Catalyst

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Nanotechnology

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Catalyst

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The front cover shows a nanofantasy, with medical nanorobots on red blood cells inside a human body (Victor Habbick Visions/SPL).

Contents

Looking ahead

Sometimes in the dark days of winter it seems that there will never be an end to coursework — but there is. Take a moment to think about how good you will feel when you hand it in — you deserve success because you've worked hard and, most importantly, followed the advice you've been given in the last few issues of CATALYST.

Those of you in year 11 have probably been thinking about what you are going to do next — A-levels? GNVQs? Will you stay at your own school or move to a college? Don't forget to look through past issues of CATALYST — we have covered a wide range of careers and given you good advice on how to gain entry to them. If you think you want to go into medical imaging or radiography after reading our articles then you're in luck because you can find out all about it on pages 6–7.

Jane Taylor

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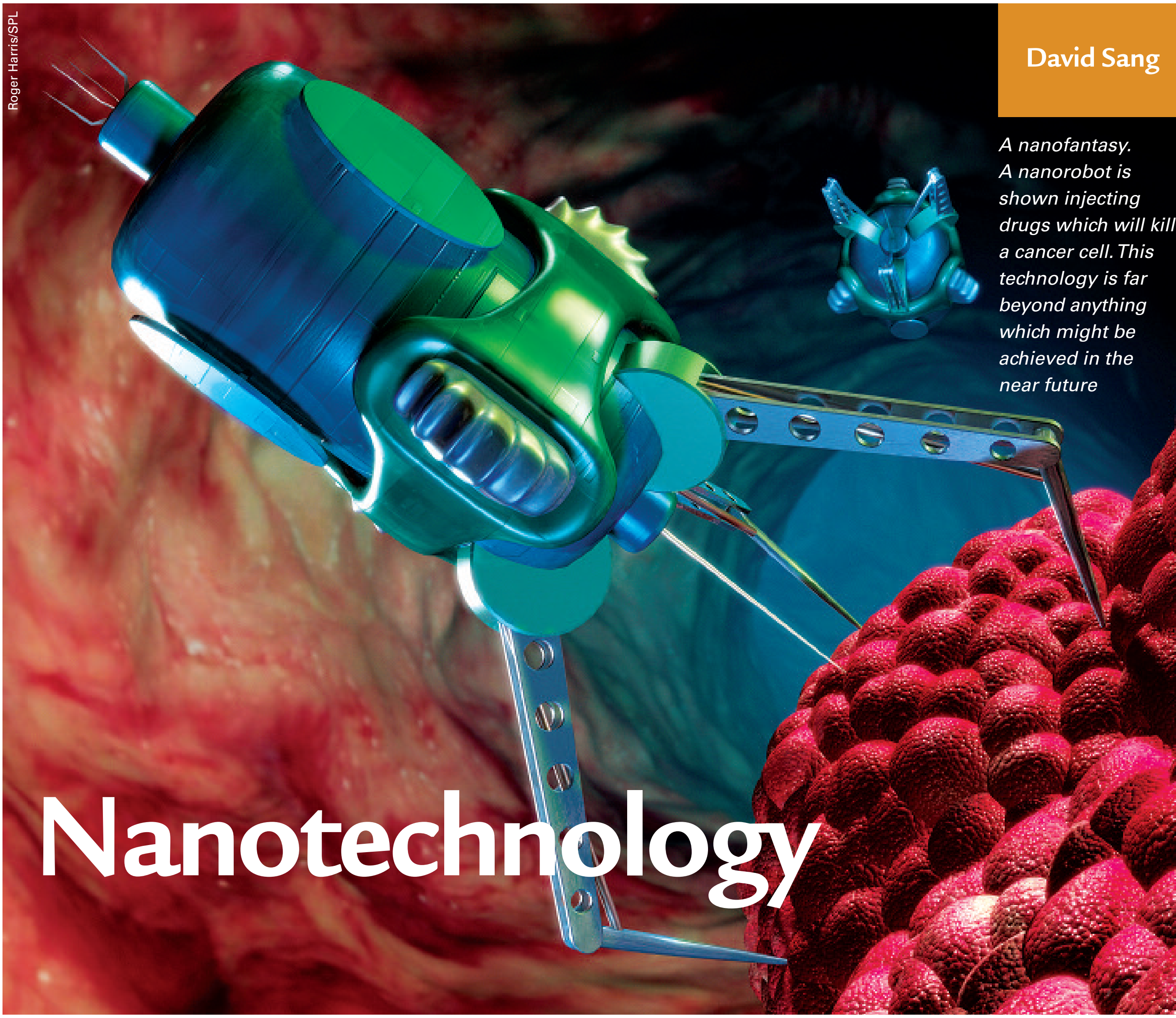
Nanotechnology

David Sang



Roger Harris/SPL

A nanofantasy. A nanorobot is shown injecting drugs which will kill a cancer cell. This technology is far beyond anything which might be achieved in the near future

Nanotechnology is the science of building tiny devices. Some people say that nanotechnology will be the answer to many of our biggest challenges — in medicine, electronics, defence and other areas of research. Others say that we are opening up a dangerous world of technologies which could get out of control, causing more problems than they solve. Who is right?

GCSE key words
Resistance
Catalyst
Sensors
SI units

'Nano' is a prefix in the SI system of units. It means one billionth, or 10^{-9}, so one nanometre is a billionth of a metre, or 10^{-9} m. The diameter of an atom is in the order of 10^{-10} m, or one tenth of a nanometre, so a nanoscale object is made of thousands of atoms. Compare this with the 10^{28} or so atoms in a typical human being. Before the advent of nanotechnology, the smallest objects we could make were described as **microscopic**; now we have **nanoscopic** devices.

Nanotechnologists have invented techniques for producing nanoscopic machines, as well as sensors and electronic components. Imagine an electric motor so small that it could fit inside a single cell. This could transform medicine. Or imagine a transistor, one hundred-thousandth of the size of those in today's computers. That could allow greatly increased computing speeds.

Today's nanotech products

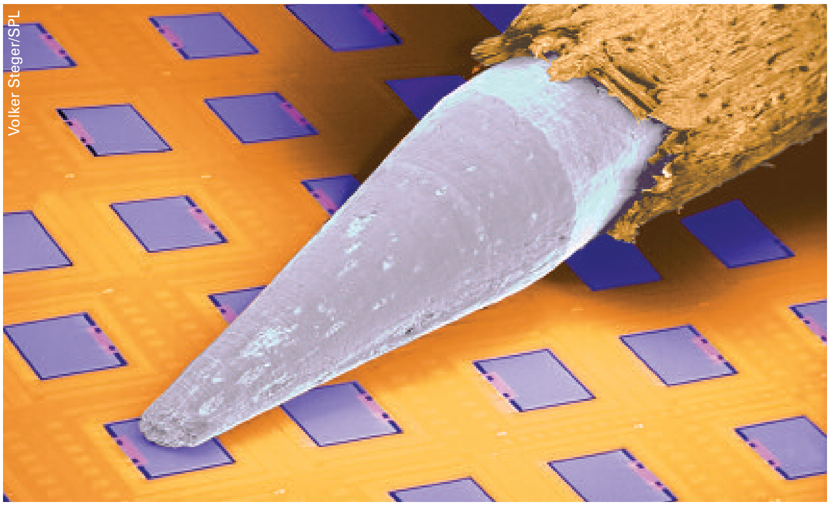
Nanotechnology is in its infancy, but we already make use of some nanoproducts.

Sun screen

The sun screen which you rub into your skin to protect you from harmful ultraviolet radiation contains nanoparticles of titanium dioxide (TiO_2). Titanium dioxide is the ultra-white chemical used in

SI prefixes
milli = 10^{-3}
micro = 10^{-6}
nano = 10^{-9}
pico = 10^{-12}
femto = 10^{-15}
atto = 10^{-18}

Some types of paint, used by artists for centuries, have been found to contain nanoscale particles.



Volker Steger/SPL

Above: *Coloured SEM of a micro-accelerator from a car's air bag. Each square is a tiny pressure sensor. A pencil tip is shown for scale*

white paint; tiny particles of it are very efficient at absorbing UV radiation. Each particle contains roughly 10^{19} atoms — that is quite a lot, on the nanoscale.

Car air bags

Car air bags use a nanotech sensor to trigger them. The sensor contains a nanoscale capacitor, formed of two plates with opposite electric charges. When the car decelerates suddenly, the plates are pushed together, changing the device's capacitance. This is detected by an external circuit which activates the release of the air bag in a matter of milliseconds.

Self-cleaning windows

Self-cleaning windows have very low friction. The same technology can be used to lubricate wheels and gears in nanomachines.

Self-cleaning windows are now fitted in many modern high-rise buildings. These have a nanofilm of titanium dioxide which acts as a catalyst, causing organic dirt on the glass to react with sunlight, so that it washes off.

Coming up

What can we expect from nanotechnology in the near future? There are several areas in which it is likely to contribute (see Table 1).

Medicine and healthcare

Medicine and healthcare are areas where a large amount is spent on research each year, so we can expect significant developments in the future.

Box 1 Cancer diagnosis

When patients have cancer, their bodies produce a range of substances known as 'biomarkers'. These are characteristic of the disease. At present, blood and urine tests are used to detect just one or two of these substances, and they are often highly inaccurate — a patient may be diagnosed with prostate cancer, for example, when in fact he is free of the disease. Now Professor Jim Heath and his team at the California Institute of Technology have built a nanosensor capable of detecting and measuring many biomarkers simultaneously.

Here is how it works. A blood sample passes over an array of nanowires. The nanowires are coated with antibodies to which the biomarkers bind; each nanowire is coated with a different antibody. The biomarkers become stuck to the nanowires, and this changes the wires' electrical resistances. Electronic circuits measure the resistances of the wires, and from this it is possible to deduce which biomarkers are present. A detailed diagnosis can then be made of the cancer type and its stage of development.

The nanowires used by Heath are made of silicon. Each wire is less than 20 nanometres thick.

Already, there has been good progress in making nanosensors which can detect signs of disease in blood and urine samples (see Box 1). Soon, we may have nanomachines for targeting drug delivery to appropriate sites in the body — at present, patients take medication which spreads throughout their bodies, when it would be more effective if it were delivered to just one type of tissue.

Energy

Energy is a major concern in the twenty-first century. Nanoscale catalysts may soon be used to produce more efficient burning of fuels, for example in car engines. Catalytic converters in car engines use the expensive metal platinum in a honeycomb form to give a large surface area on which fuel and oxygen can react. Nanoparticles of platinum would give the same surface area for much less platinum. This would cut the costs of converters dramatically.

It is now almost 50 years since the physicist Richard Feynman issued a challenge. He wanted scientists to work at the molecular scale to produce computers and machines which would have huge benefits. His talk was called 'There's plenty of room at the bottom'.

