Catalyst

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Fast reactions

How catalysts work for us

SEP
Science Enhancement Programme

Catalyst

Volume 18 Number 3 February 2008

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The front cover shows the structure of a synthetic catalyst (see the article on pages 1-3) (Clive Freeman / Biosym Technologies / Science Photo Library)

Science, pure and applied

Welcome to third issue of Volume 18 of Catalyst. Sometimes people talk about scientists as if they were divided into two camps, the 'pure scientists' and the 'applied scientists'. As you read the articles in this issue, you can think a little about the relationship between these two parts of the scientific community.

- This issue's Big Picture focuses on barnacles. You might imagine that a study of these creatures of the seashore is only of theoretical interest. However, as Gary Skinner's article shows, understanding the ecology of barnacles has led to new insights which have much wider application. They can help us, for example, to deal with an event, such as an oil spill or a tsunami, which has an impact on the environment.
- Most people recognise that we need to make better use of our energy resources, but how can we put this into practice? Jeff Keenlyside explains how, as an environmental scientist working for a local authority, he can use his scientific understanding to make a difference.
- When science is applied, it is likely to bring both benefits and risks. Stacy Eltiti describes how a scientific approach can help us to assess the risks of mobile phone technology.

There is no doubt that some scientists love the pursuit of knowledge 'for its own sake' while others enjoy the chance to work on applications of science. In the world of science which we try to bring you in each issue of Catalyst, there is plenty of room for both.

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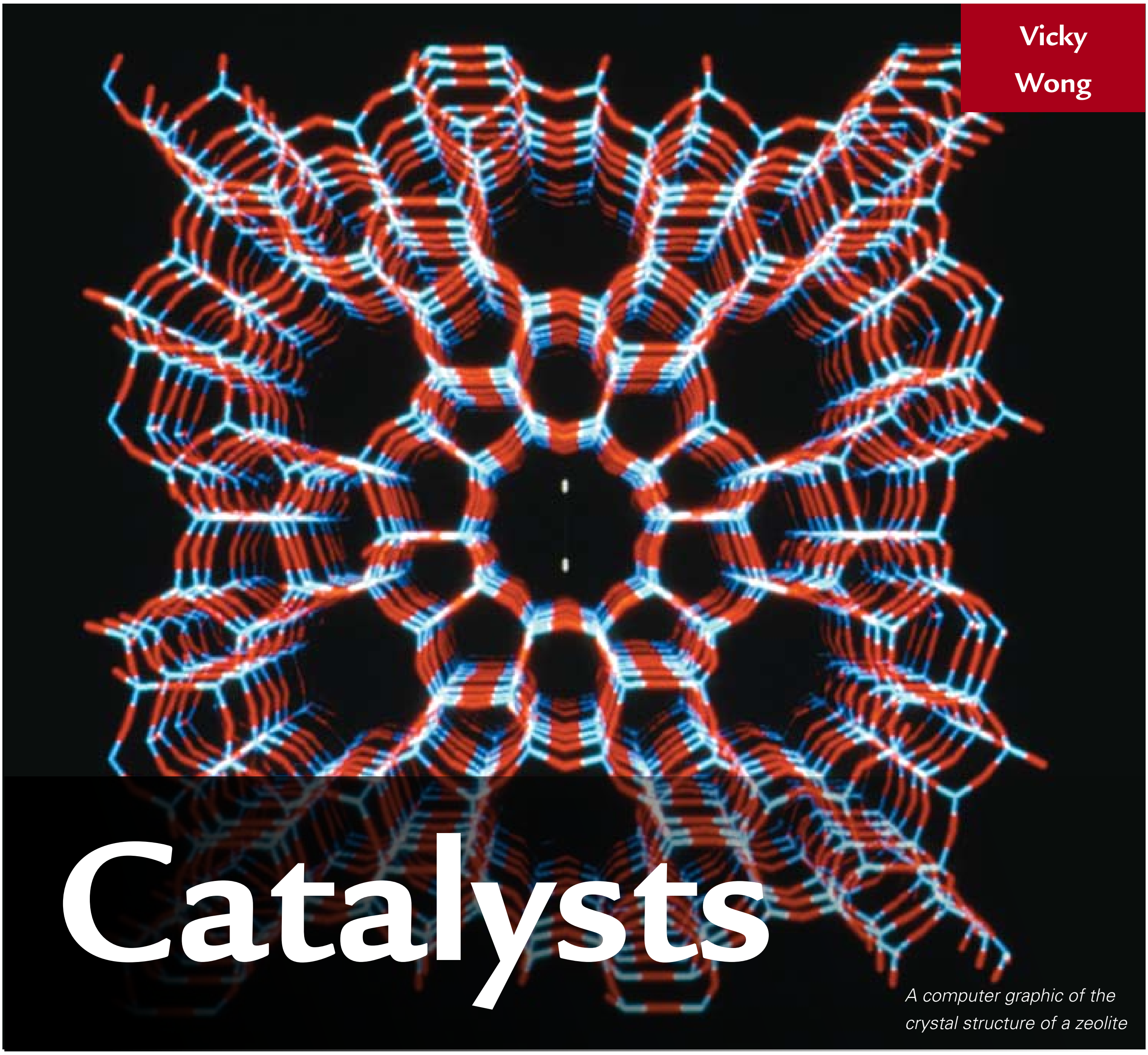


Chemical Design/SPL

A computer graphic of the crystal structure of a zeolite

Vicky Wong

Catalysts

Catalysts are both vitally important for life and critically important for our society. This article looks at what catalysts are, how they work, where they are used and how and why many scientists still study them.

Every second of every day thousands of catalysts are at work in your body. They are critical in helping you to live. They break down the food you eat in your digestive system so that you can absorb it. They build it back up again so that you can grow. They are involved in most of the molecular processes which occur in every living thing. These catalysts are called enzymes.

Catalysts are also critical in virtually every industrial chemical process. Fertilisers could not be made without them. Neither could petrol or plastics. In a single day you will encounter many products which are either made themselves using catalysts or produced using materials which are formed in catalytic reactions.

The first person to express ideas about catalysts was a Swedish chemist, Jöns Jacob Berzelius. He recognised that catalysts are able to make reactions happen at a lower temperature than they would otherwise. Current understanding is that a catalyst will take part in a chemical reaction and increase its rate, but without being used up.

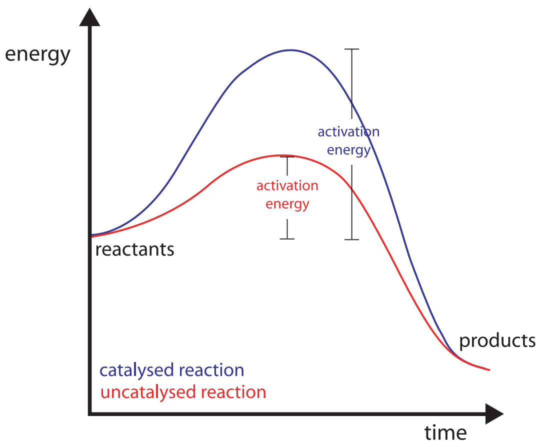
Box 1
The two types of Catalyst

- Heterogeneous (*hetero* means different) catalysts are in a different state to the reactants and products. Often the catalyst is a solid and the reactants and products are liquids or gases.
- Homogeneous (*homo* means the same) catalysts are in the same state as the reactants and products. They are often all dissolved in a solvent. The catalyst may be an acid.

Key words
catalyst
activation energy
Haber process
Nobel Prize
zeolite

How do catalysts work?

There is no single answer to this question as different catalysts work in different ways. All of them, though, give an alternative reaction pathway which has a lower energy barrier or activation energy than the uncatalysed reaction.



This diagram shows how the activation energy required for an uncatalysed reaction (top plot in blue) can be higher than the activation energy for a catalysed reaction (bottom plot in red.)

Diagram 1 shows an energy profile for a typical exothermic reaction. The products have less energy than the reactants and so the reaction gives out energy in the form of heat (it will get hot). However, for the reaction to get started, some of the bonds in the reactants have to break. This can take a lot of energy and leads to the 'hump' in the profile. The amount of energy required to break some bonds and get the reaction started is called the 'activation energy.' In general, the higher the activation energy the slower the reaction is.

A catalyst will help the reaction to take place via a different pathway. This may mean that it helps to form a very unstable and short lived molecule called a 'transition state.' If the transition state has less energy than the original activation energy then the barrier to the reaction is lower – see Diagram 1. This speeds up the rate at which the reaction can take place.

Making fertilisers

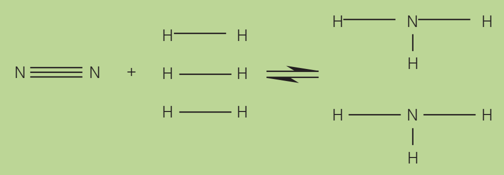
Most plants need a supply of nitrogen in the form of nitrates in order to grow well. In areas which are farmed frequently, this can be depleted from the soil. Fertiliser containing easily accessible nitrogen must be added or plants will not grow well. This fertiliser can be natural (for example, animal manure) but in the developed world it is often artificial.

In the late 1800s, natural deposits of nitrogen salts were being used to make fertilisers but it was clear that they were going to run out. The population of the world was increasing and fertilisers were vital to ensure that there was enough to eat and to avoid widespread famine.

Nitrogen gas, N_2, is plentiful; it is about 78% of the air we breathe. The trouble is that the two nitrogen atoms are held together by a very strong triple bond and a lot of energy is required to break them apart. A method for catalysing the bond breaking was urgently required and chemists around the world were working on a solution.

Box 2
Forming Ammonia

The reaction of nitrogen and hydrogen to form ammonia



A German chemist called Fritz Haber finally solved the problem in 1905. He realised that iron would act as a catalyst for the reaction between nitrogen and hydrogen, producing ammonia gas (see Box 2). It was developed into an industrial process by another German chemist, Carl Bosch, in 1914. The Haber-Bosch process is still used today to manufacture over 100 million tons of fertiliser a year. It is often claimed that this process saved the world from starvation by ensuring that there was a supply of ammonia for fertiliser manufacture. Ammonia can also be used to make explosives and so it is also possible that the process lengthened World War I as well as it meant that Germany could keep fighting.

Fritz Haber won the Nobel Prize in Chemistry in 1914 for his work on the synthesis of ammonia.

Emilio Segre Visual Archives/American Institute Of Physics/SPL

Fritz Haber who discovered that iron would catalyse the reaction between nitrogen and hydrogen to form ammonia and won the Nobel Prize in Chemistry in 1914.

Reactions at the surface

Although iron had been used successfully for decades to manufacture ammonia, by the mid-1970s it was still unknown how it worked. Another German Chemist, Gerhard Ertl, took up the challenge and decided to find out. He showed that the nitrogen's strong triple bond broke on the surface of the iron – in other words that the nitrogen molecule broke apart into nitrogen atoms before meeting a hydrogen molecule.

