and schools and with elderly patients.

The demand for hygienists in general practices is high and there are jobs with hours to suit individual circumstances. You can also work in hospitals, community dental services and the armed forces.

I qualified 20 years ago but each year I update my skills. I still love the job I do. My day is spent cleaning teeth and removing tartar deposits to prevent gum disease but an important part of my role is as a health educator. I am self-employed, working in four different practices, with the support of my own dental assistant.

Dental therapists

Like hygienists, dental therapists have an important role in promoting dental health. They work in all sectors of dentistry including general dental practice.

Dental therapists can carry out more procedures than hygienists, including taking dental X-rays, giving routine fillings in both first and permanent teeth and extracting deciduous (first) teeth under local anaesthetic. Some dental therapists take further training so that they can carry out pulp therapy treatment or place pre-formed crowns on deciduous teeth, providing emergency temporary replacement of crowns and fillings and taking impressions.

Dental therapists must be enrolled by the General Dental Council. They must have a Diploma in Dental Therapy, which is offered by six dental hospitals.

The diploma course takes about 27 months, depending where you study. The course covers preventive dentistry, dental health education, dental pathology, simple restorative procedures for both deciduous and permanent teeth, the extraction of deciduous teeth, radiography and pharmacology. You need 5 GCSE subjects graded A–C or equivalent, plus 2 A-levels or a recognised nursing qualification. Competition for places is strong.

Periodontal means 'around the teeth'.

Nigel Collins *teaches biology and is an editor of CATALYST. He is grateful to Carol Hassall for taking care of his teeth.*

Nigel Collins

Oxygen supply

Above: *Coloured electron micrograph of red blood cells. One white blood cell can also be seen*

Respiration goes on in all live cells, in all living things, all the time. Oxygen is essential for most respiration. This article explores how organisms get the oxygen they need from their surroundings and how it reaches cells. It also looks at how we can monitor oxygen transport, which is vitally important in medical care.

Respiration is the process that marks out life – it provides organisms with access to the energy stored in chemicals such as glucose, so that other life processes can be sustained. Under most circumstances the other key ingredient for respiration is oxygen. This is available from the environment, whether it be in the air above ground, in soil spaces or dissolved in water. All cells obtain oxygen from their surroundings, by diffusion down concentration gradients.

GCSE key words
Aerobic respiration
Capillary
Haemoglobin
Oxygen

How are cells supplied with oxygen?

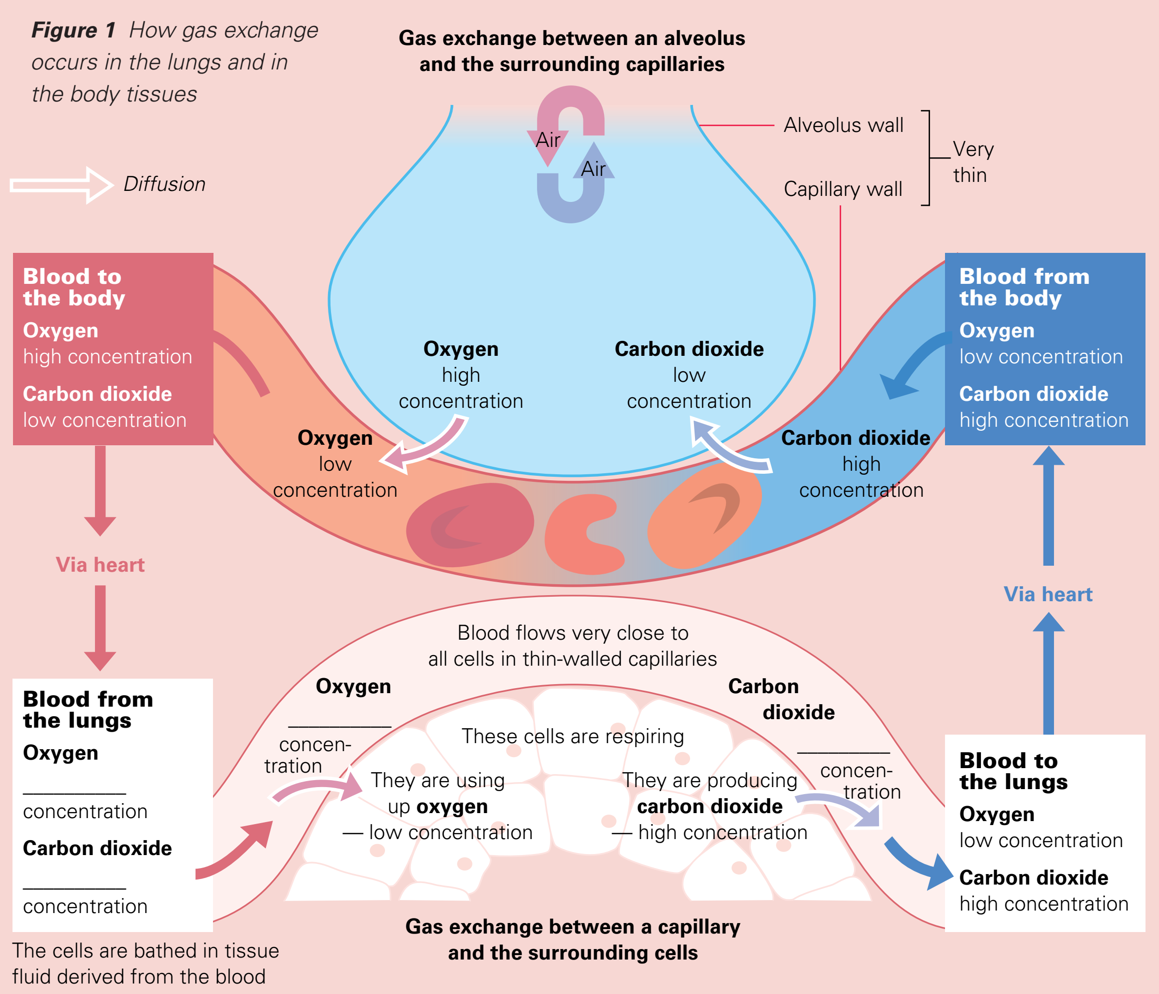
Single-celled organisms rely solely on diffusion to obtain oxygen. As they use it up in respiration their oxygen content falls. The concentration of oxygen in their immediate environment is then greater than that in the cell, so more oxygen enters by diffusion. In fact this is a continuous process – the organism uses up and is supplied with more oxygen all the time.

In larger multicellular organisms, cells still need oxygen from their surroundings. They acquire it in exactly the same way as a single-celled animal – by diffusion from the fluid in which they are bathed. This tissue fluid is formed from blood plasma at the start

Josh Sher/SPL

Pulse oximetry is a simple method of monitoring the percentage of haemoglobin which is saturated with oxygen

Figure 1 How gas exchange occurs in the lungs and in the body tissues



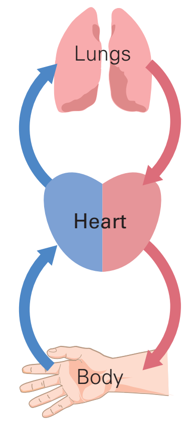


Figure 2 The basic circulatory system. Make sure you can identify major blood vessels on a full diagram of the circulatory system in your textbook

- **Complete Figure 1 in the appropriate colours and add the missing words on the lines provided.**

of capillaries. Oxygen passes out of red blood cells and diffuses through the tissue fluid to cells. No cell is more than three or four cell diameters away from a capillary.

Oxygen and blood

There is a highly efficient link between tissue fluid and the outside world. In humans this link is provided by:

- the lungs, where oxygen diffuses from the alveoli to the blood
- the circulatory system that carries oxygen very quickly to the cells of the body

Figure 1 summarises what happens in the lungs and part of what happens at the cells of the body — think hard and you should be able to complete the words that are missing from the diagram and add the appropriate colours.