Table 1 *Uses of nanotechnology*

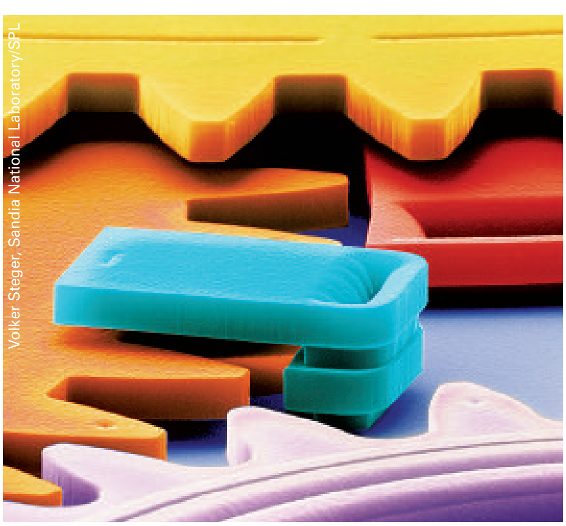
Area	Current	Near future	Distant future
Energy	Nanocatalysts	Nanomaterials for fuel cells and solar cells	
Medical	Sun screens	Nanosensors for diagnosis Targeted drug and gene delivery	Nanomachines for treatment Nanopumps and valves for artificial organs
Electronics and computing		Carbon nanotube components	DNA-based computers
Others	Self-cleaning windows	Smart packaging for foods Nano bar coding	Lab-on-a-chip analysis systems

Figure 1 *A buckyball. Nanotubes and buckyballs are nanoscale objects made of carbon atoms. They are likely to play an important part in electronic systems*

Solar cells for generating electricity are notoriously inefficient at harvesting the energy of sunlight, but nanotechnology using 'buckytubes' may result in greater efficiency. A buckytube is a cylindrical molecule of carbon. The atoms are bonded together in a similar arrangement to the C_{60} buckyball molecule (Figure 1).

Machine components

Components for tiny machines, including nanoscale motors and gears, have already been produced. Once these have been linked together, it may be possible to build tiny robotic machines capable of operating in restricted spaces – even inside the human body.



These miniature cogs and gears could form the basis of a microscopic machine. Machines on this scale are micromechanical, rather than nanotechnological. (The image was made using a scanning electron microscope; the colours were added later by computer)

Top down, bottom up

There are two ways to build nanoscale devices:

- From the top down – start with an oversize piece of material, machine it down to size, and spray on new material in atom-thin layers. (This is similar to the way in which microchips are manufactured.)
- From the bottom up – start with individual molecules and stick them together to make a device.

Ultimately, the aim is to devise **self-organising systems**. To build these you would start with an array of chemical substances, mix them together and they would turn themselves into a nanoscale device. In fact, nature got there first. Protein synthesis involves nanoscale machinery. The code in DNA is transcribed and translated by a variety of molecules which work together to make the protein molecules that are needed by our cellular processes.

Some of the most exciting nanotechnology experiments involve building devices using DNA-based systems. Short lengths of DNA are designed so that they fit end-to-end to form a desired structure. Professor Andrew Turberfield of Oxford University describes it like this: 'At its simplest, DNA nanofabrication is like building a Lego model by designing the bricks so that they can only go together in one way – then putting them in a bag and shaking it.'

The correct name for the C_{60} molecule shown in Figure 1 is buckminster fullerene.

Hope, hype or horror?

Nanotechnology is still in its early stages of development. Many grand claims have been made for it, though no doubt some of these are exaggerated. At the same time, some people have expressed concern that we may be unleashing a technology which we will not be able to control.

One of the first applications suggested was the building of 'nanobots' which could move around inside our blood and lymphatic systems, repairing damage and killing off alien cells. In fact, this is highly unlikely. The drag forces opposing a nanobot's movement in blood capillaries would be almost insuperable.

Another concern has been that someone might invent self-replicating nanobots – tiny machines which moved around, collecting raw materials and reproducing themselves. Eventually, they would dominate the planet because we would not be able to stop them in their tracks – they might even reduce everything to a 'grey goo'. Again, this is in the realms of science fiction; no one has yet come up with a realistic scheme for making such pseudo-organisms.

Regulations already exist for developing new techniques and new products. A report by the Royal Society suggests that these regulations are adequate to deal with most of the products which might emerge from the nanotechnology revolution.

• Look at www.nano.org.uk/images.htm to see more pictures of nanotech ideas.

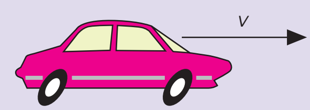
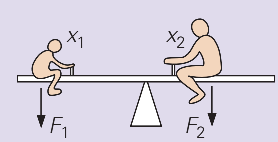
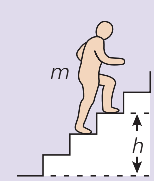
• Visit the website of the Foresight Institute (www.foresight.org). Click on 'Understand nanotechnology' on the right to see some interesting animations.

David Sang *writes textbooks and is an editor of* CATALYST.

Improve your grade

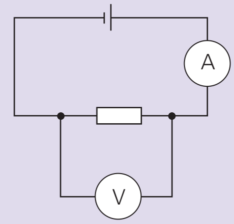
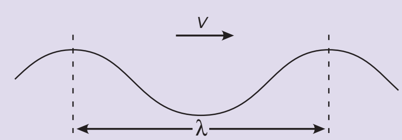
Formulae

The formulae listed on these pages are used in GCSE and Standard Grade science courses and you should know them for your exam. You should also know the units used for each quantity. Each letter in a formula stands for a number and a unit. For example '*t*' could stand for '3 seconds'.

Topic	Formula	Symbols	Notes
Mechanics			
Steady motion	$s = v\,t$	s = distance (m) v = speed or velocity (m/s) t = time (s)	
Accelerated motion	$a = \frac{v - u}{t}$	a = acceleration (m/s^2) v = final speed (m/s) u = initial speed (m/s)	
Momentum	$p = m\,v$	p = momentum (kg m/s) m = mass (kg) v = velocity (m/s)	Watch out! *m* is used for mass and m for metre
Force	$F = m\,a$	F = force (N)	So 1 N = 1 kg m/s^2
Weight	Weight= mg	Weight (N) g = 10 N/kg g is also 10 m/s^2	(Gravitational field strength on Earth) (Acceleration due to gravity)
Force of a spring	$F = k\,x$	k = spring constant (N/m) x = extension (m)	Hooke's Law
Moment of a force	Moment = $F\,x$	Moment (N m) x = perpendicular distance from the pivot to the line of the force (m)	With a balanced lever, clockwise moments = anticlockwise moments
Energy			
Work done	$W = Fd$	W = work (J) d = distance moved in the direction of the force (m)	
Power	$P = \frac{W}{t}$	P = power (W) t = time (s)	Watch out! W stands for watts *W* is the symbol for work
Potential energy	$E = m\,g\,h$	E = change in potential energy (J) m = mass (kg) g = gravitational field strength (N/kg) h = vertical height (m)	
Kinetic energy	$E = ½\,mv^2$	E = kinetic energy (J) v = speed (m/s)	
Efficiency = $\frac{\text{useful energy output}}{\text{total energy input}}$			Multiply by 100 to get the answer as a percentage
Pressure	$p = \frac{F}{A}$	p = pressure (Pa) A = area (m)	Watch out! *p* is used for pressure and for momentum
For a gas	$\frac{p_1 V_1}{T_1} = \frac{p_2\,V_2}{T_2}$	V = volume (m^3) T = temperature (K)	Watch out! Temperature must be in K not °C

Absolute temperature in kelvin (K) = temperature in degrees Celsius (°C) + 273

Five SI base units appear on these pages: m, kg, s, K and A. Other units such as N, W, J and V are derived from them.

Topic	Formula	Symbols	Notes
Electricity			
Ohm's law	$V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$	V = voltage (V) I = current (A) R = resistance (Ω)	
Charge	$Q = It$	Q = charge (C) t = time (s)	In electrolysis, the mass of a substance deposited at an electrode is proportional to the charge Q
Energy	$E = QV$ $E = VIt$ $E = Pt$	E = energy (J) P = power (W) t = time (seconds)	Or E = energy (kW hours or 'units') P = power (kW) t = time (hours)
Power	$P = VI$ $P = \frac{V^2}{R}$ $P = I^2R$	P = power (W)	
Resistors	In series $R = R_1 + R_2$	In parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	$\left(\text{also } R = \frac{R_1 R_2}{R_1 + R_2}\right)$
Transformers	$\frac{\text{primary voltage}}{\text{secondary voltage}} =$	$\frac{\text{primary turns}}{\text{secondary turns}} =$	$\frac{\text{secondary current}}{\text{primary current}}$ $\quad \frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$
Waves			
Wave speed	$v = f\lambda$	v = speed (m/s) f = frequency (Hz) λ = wavelength (m)	

λ is the Greek letter lambda.

Letting the units help

The units can often help you to get a calculation right. For example, if you know that speed is measured in metres per second, you can tell that you have to divide the distance in metres by the time in seconds. If you did anything else the answer would have the wrong units and so would be wrong. The word 'per' means the same as 'divided by' or /. So metres per second and metres/second mean the same thing.

Multiples

You need to be careful when multiples (like km instead of m) and sub-multiples (like g instead of kg) are used instead of the standard units. For example:

Question What is the density, in kg/m^3, of a cube of zinc with a mass of 890 g and a side of 5 cm?

Answer First convert g to kg and cm to m.
k stands for 1000 so 890 g = 0.890 kg

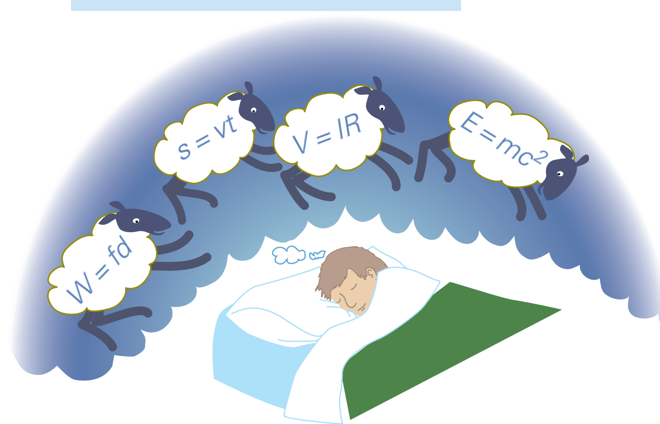
c stands for $\frac{1}{100}$ so the volume is $(5\text{ cm})^3 = \left(\frac{5\text{ m}}{100}\right)^3 = \frac{125\text{ m}^3}{1\,000\,000}$

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

So the density is $\frac{0.890\text{ kg} \times 1\,000\,000}{125\text{ m}^3} = 7120\text{ kg/m}^3$

Multiples

mega	M	1 000 000	10^6
kilo	k	1000	10^3
deci	d	1/10	10^{-1}
centi	c	1/100	10^{-2}
milli	m	1/1 000	10^{-3}
micro	μ	1/1 000 000	10^{-6}



David Chaundy *taught physics and was one of the founding editors of* CATALYST.

Your future

Radiography

Joyce Seaton is a senior radiographer. She works for the Worcestershire NHS Acute Hospitals Trust. Here she explains why she chose to be a radiographer and gives an insight into her working day, as well as how to begin a career in radiography.