Ertl also studied the reactions which form the basis of a catalytic converter in a car's exhaust. Platinum metal forms the main part of the catalyst and Ertl studied how the carbon monoxide and oxygen molecules react together on the surface to produce the much less toxic carbon dioxide.

Astrid & Hanns-Frieder Michler/SPL

A catalytic converter from a car exhaust

Marie Curie

SPL

Box 3 Nobel Prizes

The Nobel prizes are awarded each year for outstanding achievement in Physics, Chemistry, Literature, Peace and Physiology or medicine. There is also a related prize for Economics. The prizes are considered to be the highest award in Science and have a great deal of prestige. The prize winners receive about £750 000 and a medal.

The awards were set up in the will of Alfred Nobel who left his entire estate for the purpose and were first awarded in 1901. They are given in a ceremony each year on the 10th December, the anniversary of the death of Alfred Nobel.

Many famous scientists have won a prize including Ernest Rutherford, Albert Einstein, Francis Crick and James Watson. Only four people have ever won two prizes. These include Marie Curie who won both the chemistry and the physics prizes. Her daughter was also a prize winner.

For the many catalysts which are solids, the reactions will take place on their surface. As the importance of catalysts are recognised, surface science is becoming increasingly significant.

Gerhard Ertl won the Nobel Prize in Chemistry in 2007 for his work on the chemistry of surfaces.

Zeolites – crystals with huge surfaces

As reactions take place on the surface of catalysts, it follows that the more surface which is available, the more efficient the catalyst. One group of catalysts which have huge surface areas are the zeolites. It has been estimated that for some zeolites a single teaspoonful could provide a surface area of up to 500 square metres which is equivalent to two tennis courts.

The reason for this incredible surface area to volume ratio is the way that the zeolites are constructed. They consist of a series of inter-connected channels or pores which are between 0.3 and 1 nm wide. They are constructed so that almost every atom in the zeolite crystal is at a surface, which gives huge potential for catalysing reactions. Naturally occuring zeolites are mainly made of a lattice of SiO_4 units, with aluminium ions sometimes taking the place of the silicon. Chemists now make synthetic zeolites and have incorporated several other elements such as zinc, germanium and phosphorus. In the synthetic zeolites, the precise shape of the pores can be controlled and designed. The size and shape of the pores control which substances can pass through and how fast they can do so. This allows chemists great control when trying to catalyse complex reactions and zeolites have been used to help synthesise new and advanced materials.

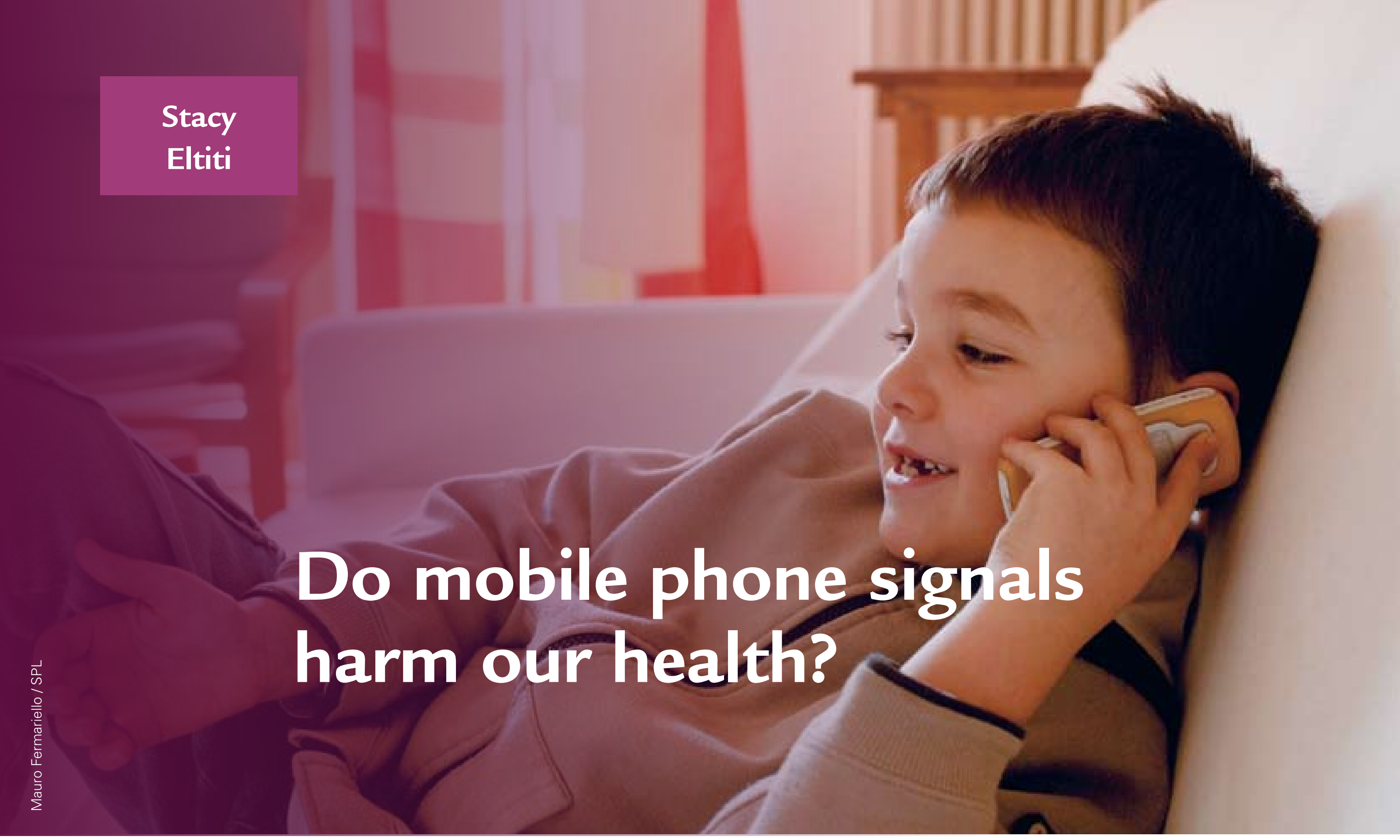
1 nm is one nanometre, 0.000 000 001 m or 10^{-9} m

Zeolites are also used in the petrochemical industry to crack large hydrocarbons. Crude oil contains a mix of many different sized hydrocarbons but there are not many uses for the larger ones. These are broken (or cracked) into smaller ones which are useful as fuels in, for example, petrol. The catalysts which are used for this are zeolites. They are also used in isomerisation reactions, turning straight chain hydrocarbons into branched hydrocarbons or vice versa.

Hydrocarbons are compounds which contain hydrogen and carbon only.

Although catalysts have been known about for over 100 years, they are still being studied in many research laboratories today. New catalysts are being discovered and these are assisting in the development of new materials and new processes. Catalysts help to make reactions 'greener' or more environmentally friendly by enabling them to take place at lower temperatures and use less starting materials.

Vicky Wong teaches chemistry and is an editor of CATALYST.



Mauro Fermariello / SPL

Stacy Eltiti

Do mobile phone signals harm our health?

A small number of people believe that their health is affected by the radiation emitted by mobile phones and their base stations. As yet, there is no scientific evidence that their symptoms are actually caused by exposure to radiation. Dr Stacy Eltiti describes a study she and her colleagues at the University of Essex carried out to see if these sensitive individuals would report symptoms when exposed to typical mobile phone base station signals.

Free Articles, 24 May 2007

Wi-Fi Fears Are "Unfounded"

Scientists have said that fears about the safety of wi-fi are unfounded. Evidence points to wi-fi transmissions being well below any likely threshold for human effects.

ITBusiness, 23 Jan 2006

University bans Wi-Fi

A Canadian university has ruled against Wi-Fi on the campus because administrators are worried about possible hazards to student health.

New Zealand Herald, 23 April 2007

Concern about Wi-Fi health danger spreads to NZ from British schools

A British furore over wireless internet technology - Wi-Fi - use in schools is raising similar concerns here.

Wi-Fi continues to be controversial.

The problem

Some people report symptoms such as headaches, memory difficulties, and cold and flu-like symptoms which they believe are caused by exposure to mobile phone radiation. We refer to these people as *sensitive individuals*. Mobile phones use radio waves, a form of electromagnetic radiation, to communicate with the nearest base station – see Box 1. If sensitive individuals are truly affected by the radiation, it is because the radiation produces a varying electromagnetic field which interacts in some way with them.

The World Health Organisation has labelled this condition Idiopathic Environmental Intolerance with attribution to Electromagnetic Fields (IEI-EMF). *Idiopathic* describes a disease with no known cause.

Box 1
Mobile phone radiation

A mobile phone system uses radio waves to carry signals between the handset and the base station.

Jason Stitt/Bigstockphoto

The radiation is most intense close to the mobile phone's aerial, and to the base station. It gets weaker as it spreads out, but the intensity also depends on how the signal is affected by objects in the environment.

The radiation from your mobile phone is strongest when you are making a call, and when you are at a distance from the nearest base station.

The research design

We wanted to know whether sensitive individuals could tell when they were exposed to mobile phone radiation, and also whether they would report poorer levels of well-being. This required a carefully-designed experiment.

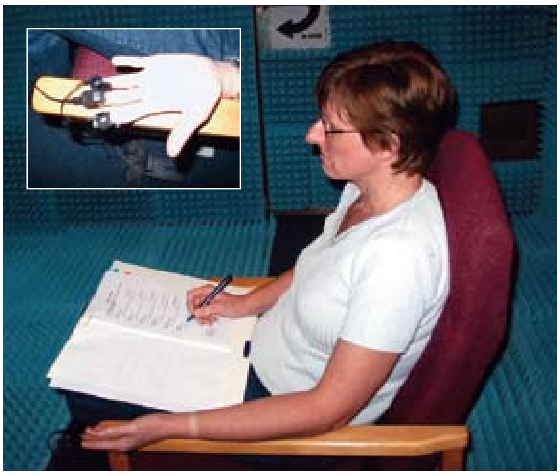
We invited two groups of people, sensitive individuals and control individuals (who did not report symptoms) to the University of Essex for four separate sessions. It was essential to have control individuals with which to compare the sensitive individuals, to see if they really did respond differently.

numbers of participants		
	sensitive	control
open provocation test	**56**	**120**
double blind test	**44**	**114**

One at a time, they sat in our specially constructed laboratory which is surrounded by metal which screens any electromagnetic radiation coming from outside. Inside the lab, we can expose people to two types of mobile phone base station radiation (see Box 1):

- GSM (global system for mobile communication) used by second generation mobile phones;
- UMTS (universal mobile telecommunication system), used by the new third generation mobile phones.