Oxygen enters the blood in the lungs, and is carried round the circulatory system (Figure 2). Most of it is carried in red blood cells. These cells are packed with **haemoglobin**, a protein. Haemoglobin 'grabs hold' of oxygen molecules in places where there is a high concentration of oxygen, such as the lungs, forming **oxyhaemoglobin**. In places where there is a low oxygen concentration, such as respiring tissues, the oxyhaemoglobin molecule changes shape and 'lets go'. Figure 3 shows how this happens. For medical

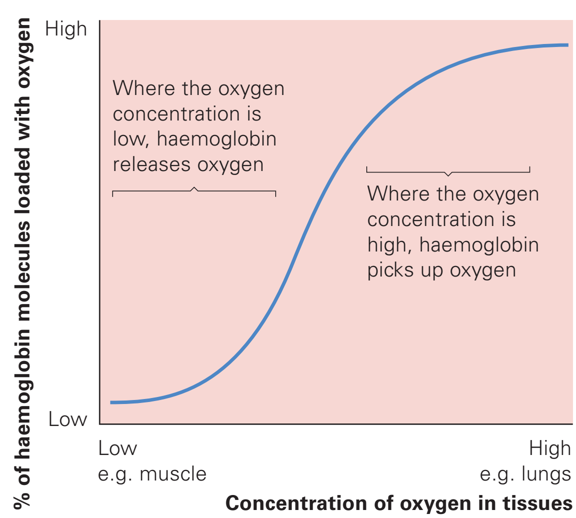


Figure 3

reasons it is often important to assess how much oxygen is being carried by the blood. This can be done using a pulse oximeter (see Box 1 on page 10). Blood leaving the lungs should be 99% saturated with oxygen.

A small amount of oxygen (about 1–2%) is carried dissolved in plasma, the liquid part of the blood.

Increased demands

When you exercise, there is an increased work rate in your body. More energy transformations take place

• **Find out more about pulse oximeters by putting this term in a search engine.**
A major supplier of the instruments is Nellcor, a US company.

• **Find out the difference between hypoxemia and hypoxia.**

Box 1 Monitoring oxygen in the blood

A **pulse oximeter** is a probe, which is attached to a patient's finger or ear lobe, or to a baby's toe, and linked to a small unit containing a microprocessor. The unit displays the percentage of haemoglobin saturated with oxygen in arteries, and a calculated heart rate. It also emits an audible signal for each pulse beat; some models have a graphical display of the blood flow past the probe. An alarm is triggered when the pulse rate becomes too fast or slow, or if oxygen saturation falls below 90%.

The probe contains a dual light source and a photodetector, which are used to measure the amount of oxygen that is combined with haemoglobin in the blood (Figure 4). The light is at two wavelengths, red and infrared (650 nm and 805 nm). Each wavelength is absorbed differently by haemoglobin, depending on whether the haemoglobin is saturated with oxygen or not. By calculating the absorption at the two wavelengths the microprocessor can compute the proportion of haemoglobin which is oxygenated.

How does the pulse oximeter detect oxygen only in arteries and not in veins? The microprocessor is programmed to register blood flow coming in strong pulses, as happens in the arteries. It ignores flow in veins because the pulse is weaker. Under some circumstances a pulse may be weak in an artery and the pulse oximeter may not work.

Pulse oximeters are used:

- To monitor oxygenation and pulse rates in people under a general anaesthetic and while they are recovering from the anaesthetic. The oxygen saturation of their blood should always be above 95%.
- To monitor patients in intensive care who cannot breathe without a mechanical ventilator. Oximeters detect problems with oxygenation before they are noticed clinically. They are used as a guide when weaning the patient from ventilation and also to help assess whether a patient's oxygen therapy is adequate.
- On hospital wards and in casualty departments. When patients are sedated for procedures such as endoscopy, oximetry has been shown to increase safety by alerting the staff to unexpected lack of oxygen (**hypoxia**).
- To monitor premature babies whose lungs are not fully developed. A premature baby cannot breathe at the same time as it is feeding. If it is linked to a pulse oximeter, the alarm warns when the blood oxygenation reading drops. The baby is then given a whiff of oxygen until the reading is high enough, when feeding can start again.

There are a number of reasons why doctors and nurses exercise great care when using a pulse oximeter. For example, a patient with anaemia may have the same percentage oxygen saturation levels as a patient with a normal haemoglobin value. Although all the haemoglobin molecules are carrying oxygen, the anaemic patient has fewer haemoglobin molecules. The total arterial oxygen content in this patient's blood is therefore lower, and less oxygen is reaching the cells. If oxygen demand increases or oxygen supply decreases an anaemic patient may be at risk.

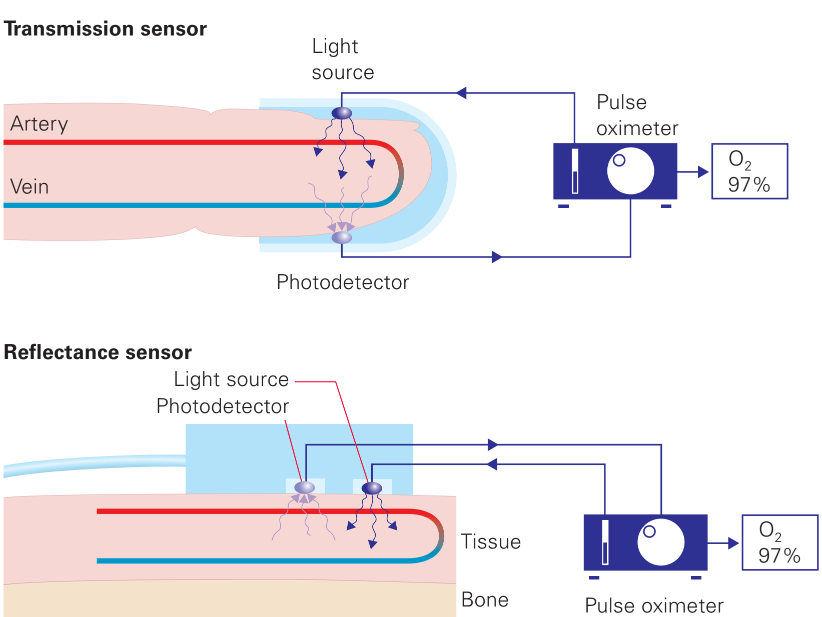


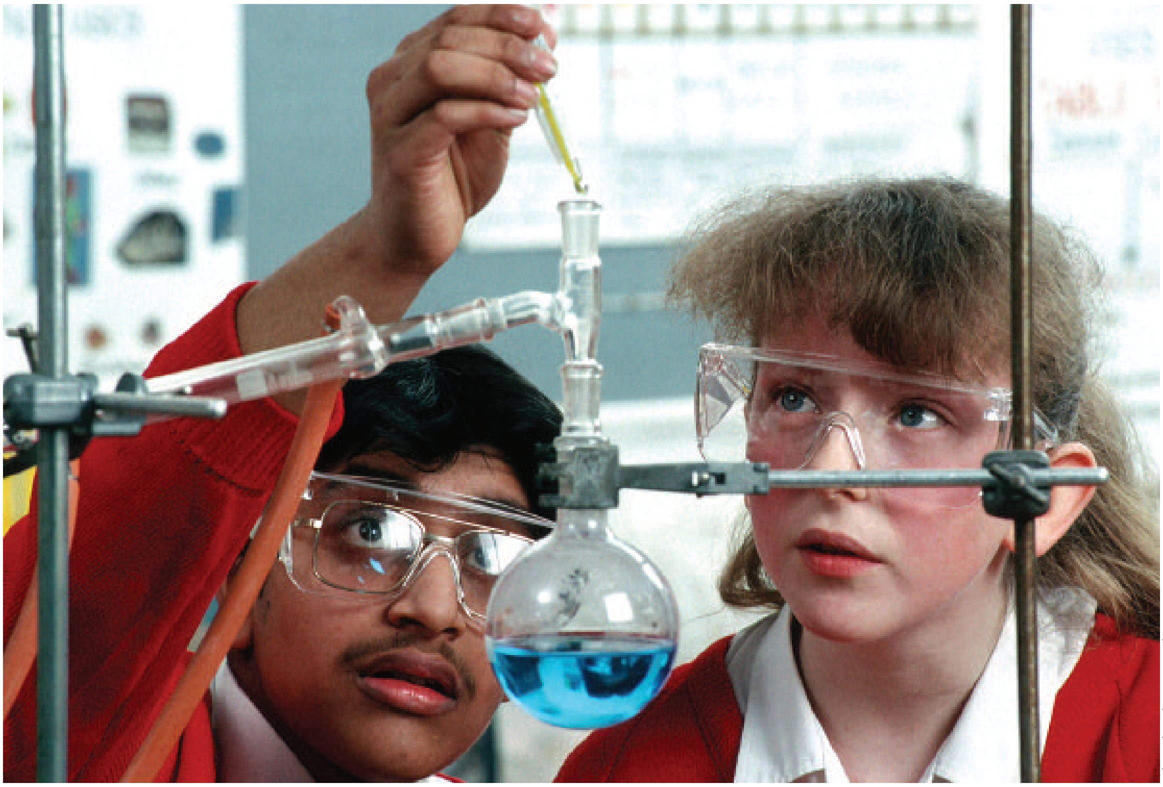
Figure 4 *How two types of pulse oximeter work. They ignore reflections from blood in veins, where there is no significant pulse*

and therefore more respiration must occur. This means that muscle cells need more sugar and oxygen and have to get rid of more carbon dioxide. Respiration is not 100% efficient — heat is produced and must be moved to the surface layers of the skin where it is lost to the surroundings. All of this means that:

