Catalyst

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Face of the Sun

What sunspots can tell us

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Catalyst

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The front cover shows a single sunspot (see the article on pages 4-5). This is a computer-generated model of a sunspot. Its diameter is about 50 000 km, four times that of the Earth. Image ©UCAR, courtesy Matthias Rempel, NCAR

Contents

World-changing science

Bacteria: they're good, they're bad, they're everywhere. In this issue of CATALYST, we look at two ways in which we can use bacteria.

- On pages 6-8, Claire Goncet and Sandra Messenger of Edinburgh Napier University describe how we can use bacteria to make biofuels from waste. Napier University hit the headlines recently with their method for making biodiesel from the waste products of whisky distilling.
- And on pages 9-12, Suzy Moody of Swansea University describes her work on the antibiotic-producing bacterium Streptomyces. She has been investigating the role of antibiotics in the warfare between different species of bacteria.

All that and computer games, iron in the oceans, and spots on the Sun.

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Catherine Lichten

Key words
climate change
carbon dioxide
phytoplankton
hypothesis

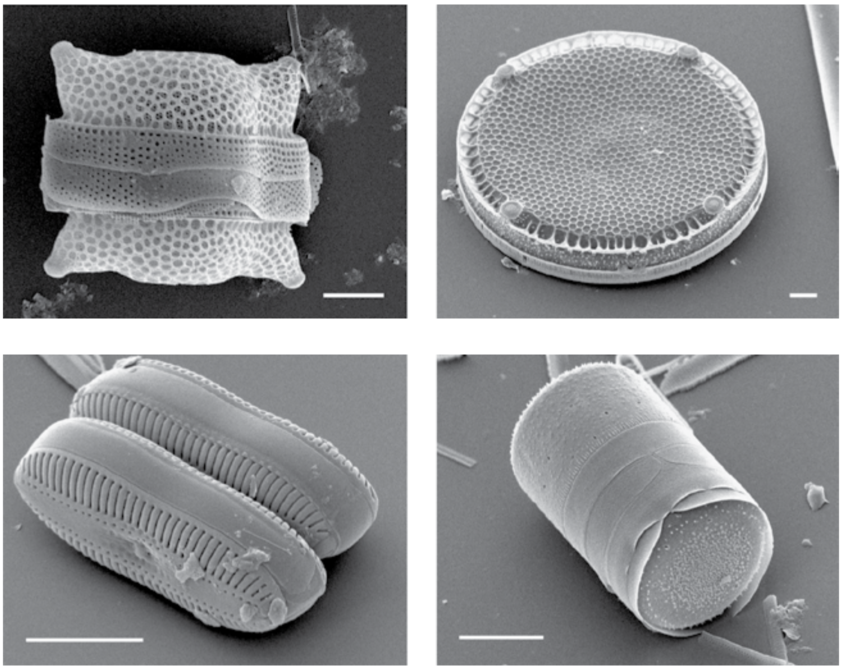
Ocean Iron Fertilization

Capturing carbon to slow climate change

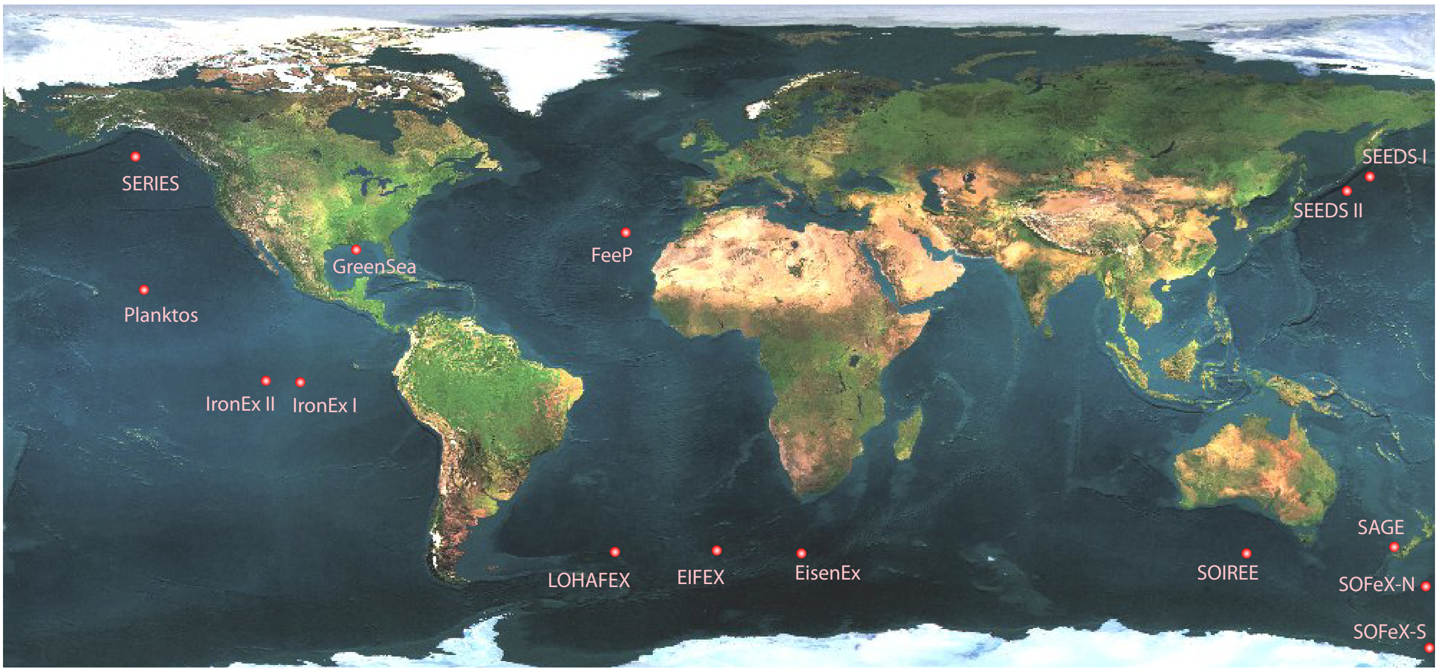
Pouring iron into the oceans. Is this a valuable new way to deal with climate change or reckless tampering with the sea? Catherine Lichten investigates.