While in the lab, individuals could watch a Blue Planet video. We could also give them simple tasks, such as mental arithmetic, and tests of memory and concentration. They reported their level of well-being together with any symptoms they experienced, such as anxiety, tension, arousal (agitation), relaxation, discomfort and fatigue. At the same time, physiological measurements were taken continuously: blood volume pulse, heart rate and skin conductance.

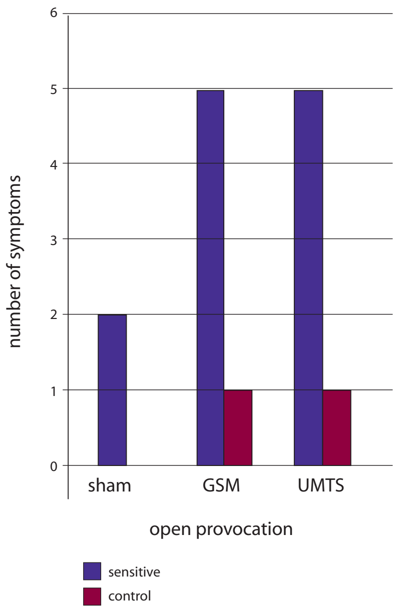

S.Eltiti

A participant in the test; sensors on her fingers record her heart rate etc, and she is recording her own sensations.

Session 1: Open provocation test

Session 1 was different from the other three. It was designed to gain background information against which to compare the later tests.

In this test, both the participants and the experimenters knew when the base station was on or off, and when it was on they knew whether it was emitting GSM or UMTS signals. A test of this sort is called an *open provocation test*; it is open because everyone knows the conditions. In this test, each exposure lasted 15 minutes.



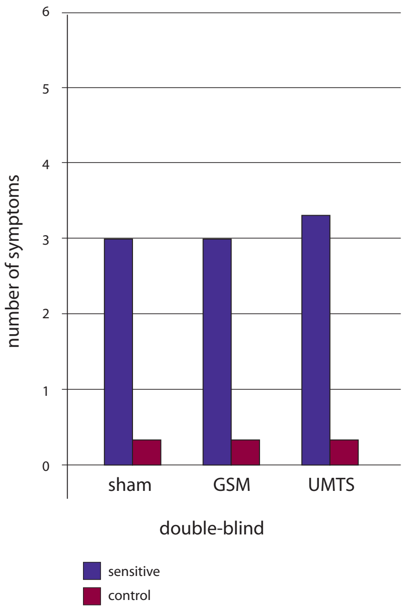
Graph 1: Results of the open provocation test.

Findings: The histogram, Graph 1, shows the results of the open provocation test. 'Sham' indicates when the base station was switched off. You can see that sensitive individuals reported more symptoms and poorer levels of well-being when they knew the radiation source was switched on. Control individuals declared far fewer symptoms – none at all when the source was switched off.

But does this mean that the sensitive individuals really were affected by the radiation? That was the question we set out to answer in the next test.

Sessions 2-4: Double blind test

The participants returned on three more occasions. Each session lasted 50 minutes. During one session, they were exposed to GSM radiation, during another to UMTS radiation, and during a third to no radiation. The order varied, and neither the participant nor the experimenter knew whether the radiation was on or off. A test like this is described as **double blind**. It was important that the experimenter did not know, because they might have given unintentional indications to the participant. As before, the participant sat in the screened laboratory, watching a video, performing simple tests and recording their symptoms.



Graph 2: Results of the double blind test.

Findings: Graph 2 shows the results. Although sensitive individuals still reported more symptoms than the control individuals, they reported the same level of health whether the radiation was on or off. The only difference was slightly raised levels of arousal during the UMTS compared to the sham condition. For control individuals, there was no difference in self-reported health when the radiation was on compared to off.

Mobile phone frequencies:
850, 900, 1800, 1900 MHz

Bluetooth: 2400 MHz

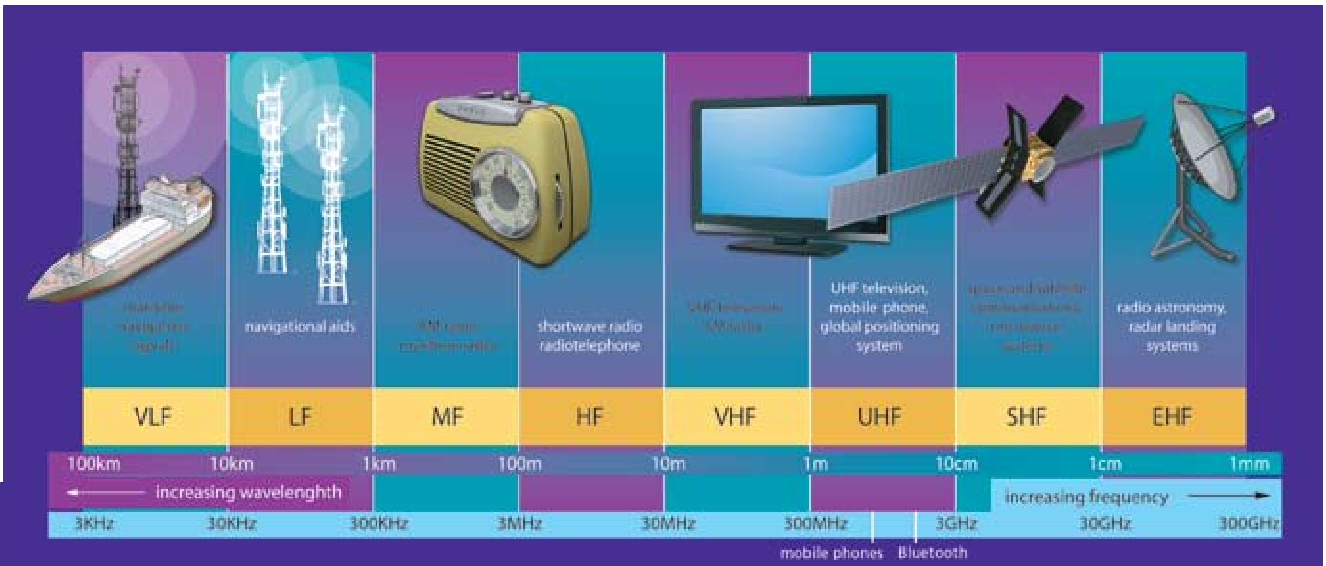
A third test

During their first visit to our lab, we conducted a quick test in which the participants were exposed to radiation three times for five minutes; at the end of each five minutes, they said whether they thought the radiation was on or off. This was another double blind test; neither the participant nor the experimenter knew whether the radiation was on or off. Participants were also asked to make a judgement as to whether the base station was on or off at the end of sessions 2, 3 and 4. We found that neither the sensitive nor the control participants were any better than chance at detecting when the base station was switched on.

Conclusions

Our study indicates that short-term exposure to mobile phone base station radiation does not affect the health and well-being of sensitive or control individuals. It is important to recognise the limitations of this study. Since we tested only short-term exposure to electromagnetic fields, we are unable to draw any conclusion about long-term health effects. Nor can we say whether people may be affected by other types of electromagnetic radiation – see Box 2.

Dr Stacy Eltiti was a research officer in the Department of Psychology at the University of Essex. She is now an Assistant Professor in Rosemead School of Psychology at Biola University, California.



Box 2
Radiation around us

There are many types of electromagnetic radiation to which we are exposed each day. Some of these come from technology. For example, radio waves used for broadcasting radio and TV programmes are all around us, and have been for decades. No-one has yet identified any health problems arising from this exposure. More recent developments include mobile phone signals, wi-fi (wireless broadband etc.), and Bluetooth. Each uses a different part of the electromagnetic spectrum.

Look here!

You can download the published report of Stacy Eltiti's work at **www.ehponline.org/docs/2007/10286/10286.pdf**

For more about mobile phones and how they work, see the article in Catalyst Vol 16 issue 1, available in our archive: **www.sep.org.uk/catalyst**

Ian Boddy/SPL

Victor De Schwanberg/SPL

Food Additives

A recent study showed that some children may become more hyperactive after consuming certain food colourings. This has led to calls from some groups for all food additives to be banned. What do you think?

Key words
double blind
placebo

What are food additives?

Food additives are not new. For centuries people have been putting colourings, flavourings and preservatives into their food. Since 1986 additives have to be identified with an E-number. E stands for European and shows that a particular additive has been licensed for use in the EU. If a food contains additives, this must be declared on the packaging.

Food additives fall into 6 categories:

- Colours
- Sweeteners
- Antioxidants
- Preservatives
- Texture modification – emulsifier, stabilizer, thickener, gelling agent
- Flavourings.

Some additives can have different functions in different foods. For example, vitamins and minerals which are added to foods are considered to be 'fortifying' the food and are not counted as additives. Confusingly, sometimes ascorbic acid (vitamin C) is used as an antioxidant and then it is given an E-number, E300.

Many other additives are also familiar. E260 is acetic acid (also known as ethanoic acid). This is the main constituent of vinegar. E150 is caramel which can be made by burning sugar. E500 includes sodium carbonate which includes the main ingredient of baking powder. If you are feeling rich, E175 is gold (sometimes used in Indian celebratory meals).

Some additives are natural, some are manufactured by the chemical industry. Some, like vitamin C, can come from either natural or artificial sources. As with every other component of food, however, all additives are chemicals. Even organic food can contain a certain number of additives.

The most important food additives are arguably the preservatives. These keep food fresh and keep the numbers of microbes down so that we do not get food poisoning. People have been preserving food for thousands of years using chemicals. This has included using acetic acid in vinegar to pickle food, nitrates and nitrites to cure meats and gelling agents such as pectin to make jam.

In addition to the 'E numbers' there are a large number of compounds which can be added to improve the flavour of a product. These do not have an E number. There are nearly 3000 flavourings which can be legally added to foods.

Are additives harmful?

The answer to this question is probably that some additives are harmful at certain levels to some people. All additives are subjected to continuing safety checks and sometimes some have their licence withdrawn and can no longer be used if they are found to be unsafe.

Most food intolerances are caused by naturally occuring molecules in food. For example, some people cannot tolerate gluten which is a component of wheat. Others have a reaction to lactic acid which is found in milk and dairy products. The solution to these intolerances is to avoid the foods which cause the problems and the same is probably also true of additives.

Do colourings cause hyperactivity?

The Food Standards Agency (FSA) recently commissioned a study to see if there was a link between certain food colourings and hyperactivity or attention deficit disorder (ADD) in children. They selected a group of 130 children aged 3 and 8 who had a range of hyperactivity from none or very mild to severe cases. They were studied for 6 weeks in a **double blind** trial. The children were given a drink every day of each week – but in some weeks it contained colourings and preservatives and in other weeks it did not – it was a **placebo**. Neither the parents nor the researchers knew at any given time which children were consuming the colourings.