Why did I choose radiography as a career? A week's work experience in a local hospital gave me a taste of the various departments. I had enjoyed science at school and, although I found the pathology department fascinating, it was the X-ray department that really captured my imagination. It was bristling with activity. Radiographers were carrying out examinations not only in the department, but also on the wards, in the operating theatre, and working in accident and emergency, as part of a well-oiled team.

• To find out about other types of medical imaging read the article in CATALYST Vol. 16, No. 2.

This was the ideal career for me. I have always been a people person and I love taking a good picture. Box 1 gives you an insight into my typical working day.

Types of radiography

We have certainly come a long way since Wilhelm Röntgen noted that the bones of his hand were more opaque than flesh to his newly discovered invisible rays. Bones are only part of the story. **X-ray** examinations can also be carried out using a 'dye' or contrast material, a substance with a high atomic number (see Box 2). This can outline a variety of body structures and vessels either as a static picture or when moving, as in **fluoroscopy**.

Other diagnostic imaging techniques include **CT** (computed tomography) and **MRI** (magnetic resonance imaging) scanners. These can produce three-dimensional images, enabling diagnosis and accurate measurements for treatment planning.

Box 1 A typical working day

I switch on the equipment at the start of a new day, as a nervous student enters the X-ray room in the imaging department. The work is often unpredictable, but there is a pre-booked appointment for a kidney investigation today. I am to assess the student as she performs the entire examination. I talk to her while she calms down a little; she smiles and leads the patient reassuringly to the couch.

The control image, the first of a series, appears in front of me on the computer screen. Our new department is film-less. We no longer have a darkroom or smelly chemicals. Instead, we have a picture archive computer system (PACS) which is part of a new national programme for IT being delivered by the NHS. This enables digital images to be viewed at different hospitals. This is only one of the many exciting changes I have seen in radiography over the years.

The radiologist now arrives. He is a doctor who specialises in radiology. He has given us the go ahead to do the IVU (intravenous urogram), and will interpret the images when we have finished. He stays to give the injection of contrast. This is iodine-based and can cause an allergic reaction, so the patient is informed and observed carefully.

A certain amount of skill is now needed to align patient, X-ray tube, and image receptor speedily to obtain an image of the first flush through the kidneys. In this case, we are looking for evidence of kidney stones. These can be removed by the surgeon in theatre, and the radiographer is often needed to help him locate them. On studying the next images it appears that any stones have now gone.

The relieved patient is given instructions to go back to the doctor and a satisfied, happy student tidies away.

X-ray fluoroscopy image generated during a kidney investigation

Richard Haynes/Worcestershire Acute Hospitals Trust

Box 2 Atomic number

The higher the atomic number of a material the more difficult it is for X-rays to pass through it. Bone has an effective atomic number of 14 because it contains calcium and phosphorus as well as other lighter substances. The effective atomic number of soft tissue is about 7. Barium (atomic no. 56) salts are used to show up the alimentary canal in X-rays, and in the plaster on X-ray room walls. Lead salts are used in making the protective lead glass and lead-rubber aprons and gloves.

Another 'scan' which is well known about now is **ultrasonography**. This technique uses ultra high frequency sound waves to produce a moving image. It is used to look at babies before they are born to check that they are developing correctly.

Scans are also done in **nuclear medicine departments**. A radioactive isotope is administered to the patient and its radiation shows up how particular organs are functioning (see 'Radioactivity in medicine' on pages 11–13).

Becoming a radiographer

It is important to have spent some time in an X-ray or a radiotherapy department before applying to universities. Contact the personnel department at your local hospital to arrange this.

Box 3 Types of radiographer

There are two types of radiographer: diagnostic and therapeutic.

- **Diagnostic radiographers** produce images which can be used to diagnose conditions (as discussed in this article).
- **Therapeutic radiographers** work alongside specialists in cancer (oncologists). They use radiation with great accuracy to destroy harmful, fast-growing cells without damaging healthy ones. The same patient can be seen many times as the treatment progresses and will need considerable reassurance.

Box 4 Useful websites

www.newgenerations.org.uk
www.radiographycareers.co.uk
www.nhscareers.nhs.uk
The site for the Society of Radiographers is very helpful and has online videos:
www.sor.org.uk

Richard Haynes/Worcestershire Acute Hospitals Trust

Above: *Joyce with the X-ray machine used for the procedure described in Box 1*

Qualifications

Ideally you need to have an interest in science and good GCSE grades, as well as at least two A-levels or equivalent. However, the requirements do vary between universities.

At university, as well as attending lectures on the 3-year BSc course, students are given clinical placements where they receive practical training and see different imaging techniques.

Skills and qualities

As well as the obvious technical skills that are needed for the profession, it is important to be able to communicate well, to have compassion and to care about others.

When Marie Curie was recruiting for her radiology car in the First World War she said that her workers needed to be '*débrouillard*'. Roughly translated this means 'able to figure things out'. I believe that quality still holds true for radiographers today.

• Check out atomic numbers on a periodic table (www.chemicalelements.com).

Career progression

Radiographers can go on to specialise in the different types of imaging and have the opportunity to follow a postgraduate certificate, diploma or masters degree. There is scope for management positions, teaching and research, or work in the private sector, the armed forces, forensics, or overseas, where British radiographers are highly valued.

• To view a selection of images including a kidney investigation select image gallery on www.radiologyinfo.org

Nigel Collins

Plants and mineral nutrients

Right: *Tomato plants growing hydroponically in a glasshouse*

If a plant or tree were to be burned, most of it would go up in smoke, but part of it would be left behind as ash. This article looks at the chemicals that make up the ash and the role they play in the life of the plant, as well as at some novel ways they can be supplied to plants.

GCSE key words
Plant nutrition
Photosynthesis
Mineral ions
Deficiency symptoms
Nutrient cycling

Photosynthesis is an amazing process. Plants use carbon dioxide (CO_2) from the air and water (H_2O) from the soil to synthesise a wide range of carbohydrates and lipids. With the addition of the element nitrogen (N), taken up via the roots in nitrate ions (NO_3^-), plants can also make amino acids (to be joined together into proteins) and nucleic acids. Two other important mineral ions that plants take up via their roots are phosphorus (P), as phosphate ions, and potassium (K).

- **Nutrients such as nitrogen (N) are cycled. Check your understanding of the nitrogen cycle. What happens to P and K?**

NPK

These three elements are all essential for plant growth. Compared with the mass of the plant to whose structure they contribute, the amount needed is small. Nevertheless, sufficient quantities are needed for them to be called **macronutrients**. Other macronutrients are:

- magnesium (Mg) — a component of chlorophyll molecules
- calcium (Ca) — a component of plant cell walls (see Box 1)
- sulphur (S) (see Box 2)

More details about macronutrients are given in Table 1, including brief descriptions of what happens when plants are short of particular macronutrients. **Micronutrients**, which are needed in very small quantities, include iron (Fe) — this is important in enzymes involved in respiration.

Why are fertilisers needed?

When a crop is harvested many nutrients are removed from the soil. Sugar beet, for example, is grown for its root, which can contain 16% or more sugar. When it is harvested the leafy top of the plant, together with the point of attachment to the root, called the crown, is cut off the root. After the root has been lifted these waste parts may be used as animal feed or may be ploughed in to the soil to decompose.

Table 1 *Macronutrients*

Mineral elements and ions	Needed for	Symptoms if not enough is available
Nitrogen (as nitrate, NO_3^-)	It is a constituent of DNA, RNA and the amino acids which are used to build protein molecules	Pale, lower leaves which are yellow or dying; light green to yellow appearance of leaves, especially older leaves; stunted growth; poor fruit development
Phosphorus (as phosphate, PO_4^{3-})	It is a component of cell membranes and ATP. It is essential for reproduction and photosynthesis and is involved in energy transfer and the formation of oils, sugars and starches. It also helps maturation, blooming and root growth	Slow development; poor growth, flowering and fruiting; leaves may appear purple
Potassium (as K^+)	It activates many enzymes, encourages flowering and is important in osmosis. It also builds disease-resistance and improves fruit quality	Older leaves yellowing around edges and then dying; poor growth; vulnerable to disease

Approximately 90% of all cut fresh flowers purchased in the UK are grown hydroponically. An estimated 65% of all fruit and vegetables purchased from supermarkets are also grown in hydroponic systems.

Box 1 Calcium: a useful chemical for improving soils

Calcium is an important mineral in the life of plants. It is a component of the calcium pectate that helps glue cell walls together in young plant tissues. Although there are few soils where the availability of calcium ions to plants is so low that it causes any problem, calcium, in the form of lime, is often applied to soils. This is because it has another important use. Lime is used to help adjust the pH of agricultural soils when they are too acidic for successful crop growth.

Lime used to be made by heating limestone (calcium carbonate) to more than 825°C, which produced calcium oxide (quick lime), or, once water was added, calcium hydroxide (slaked lime). Nowadays most 'lime' applied to fields is limestone or chalk that has been crushed.

Box 2 Sulphur: an overlooked mineral nutrient

Sulphur is an important element in small quantities in the structure of certain amino acids (and hence proteins). Deficiency in soils leads to a decrease in productivity, poor crop quality and higher susceptibility of plants to certain diseases.

Until quite recently sulphur deficiency was not a significant problem in the UK. For much of the time since modern agriculture systems started and yields were recorded, people burnt sulphur-rich coals in their houses, factories and power stations. The sulphur dioxide produced ended up back in soils as sulphate ions. However, the use of low-sulphur fuels has resulted in a reduction in sulphur emissions to the environment and sulphur deficiency is now an important and increasing problem not only in the UK, but worldwide.

In common with all living cells, the cells of roots need oxygen for respiration. Root cells do a lot of work because mineral ions are taken up by active transport. This requires energy from respiration and hence a good supply of oxygen.

Table 2 shows just how much of a number of nutrients is removed when a crop of sugar beet giving a good yield of 50 tonnes per hectare is harvested. These nutrients must be replaced by using fertilisers — either natural ones, such as farmyard manure, or artificial, inorganic fertilisers.

Table 2 *Amount of nutrients removed from the soil by a crop of sugar beet*

Element	Tops and crowns ploughed in (kg/hectare)	Tops and crowns used as animal feed (kg/hectare)
N	65	170
P	30	65
K	90	235
Na	10	90
Mg	10	20
Ca	60	85

Martyn F. Chillmaid/SPL

Below: *Two bags of fertiliser. The bag on the left has a mixture of nitrogen, phosphorus and potassium, but the one on the right does not contain any nitrogen*

Any system to grow plants in outer space is based on hydroponics.