- the heart beats faster and more strongly
- the rate and depth of breathing increases
- blood vessels near the skin surface dilate

The extent to which these happen depends upon the nature of the exercise. If it is at a sustained, steady rate, as in a long-distance race, the heart's output and ventilation of the lungs will settle to a new and higher level, matching oxygen supply to the needs of the body. If on the other hand you are running flat out, a point is reached at which the muscles cannot be supplied with oxygen fast enough, anaerobic respiration starts to occur, lactic acid builds up and you are forced to stop.

Nigel Collins *teaches biology and is an editor of* CATALYST.



educationphotos.co.uk

Keith Bowker

GCSE key words
Risk assessment
Safety
Coursework

Safety in the lab

Practical chemistry experiments give you hands-on experience of chemicals and chemical apparatus. They are enjoyable, but every chemistry teacher can tell you stories of people who didn't follow the rules, and came to a nasty end. You need training in identifying, assessing and controlling risks if you want to keep yourself intact.

Health and safety laws about activities in school chemistry laboratories are intended to stop you getting hurt or hurting others. You are constantly supervised when you do activities in the chemistry lab, so relatively few accidents occur. But when they do they can be serious.

All your practical work in the laboratory should have had a **risk assessment** carried out on it before you start. The risk assessment will have spotted any hazards associated with a practical experiment and will have detailed safe ways to do the experiment.

Chemicals can be hazardous; most have at least one hazard. A substance may be toxic if you swallow or inhale enough (even sodium chloride — table salt), it may be flammable (it will catch fire if placed near a flame), or it may be corrosive (see Box 2). The risk assessment looks at the likelihood of an accident occurring under the conditions in which you are using the chemical in the lab. As an example, keeping flammable solvents to small quantities and away from naked flames or very hot surfaces will reduce the risk of fire. There is still a risk of vapours igniting, but it is much smaller.

Box 1 Warning signs and labels

Prohibition signs are red and shaped like road signs. The symbol in the middle indicates what is prohibited

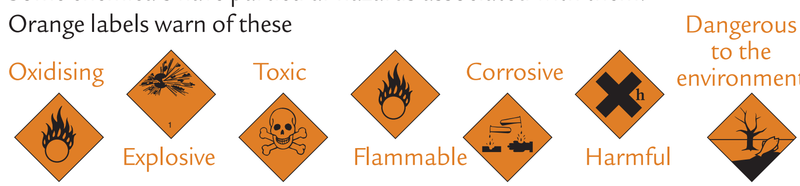
Mandatory signs are circular signs with a white picture on a blue background. They give instructions that must be followed, e.g. eye protection must be worn

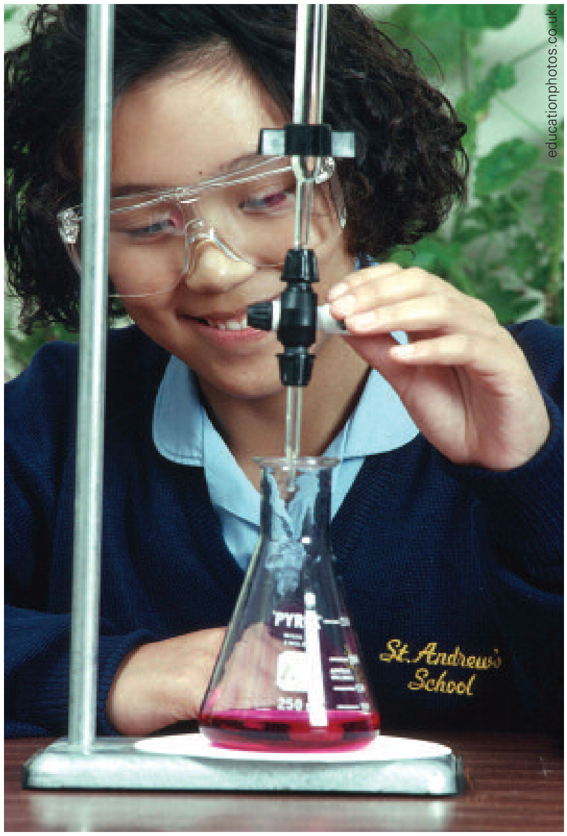
Warning signs are a black triangle on a yellow background and are used to warn of risks in science

Safe condition signs are white on a green background and give information, e.g. the location of the first aid box, or fire exit routes

Box 2 Hazard symbols

Some chemicals have particular hazards associated with them. Orange labels warn of these





Right: Remember to wear safety glasses when using chemicals

Simple rules

The key to working safely is to follow the **safety rules** for the laboratory. Ask your teacher if you don't understand the instructions – don't guess or you could make a dangerous mistake. Tell your teacher if you think anything is dangerous, damaged or faulty.

Follow your **instructions** carefully. Always add chemicals in the order they are given in the recipe – it can make a big difference. For example, you must always add acid to water and not the other way round. Water added to acid gives out a lot of heat and the vapour formed may spray acid over you.

Keep to the **quantities** shown in the instructions. Scaling up the volumes of ingredients can also make a significant difference to the outcome of a reaction.

Mop up **chemical spills** quickly, using the right materials. There are special spill kits for dealing with particular chemicals, such as mercury. Teachers and technicians need to know about spills as soon as possible to prevent them spreading – it is quite hard to get chemicals out of shoes!

Be careful about **breakages**. Broken glass in the sink is hard to spot and people can – and do – cut themselves. Glass goes in a special glass bin for the safety of anyone dealing with waste.

Don't eat, chew gum or drink in a laboratory – you may ingest harmful chemical traces.

Clean up thoroughly when you have finished an experiment. Don't leave traces of chemicals on the work surface – other people may unknowingly touch them and be harmed. Traces of acids and alkalis cause bad burns and damage your clothes.

Hazardous liquids or substances should never be put into unlabelled or wrongly labelled bottles. An unlabelled beaker of clear liquid *might* contain water – but it could be sulphuric acid or ethanol. Don't leave unlabelled containers around on the lab bench. Ask your teacher before pouring chemicals away down the sink. If you do, then use plenty of water to dilute the chemical.

Wash your hands using soap and water every time you leave the laboratory. This is particularly important if you are just about to go for lunch – you don't want to eat your chemicals along with your food! Dry your hands using the towels or dryers provided. It makes sense to cover any open cuts on your hands before you start work.

First aid

Occasionally things go wrong and first aid is needed. All injuries, however slight, must be reported to your teacher. Schools have trained first aiders and some have qualified nurses. Specific chemical injuries require specialist treatment from someone who knows what to do.

If you have an accident it is important to reduce the amount of chemical in contact with your skin or eyes quickly. Chemical and heat burns, for example, should have 10 minutes under cold running water. There should be a green first aid box in every laboratory.

Protective clothing and equipment

Use the protective equipment and clothing required by the school. Safety glasses are a must when working with chemicals. Even rinsing a dropping pipette under a tap can cause splashes at eye level. It may feel strange or silly wearing protective clothing but you must follow this rule for your own well-being.