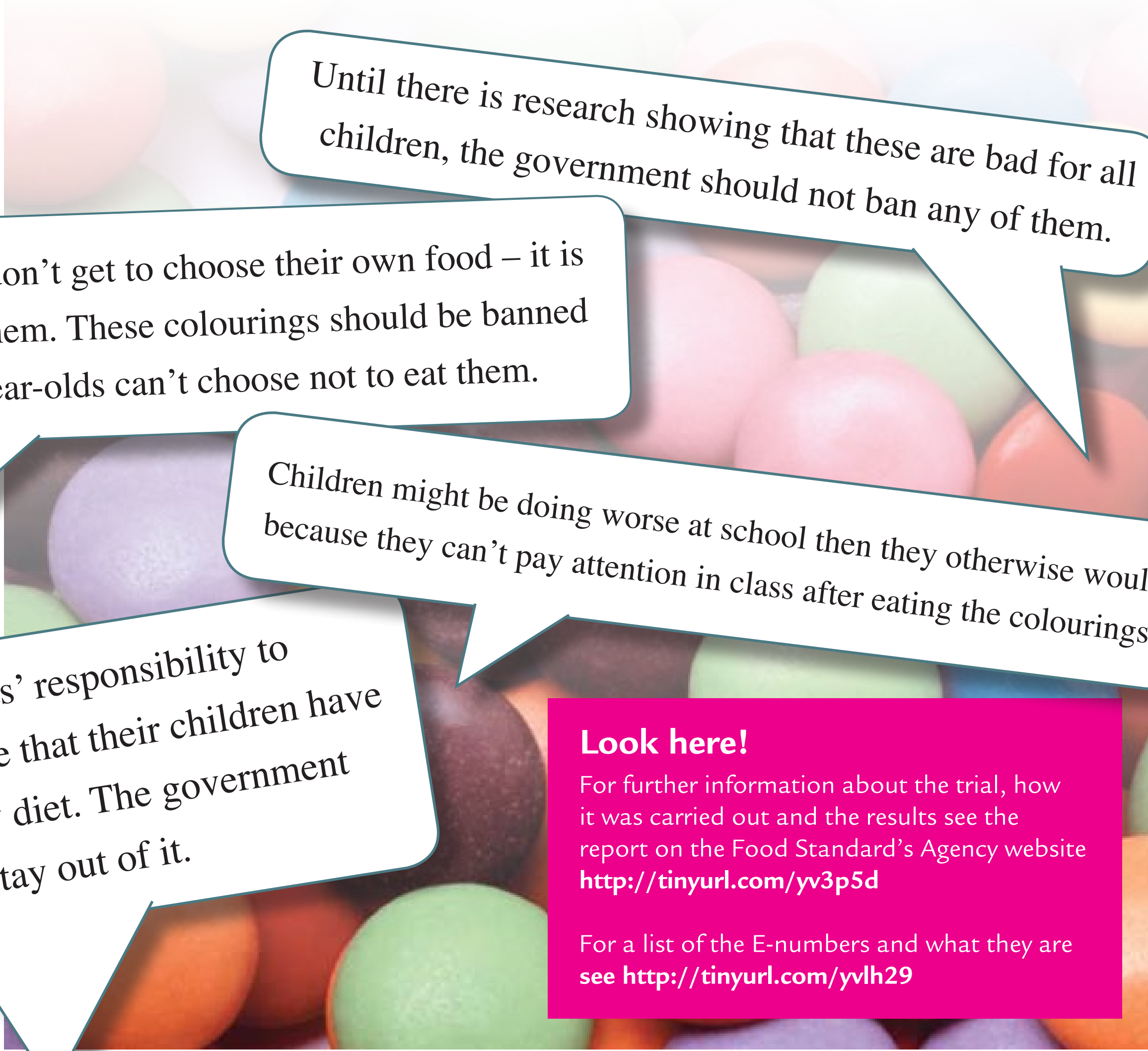
Assessment was carried out in the child's pre-school or school and included a daily observation by a research assistant. In addition, ratings of the children's behaviour were made by parents and by teachers throughout the six-week study period. The parents and all members of the study team were 'blind' (they did not know whether the child was having the colourings or the placebo), apart from the study administrator.

When all the results were in, they were analysed. The researchers found that children responded in different ways to the colourings. Some showed markedly worse behaviour when they had eaten the colourings; others showed very little difference. For the group as a whole, though, there was an increase in the level of hyperactivity when the colourings were consumed.

There have been various studies by other teams of researchers and the results of them altogehter are so far inconclusive. None of the food colourings which were monitored have been banned.

For debate

The following views have been expressed in various newspapers and websites about the food colourings debate. What do you think?



Victor De Schwanberg/SPL

Look here!

For further information about the trial, how it was carried out and the results see the report on the Food Standard's Agency website **http://tinyurl.com/yv3p5d**

For a list of the E-numbers and what they are **see http://tinyurl.com/yvlh29**

Gary Skinner

Battle of the barnacles

Competition on the seashore

The photograph on the centre pages shows a rock wall on a British rocky shore. It is covered with various intertidal animals, mainly barnacles. Have a good look at the image; you should be able to see barnacles of two different species and, amongst them, and even sometimes in their old shells, other animals, mainly shelled ones called molluscs. This image can be used to go on a virtual tour of this part of the rocky shore, and to see – nearly first hand – some important principles of ecology.

Much of the UK coastline is rocky, and the parts washed by the sea from high to low tide are called rocky shores. The region between the tides is the littoral zone, home to many species of animals and algae (but no true plants).

A day spent searching for living creatures on a rocky shore, it is claimed, can yield creatures from over twenty different **phyla** (singular phylum; see Box 1). One of the major phyla to be found is the **arthropods** and some very obvious jointed-legged animals (*arthropod* means *jointed limb*) such as crabs, lobsters and shrimps are commonly found here. Also common on rocky shores are many different kinds of shelled animals, belonging to the phylum **molluscs**, very like the well known land snails.

One group of animals, though, seems to defy this clear cut distinction; they are jointed legged animals living in shells! These are the barnacles; arthropods which live as tiny larvae in the sea and then cement themselves, head down, on suitable rocks, build a shell, poke their legs out of the top of it and start to filter feed! Barnacles like this are called acorn barnacles, and they occur in mind boggling numbers on most rocky beaches around the world.

A British barnacle, Semibalanus balanoides, reveals its legs when the tide comes in.

Box 1
What is a phylum?

The Animal Kingdom is divided into over 30 major groups, or types of animal life; these are called phyla. Large ones include the arthropods (insects, crustaceans, arachnids including spiders), echinoderms (starfish, sea urchins etc.), molluscs (snails, slugs, squids, octopuses etc.) and many others. Our phylum is the chordates and includes mammals, fish, amphibia, reptiles and birds.

British barnacles

There are over 1000 species of barnacle known in the world, but anyone starting a study of these fascinating animals in the UK only has to cope with four, and even one of these is a foreigner! Like most tiny organisms, these do not have common names and we have to use their Binomial Latin Names (see Box 2). The native species are:

Chthamalus montagui
Chthamalus stellatus
Semibalanus balanoides

The only other commonly found littoral species is an Australian barnacle called *Elminius modestus,* first noticed in Chichester Harbour in 1945. It is now found all around Britain and parts of north west Europe.

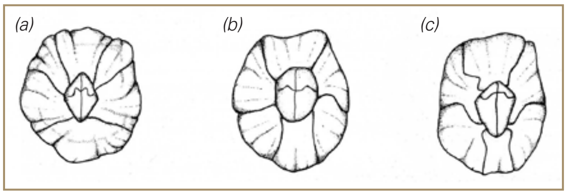
Barnacles could possibly be confused with one other group of shelled animals on the shore, the limpets. These are generally much bigger than barnacles (although young ones may not be) and do not have any sign of an opening at the top, or legs that emerge.

All adult acorn barnacles are fixed to a surface, usually rocks on a rocky shore, but also limpet shells and other solid objects. They have a conical shell, with plates that open on the top to let out the feeding legs. The shell consists of a number of calcium-based (calcareous) plates (4 or 6) with a flat top. When the tide is out, the plates close and the animal is in a box, which helps to stop it from drying out until the water comes back.

The number and arrangement of these outer plates, and the shape of the top, are used to identify barnacles. This can be done on the shore with a good hand lens (10×). The simplest way to decide which species you have is to look carefully at it and compare with good drawings and photographs.

Chthamalus montagui

Semibalanus balanoides



Fish J.D. and Fish S. A Student's Guide to the Seashore (2nd Edn) Cambridge, 1996

(a) Semibalanus balanoides
(b) Chthamalus stellatus
(c) Chthamalus montagui

Three British barnacle species; note that, in ***Chthamalus****, the central lines cross at right angles.*

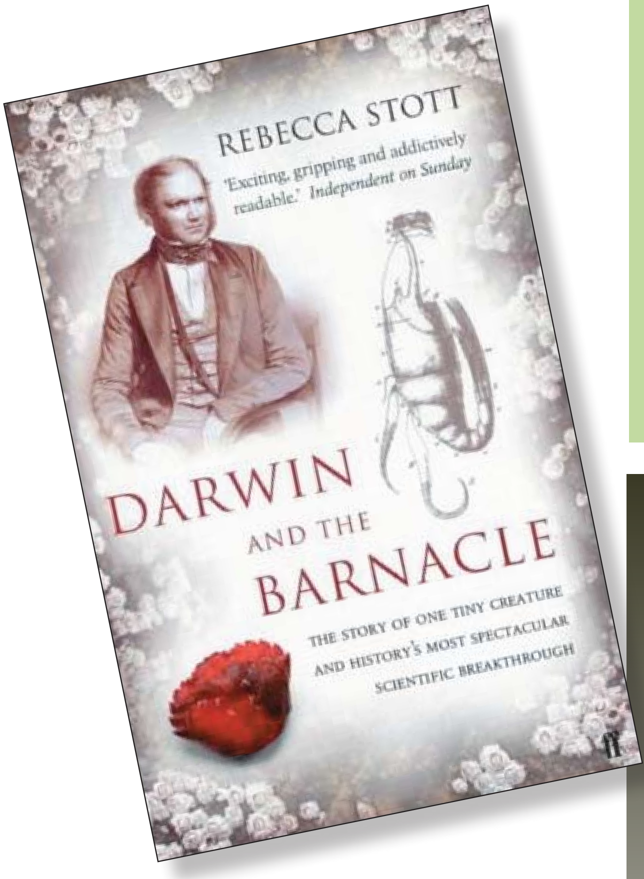
Box 2
Binomial names

All living things belong to a genus (humans are in the genus *Homo*) and within that, a particular species, humans are sapiens, so *Homo sapiens*. Both names are always printed in italics (or, when written, underlined), and the genus name must be capitalised, the species one lower case, as shown. Try to find out the binomial names of a few familiar animals and plants; this should be easy on the internet.