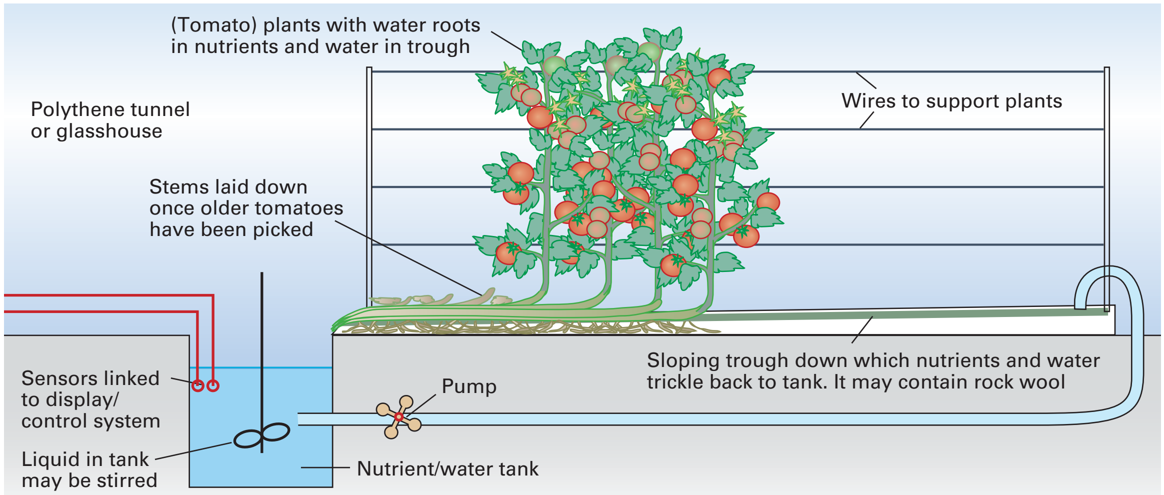


Figure 1 *Tomato plants being grown hydroponically*

Hydroponics

One downside to hydroponic systems is that where one reservoir serves a lot of plants, any disease can spread very quickly among them.

Although most plants grow in soil, soil is not essential. Plants can be grown with their roots in water to which the necessary minerals have been added. However, without soil to anchor their roots, plants grown in such a system require artificial supports.

In fact, plants grown in this way develop what are known as 'water roots' — these form a very fine mesh, directed at absorption rather than anchorage. Such rooting systems are on nowhere near the scale of those found in soil, which develop to anchor the plant and grow into fresh patches of soil all the time, where there will be untapped sources of minerals and water.

● Why is the film of water so shallow in the Nutrient Film Technique of hydroponics? (Answer below.)

Salad crops

Many salad crops are grown hydroponically (Figure 1). They are grown in gently sloping shallow troughs which have a thin film of water and nutrients, 1–3 mm deep, trickling down them to a tank. A pump is used to return the water to the top end of the trough. This Nutrient Film Technique was the first system devised.

Tomato plants are often grown in this way, supported on wires as they grow, flower and fruit. As soon as the ripe tomatoes have been harvested the plants can have their stems lowered to the ground. The younger parts are left upright and go on to flower and fruit themselves. By the end of the season the plants can be many metres long, linked through a long horizontal stem to roots far back in the nutrient film. Sometimes the plants are rooted in an inert supportive material through which the nutrients trickle. An example of this is rock wool.

● Find out more about cutting edge hydroponics at www.1-hydroponics.co.uk/main.htm

Office plants

You may see plants in public buildings and offices growing out of a pot full of brown granules. This is another system of hydroponics. In this system the roots are provided with support by an inert material, such as baked clay granules which are porous.

In the simplest of such systems there is a pot within a pot. The inner pot contains the plant's water roots among the granules and has slits to allow free flow of water and minerals. The outer pot contains water and minerals. Capillary action keeps the granules moist.

A water level indicator is built into the outer pot, showing maximum/optimum/minimum levels. The water level is allowed to fall as transpiration and evaporation occur. This drop also ensures that the roots receive enough oxygen.

Mineral nutrients are added as slow release cartridges or tablets. The precise type used depends on the hardness of the water. This system does not have a pump.

Figure 2
A hydropod

Design and copyright held by Esoteric Hydroponics Ltd **www.1-hydroponics.co.uk**

Optimising plant growth

Much more sophisticated systems have been developed to optimise plant growth, such as the hydropod shown in Figure 2. Water and nutrients are pumped from the reservoir up into the inert growth medium to flood it for a few minutes. Stale air is pushed up and away from the roots. The water and nutrients then fall back into the reservoir, leaving the roots and the granules covered in a film. Fresh air flows in around the roots, bringing in more oxygen for respiration. Under these conditions plants can grow much more quickly than in soil.

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

The film is shallow so that the roots are not deprived of oxygen for respiration.

Radioactivity in medicine

Emily Cook

BSIP, Raguet/SPL

Left: *Doctors examining the results of a patient's PET scan*

GCSE key words
Isotope
Half-life
Meiosis
Mitosis
Mutation

Radiation has many uses in medicine, both in finding out what is wrong with a patient (diagnosis) and in the treatment of cancer (therapy). In the last issue of CATALYST, we looked at the medical uses of electromagnetic radiation. In this issue, we focus on the uses of radiation from radioactive materials.

Radioactivity has been used in medicine since soon after it was discovered in 1896. For a while it became the latest health fad: people drank water with radium in it, put it in their baths and even made toothpaste out of it. Many people claimed that radiation cured all kinds of diseases, and an article in the reputable publication the *American Journal of Clinical Medicine* stated that: 'Radioactivity prevents insanity, rouses noble emotions, retards old age, and creates a splendid youthful joyous life.'

However, it soon became apparent that the people who used these products regularly or worked with radiation, such as the girls who painted radium on the faces of watches to make them glow, were suffering from a number of symptoms. These included burns, hair loss, bone diseases and various types of cancer.

Although the manufacturers of these products made false claims about their benefits, and radiation in large doses can be dangerous, radiation has many uses in modern medicine.

What radiation does to cells

There are three types of ionising radiation: alpha (α), beta (β) and gamma (γ). When a cell absorbs radiation, it may damage the DNA inside the nucleus:

- Sometimes the cell can repair itself with no lasting damage.
- Sometimes the cell repairs itself but with a change in its DNA code (a **mutation**).
- Sometimes the cell is unable to repair itself and dies.

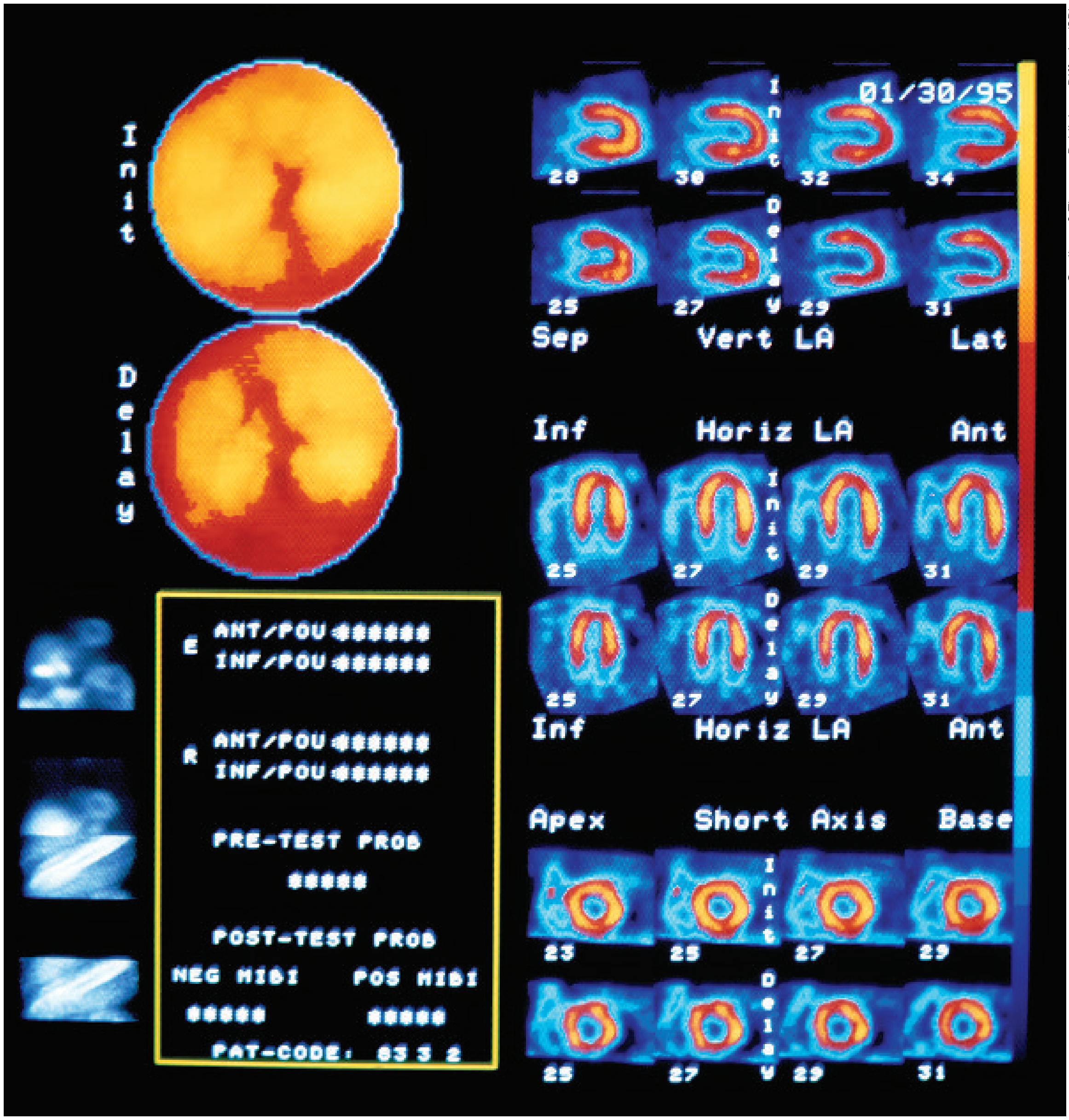
Not all mutations are harmful, though some can kill the cell or cause it to become cancerous and start dividing more rapidly. Cells that are dividing (by **mitosis** or **meiosis**) are more susceptible to radiation damage, so are more likely to be killed.

Fifty years ago, one of CATALYST's editors had a verucca dealt with by having a tiny pellet of radium plastered onto the sole of his foot. He lived to tell the tale!

Beta particles are usually negative (–), but they can be positive (+).

- **Which gives greater cause for concern – radiation causing mutation as mitosis is occurring or as meiosis is occurring? (Clue: Think of the type of cells produced by meiosis. Answer is on page 13.)**

Right: *Coloured SPECT scans of blood flow through a human heart*



Ouellette & Theroux, Publiphoto Diffusion/SPL

- **To see more images, search for 'nuclear medicine' in Google Images (www.google.co.uk/imghp).**

Most gamma-emitting isotopes also emit either alpha or beta radiation. Technetium-99 is useful in nuclear medicine because it emits only gamma radiation.

Beta+ particles are also known as positrons or positively-charged electrons; they are particles of antimatter.

When any particle of matter meets its antiparticle, they annihilate, leaving only energy in the form of gamma rays.

Nuclear medicine

Nuclear medicine uses radioactive **isotopes** (radioisotopes) to find out what is going on *inside* the body. X-ray images show the structure of the body, so can only be used to diagnose things like broken bones and some tumours. Unlike X-ray images, nuclear medicine follows what happens to certain chemicals as they pass through the body and so can see if an organ is doing its job properly. The chemicals, called tracers, are labelled with a radioactive isotope and their path through the body can be followed by detecting the radiation they emit.