The year is 2200. Amidst gusting winds, churning waves, and across vast expanses of the stormy Southern Ocean, ships carrying teams of scientists and engineers stake out their territory, preparing to release hundreds of tons of iron dust into the sea in an effort to save the planet. Could this be the start of the next Armageddon sci-fi flick, or a clever, realistic (and economically lucrative) solution to managing global warming?

This activity is called ocean iron fertilization (OIF). The idea behind it is to slow climate change by using a process that already occurs naturally. Nature has a way to draw carbon dioxide (CO_2) from the air down into the ocean. If we could speed that process up, we might be able to prevent the climate change that results from CO_2 building up in the atmosphere, or so the thinking goes. But many worry that fiddling with the Earth's natural processes got us into the climate change mess and won't get us out of it.



Electron microscope images of the shells of diatoms, one of the most common types of phytoplankton. Size bars are 10 μm. Image courtesy of Mary Ann Tiffany, San Diego State University, published in Bradbury J: Nature's Nanotechnologists: Unveiling the Secrets of Diatoms: PLoS Biol 2004.

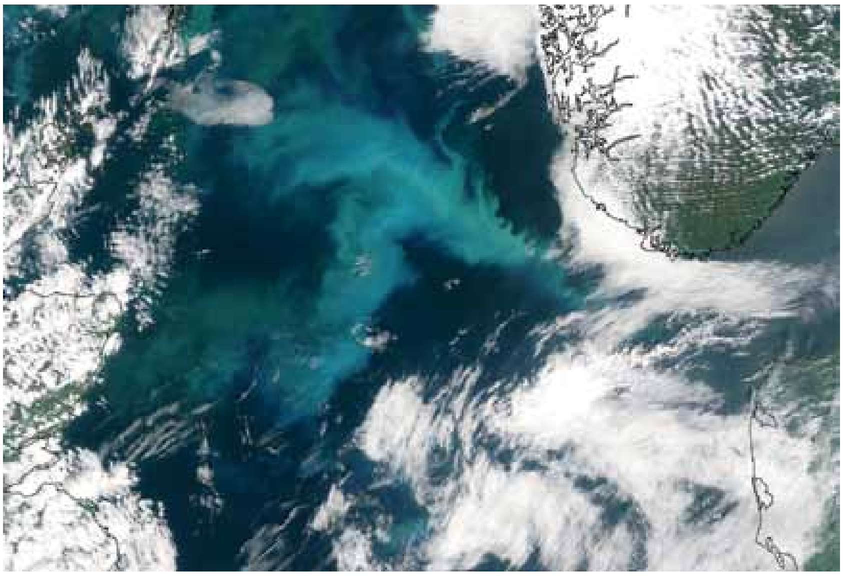


Locations of OIF experiments also showing commercial demonstrations by the companies Planktos and GreenSea Ventures

Due to the scarcity of scientific data about the effectiveness and long-term consequences of the method, a debate rages among environmentalists, scientists, and private companies whether dumping iron into international waters would reverse global warming or cause irreparable damage to the Earth's ecosystem.

How would it work?

The existing natural process for transferring carbon from the air to the ocean centres on phytoplankton, the organisms which form the foundation of the marine food web. These organisms carry out photosynthesis, taking up CO_2 from the atmosphere. When they die and sink to deeper water, the carbon within them enters long-term storage that could last for decades or centuries. Having more phytoplankton around should mean more photosynthesis would happen, which would mean more carbon getting taken from the atmosphere and brought down for deep-ocean storage.



Phytoplankton bloom in the North Sea. The UK is on the left.

How can we increase the activity of phytoplankton? To answer this question, we have to look back twenty years at work done by oceanographer John Martin. At the time, scientists were puzzled about so-called 'desolate zones' in the ocean. These were areas that were high in many nutrients but were home to surprisingly little marine life.