What barnacles can teach us

One fascinating fact about rocky shore species is that they are distributed in bands or zones on the shore and, as such, show very simple and easily understood patterns of distribution. Studies of patterns of distribution in relatively simple habitats like this have been very helpful in finding out the sorts of factors controlling why animals and plants live where they do. When oil spills have affected rocky beaches, knowledge of the biology and ecology of the species living there has proved useful in understanding how to best manage the spillage.

Because people have been interested in these fascinating animals for a long time, they are also now useful for scientists looking for climate change effects. A long set of data, collection starting in the 1950s, exists about barnacle distribution around British shores, and these are now being looked at again and compared with the present day pattern. There are many indications in the data that warming is taking place, for example the warm water species *Chthamalus montagui* is found in more places in Scotland than it used to be. The favouring of *Chthamalus* by the warmer seas has released it from competition with *Semibalanus*, which is therefore suffering. These studies show that, no matter how sophisticated our instrumentation gets, living things are still often the most sensitive way of finding out what is going on in the environment.



Charles Darwin was fascinated by barnacles. He spent eight years observing, dissecting and classifying them before he started his main work on the ***Origin of Species.***

Barnacle patterns

One of the best understood patterns found is that of the mid-shore barnacles, the two *Chthamalus* species and *Semibalanus balanoides*. Joseph Connell, working on the Scottish island of Cumbrae, surveyed the distribution of barnacle species, and from his observations came up with some hypotheses. He observed that *Chthamalus* occurs higher on the shore than *Semibalanus*, and suggested that it was stopped from living further down by competition with *Semibalanus*.

He tested this idea by taking rocks with *Chthamalus* from high on the shore and screwing them to rocks lower down, amongst the *Semibalanus*. Over the next year or so he observed what happened, removing any *Semibalanus* that came near the *Chthamalus* in some cases, leaving them in others. He found that, where *Semibalanus* were removed, the *Chthamalus* did perfectly well. Figure 1 shows one of his many graphs of this experiment.

Connell's studies were amongst the first where, instead of just observing animals and plants in nature, a scientist experimented on them where they lived. This is **experimental ecology**.

Figure 1
One of Joseph Connell's graphs, showing the effect on ***Chthamalus*** *barnacles when* ***Semibalanus*** *barnacles were removed from nearby.*

Look here!

Find out what factors (other than competition) Joseph Connell thought might be affecting where barnacles live; he talks about his famous paper here: **www.garfield.library.upenn.edu/classics1981/A1981LP44800001.pdf**

All the photographs in this article, plus many more, together with virtual tours of rock shores and other habitats can be found at: **www.britishecologicalsociety.org/education2/index.php?cat=17** and click on habitats/rocky shores or sand dunes. The work to produce these websites was funded by the British Ecological Society

British Ecological Society

Try This

Surveying barnacles

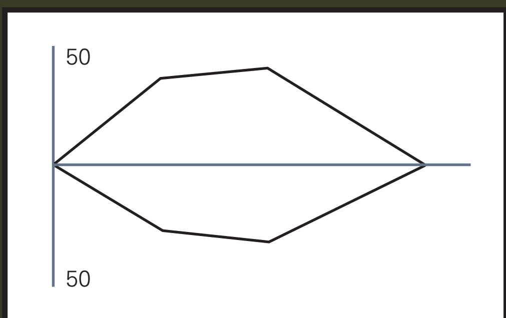
The rocks where the large photo was made.

Before visiting a rocky shore, try surveying the barnacles on the large photo (centre pages).

- Make a quadrat by cutting a 10 cm square hole in a sheet of card.
- Place your quadrat at different points along a vertical line on the photo, count the barnacles of each species in the quadrat and record your results in a suitable table.
- Plot a kite diagram (Box 3). Look for where *Chthamalus* is found and where *Semibalanus*. What pattern do you see?

Box 3
Drawing a kite diagram

Draw x- and y-axes as shown. The x-axis represents distance along the transect line. Mark the y-axis up to half the highest number of barnacles found on either side of the x-axis. Now plot half the result on each side, as shown. Finally, join up the points, again as shown. This is not easy to do with Excel, but there is software (called Field Studies) to do it; you may have this at school. The diagram represents results where no barnacles were found in the first quadrat, about 80 in the second, 90 in the third and none in the fourth.



Quadrats are placed at intervals along a line called a transect.

Comparing results

If you look into the research about the distribution of barnacles on a shore you will find lots of results from around the world. Try to look for British examples, or else you will be dealing with different species and you will be confused by this. Figure 2 shows a typical example, in this case from a rocky shore in Devon.

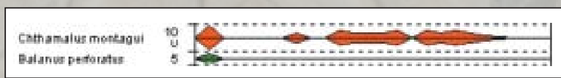


Figure 2 A kite diagram for two barnacle species, surveyed on a rocky shore in SW England.

What are its most important features of this graph? Do your results fit with it? Do you agree with Joseph Connell?

Gary Skinner teaches biology and is biology editor of CATALYST.

How the photograph was made

The image on the centre pages was made using a very high resolution digital camera (10 million pixels), taking 14 overlapping images down the rock wall. These were then 'stitched' together using special software (PhotoVista). This gives a huge image of nearly 100 Mb, and thus immense detail of the tiny animals seen.

David Sang

Silent flight

Key words
sound
noise
absorption
fuel efficiency

Aircraft noise has been reduced considerably over the last 50 years. However, people living near airports still suffer greatly from noise; there are protests when new airports, runways and extended flying hours are proposed. And yet most people want the opportunity to fly. The Silent Aircraft Initiative set out to design a much quieter aircraft. Here we describe the results of this project.

Taking the initiative

The Silent Aircraft Initiative is a collaboration between scientists and engineers at two universities, Cambridge (UK) and the Massachusetts Institute of Technology (USA). Professor Ann Dowling of Cambridge University explained its aim.

With air travel predicted to double in the next 20 years, the Silent Aircraft Initiative was launched to address the problem of reducing noise pollution. The result of our work would be a greener, quieter aircraft.

We have worked with many companies in the civil aviation industry to create the design we have today.

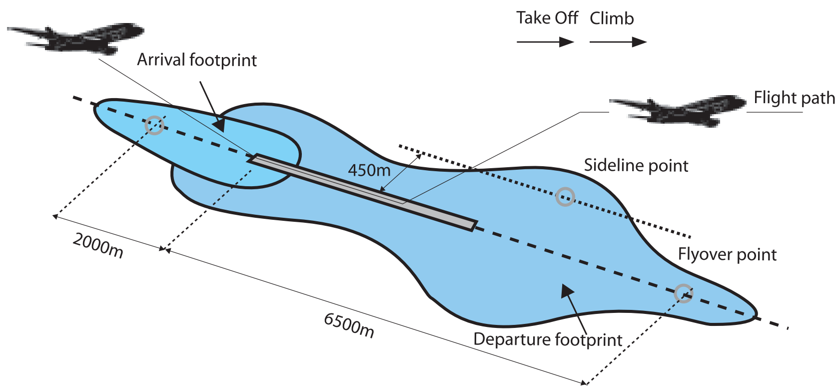
The target was to design an aircraft whose noise level would not exceed 63dB (decibels) outside the airport perimeter – that's 25 dB less than today's level, and comparable to everyday background noise in an urban environment. Because of the way the decibel scale works, the aim represented a reduction to just 0.3% of current figures (see Box 1).

The project has come up with a design, the SAX40, which is predicted to do this and which, perhaps surprisingly, has another green benefit – it consumes less fuel than conventional aircraft.

Noise annoys

Aircraft are noisy while both taking off and landing. The affected areas are called the arrival and departure footprints. Together, they cover about 10 km^2.

Noise is unwanted sound, and sound is vibrations in the air. How does an aircraft produce sound?



The target

215 passengers

cruising speed Mach 0.8 (230 m/s)

range 9000 km

noise level 63 dB at airport perimeter

Most modern aircraft use jet engines (see Box 2). There are two sources of noise from a jet engine:

- the fan at the front (these are the blades which you may have seen rotating at the front of the engine, and which suck air into it);
- the propulsive jet at the back which pushes out hot gases at high speed to propel the aircraft forwards.

These are the main contributors to aircraft noise on take-off. On landing, there is another source:

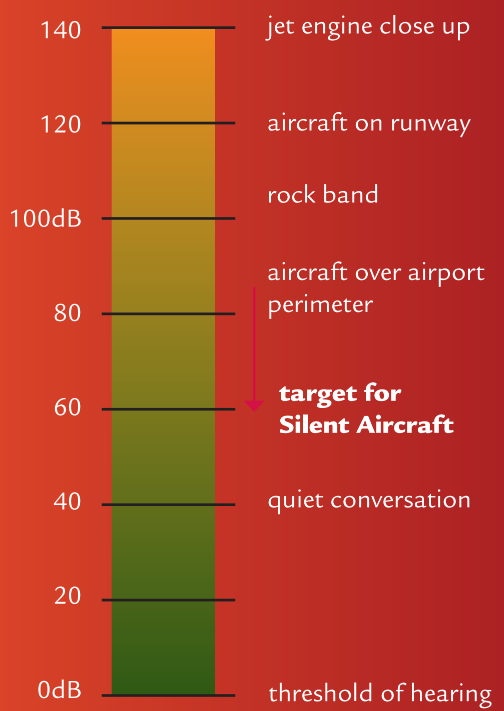
- the aircraft has its landing gear down and wing flaps extended to reduce speed; the flow of air around these structures is very turbulent and this produces more noise.

So the challenge of the Silent Aircraft Initiative was to tackle each of these sources of noise.

Box 1
Sound scales

The decibel scale of sound measurement takes account of the fact that our ears can hear sounds with a great range of loudnesses. The faintest sound we can hear is the zero of the scale, 0 dB. Each 10 dB step up the scale corresponds to an increase in energy by a factor of 10. So 50 dB is 10 times as energetic as 40 dB. This is called a logarithmic scale.

Our ears are very sensitive to sound energy – the threshold of hearing, 0 dB, corresponds to 10-12 joules of energy falling on 1 m2 each second, or less than 10-16 J on your eardrum.



Shaping up

The design of the new SAX40 aircraft is striking. It is a single flying wing, also known as a Blended-Wing-Body (BWB). This shape of airframe has several advantages.