The radioisotopes are produced in generators in which isotopes with long half-lives (e.g. molybdenum-99, half-life 67 hours) decay to isotopes with shorter lives (e.g. technetium-99m, half-life 6 hours). The shorter half-lives are necessary so the patient does not stay radioactive for much longer than the time it takes to get the images. In fact everyone is slightly radioactive as we have isotopes in our bodies that were taken in as part of food or drink.

The isotope with the shorter half-life is drawn out of the generator in a solution and can be made into a range of drugs (radiopharmaceuticals) that are absorbed by different parts of the body. The radiopharmaceutical is drawn up into a syringe shielded with lead and its dose checked before it is injected into the patient.

The gamma rays given off by the radioisotope are detected by a gamma-camera (a detector that is sensitive to gamma rays). This is connected to a computer and gives an image of the distribution of the isotope in the patient. The image shows where the drug is absorbed, and if several pictures are taken over a period of time it can also show how quickly the isotope is absorbed.

Boxes 1 and 2 describe how two different types of gamma-cameras work.

Box 1 SPECT

SPECT (single photon emission computed tomography) uses a gamma-camera on a ring, which moves around the patient in a circle, taking pictures from many different positions. These pictures go to a computer which produces an image that is a 'slice' through the patient.

The images can either be viewed as a series of slices, or can be made into a three-dimensional image. The process of getting slices is called **tomography** and can also be done using X-rays. This is called CT (computed tomography).

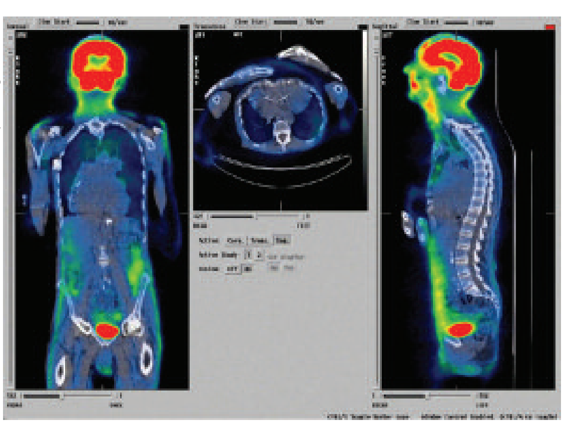
The doctor can see even more information if the X-ray image and SPECT image are combined.

Box 2 PET

PET (positron emission tomography) scanning uses isotopes emitting beta radiation. A beta+ particle travels only about 1 mm before losing its energy and slowing down. When it slows down enough, it will meet a negative electron from a nearby atom and they will annihilate, leaving no particles. Their energy is converted into two gamma rays which travel in opposite directions so that momentum is conserved.

A PET scanner has a ring of detectors so that both gamma rays are seen, and is connected to a computer which can work out where the gamma rays came from and produce an image.

Not all hospitals have PET scanners as they need machines called cyclotrons nearby to produce the beta+ emitting isotopes. The isotopes have a shorter half-life than the gamma emitters used in traditional nuclear medicine (e.g. carbon-11, half-life 20.5 minutes).



University College London

A combined PET/CT scan

Radiotherapy

Radiation is not just used for diagnosis, but can be used for treating cancer. This is called **radiotherapy**. Radiotherapy uses the fact that ionising radiation damages cells, and high enough doses can kill them. The cells in cancerous tissue are dividing rapidly. This makes them more susceptible to damage by radiation than healthy cells, so there is a higher chance that they will be killed and the healthy cells will recover.

Even so, care must be taken to ensure that only the malignant cancer cells, and not the surrounding healthy tissue, receive a high dose of radiation. This is done by mounting the system on a ring so that it can rotate around the patient, with the tumour at the centre of the rotation. In this way the tumour gets a higher dose of radiation than the surrounding healthy tissue.

Some radiotherapy machines use the radioactive element cobalt-60, which emits gamma rays and has a half-life of 5.2 years. It does not need a short half-life as it is not inside the patient, and the machine keeps the cobalt-60 in a 'head' with lead shielding around it that the gamma rays cannot pass through. More recent radiotherapy machines have linear accelerators instead of a radioactive source. Linear accelerators (linacs) produce high energy X-ray beams, which are electromagnetic like gamma rays.

Conclusion

Although radiation needs to be handled with care, it can be used in many different ways to diagnose and treat illnesses, and new ways to use radiation to care for people are still being found.

***Emily Cook** was a science teacher. She now works in the Department of Medical Physics and Bioengineering at University College London.*

Elekta

***Above:** A patient being treated in a linear accelerator*

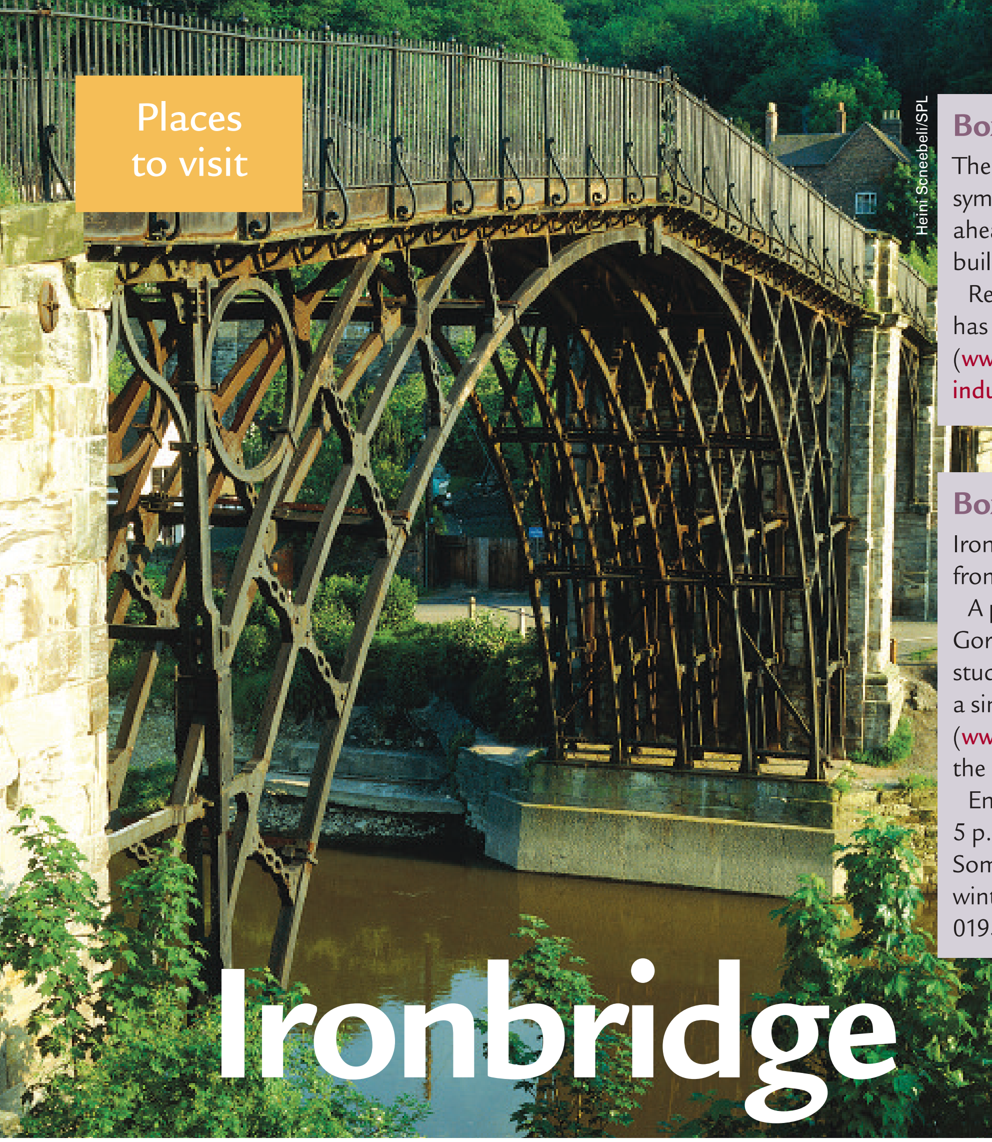
● Patients who have undergone diagnosis or treatment in which a radioactive substance has been introduced into their bodies may be warned to flush the toilet several times after use, and to avoid kissing anyone. Can you think why?

By developing more *sensitive* detectors of radiation, the dose of radioactivity given to a patient can be reduced. This means there is less risk to the patient's health — the balance of *benefit* to *risk* is improved.

Meiosis. Sex cells would be affected, so the mutation might be passed on to all cells in any child developing if the sex cell is involved in fertilisation.

Places to visit

Ironbridge



Heini Sconeebeli/SPL

Ironbridge Gorge near Telford in Shropshire is known as the birthplace of the Industrial Revolution. The Gorge has been declared a World Heritage Site and it is an ideal place to study science in its historical, social and geographical context.

Ironbridge is particularly associated with two men who lived and worked there in the eighteenth century. Both were called Abraham Darby:

- In 1709, Abraham Darby I produced high-quality iron by fuelling a blast furnace with coke (see 'Iron' on pages 17–19 for more details).
- In 1779, his grandson Abraham Darby III built the Iron Bridge itself to celebrate the potential of iron as a structural material (see Box 1).

At the gorge, you can see both the bridge and Abraham I's blast furnace, but there is much more besides. For example, a small Victorian town covering 12 hectares has been recreated at Blists Hill. It includes shops, a pub, factories, a working foundry and iron rolling mill. All the museums you can visit at Ironbridge Gorge are listed in the margin.

The museums of Ironbridge Gorge are:

- **the Iron Bridge and Tollhouse**
- **Blists Hill Victorian Town**
- **Coalport China Museum**
- **Tar Tunnel**
- **Jackfield Tile Museum**
- **Museum of the Gorge**
- **Coalbrookdale Museum of Iron**
- **Darby Houses**
- **Broseley Pipeworks**
- **Enginuity**

- **Go to the BBC history website to see an excellent animation of Darby's blast furnace (www.bbc.co.uk/history/games/blast/blast.shtml).**

Box 1 The Iron Bridge

The Iron Bridge is one of the most recognisable symbols of the Industrial Revolution. It was so ahead of its time that it would have been like building London's Millennium Bridge out of glass.

Recent work in association with English Heritage has determined how the Iron Bridge was built (www.bbc.co.uk/history/society_culture/industrialisation/iron_bridge_01.shtml).

Box 2 Visitor information

Ironbridge Gorge is easy to find. It is clearly signed from Junction 4 of the M54.

A passport to see all ten sites of the Ironbridge Gorge Museum Trust costs around £9 for students. (You don't have to visit them all during a single visit.) See the museum's website (www.ironbridge.org.uk) for admission prices to the individual sites, as well as details of workshops.

Enginuity is open 7 days a week from 10 a.m. to 5 p.m. except for 24–25 December and 1 January. Some of the other sites close earlier during the winter months or close altogether. Phone 01952 884391 or check the website for more details.