Fire

Take care when handling solvents and other flammable substances – keep them away from naked flames. Make sure that you know where the fire alarm button and fire exits are. Pay attention during fire drills so that you know *all* the routes out of every lab you are taught in. Avoid using volatile hair products – they have been known to ignite when too close to a Bunsen burner.

Finally

Remember these four important rules:

- **Learn** how to work safely.
- **Obey** safety rules.
- **Ask** your teacher if you don't understand any instructions.
- **Report** to your teacher anything that seems dangerous, damaged or faulty.

***Dr Keith Bowker** is Director of Health and Safety at Oxford University and a partner in Oxford Safety and Risk Management, a leading UK health and safety consultancy specialising in the school sector.*

Do your own risk assessment

A **hazard** is anything with the potential to cause harm. A **risk** is the likelihood of harm actually being caused. Practical work in science is potentially dangerous, but you are expected to manage your working environment to ensure the safety of yourself and others. These words or something very similar are found in the section on coursework in the specification for each GCSE exam board.

Before you start practical work in science a **risk assessment** has to be done. It is important to work out the possibility of an accident — high, medium or low — and the probability of harm — again high, medium or low. In experimental design the aim is for low/low... and then you proceed.

Your teacher will have already done a risk assessment before you carry out an experiment in class. They will talk through the experiment before you do it, pointing out any hazards and potential dangers.

Table 1 shows an example risk assessment for boiling a small amount of ethanol in a test tube. Unless all Bunsen burners in the laboratory are turned off after beakers of water have been heated, there is a high probability of igniting ethanol vapour when a test tube of ethanol is heated in the water. The probability of burns or a fire is medium to high. This is too risky. Bunsen burners must be turned off before tubes containing ethanol are placed in the beakers of hot water. Even better and safer, use a thermostatic water bath.

What to do

Pick a different experiment — one you have done recently — and do a risk assessment on it. Use a computer, and set up a table like Table 1 using Word or Excel. Fill in the details relevant to your experiment, using your textbooks and the school library to help you find out the risks associated with different chemicals and pieces of apparatus.

Your teacher may be able to show you the Student Safety Sheets supplied by CLEAPSS. These tell you what the hazards are and the control measures for reducing risk when using particular chemicals or procedures. When you move on to A-level science courses you will be expected to play a more active role in risk assessment.

Keith Bowker

Table 1 *Risk assessment*

Title of experiment: Heating ethanol

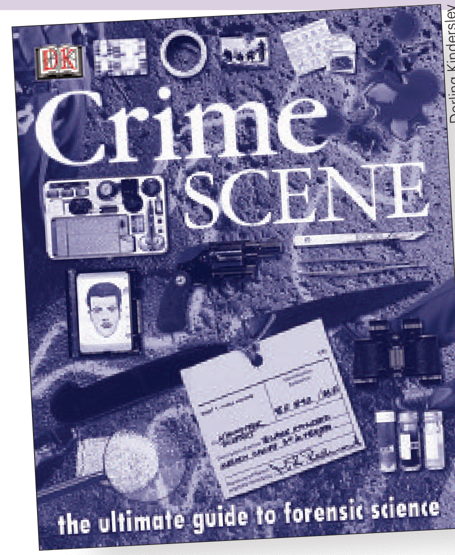
Chemical	**Amount used**	**Hazard**	**Probability of accident**	**Probability of harm**	**Control measures**	**Source(s) of information**	**Disposal**
Ethanol	10 cm^3	Flammable	High, with naked flames	Medium/high	Wear safety glasses. Turn off naked flames when ethanol is heated. Heat the tube indirectly in a beaker of hot water or thermostatic bath. Point the tube away from people	Bottle label. Teacher: past experience and CLEAPSS Student Safety Sheets	Wash away with plenty of water
Apparatus		**Hazard**	**Probability of accident**	**Probability of harm**	**Safety precautions**	**Source(s) of information**	
Bunsen burner		Hot — risk of burn	Medium/low	Medium	Wear heatproof gloves. Keep a careful watch over Bunsen	Teacher: past experience and CLEAPSS Student Safety Sheets	
Beaker of hot water		Hot — risk of scald	Medium/low	Medium	Wear heatproof gloves		
Test tube		Hot — risk of burn or scald	Medium/low	Medium	Use tongs		
Tripod		Hot	Medium	Medium	Wear heatproof gloves		

Reviews

Books and films

book

Crime Scene: the Ultimate Guide to Forensic Science, by Richard Platt



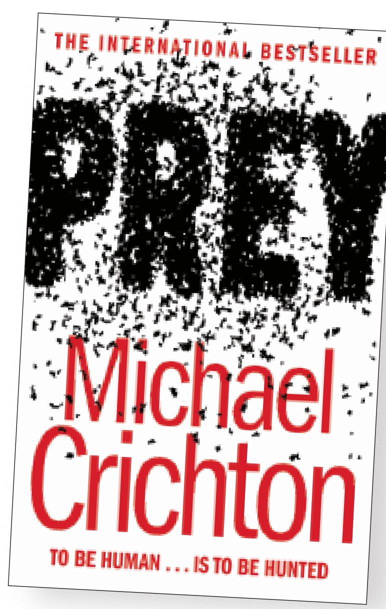
Forensic science is fascinating — even though some of you might not want to admit it. Each magazine-style double page spread in this excellent book explains one aspect of forensics. There are the topics you would expect — what can be learnt from fingerprints, marks and wounds, bloodstains and dental records — but also less familiar areas. I learnt how the population of maggots and other decay organisms changes the longer a body has been dead.

Topics such as facial reconstruction, forensic anthropology, lie-detector tests and psychological profiling are regulars on television and this book gives an informative account of the science underpinning them. As well as the science there are examples of real cases showing the techniques used, photos, computer simulations and diagrams, and as you might expect, some gruesome images as well. This book is going to be by my side next time I watch my favourite murder mystery on television.

Published by Dorling Kindersley, price £14.99.

book

Prey, by Michael Crichton



Many of you will know Michael Crichton's work through the *Jurassic Park* films and *ER*. His stories are impressive adventures with a good solid scientific thread running through them. *Jurassic Park* used the idea of recovering and copying dinosaur DNA to regenerate dinosaurs, but the thrills came from scientific theories of dinosaur behaviour, as members of the human cast fled from pursuing raptors and tyrannosaurs.

In *Prey*, Michael Crichton turns his attention to nanotechnology and couples it to another aspect of comparative psychology — collective intelligence. The plot involves a cutting-edge technology company which is developing ever-smaller remote spying cameras. The cameras need to be mobile, tiny enough to avoid detection and able to seek out their target.

The company uses molecular technology to create microscopic particles which have a significant property — they can seek a goal just as tiny algae can swim towards light. The problems begin when particles escape and swarm together, reproduce and start to evolve intelligence. The swarms learn to hunt prey, including the humans who created them.

The story is gripping and by the time you find out whether Jack Forman has managed to save his wife, and the world, you will know more than you ever imagined about molecular assembly.

If you like Michael Crichton, try books by Robin Cook as well.

Published by HarperCollins, price £6.99. Also available as an audio CD and as a digital download.

The chemistry of the rings

Topfoto

The Lord of the Rings Special Extended Edition will be issued on DVD this winter. Did you realise that chemistry played a large part in getting the book on to the screen?

The Hobbits' feet and ears were made from foam latex, as were 2000 full body suits for the Orcs and Uruk-hai, and 10 000 prosthetic faces. Rubber latex (or 1,4-polyisoprene) is found in tissue beneath the bark of the rubber tree. A slit in the bark allows the latex to ooze out. In order to make the latex 'set' it is **vulcanised** – treated with sulphur and heated. This causes cross-linking to occur between the molecules and makes the latex more rigid. It is made more pliable by foaming – soap is added to the latex and air blown through so it is full of bubbles when it sets. For the body parts silicone was often layered on top of the latex to allow the finer details of skin and features to be picked out.

Some of the non-human parts in the film involved actors wearing many different prosthetic devices. It took 10 hours for the actor playing Lurz, the leader of the Uruk-hai, to have all his prosthetic parts and make-up applied.