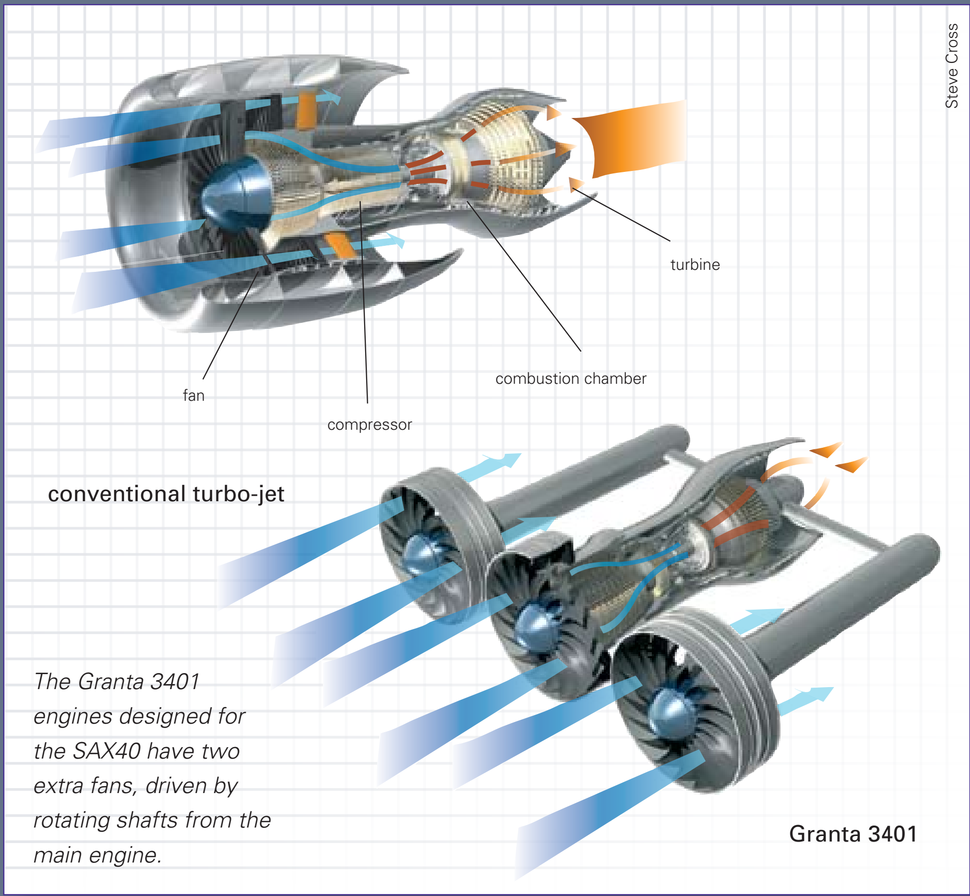
In a conventional aircraft, the wings provide the lift needed to take the aircraft off the ground. In a BWB design, the body is also shaped to give lift. This helps to reduce fuel consumption.

For noise reduction, the engines can be mounted on top of the airframe. Noise coming forward from the fans at the front of the engines is shielded from listeners on the ground; some is reflected upwards.

The design also allows the aircraft to approach the landing runway at a slower speed (less noise from the airframe), and at a steeper angle of descent (again, reducing the noise level at the airport perimeter).

The design has no flaps or slats to control its speed and lift; instead, the leading edges of the wings are designed to droop for landing. The ends of the wings are tipped up, reducing turbulent air flow.

	passenger miles per UK gallon
SAX-40	~149
Toyota Prius hybrid car	~144 with 2 people
Boeing 777	103-121
Boeing 707	55-70



The Granta 3401 engines designed for the SAX40 have two extra fans, driven by rotating shafts from the main engine.

Box 2
Jet engines

Jet engines provide the thrust needed to make an aircraft move forwards. They do this in two ways:

Fuel and air are burned together in the combustion chamber. The hot exhaust gases push out of the nozzle at the back, creating thrust.

On the way, they turn a turbine, which turns the fan at the front of the engine. This sucks air into the engine. Some of it is compressed into the combustion chamber, but some passes around the outside of the engine and out of the back, creating more thrust.

Engine design

The engines designed for the SAX40 are novel. There are three, and each has three fans driven by a central core (see Box 2). Engines like this would produce enormous amounts of drag if they were hung below the wings, but the shape fits well into the airframe so that there is little air resistance. Because the three fans are relatively small, they can spin more rapidly and this gives higher frequency noise which is more easily absorbed. Also, the engines suck in the air which is passing closely over the aircraft body – this air would normally create a wake and hence drag on the aircraft.

A conventional jet engine is noisy, but the source of the noise is actually several metres *behind* the engine, where air turbulence is greatest. This makes it very difficult to deal with. The engines of the SAX40 are different. They have long outlet ducts which are lined with acoustic absorbing materials. The engines also have variable-area exit nozzles. These can be constantly adjusted to give low noise on take-off and maximum fuel efficiency when the aircraft is cruising.

Will it ever fly?

The SAX40 is simply a design. The various engineering ideas which have been built into it have been tested using computer software, and simulations show that the desired reduction in noise can be achieved. They also show that the aircraft will be more fuel-efficient than current models, achieving 149 passenger-miles per gallon of fuel (comparable to today's best cars).

However, technological challenges remain. For example, are there materials strong enough to build the aircraft? Ann Dowling explains the tasks that remain:

The SAX40 is very much a work in progress. Composite structures are increasingly used in 'tube-and-wing' aircraft, so it is feasible that strong enough composites will exist in the future.

Several PhD students from the team at Cambridge are still working on details of the design, and we are meeting NASA soon to discuss the next stage.

The target is a quieter, greener passenger aircraft by 2030. Watch this (aero)space.

David Sang is an editor of CATALYST. *Thanks to Prof. Ann Dowling of Cambridge University for help with this article.*

Look here!

The Silent Aircraft Initiative is at **www.silentaircraft.org**

Greener by Design, a sustainable aviation group: **www.greenerbydesign.org.uk**

More about how jet engines work: **www.rolls-royce.com/education/schools/how_things_work**

Jeff Keenlyside

Applying the science

Kirklees Council covers a large area of West Yorkshire, including two major towns, Huddersfield and Dewsbury.

Jeff Keenlyside works as an Environment Officer for Kirklees Council in West Yorkshire. Here he describes the part that local councils can play in tackling problems in the environment.

Most scientists concerned with the environment accept the science of climate change and that it will have a serious impact on our lives. However, that scientific understanding is wasted if it is not applied in our everyday lives. Local authorities (councils) are often in the front line, applying the science and making it work to benefit the public.

Reducing carbon emissions

Kirklees Council has been at the forefront in demonstrating the use of renewable energy technology. In order to help reduce carbon emissions it has pioneered the installation of photovoltaic cells and wind turbines to generate electricity on municipal buildings. Local woodlands are harvested to feed woodfuel boilers to reduce carbon emissions; at the same time, this improves woodland habitats for wildlife.

However, the emission savings made by using renewables are minor in the context of what we need to do. This is acknowledged in the national debate about how we move away from fossil fuels to alternative energy sources such as wind, wave and nuclear power. This debate ignores the gross inefficiency of our national housing stock. A large proportion of houses are poorly insulated so that much of the energy used to heat them is wasted.

Within Kirklees a decision has been taken to fund cavity wall and loft insulation for all homes within the district. The principle here is to apply technology appropriately and cost-effectively to deal with energy inefficiency and reduce the demand for energy. This is a much more sustainable approach.

The council also aims to ensure that new houses and buildings are built to the highest standards of energy efficiency and have built in renewable energy installations, where possible, over and above that required by central government. This will help to minimise the increase in carbon emissions and air pollution.

Local councils and sustainable lifestyles

We all have a personal responsibility to prevent environmental damage in our everyday lives. For example, it is better to walk or cycle a couple of miles to school or work than to travel by car. However, it isn't always easy for us to make the right environmental choices.

Local authorities can make a big difference here. For example, if we have traffic-free, safe cycle routes we are more likely to cycle than drive a car to get to local facilities. It is councils which play a leading role in providing such facilities. They are also involved in the wider planning issues which enable our towns, cities and countryside to be developed in more sustainable ways.

In Kirklees, we try to ensure that new developments are located where they will reduce the need to travel to work and to access other facilities, like shops and sports centres. This will help reduce carbon emissions and cut air pollution.

We are also developing a district wide Green Network of greenways and green spaces to provide safe and attractive cycling routes. This will make it easier for people to live healthier and lower-impact lifestyle. There's another benefit: a connected network of green spaces provides more opportunities for wildlife to move around and adapt to changing climatic conditions.

Solar PV panels and wind turbines help supply electricity to council buildings (Civic Centre, Huddersfield).

Houses with both solar water heating and PV electric panels at Primrose Hill Solar Village, Huddersfield. This development of 121 homes was part of a regeneration scheme, reducing fuel costs for tenants as well as greenhouse gas emissions. Some of the houses were reburbished, resulting in significant savings of emissions when compared to new buildings.

Land use and the impact of climate change

Climate change may result in more extreme conditions – hotter summers and colder winters, more droughts and floods. Scientific understanding has a part to play in tackling this. Take changing patterns of rainfall, for example.

In the past, most land has been considered for single use such as agriculture, housing, industry, etc. It is only recently that we have realised the environmental implications of this. For example, the extensive hard surfacing of urban areas leads to rapid run-off of rainfall. This increases the frequency and severity of flooding and reduces the amount of water stored underground. The lack of stored water then reduces river flows in drought conditions and results in less water being available for our own use.

Now we are trying to ensure that new development does not add to the rapid run-off of rainwater. We are exploring the possibility of storing water in wetlands – low-lying areas along the river valleys. This will help to reduce the incidence of flooding, stop rivers drying up in the summer and reduce the impact of water pollution.

Wetland areas like this should not be drained – they provide valuable protection against flooding.

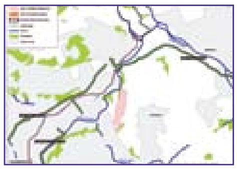
Working for the council

Increasingly, councils need to draw on people with a greater understanding of the science behind the issues and who can apply scientific principles to enable us to live a more sustainable lifestyle. I am one of those people.

I work in Kirklees Council's Environment Unit.. The Unit's role is to lead on delivering the council's Green Ambition. Our aim is to significantly reduce environmental impacts within the district, with a focus on carbon emissions and the more sustainable use of land.

I have an Environmental Science degree from Bradford University and my main work area is in the field of biodiversity. Others in the Unit have responsibilities which include: developing a low carbon planning system; supporting renewable energy projects (including wood fuel and small scale hydro schemes); managing the home energy efficiency work; monitoring the Council's involvement in the Emissions Trading Scheme; sustainability appraisals; and a whole range of work relating to greening the Council's business and operations.

It is important to be clear about what can be achieved within a local authority's remit, however, as its powers are limited and dictated by central government. Even so, the progress made at Kirklees and other leading councils is pioneering a way forward for others to follow and, hopefully, build on.