Hands-on at Enginuity

Enginuity is the most recent addition to the ten sites that make up the Ironbridge Gorge Museum Trust. It sits close to Abraham Darby's original blast furnace. Perhaps some of his ingenuity will rub off on the next generation of engineers when they get their hands on Enginuity's twenty-first-century exhibits?

Enginuity has four sections:

- **Materials and Structures** includes an interactive X-ray machine that allows visitors to look inside manufactured objects to see how they are put together.
- **Systems and Control** demonstrates different ways of moving water, including an Archimedes Screw. The infrared-controlled 'Robot Explorer' can be navigated through a maze with the help of the robot's onboard video, demonstrating why robots are used for dangerous or inaccessible tasks. You can test your speed and accuracy against another robot in the 'Giditron Robot Challenge'.
- Among the **Energy** exhibits, visitors are invited to pull a real locomotive and investigate pistons, flywheels and wind turbines. In 'Power Valley' you can try to control sluice gates to maximise the electricity generated without flooding the valley.
- There are several **Scan-It** stations. By pointing at any of the nearby question marks, visitors can watch an entertaining video about the associated exhibit.

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

Ironbridge quiz

Puzzle

Answer the following questions, then fit the answers into the grid. Rearrange the letters which fall on the shaded squares to form the name of the person who supervised the building of the first iron bridge.

All the answers to this quiz can be found on the education pages of the Ironbridge website (**www.ironbridge.org.uk**).

Questions

The Ironbridge site has been preserved as a ________ ________________ ________ so it attracts visitors from all over the world. (5, 8, 4)

Where the China museum and the bottle kilns can be found: ________________ . (8)

The whole site contains ten ______________ .(7)

Where you can study life in a small industrial community: __________ ________ ________________ ________ . (6, 4, 9, 4)

A Victorian factory opened in 1874: ____________ ________ __________. (9, 4, 6)

A true Victorian time capsule opened in 1881: ________________ ________________ . (8, 9)

The original blast furnace is preserved opposite this place: ____________________________ __________ ___ ________ . (13, 6, 2, 4)

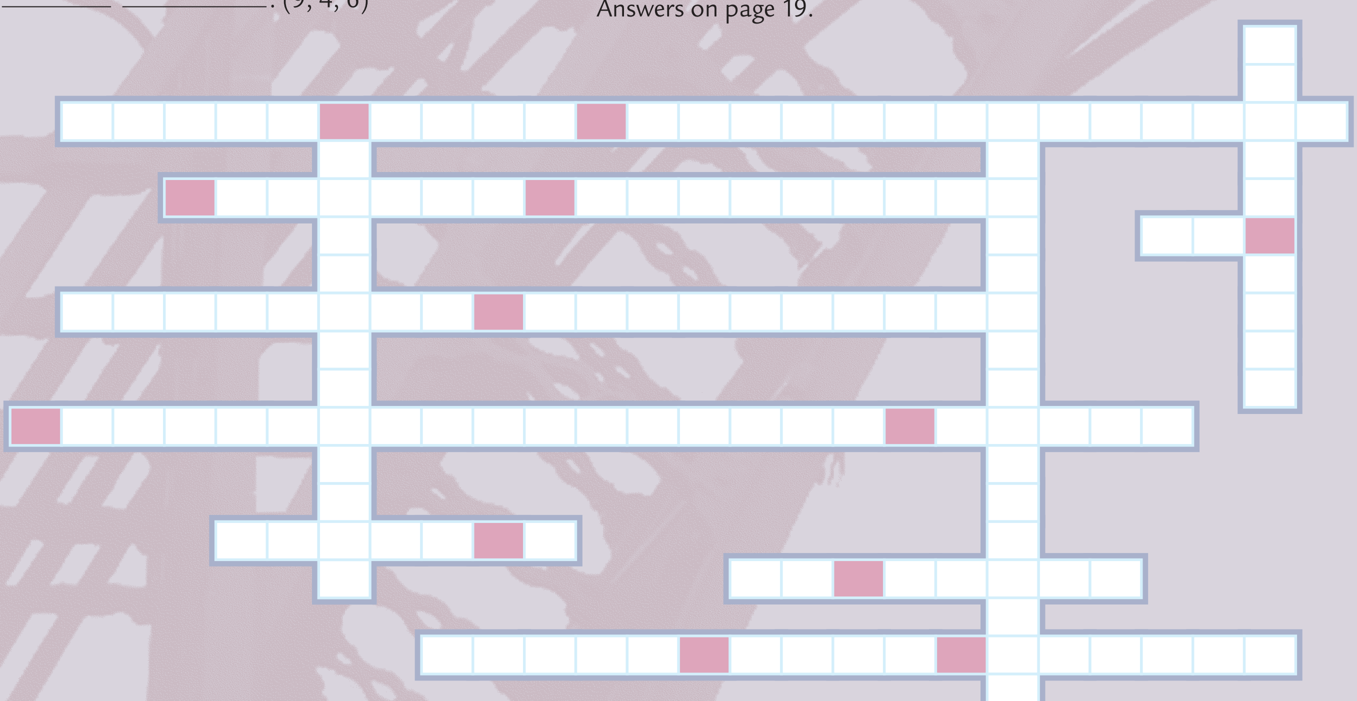
A tunnel in which a natural resource was found: _____ . (3)

Originally built by the Darby family, this is furnished in typical mid-Victorian style: ________________ ________ . (8, 5)

This place provides an insight into public health: __________ ___ _____ ________. (6, 2, 3, 5)

The whole area and museums is called: ________________________. (10)

Answers on page 19.



Places to visit

The Science of Aliens

The Science Of Aliens — the biggest and most in-depth exhibition to examine the possibility of life on other worlds — is at the Science Museum at South Kensington in London until the end of February 2006, when it starts an international tour. The Science Museum is offering CATALYST readers a free visit. Why not go this half term?

The Science of Aliens explores our eternal fascination with life on other planets and the work of leading scientists who have used the latest discoveries and scientific principles to imagine alien worlds and creatures. Cutting edge hands-on displays let you interact with these scientifically-based creatures.

TopFoto

The zones of the exhibition

The exhibition is divided into four distinct zones:

- **Alien Fiction** (zone 1) explores our fascination with alien life in fiction. It looks at aliens in films, television and literature — from *The Blob* to *ET* to *The Predator*. Visitors will be greeted by the imposing Alien Queen from James Cameron's *Aliens* movie and a host of other science fiction alien creatures including The Vogons and a family of Clangers.
- **Alien Science** (zone 2) investigates some of the real but extremely weird creatures that thrive on Earth, before embarking on a journey around our solar system and into deep space in search of alien life. You can investigate frightening specimens from Earth's deepest oceans, explore the amazing evolution of life on Earth and find out how this helps scientists understand the possibilities for alien life. Massive globes and an interactive galaxy map explore the latest planetary science.
- **Alien Worlds** (zone 3) features two planets created by leading scientists from around the world for a documentary shown on Channel 4. Scientists used the science in zone 2 to help them imagine the kind of life that could evolve on two fictional worlds — Aurelia and Blue Moon. Giant interactive landscapes enable you to interact with the creatures, learn more about them and influence their behaviour, making them hide, hunt and move around their planets, before triggering world-altering global events.
- **Alien Communications** (zone 4) looks at the search for alien intelligence. It shows how scientists are listening for signals from outer space and how they have attempted to communicate with alien civilisations. You can listen to space and compose a message to an alien — scientific or spiritual, welcome or warning.

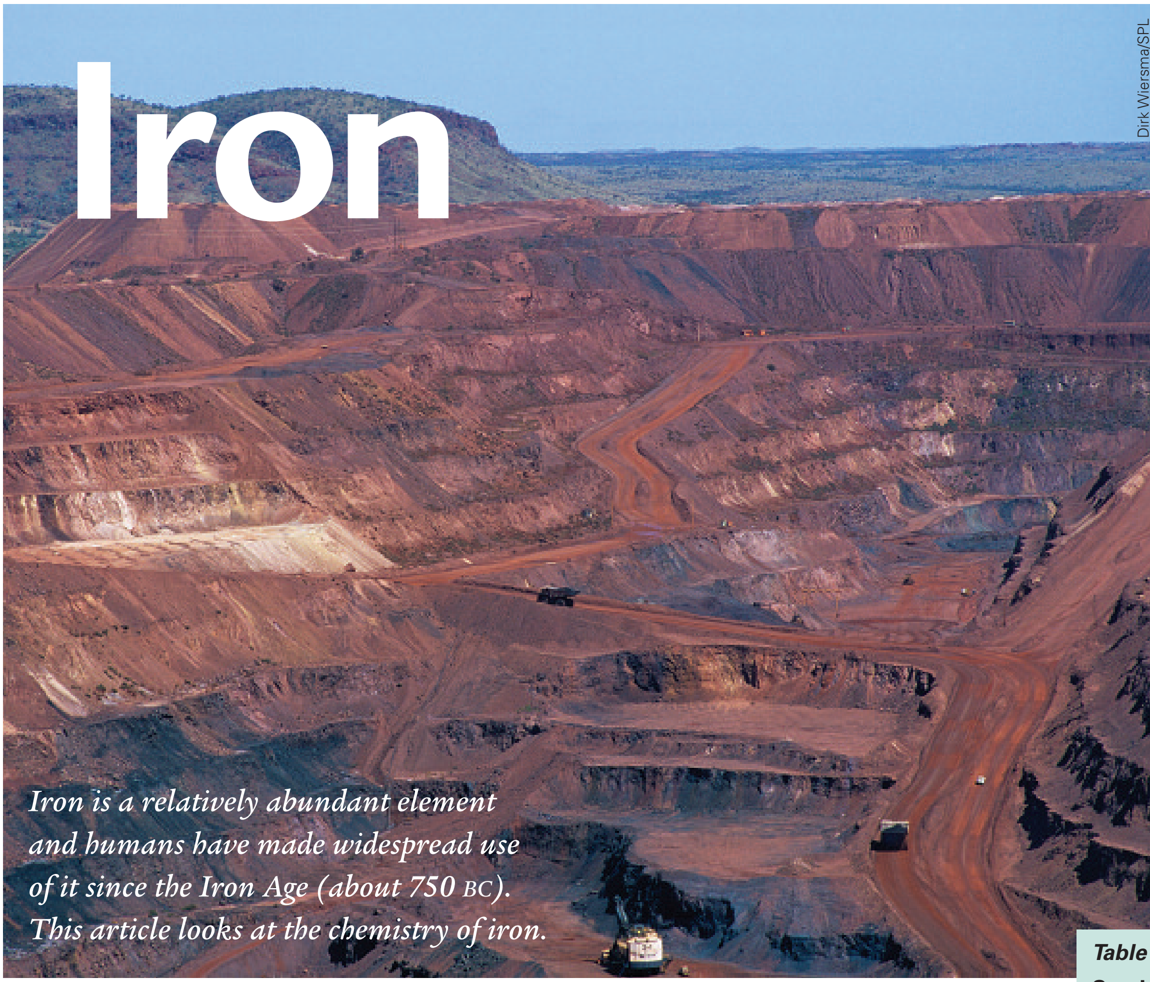
Box 1 Visitor information

The Science of Aliens runs until 26 February 2006. Admission to the main areas of the Science Museum is free. If you produce this copy of CATALYST, you can also enter the exhibition free, but anyone accompanying you will have to pay. Tickets can be pre-booked at www.sciencemuseum.org.uk/aliens or by calling 0870 906 3890. Information about the exhibition is also available by texting GO ALIENS to 85080.