Legolas and the other elves needed pointed translucent ears made from gelatine. Gelatine is a natural substance made by boiling the skins, bones and tendons of animals. It is often used as a thickener in sweets. However gelatine dries out very quickly under the heat of filming lights, and dissolves in water, so many thousands of pairs of ears were finally needed.

Foundry techniques used in the Middle Ages combined with modern chemicals and processing were used to make the 2000 weapons and 1000 suits of armour needed for the films. Steel and brass weapons would have been too dangerous in the close-up fight scenes, so a plastic called polyurethane, from which car seats are made, was used instead. This was light and wouldn't cause too much damage if an actor was accidentally hit with a polyurethane weapon during filming.

When you watch the film keep an eye open for the chemistry of the rings – chemistry plays a part even in Middle Earth.

The word prosthetic describes any artificial structure made to replace a body part, for example prosthetic limbs used by those who have lost limbs through accident or illness.

Puzzle

Safety quiz

Use your general knowledge to join up the hazard symbols on the right with the substances listed on the left. Ask your teacher for help if there are any you don't know – or ask to look at their collection of Hazcards (these are cards issued to schools which list the risks associated with various chemicals), or other sources of safety information.

Are there any that have more than one hazard associated with them? The results of this exercise may surprise you. Answers are given on page 19.

Substance

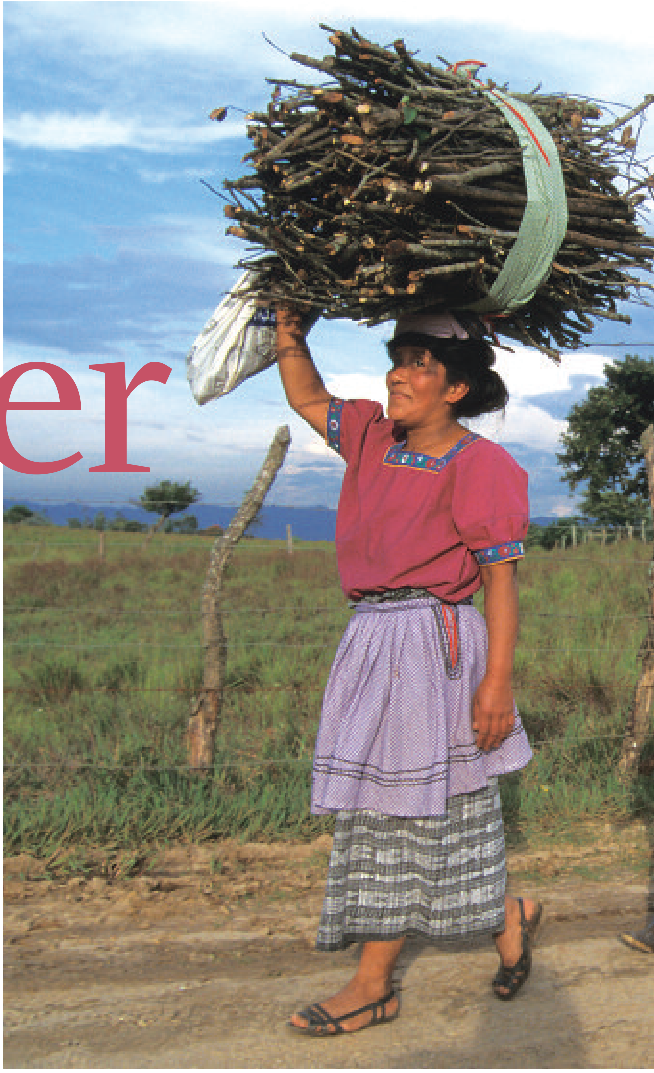
Sulphuric acid
Ethanol
Sodium hydroxide
Uranium(IV) oxide
Hydrogen peroxide
Potassium cyanide
Ethanoic (acetic) acid
Methane
Potassium manganate(VII)
Copper sulphate
Calcium hydroxide solution (lime water)

Hazard

Janet Taylor

Wood is a renewable source of energy. Could we use wood to generate electricity in the UK, and what are the advantages and disadvantages?

Tree power



Humans have been using the warmth and light from wood fires for hundreds of thousands of years. Even now up to half the people in the world cook their food on open fires. Wood fuel is news again now because it is a renewable source of energy. At present almost all our energy comes from fossil fuels and in the long term these will run out. Burning fossil fuels also releases carbon dioxide and contributes to global climate change. We need to replace them with renewable and more sustainable sources of power.

The government has set a target for 10% of our electricity to be generated from renewable sources by 2010. At present, renewables supply only 1.5% of UK electricity.

- **A useful website is: http://www.woodfuelresource.org.uk**

Biomass

Trees are made of **biomass**. This term covers material from both plants and animals. Wood, straw, animal dung and domestic refuse are all biomass fuels.

Biomass stores energy from the Sun. Chemical reactions harness the energy in sunlight to synthesise energy-rich compounds. This is the process of **photosynthesis**. Carbon dioxide from the air and water from the ground are combined in this process to make the carbohydrates that are the main building blocks of biomass. When biomass is burnt the carbohydrates react with oxygen from the air to make

- **A tree weighs several tonnes. About half this mass is carbon. Where have the carbon atoms come from?**

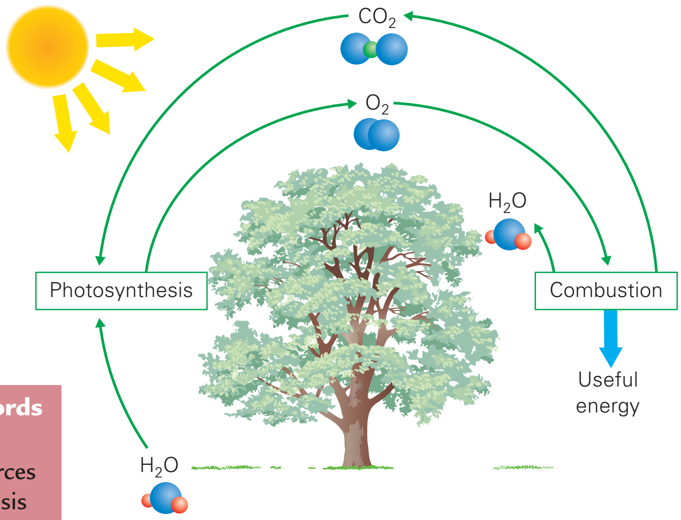


Figure 1 *When it burns, wood fuel gives off only the carbon dioxide it took from the atmosphere when it grew*

Box 1 Renewable and sustainable energy sources

Wind, wave, tidal, solar voltaics (PV), hydro, geothermal and biomass are all renewable energy sources. They are called **renewable** because they do not get used up. However they have another very important advantage over fossil fuels. They do not increase the amount of the greenhouse gas, carbon dioxide, in the atmosphere.

Nowadays the word **sustainable** is often used in connection with renewable energy sources. To be sustainable, an energy source must not run out, damage the environment, create health hazards or cause wars or social injustice. A sustainable energy source is one whose use now will not make it more difficult for future generations to meet their needs.

GCSE key words
Biomass
Energy resources
Photosynthesis
Renewables
Sustainability

Wood is a source of energy for many people around the world, including this family in Guatemala

carbon dioxide and water again. The biomass gives off *only* the carbon dioxide it took from the atmosphere when it was growing (Figure 1). If the forests that supply the fuel wood are replanted at the same rate they are cut down then the wood is a renewable energy source.

Have we got wood to burn?

About 9% of the total land area of Great Britain is woodland. This could give a sustainable yield of nearly 700 000 tonnes of air-dried wood per year. In the past, wood was harvested as the raw material for making paper but the paper industry has shifted overseas. We also import timber for the building industry, so today we only harvest half the yearly growth of wood from our forests.

Table 1 shows that wood is a less concentrated store of energy than any of the fossil fuels. Because it is bulky the use of wood increases lorry traffic. However, a wood-fuel industry could help to create jobs in the countryside.