GIS (Geographical Information System) mapping tools build up layers of information so that we can see how they relate to each other.

Jeff at work

Alex
Lam

Diabetes in young people

The search for genetic links

Juvenile diabetes is a genetic disease, but the causes are still not entirely known because of its complexity. This article describes what is being done to improve our understanding of the genetics behind this disease, and the range of activities in medical research.

Going to work with diabetes?

Jason Cooper has been diabetic since he was a teenager. Each morning after breakfast, he injects himself with a dose of insulin, kisses his wife Irene and daughter Maddi goodbye, then hops on his bicycle to Addenbrooke's Hospital in Cambridge. But he is not about to see a doctor regarding his diabetes. He works there everyday at the medical genetics department in the University of Cambridge, and his work is about understanding the genetics of juvenile diabetes.

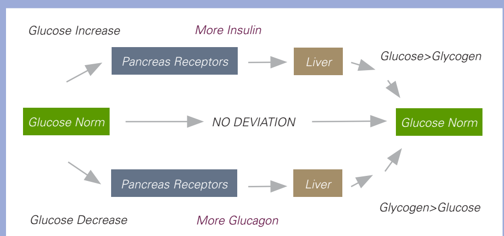
What is juvenile diabetes?

Juvenile diabetes, also known as Type 1 diabetes, affects over 200 000 people in the UK. People who suffer from this disease have an inadequate supply of insulin, a hormone that is essential for maintaining blood glucose at a constant level – see Box 1. In diabetics, the insulin-producing cells in their pancreas are destroyed by their body's own immune system (which normally defends against infections). As the disease develops, less and less insulin is produced, blood glucose levels rise and, without treatment, the patient may suffer from a hyperglycaemic (high blood sugar) reaction which can be life-threatening. This can be for a whole host of reasons, including damage, over a long time, to the heart, kidneys and blood vessels. In the short term, a condition known as Diabetic Ketoacidosis may develop; this causes the blood pH to become too low for the proper functioning of enzymes. Finally, there may be osmotic problems which lead to the production of a lot of urine, which can lead to dehydration and, eventually, coma.

Jason Cooper

Box 1
How insulin helps to control blood sugar?

At some time after a meal (after some digestion has happened), the level of sugar in the blood starts to rise. This is detected by cells in the pancreas, which respond by secreting the hormone insulin. This is carried all over the body in the blood (as are all hormones) but it has its main effect on cells in the liver. These are stimulated to take up glucose from the blood and make it into the polysaccharide glycogen, and so blood sugar falls back to normal. Later, when blood sugar starts to fall, the pancreas is stimulated to secrete another hormone, glucagon, which has more or less the reverse effect of insulin, raising the blood sugar.

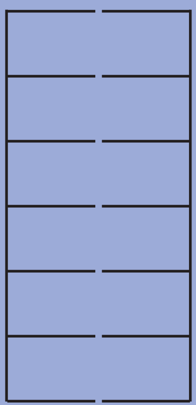


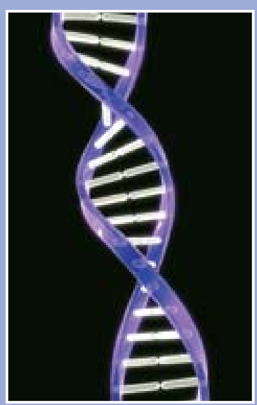
Key words
Genetic disease
Diabetes
Allele
Gene therapy

After diagnosis, insulin replacement is usually given by injection. Good control of blood glucose levels is critical in minimising long term complications and improving long term survival. Although most patients do not have relatives in their immediate families who also suffer from the disease, juvenile diabetes is a genetic disease as scientists have identified that certain DNA sequence variations (variations in the sequence of bases along the DNA molecule) increase the risk of developing juvenile diabetes.

Box 2
DNA Base Sequences

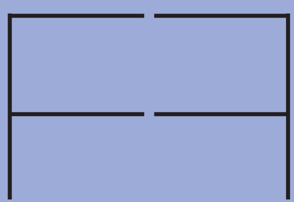
A DNA molecule consists of two strands (the Double Helix), each one is made up of many molecules called nucleotides joined together in a chain, like half a ladder. With the other (matching or complementary) chain the whole structure resembles a ladder which is then twisted into a spiral (helix).





James Steid/Bigstockphoto

Each half ladder, as mentioned, is made of nucleotides joined together. The important bit of the nucleotide is the BASE sticking out from it. These bases join with those on the other half ladder, to make the rung:



In addition, one of the half ladders carries a sequence of bases (the base sequence) which carries the genetic information. It is these sequnc3es which make us who or what we are, and which vary to cause differences, including diseases, such as juvenile diabetes.

How are the risk sequence variations identified?

It is now known that over 99% of the approximately three billion bases of the human genome are identical amongst individuals. Interestingly, a small proportion of the remaining DNA could be important for explaining what makes people different - for example, why people are different in height and why some people may be more susceptible to certain genetic diseases than others. Scientists such as Jason and his colleagues survey DNA sequence variations on every chromosome from thousands of people with and without the disease. This provides clues to scientists in identifying which DNA sequence variations are involved in the disease process. The basic idea of the strategy is that if there is a version of a sequence (called an allele) that contributes to increasing risk of the disease, this risk-allele should be observed more frequently in patients than in the unaffected subjects – see Figure 1.

See Box 3 on page 21 if you are uncertain of some of the genetics terms used in this article.

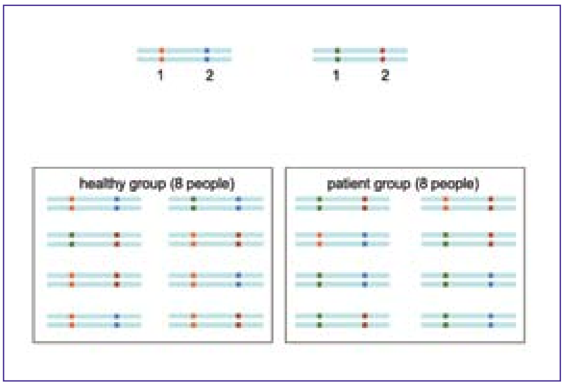


Figure 1 *Consider two sites with sequence variations (1 and 2) in the genome. There are two alleles (red or green) for site 1, and two alleles (blue or brown) for site 2.*

When we inspect the genomes of healthy people and patients, it appears that the green allele in site 1 is more frequently found amongst the patients. The blue and brown alleles of site 2 appear evenly spread across the healthy and disease groups. This suggests that the green allele of site 1 is more likely to be a risk-allele than the other alleles observed.

By contrast, observing the different alleles of a disease-neutral sequence variation would be equally likely in patients and in unaffected subjects. "The huge challenge in detecting the DNA sequence variations with an increased risk of juvenile diabetes and many other complex diseases is that, unlike single gene disorders (such as Cystic Fibrosis), the disease is driven by multiple sequence variations located throughout the human genome, as well as by the environment," Jason explained.

"As the majority of disease-associated sequence variations are expected to make only a small contribution towards the risk of the disease, to detect them we need to conduct big studies with large numbers of patients and unaffected subjects."

	Single Gene Disorders	Multi-factorial Complex Diseases
Examples	Cystic Fibrosis, Huntington's Disease, Haemophilia	Juvenile Diabetes, Rheumatoid Arthritis, Multiple Sclerosis
Incidence	Tend to be rare	More common, incidence often varies between populations / ethnic backgrounds
Disease inheritance	An individual who inherits a disease-allele either develops the disease or becomes a carrier (if the disease is a recessive trait)	Inheriting one or more risk-alleles could increase the risk of the individual developing the disease
Genetic location	Disease-allele(s) are usually found within a single gene (for example: the CFTR gene for Cystic Fibrosis)	Risk-alleles can spread over multiple locations in the genome and are sometimes found on a stretch of DNA outside genes
Environmental influence	Generally not influenced by external factors	Genetic risk of disease is greatly modified by the environment, for example: smoking, diet and infections
Disease mechanism	Disease-allele introduces changes in gene sequence which leads to disruption of the protein's or enzyme's normal functions	It is not entirely clear but the changes introduced by risk-alleles are likely to be very subtle and complicated

***Table 1** compares single gene disorders and complex genetic diseases*

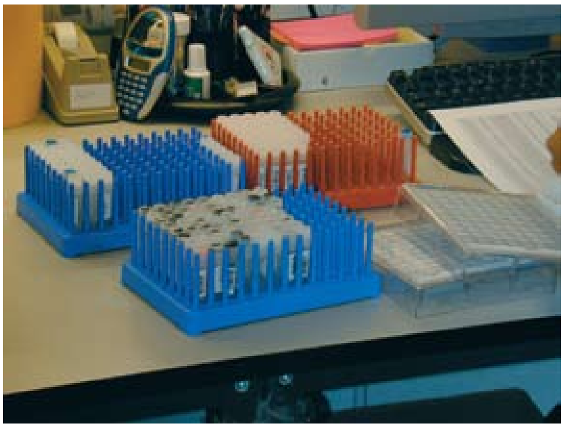
Researchers in action

A statistician uses software to look for patterns in the data. He or she is also involved in designing research projects to ensure that the data produced is useful.

Jason works as a statistician at the Diabetes and Inflammation Laboratory (DIL) in the University of Cambridge with over 50 colleagues. "We have many people from a wide range of disciplines working here in the DIL," said Jason. The laboratory has connections with many hospital doctors and nurses for recruiting patients and healthy volunteers from all over the UK and many parts of Europe. Once the blood or mouth swab samples have arrived at the laboratory, there are molecular biologists who extract and process the DNA. They do so to ensure the high quality and continual supply of DNA for experiments.

DNA samples are stored in liquid nitrogen at -196°C for future use.

Robotic machines are run by the geneticists to record hundreds of thousands of DNA sequence variations simultaneously. This technology has only been available in recent years and has revolutionised the research by empowering the scientists to survey more than 500,000 sequence variations very rapidly. The geneticists also work with the statisticians because many detection methods are based on mathematical models. As the data which the DIL is dealing with are large and complex, sophisticated computer systems are necessary to manage the records carefully and perform the analyses efficiently. Vincent Everett is the computer systems manager of the laboratory. "There are about ten I.T. professionals working here and we do a lot of computer related tasks such as designing a barcode catalogue system for the DNA samples and creating database software for integrating the information we generate at different stages of our research. Besides biology, skills in mathematics and computer science can also be readily applicable in medical research."