Prices: Adult £8.95/Concession £6.25/Education £4.00 per child/Family 2 + 2 £26.00/Family 1+2 £18.50. Group concessions are available.

Iron

Paul Silverwood


Dirk Wiersma/SPL

Left: *An iron ore mine in western Australia*

Iron is a relatively abundant element and humans have made widespread use of it since the Iron Age (about 750 BC). This article looks at the chemistry of iron.

GCSE key words
Iron
Iron manufacture
Steel
Oxidation and reduction

Iron is an Anglo-Saxon word. The Latin for iron is *ferrum*, hence Fe.

Table 1 *Properties of iron*

Symbol	**Fe**
Atomic number	26
Density	7.9 g/cm^3
Atomic mass	55.85
Atomic radius	124.1 pm
Common ions	Fe^{2+} and Fe^{3+}
Melting point	1538°C
Boiling point	2861°C

The **core** of the Earth (which is approximately 3440 km in radius) is thought to be largely composed of iron. The metal is also the fourth most abundant element by weight in the Earth's **crust**. It is plentiful elsewhere in the universe too (see Box 1).

Table 1 lists the key properties of iron. It is a cheap, abundant and useful metal, but iron must be extracted from its ore before it can be used.

Iron ore

Iron ore is a mineral substance which, when heated in the presence of a reducing agent, yields metallic iron (Fe). It normally consists of iron oxides, the primary forms of which are magnetite (Fe_3O_4) and haematite (Fe_2O_3).

Iron ore is the main source of iron for the world's iron and steel industries. Almost all iron ore (98%) is used in steelmaking. Iron ore is mined in about 50 countries, but just seven of these countries account for about three quarters of total world production. Australia and Brazil, in particular, dominate the world's iron ore exports.

Box 1 Iron in space

Iron is found in the Sun and many types of stars. It is the heaviest element which can be made in the nuclear fusion furnace that runs in the centre of a typical star. The nuclei of its atoms are very stable, so once the core of a star has become mainly iron, that star has run out of its primary energy source.

Extraction of iron

Before 1709, furnaces could only use charcoal to produce iron. At the beginning of the eighteenth century, forests were being cleared for farmland and timber. This meant that charcoal became expensive. Although coal was cheap and plentiful, it could not be used for iron extraction because it contained sulphur which made the iron too brittle to be of any use.

However, in 1709 Abraham Darby succeeded in smelting iron with coke. This technological achievement allowed a major expansion of the iron trade and, ultimately, it helped lead to the Industrial Revolution.

In the space of 40 years, the Darby's home at Coalbrookdale went from being a small village to a major industrial site which employed about 500 people (see 'Places to visit', page 14). After 1709, the first cast-iron bridge was made there and built over the River Severn at Ironbridge and the first cast-iron framed building was built upriver at Shrewsbury.

A remarkable iron pillar, dating to about AD 400, remains standing in Delhi, India. This solid shaft of wrought iron is 7.25 m high and 0.4 m in diameter.

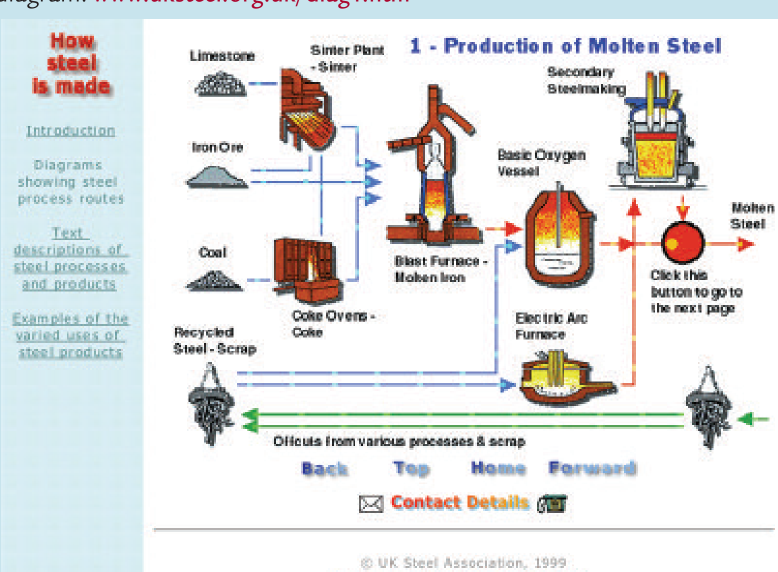
- **Look up iron in the periodic table on the Radiochemistry Society website (www.radiochemistry.org/periodictable/index.shtml).**

Time exposure photograph of a blast furnace in a steel foundry

David Guyon/SPL

Box 2 Useful website

To find out more about how steel is made go to the following page on the UK Steel Association website and click on the links in the interactive diagram: www.uksteel.org.uk/diag1.htm



Box 3 Raw materials for a blast furnace

Coke	From coal heated in the absence of air
Limestone (calcium carbonate)	Quarried in the Peak District (in Derbyshire)
Iron ore (haematite, Fe_2O_3)	From Australia

The blast furnace

The furnaces devised in the 1700s were developed further into the modern blast furnace. The purpose of a blast furnace is to chemically reduce iron oxides into liquid iron known as ‘hot metal’ (Box 2).

What is a blast furnace?

A blast furnace is a huge, steel stack which is lined with refractory brick. Iron ore, coke and limestone (Box 3) are dumped into the top, and preheated air is blown — or blasted — in at the bottom. The iron ore, limestone and coke are sintered together first to make large lumps around which the gases can flow readily. The air blast is preheated by heat exchangers which extract heat from the hot waste gases heading out the top of the furnace.

Liquid iron

Because the furnace temperature is in the region of 1500 °C, the metal is produced in a molten state and runs down to the base of the furnace. The raw materials take 6–8 hours to descend to the bottom of the furnace where they become liquid slag and liquid iron.

Liquid iron is drained from a tap hole near the bottom of the furnace at regular intervals. The impurities (CaS and CaSiO3) form a liquid that floats on top of the molten iron. This slag is collected after the denser iron has been run out.

Hot air

The hot air that was blown into the bottom of the furnace ascends to the top in 6–8 seconds, after being involved in numerous chemical reactions in the furnace (the back page has more details). The waste gases which leave the blast furnace at the top are mainly carbon dioxide, carbon monoxide and unreacted nitrogen (from the air).

A continuous process

The production of iron in a blast furnace is a **continuous process**. The furnace is heated constantly and is recharged with raw materials from the top while it is being tapped from the bottom. Iron making in a furnace usually continues for about 10 years before the furnace linings have to be renewed.

Energy costs

The energy costs of the operation are kept to a minimum by collecting and cleaning the hot gas that leaves the furnace. This gas contains a lot of carbon

Molten iron being tapped from a blast furnace

- Look up any elements with which you are unfamiliar in one of the web-based versions of the periodic table.

Table 2 *Steel alloys*

Name	Approximate composition	Special properties	Use
Manganese steel	86% Fe, 13% Mn, 1% C	Toughness	Drill bits
Stainless steel	73% Fe, 8% Ni, 18% Cr, 1% C	Non-rusting	Cutlery, sinks
Cobalt steel	90% Fe, 9% Co, 1% C	Hardness	Ball bearings
Tungsten steel	81% Fe, 18% W, 1% C		Armour plate

monoxide. It can be reused as a fuel for other steel-making processes, as well as to heat up the air blast to the furnace.

Overall equation

The overall equation for what goes on in a blast furnace is:

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

Iron into steel

The metal that leaves the blast furnace contains between 4% and 5% carbon. This much carbon makes a hard but brittle metal which is not much use. The carbon is reduced to about 0.1% by blowing pure oxygen through the molten metal in a converter. This burns off the excess carbon as carbon monoxide and carbon dioxide.

The iron, which is now called steel, is ready for use. The steel that remains can be turned into an alloy such as stainless steel or tungsten steel by the addition of transition metals which confer specialised properties to it (Box 4).

Paul Silverwood is Director of Studies at Benenden School and was formerly Head of Chemistry at St Edward's School, Oxford.

A modern furnace produces about 10 000 tonnes of iron per day.

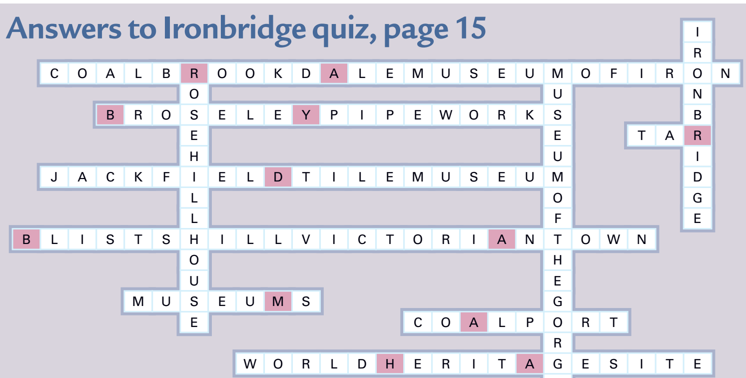
An alloy is mixture of elements, of which a metal is the main component.

Box 4 Alloys

Iron itself is hard and brittle so it is normally made into alloys:

- Pig iron is an alloy containing about 3% carbon with varying amounts of sulphur, silicon, manganese and phosphorus.
- Wrought iron contains only a few tenths of a percent of carbon, is tough, malleable, less fusible and usually has a 'fibrous' structure.
- Carbon steel is an alloy of iron with small amounts of manganese, sulphur, phosphorus and silicon.
- Alloy steels are carbon steels with other additives such as nickel, chromium or vanadium (Table 2).