Table 1 *Energy content of fuels*

Fuel	Energy content (kJ/g)
Wood (air-dried)	15
Paper (stacked newspapers)	17
Dung (dried)	16
Straw	14
Domestic refuse	9
Oil	42
Coal	28
Natural gas	55

Above: *Coppice plantations like this can provide new habitats and encourage bio-diversity. They need smaller amounts of agricultural chemicals than arable crops*

Box 2 Growing energy

The best energy crop for northern European conditions is coppiced willow. Saplings are planted and, after 1 year, cut back close to the ground. This is called **coppicing**, and it stimulates several new woody stems to grow. The crop is allowed to grow for 2–4 years and then the stems are cut. The plant will grow more stems so the cycle is repeated. One hectare of land can produce 10 tonnes of air-dried wood per year.

There is debate about whether we have enough land to grow sufficient energy crops.

Converting wood energy into heat and electricity

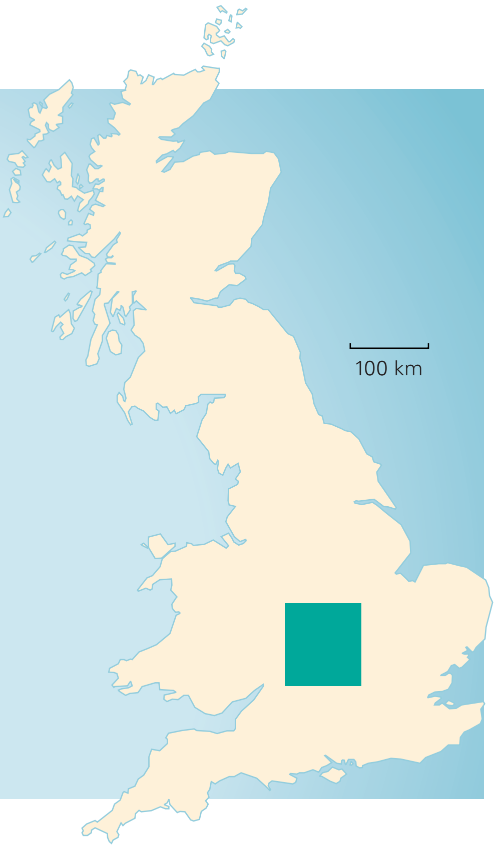
Domestic and community heating projects are already using the thinnings and trimmings from existing woods and forests. Landowners and farmers are increasing the supply of wood fuel by growing 'energy crops' like willow or poplar. The wood-fired heating system at Weobley School in Herefordshire uses 150–300 tonnes of wood chips every year.

Below: *The 350 kW boiler at Weobley School in Herefordshire was installed in 1998 to heat the primary school, the adjacent secondary school and the schools' swimming pool*

Box 3
How much electricity could energy crops produce?

Energy crops can be grown on farmland that is not needed for food. The area could be 1 million hectares by 2010. This is 10 000 km^2, about half the area of Wales (see map).

By 2010 energy crops *could* generate 1000–2000 MW. This is less than 2% of our electricity. In the long term, if 10% of the farmed area of the UK were to be planted with willows for coppicing, 9000 MW could be produced, enough for two large cities.



Purpose-built biomass power stations that generate electricity from wood burning are being planned and built. Wood can also be burnt in combination with coal (co-firing) in existing power stations.

Gasification and turbines

Today the furnaces that burn wood for space heating are clean and efficient. But when it comes to generating electricity the favoured method is more hi-tech. Biomass is converted to power in an IGCC (integrated gasification combined cycle) power plant.

Gasification is a combustion process in which the reaction is 'starved' of oxygen so that it is not completely oxidised. Wood is mainly composed of carbon, hydrogen and oxygen. If it is oxidised completely the carbon and the hydrogen atoms form carbon dioxide and water:

$$C + O_2 \longrightarrow CO_2$$
$$2H_2 + O_2 \longrightarrow 2H_2O$$

During gasification wood fuel is heated with a mixture of gases and air in a sealed container. The mixture doesn't contain enough oxygen for all the carbon and hydrogen atoms to be completely oxidised. The overall reaction with the carbon atoms is:

$$2C + O_2 \longrightarrow 2CO$$

The gas produced is mainly carbon monoxide with some hydrogen, hydrocarbon gases and nitrogen. Tar and ash, formed as by-products, are washed out of the mixture. The gas can still burn and is now the fuel for a combined cycle gas turbine (CCGT) plant.

In these power plants the hot gases produced by burning the carbon monoxide turn the first turbine. They then also heat a boiler to make steam, which drives a second turbine. Both turbines turn generators, which produce electricity. Combining them makes the system very energy efficient.

Carbon monoxide is a deadly poison but good engineering and good practice at the plant make the risks negligible. IGCC is a clean technology.

__Below:__ During the Second World War there was a shortage of petrol and 1 million vehicles ran on gas from wood or charcoal. Here mechanics are fitting a gas-producing unit to a car

Topfoto

The ARBRE project

ARBRE stands for ARable Biomass Renewable Energy. The project was set up in Yorkshire. It was a prototype for a 10 MW IGCC plant, using forest residues and energy crops. The hope was that it would be the first of many for Britain.

The plan was to fuel the plant with forest residues at first and then switch to coppiced willow. By May 2000 some 500 hectares had been planted, with a further 625 hectares to be established within the year. There were many difficulties. Farmers were reluctant to grow willow, harvesting was difficult and expensive. At the end of May 2003, Yorkshire Water, the owners and instigators of the ARBRE project, sold the company, and it was shut down. The plant had produced electricity for just 8 days.

The future

Wind power provides the largest share of renewable electricity. But there are days when there is hardly any wind across the whole of the UK (this happened for a few days during the cold spell in January 2003). It is essential to have other types of power station to back up windfarms on windless days.

Power stations fuelled by wood and other types of biomass have the great advantage of being able to generate electricity on demand. The failure of the ARBRE project was a setback, but new projects must be encouraged. Energy crops are both green and flexible.

Janet Taylor *is a science teacher and has contributed to many websites and textbooks.*

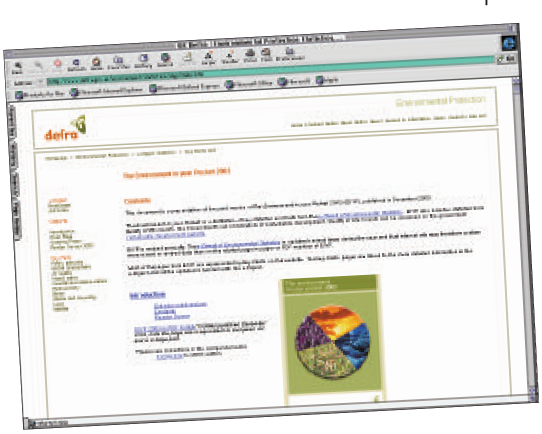
Our environment

The Environment in your Pocket

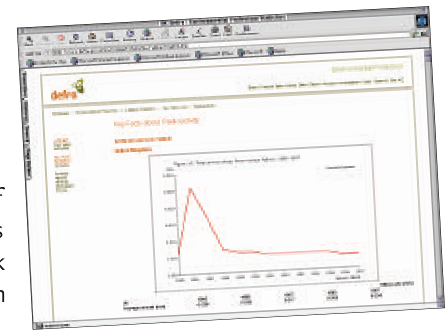
Learning about the ways in which humans have affected and are affecting our environment is part of your GCSE science course. We quite often have articles about environmental matters in CATALYST. In this issue examples are 'Tree power' (page 16) and 'Radioactivity and wildlife' (page 1). If you have to investigate an environmental topic as part of your science work, there is a useful small booklet produced by the government's Department for Environment Food and Rural Affairs (DEFRA). It is also available online at **http://www.defra.gov.uk/environment/statistics/eiyp/index.htm**

The Environment in your Pocket is literally that – a small A6-format booklet containing 65 pages packed with clearly presented tables and graphs about key features of the UK environment. You can request a free copy for yourself by e-mailing **defra@iforcegroup.com** – ask for the A6 version. Topics include global atmosphere, air quality, inland water, coastal and marine waters, radioactivity, noise, waste and recycling, land and wildlife.