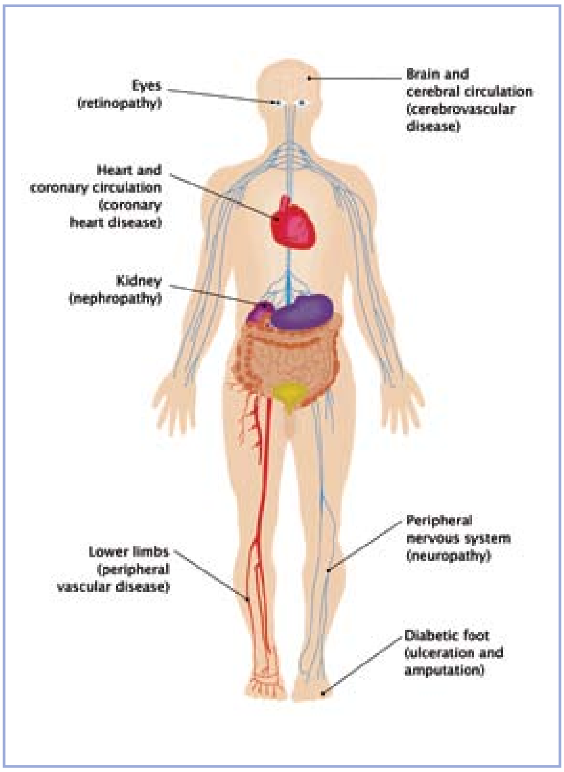
Each plastic tube contains an individual DNA sample.

What benefits will this work bring?

Laboratories such as the DIL hope to understand how the disease develops and, ultimately, to help prevent the disease. Since 2000, when the DIL was first established, they have found several DNA sequence variations, identifying regions of the human genome that influence juvenile diabetes susceptibility in Western European populations. Once a sequence variation has been identified, there are still many additional experiments required for scientists to understand how the sequence variation would lead to the destruction of the insulin-producing cells. For example, the changes caused by the DNA sequence variation to protein (e.g. enzyme) function and abundance, and subsequently to the immune system, are studied using biochemistry and cell biology techniques in the DIL.

When scientists have a better understanding of which DNA sequence variations are involved and how they are involved in juvenile diabetes, there will be more opportunities for finding new treatments, such as new drugs. Another future possibility is gene therapy whereby the genes containing risk alleles are replaced by protective alleles. For this purpose, the identification of the genetic factors involved in the disease is essential.

A further prospect comes from the observation that some patients can respond to different drugs with varying degrees of success. In the future doctors might be able to prescribe treatments to individuals according to their genetic background and environmental exposure. The successes of the possibilities mentioned above will depend on the advances in science and the dedication of the scientists for many more years. Indeed, defeating a disease like juvenile diabetes is a very long battle. Nevertheless, a great deal of progress has been achieved by the DIL and other international efforts in recent years. It is hoped that having a cure for the juvenile diabetes sufferers like Jason will one day be a reality.



Diabetes Atlas, International Diabetes Federation

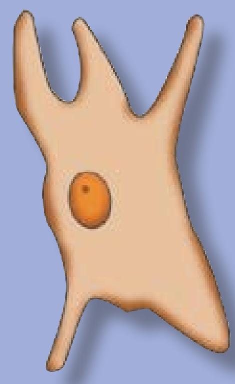
The major diabetic complictions

Alex Lam is currently studying a PhD degree in genetics at the University of Edinburgh. He worked in the DIL at the University of Cambridge as a computer associate from 2001 to 2005.

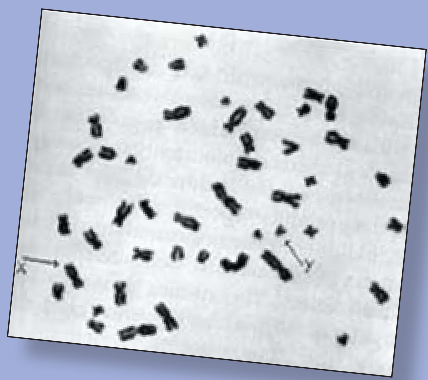
Look here!

The DIL is supported by the charities Juvenile Diabetes Research Foundation (JDRF) and the Wellcome Trust. Information on juvenile diabetes can be found on the webpage of JDRF and Diabetes UK.
www.jdrf.org
www.diabetes.org.uk
www-gene.cimr.cam.ac.uk/todd/

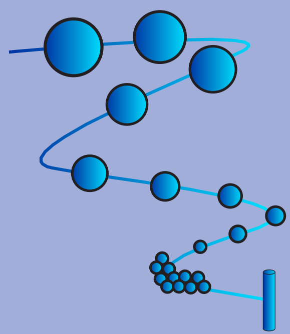
Box 3 Basic genetics



The cell nucleus contains all the genes of that organism. In a human, all the genes of that person, the GENOME

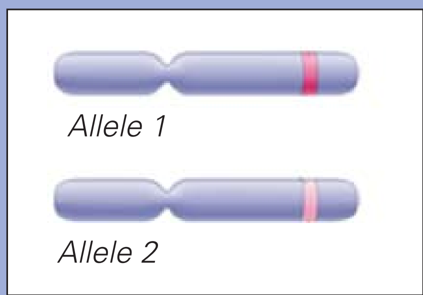


These genes are packaged on structures called chromosomes, 46 in humans. Like a string of beads on a wire, they are coiled up into the chromasome.



Each gene may exist in many forms, each one is called an allete, and this variation in which allele of each gene we have is at the heart of what makes us all different.

Genes (and therefore alleles) are made of DNA, and the information they carry is stored in the sequence of bases.

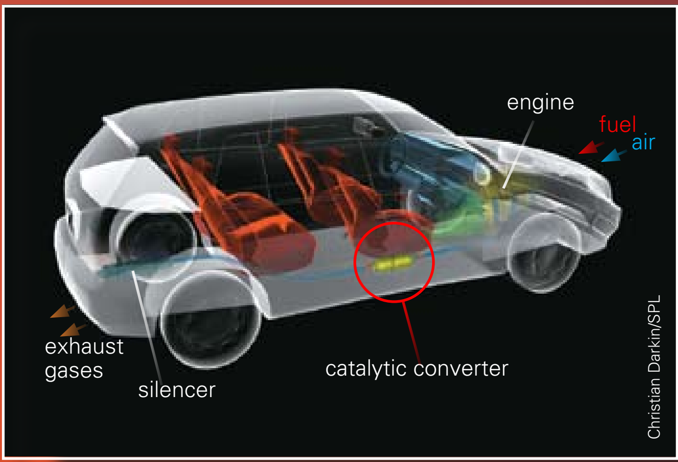


Diabetes Atlas, International Diabetes Federation

Published incidence rates of type 1 diabetes in children (0-14 age range) (cases per 100,000 population per year)

Catalytic converter

A *catalytic converter* is part of a vehicle's exhaust system. It removes harmful substances from the exhaust gases.



Reactions in the engine:

- Hydrocarbon fuel burns with oxygen: hydrocarbon + oxygen → carbon monoxide + carbon dioxide + water
- Nitrogen from the air is also oxidised: nitrogen + oxygen → nitrogen oxides (NO_x)

Exhaust gases contribute to urban smog. Carbon monoxide is poisonous. Nitrogen oxides cause acid rain.

Reactions in the converter:

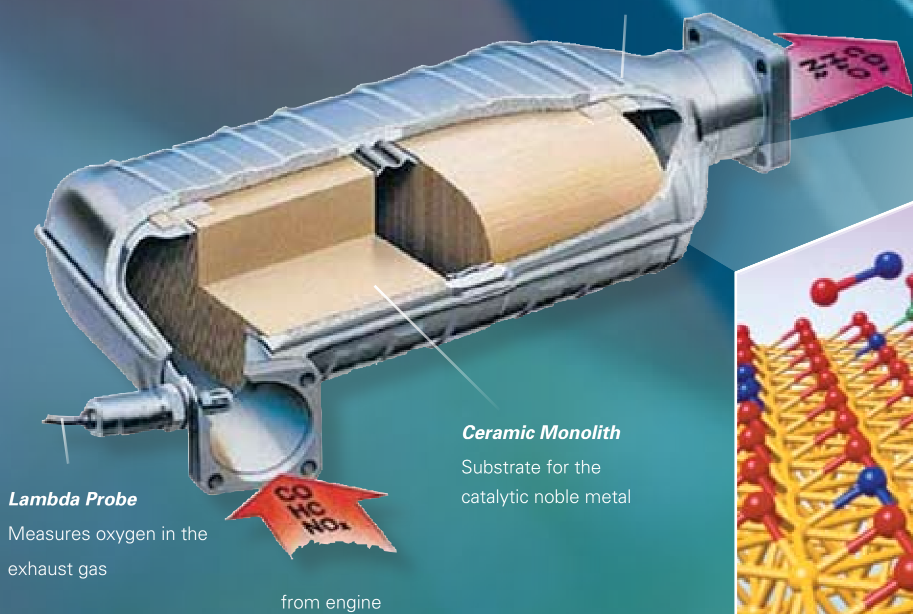
- Unburned hydrocarbons are oxidised: hydrocarbon + oxygen → carbon dioxide + water
- Carbon monoxide is oxidised: carbon monoxide + oxygen → carbon dioxide
- Nitrogen oxides are reduced: nitrogen oxide → nitrogen + oxygen

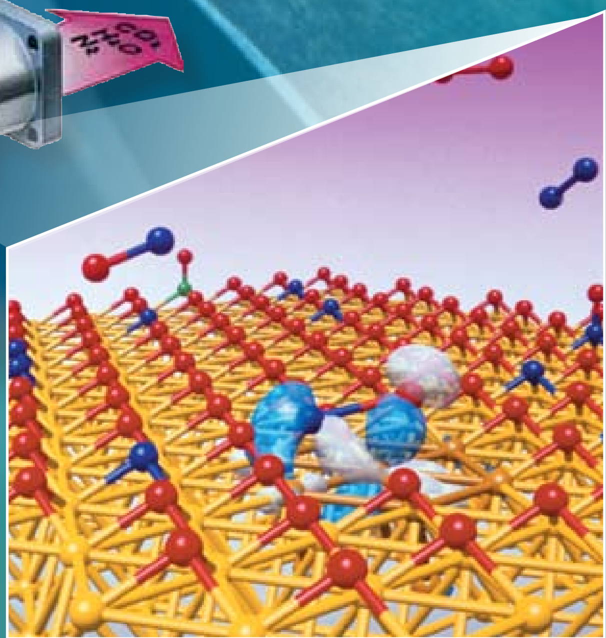
What's inside?

Inside the catalytic converter, hot exhaust gases and oxygen pass over unreactive metals (platinum, palladium, rhodium). These metals are coated on a ceramic or steel honeycomb, to give a large surface area. They catalyse the reactions which reduce the toxicity of the exhaust gases.

On the surface

The chemical reactions in the catalytic converter take place on the surface of the precious metal catalysts. A large surface area and a high temperature speed up the reactions.





Background:Nigel Yeo/Bigstockphoto