Answers to Ironbridge quiz, page 15



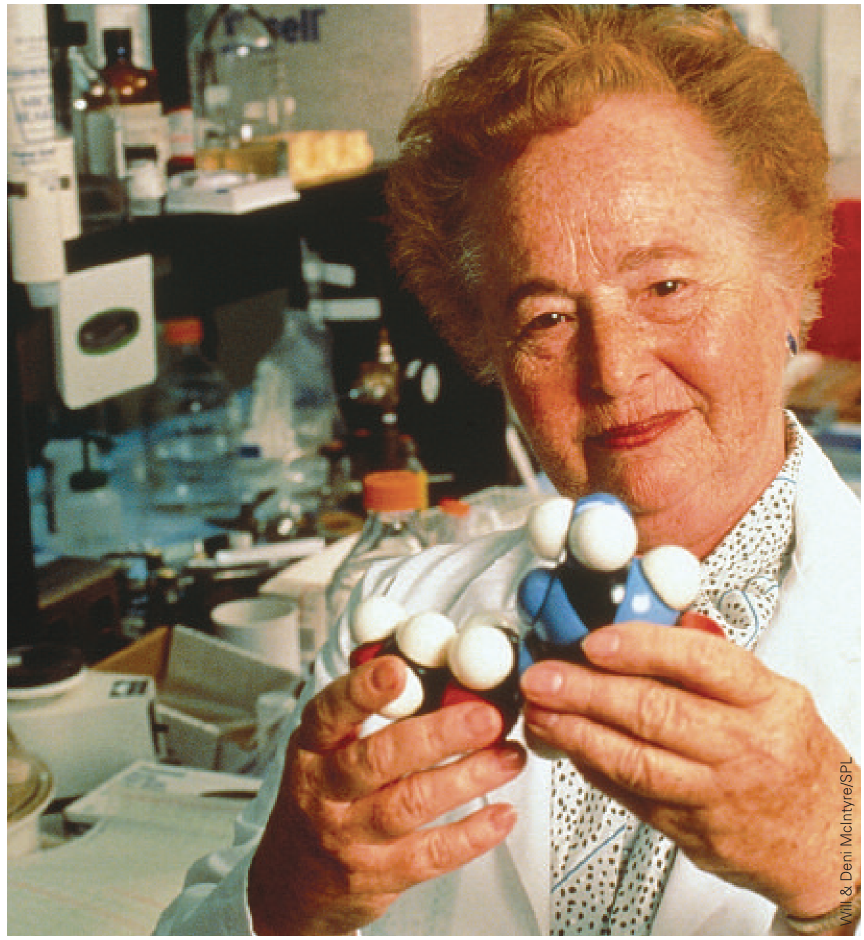
Name of the person who supervised the building of the first iron bridge: **Abraham Darby**.

A life in science

Gertrude (Trudy) Belle Elion (1918–99) was an exceptional team player. She cared more about getting something useful from her work than making a name for herself. People are alive today because of her research, and the knowledge that her work made a difference to people's lives was important to Trudy.

'It's amazing how much you can accomplish when you don't care who gets the credit'

(Gertrude Belle Elion)



Will & Deni McIntyre/SPL

Gertrude B. Elion

Trudy was born in New York in 1918. Her parents were immigrants from Eastern Europe. Trudy did so well at school that she was accelerated ahead of her classmates. Her grandfather, who was a scholarly watchmaker, encouraged Trudy in her studies.

Two events then happened which were to shape Trudy's future life:

- Her grandfather died from stomach cancer – this prompted Trudy to decide that she wanted to find a cure for cancer.
- Her family lost their savings in the Depression – this meant that although her parents valued education for girls they could not afford to educate Trudy beyond school.

Trudy's parents were teenagers when they emigrated and had to educate themselves as well as work.

Education

Trudy got a place at Hunter College, New York, where tuition was free. She studied chemistry there – an unusual choice even in an all-girl college – and graduated with distinction. However, although universities would take her to do a PhD, Trudy could not get the necessary financial assistance. So she looked for a scientific job instead.

At the time, most people thought it was a waste to educate girls beyond school.

Finding work

Despite her qualifications, Trudy could not find any scientific work. Employers did not want 'distracting' women in laboratories. She did a series of temporary and part-time jobs to gain experience. Trudy saved her wages to pay for a Master's degree and 18 months later enrolled at New York University. She worked on her degree in the evenings and at the weekends, graduating as the only woman in her class in 1941.

During this time Trudy met Leonard Canter, a young mathematician. They planned to marry, but Leonard died of a bacterial infection. His death reinforced Trudy's ideas about using science to develop drugs. She never married – in those days people thought that married women should not work.

Hitchings and Burroughs Wellcome

The Second World War gave Trudy the chance she was waiting for. Many scientifically qualified men were fighting in the war so women were allowed to work as technicians. She came across a drug company, Burroughs Wellcome, and asked about work.

Box 1 New research methodology

Hitchings and Elion's approach to developing drugs was ground-breaking. Other researchers tested chemicals randomly in the hope that something would be effective. Hitchings was more logical. He knew that sulphonamide drugs interfered with bacterial metabolism so there must be other substances that also interfered with cell processes.

Hitchings and Elion used knowledge of cell biochemistry to design molecules that would interfere with cellular activities. They knew cells needed nucleic acids to reproduce, so they searched for substances to interfere with DNA synthesis in cancer cells and bacteria. Ideally a drug would interfere with processes in the harmful cells but not affect normal cells.

This approach, based on cell biology and differences between healthy and diseased cells, is the standard research method used today.

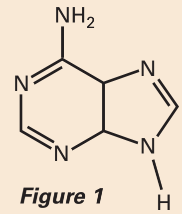


Figure 1
Adenine

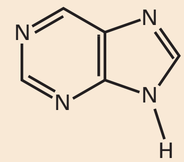


Figure 2
A general purine structure

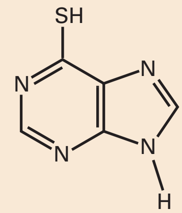


Figure 3 *6-mercaptopurine (6-MP). This molecule interferes with DNA synthesis because it is so similar to the adenine that cells need*

Box 2 Purines

Purines (Figure 1 and 2) are a group of widely occurring substances, including caffeine. Adenine (A) and guanine (G) in DNA are purines. They have a two-ringed structure containing carbon and nitrogen.

In 1944 Trudy joined the research lab at Burroughs Wellcome and began a life-long collaboration with her boss, Dr George Hitchings. The lab was looking for new drugs, but Hitchings took a different line from the usual methodology (Box 1). They worked on the chemicals in DNA. Trudy worked on purines (Box 2), synthesising molecules that might interfere with DNA duplication.

Trudy also started a PhD, but she had to give up after 2 years because the college did not like the fact that she only worked in the evenings. She was unhappy about her lack of proper qualifications. However, Dr Hitchings encouraged all his research assistants to publish their research so Trudy Elion began to make a name for herself.

Breakthrough

Trudy created and investigated hundreds of purine compounds. It took years to find di-aminopurine, which stopped mouse leukaemia cells reproducing. Unfortunately, it was too damaging to healthy cells for use in medicine, but it showed that Hitchings and Elion's theory was sound.

A similar molecule – 6-mercaptopurine (6-MP) – helped some leukaemia patients, but it wasn't a cure (Figure 3). More research led to a better version which boosted patient survival rate to 50% – and the drug is still in use today. Another 6-MP derivative was found to reduce uric acid production and it is used to treat gout.

6-MP also reduces immune system activity. The research group developed a similar compound – azathioprine – that depressed the immune system. The potential of this substance for helping transplants was spotted. After successful trials using dogs, it was tried on humans. Azathioprine (Imuran) enabled the first successful kidney transplant between unrelated people in 1961.

Anti-viral drugs

Early on in her research, Trudy observed that some compounds affected viruses but were too toxic to be useful. When more had been learned about viral reproduction she went back to her earlier work and focused on chemicals that could target bacterial and viral nucleic acids. The result was trimethoprim, for treating meningitis, septicaemia and other infections, and pyramethamine, for malaria.

Trudy Elion became head of the research lab after Dr Hitchings retired. In the 1970s, the lab released Acyclovir which was the first effective anti-viral medicine. Later, the team developed AZT – this anti-HIV drug was released a year after Trudy had retired in 1984.

As for the PhD – Trudy was awarded an honorary doctorate by George Washington University to recognise the work she had done. It was the first of many.

Unless drugs are given to supress the immune system a transplant is rejected because the patient's immune system attacks it.

The Nobel prize

In 1988 Elion and Hitchings were awarded the Nobel prize in physiology or medicine. This came so long after their research that it was quite a surprise. Trudy's award was also unusual as she had no PhD, worked in the drug industry and was female. When she and Hitchings were nominated there were concerns about her contribution. However, Trudy's publication record and the work done after Hitchings' retirement soon showed how much she was involved in the discoveries.

When Trudy began her research at Burroughs Wellcome, no one knew the structure of DNA, but its components had been identified.

Retirement

After retiring Trudy Elion remained active in science. She communicated the excitement of science to many others, and gained pleasure from feeling that she had made a difference to people's lives, and had encouraged young people, especially women, to follow their interest.

Jane Taylor *teaches biology and is an editor of* Catalyst*.*

Chemistry in a blast furnace

A great many reactions, of different types, go on inside a blast furnace.

The hot air blast to the furnace burns the coke and generates a lot of heat (the reaction is highly exothermic):

$C + O_2 \longrightarrow CO_2$ **Oxidation**

The heat is sufficient to decompose the limestone, producing calcium oxide and more carbon dioxide:

$CaCO_3 \longrightarrow CaO + CO_2$ **Decomposition**

Since there are now high concentrations of carbon and carbon dioxide present, they will react together:

$CO_2 + C \longrightarrow 2CO$ **Redox**

The calcium oxide removes sulphur and other acidic impurities (such as silicon dioxide) from the iron ore:

$FeS + CaO \longrightarrow CaS + FeO$

$SiO_2 + CaO \longrightarrow CaSiO_3$ **Neutralisation**

The carbon monoxide *reduces* the iron ore to iron in a series of steps:

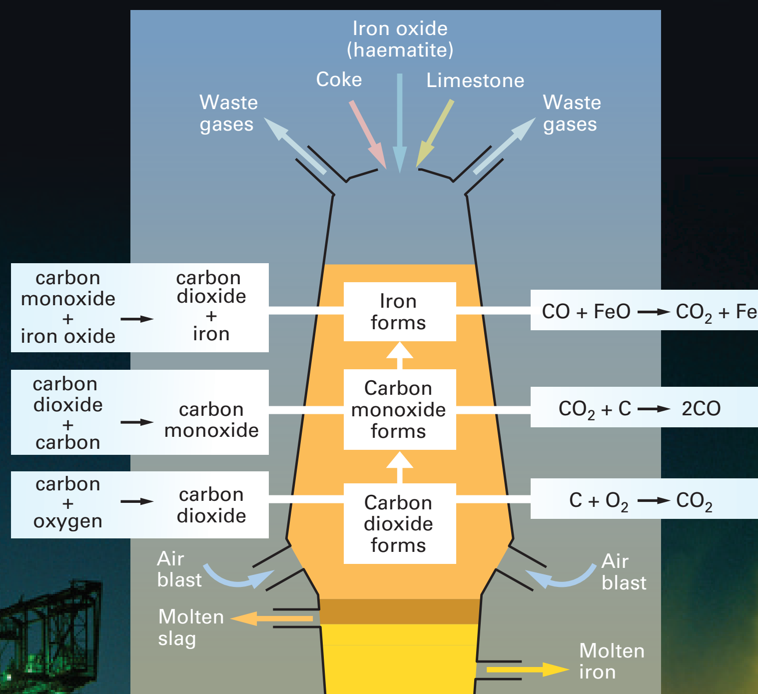
$3Fe_2O_3 + CO \longrightarrow CO_2 + 2Fe_3O_4$ **Redox**

$Fe_3O_4 + CO \longrightarrow CO_2 + 3FeO$ **Redox**

$FeO + CO \longrightarrow CO_2 + Fe$ **Redox**

The overall equation in a blast furnace is:

$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$



Redcar steelworks at night

Martin Bond/SPL