The website contains additional information – including two interesting pages related to radioactivity and wildlife. Go to the website and click on *Radioactivity*, then, under *Artificial sources* in the table, on *Fallout*. This takes you to a page that clearly shows the impact of Chernobyl on radioactive fallout in the UK. Then click *Back* once and click on *Monitoring with RIMNET after Chernobyl reactor accident* in the table. This shows the monitoring network that has been set up across the UK. Before the Chernobyl accident there was very little capacity to measure fallout across the UK. After above-ground testing of nuclear weapons was stopped people became less concerned about radioactive fallout. Chernobyl was a wake-up call for politicians and scientists. You can see how fallout from nuclear weapons testing compares with that from Chernobyl by clicking on *Fallout sources of radiation* on the *Fallout* page.



Radioactive fallout is just one of the things you can explore on this fascinating site – use it to look further into other aspects of human impact on the environment.



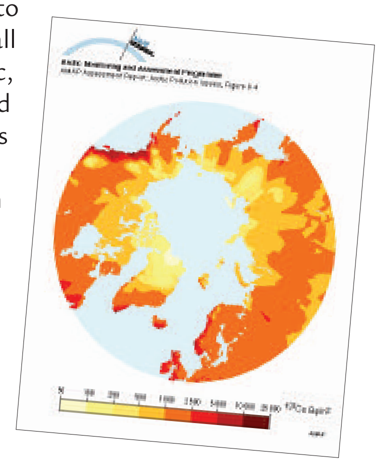
Arctic monitoring and assessment programme

The north pole was first reached by Matthew Henson and Robert Peary in 1909. Now you can explore the Arctic environment with a few clicks on your mouse. Log on to the programme's website at

http://www.amap.no/maps-gra/maps-gra.htm

This provides you with access to thumbnails and download routes for all sorts of information about the Arctic, including its physical, geographical and ecological characteristics, as well as its inhabitants,

There is also a wealth of information about contaminant pathways and transport, including persistent organic pollutants (POPs), heavy metals, radioactivity and acid rain. Climate change and ozone depletion and ultraviolet radiation are covered, as well as the effects of all this on human health.



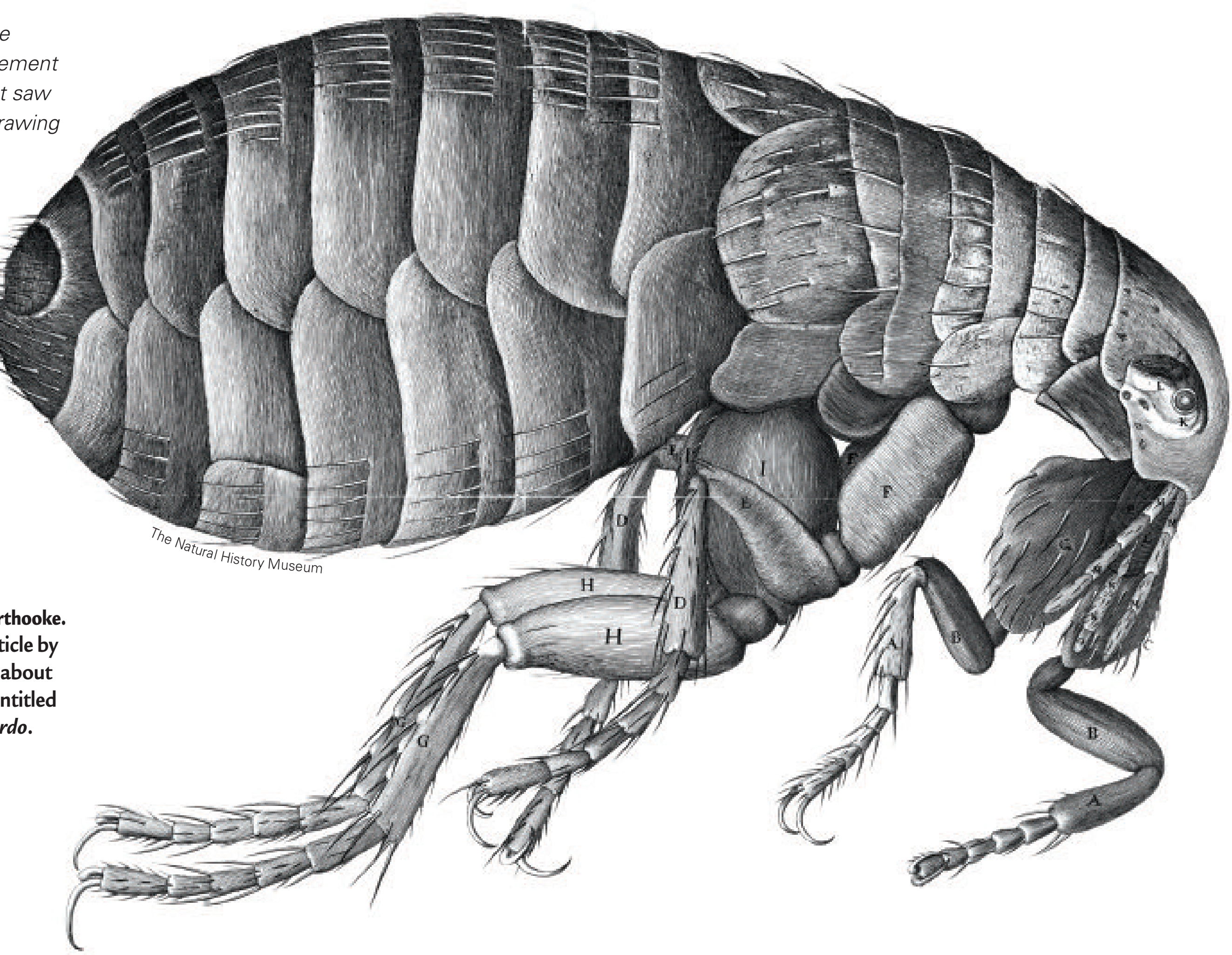
Answers to safety quiz, page 15

Substance	Hazards
Sulphuric acid	Corrosive (or irritant, depending on strength)
Ethanol	Flammable, irritant
Sodium hydroxide	Solid: corrosive, toxic. Dilute: irritant
Uranium(IV) oxide	Radioactive, toxic
Hydrogen peroxide	Oxidising, corrosive, irritant
Potassium cyanide	Toxic
Ethanoic (acetic) acid	Neat: flammable, corrosive. Dilute: irritant
Methane	Flammable
Potassium manganate(VII)	Oxidising, irritant
Copper sulphate	Irritant
Calcium hydroxide solution (lime water)	Irritant

A life in science

Robert Hooke

Right: *Imagine people's amazement when they first saw this detailed drawing of a tiny flea*



- **The website http://www.roberthooke.org.uk has an article by Allan Chapman about Robert Hooke entitled *England's Leonardo*.**

Right: *A portrait, believed to be of Robert Hooke, in the Natural History Museum*

The Natural History Museum

- **Borrow *The Curious Life of Robert Hooke: The Man who Measured London* by Lisa Jardine (2003) or *The Man who knew too Much* by Stephen Inwood (2002) from your public library.**

- **Find out more about the other scientists who appear in Hooke's story.**

You may have heard of Hooke's Law, relating to springs and elastic materials and what happens when they are stretched. But who was Hooke?

Robert Hooke, who lived from 1635 to 1703, was a man of many interests. He invented the universal joint used in all cars and many other mechanical devices, designed a balance wheel for a watch and, as part of his wide-ranging observations using a microscope, first coined the term 'cell'. Hooke was involved with The Royal Society from its formation – he was employed by the society as an experimenter and demonstrator. His work in astronomy led him into conflict with Newton, who became much more famous. Although Hooke took an important part in the rebuilding of London after the Great Fire, you are more likely to have heard of Christopher Wren in this context.

Box 1 *Micrographia*

Hooke's *Micrographia* contains the results of a series of observations and experiments conducted between 1661 and 1664. When copies first appeared in January 1665 at a lavish 30 shillings each, the book had a tremendous impact. Samuel Pepys was captivated and sat reading until 2 in the morning, saying it was 'the most ingenious booke that ever I read in my life'.

Hooke could write vivid and powerful prose in an accessible style. It was, moreover, the first proper picture-book of science. Its 60 'observations' were accompanied by 58 beautiful engravings of objects seen beneath the microscope or with a telescope. Among these were regular empty spaces in sections of cork. Hooke described these as 'cells', bounded by 'walls' because they reminded him of the cells in which monks live in a monastery. The word cell is still used today.

Although *Micrographia* sounds as though it is mainly about small things it also contains:

- a description of the earliest investigation of the colours of thin plates of mica with an explanation based on interference of light rays
- observations on soap bubbles
- a theory of light as a transverse vibrational motion
- a definition of heat as a property of a body arising from the vibration of its parts
- a discussion on the true nature of combustion
- observation of a group of lunar craters made with a 30 foot telescope

Curator of experiments

Hooke was employed by The Royal Society to conduct experiments supporting other people's work and to carry out demonstrations. He became actively involved in research himself and wrote and talked extensively about his findings. Topics he investigated included:

- the nature of the air and its relationship to respiration and combustion
- the laws of falling bodies
- improvements to diving-bells
- methods of telegraphy
- the relationship of barometric readings to the weather
- transfusion of blood

It seems clear from comments at the time that it was exciting to be present when Robert Hooke was demonstrating — he was something of a showman with a dramatic sense. Today he might have been a Royal Institution Christmas Lecturer. He invented instruments throughout his career, from his first devising of an airpump for Robert Boyle in 1659 to his last recorded scientific utterance in December 1702, when he was trying to devise an improved instrument to measure the Sun's diameter.

Box 2 Timeline

1635 Born in Freshwater, Isle of Wight, on 18 July, son of Rev John Hooke. Robert was a fast learner and was good at making things, including mechanical toys. A visiting artist, struck by Robert's draughtsmanship, advised Rev Hooke to settle upon an artistic career for his son.

1648 After the death of his father Hooke went to London and, dropping art, soon joined Westminster School.

1653 Attended Christ Church, Oxford. Became a close friend of Christopher Wren, another pupil from Westminster.

1655 Assistant to Robert Boyle, helping in construction of an air pump.

1662 Appointed Curator of Experiments at The Royal Society, the first salaried research scientist in Britain.

1663 Elected to be a Fellow of The Royal Society.

1664 First to infer that the planet Jupiter rotated.

1665 Hooke's post of Curator at The Royal Society was made permanent.
Micrographia was published.
Plague hit London and Hooke moved to Epsom.

1666 Made drawings of Mars which allowed others to work out its period of rotation more than 200 years later.
As the plague abated, meetings of The Royal Society resumed in London. Hooke suggested measuring the force of gravity using a pendulum. He showed that the centre of gravity of the Earth and the Moon describes an ellipse around the Sun.

1667 After the Great Fire Hooke put forward proposals for rebuilding the City of London. His plan was not adopted, but he was appointed as one of six city surveyors, along with Christopher Wren. Hooke and Wren designed the Monument to the Great Fire.

1672 Hooke published a paper on diffraction of light, in which he included objections to Newton's paper published the month before. Hooke continued to make telescopes and conduct astronomical observations.

1675 Isaac Newton published *Discourse on Colour*. Hooke objected that much of the material was already contained in *Micrographia*. Newton acknowledged that Hooke's work had helped him.

1676 Hooke published *A Description of Helioscopes*, describing the principles of spiral springs.

1677 Hooke became secretary to The Royal Society.

1678 Hooke published papers on comets, including a statement of the inverse square law of gravity (though he had no proof of it). In another paper he gave an account of elasticity and the kinetic theory of gases that matches current ideas.

1679 Hooke wrote to Newton, which induced Newton to 'resume his former thoughts concerning the Moon'.

1684 onwards Robert Hooke continued to invent, including a practical system of telegraphy and the universal joint. He observed and tried to explain the motion of the Sun among the stars, the nature of fossils and the succession of living things on Earth.

1700 Edmond Halley described Hooke's last invention, a marine telescope, to The Royal Society.

1703 Hooke became blind and his legs swelled — possibly a consequence of diabetes.

1704 Hooke died at Gresham College, 3 March, and was buried at St Helen's Bishopsgate. His remains were exhumed and reburied in 'north London' sometime in the nineteenth century. The location of his grave is unknown.

Nigel Collins *teaches biology and is an editor of* CATALYST.

Geiger counter

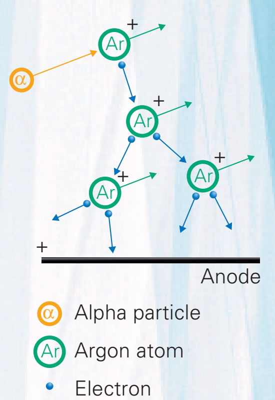
Philippe Psaila/SPL

A Geiger counter is probably the most sensitive instrument you will come across at school. Each click you hear represents the radiation from the decay of a single radioactive atom.

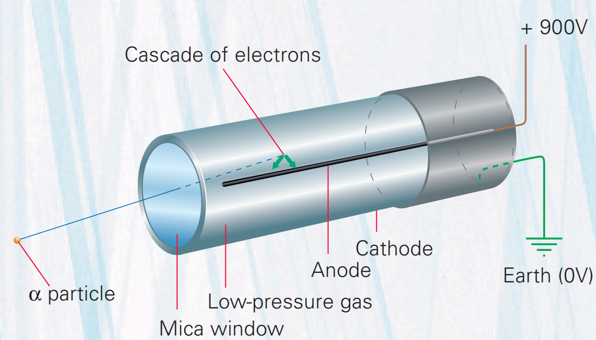
A Geiger counter detects all the alpha and beta radiation which enters the tube. It also detects some gamma radiation, but 98% of gamma radiation passes through it unaffected.

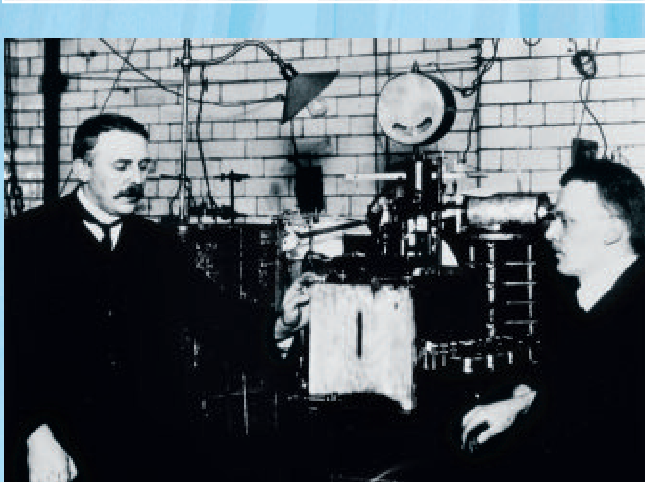
An alpha particle collides with an argon atom; an electron is knocked off the atom, and so the argon atom becomes a positive ion.

The electron is attracted towards the anode. If it collides with another argon atom, another electron is released. Each of these may then ionise more argon atoms. Eventually a cascade of billions of electrons reaches the anode. This flows as a pulse of current in the external circuit.



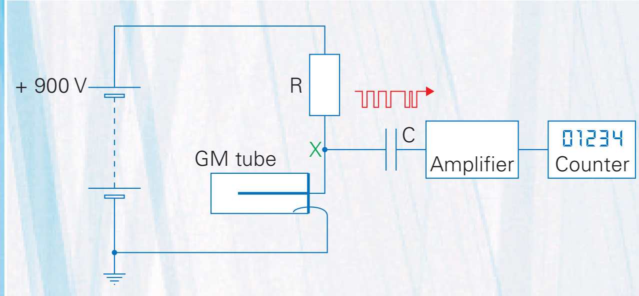
The Geiger-Müller (GM) tube is a metal or glass cylinder, which acts as the cathode. A central metal rod is the anode. At one end of the tube is a thin 'window' of mica. Radiation can enter the tube through this window. Inside the tube is a low-pressure inert gas, usually argon or neon.





Peter Fowler/SPL

Hans Geiger (right, inventor of the Geiger counter) and Ernest Rutherford (who discovered the structure of the atom) in their laboratory at Manchester University, about 1908



The GM tube and the resistor R form a potential divider. When radiation ionises the gas in the GM tube, its resistance drops. The voltage at point X drops. A sequence of pulses passes through the capacitor C to the amplifier and counter.