It turned out that the zones were rich in many nutrients except iron. Martin hypothesized that iron was the limiting factor keeping phytoplankton from growing in the desolate zones. He thought that if you could add iron to desolate zones, phytoplankton would start growing like crazy.

Martin also hypothesized that this increase in the phytoplankton concentration would reduce the levels of atmospheric carbon. He famously proclaimed, "Give me half of a tanker of iron, and I'll give you the next ice age."

In short, to get more phytoplankton, you'd dump iron into the ocean. The idea is irresistibly simple: add iron, get plankton, stop climate change. But does it work?

The proof is in the (iron-fertilized) pudding

Since Martin described his 'iron hypothesis', research groups around the world have completed 13 fertilization experiments. They have monitored the effects of adding hundreds to thousands of kilograms of iron sulfate to the oceans to patches ranging in size from 40 to 300 square kilometres (see figure). Iron sulfate is the compound of choice because it dissolves in seawater and it's an industrial by-product, so it's not too difficult to obtain.

Their results validated the first part of Martin's hypothesis. Increasing the iron concentration in the fertilized areas created phytoplankton blooms visible by satellite. This phytoplankton growth explosion confirmed that it was a lack of iron that had previously kept plankton numbers low.

The second part of the hypothesis, that increasing the phytoplankton population would help transfer CO_2 out of the atmosphere and into long-term storage, has yet to be proven true. So far, most experiments have been focused on simply testing the first part, and it is difficult to determine whether the carbon taken up by iron-induced blooms goes into long-term storage.

A recipe for disaster?

Pressure to address climate change is building all the time, but scientists have yet to discover whether or not OIF is an effective, practical solution. In a 2008 article in the journal *Science*, written by 16 iron fertilization researchers, oceanographer Ken Buesseler explains, "Although [our] experiments greatly improved our understanding of the role of iron in regulating ocean ecosystems and carbon dynamics, they were not designed to characterize OIF as a carbon mitigation strategy." Still, entrepreneurs and economics experts have taken an interest in OIF. And scientists and environmentalists have begun to worry that politicians and businesses will push to start using it before all the facts are in.

Of major concern is the fact that no one knows what the long-term effects of OIF would be. The marine ecosystem is a complex network of chemical, physical, and biological processes. Disturbing it would undoubtedly have effects beyond the what is intended, but those are hard to predict. Potential side-effects include disrupting the ecosystem, affecting organisms all the way from bacteria up to whales, making the ocean more acidic, reducing the levels of dissolved oxygen that fish breathe, and even increasing levels of other greenhouse gases in the atmosphere.

A natural laboratory: Volcanoes can act as natural sources for iron fertilization as volcanic ash is rich in iron, and researchers have noticed that atmospheric CO_2 levels dip following major eruptions. The photo shows Iceland's Eyafjallajökull erupting in March, 2010. Scientists from the National Oceanography Centre in Southampton made two visits to the North Atlantic in the summer of 2010 to explore the effects of the ash from Eyafjallajökull.

Is it legal?

Although existing regulations could apply to OIF, the laws are ambiguous because OIF is regulated by more than one UN convention. As of a few years ago, none of those addressed OIF directly, but additional legislation is in the works.

Two relevant conventions restrict pollution and ban the dumping of waste. They allow OIF for 'legitimate scientific research' but could restrict the large-scale OIF that businesses might carry out. The UN Convention on the Law of the Seas governs general conduct on the high seas. Its general assembly has not passed any specific resolutions on OIF, but did support calls for further OIF research and bans on large-scale OIF. Yet another convention bans large-scale fertilization and applies to OIF insofar as large-scale fertilization could impact the marine food web.

A 'United Nations convention' is an agreement between nations; nations agree to abide by it, but it may not have the force of law.

On the whole, regulation remains incomplete, but the wheels of policy-making have been set in motion. Through OIF's rapid evolution from a purely scientific pursuit to an attractive, prospective quick-fix for climate change, it has become clear that specific legislation is required.

The Polarstern is a German research vessel which has taken part in iron-seeding experiments.

The bottom line

As the reality of climate change sets in, we face the dilemma that, as much as we want to prevent climate change, we are reluctant to reduce our energy consumption and greenhouse gas emissions. In light of this, possible solutions that don't require us changing our behaviour have an irresistible appeal.

OIF remains controversial because no one knows what its impacts will be, but we cannot truly resolve the controversy without actually carrying it out. Instead of that, we must use the evidence available to predict whether it would be a safe and effective activity. There is little doubt that climate change is upon us, but no amount of panic over global warming or economic potential will change the risks and benefits. Legislation must reflect the available evidence so that the lure of profits and the urge to find a quick fix for climate change cannot overshadow the facts about its side-effects and effectiveness.

***Science* is a prestigious scientific journal, published in the USA.**

Catherine Lichten is studying for a PhD in Biology at Edinburgh University. A version of this article appeared in EUSci, the Edinburgh University Science Magazine, April 2010.

David Sang

Solar surface

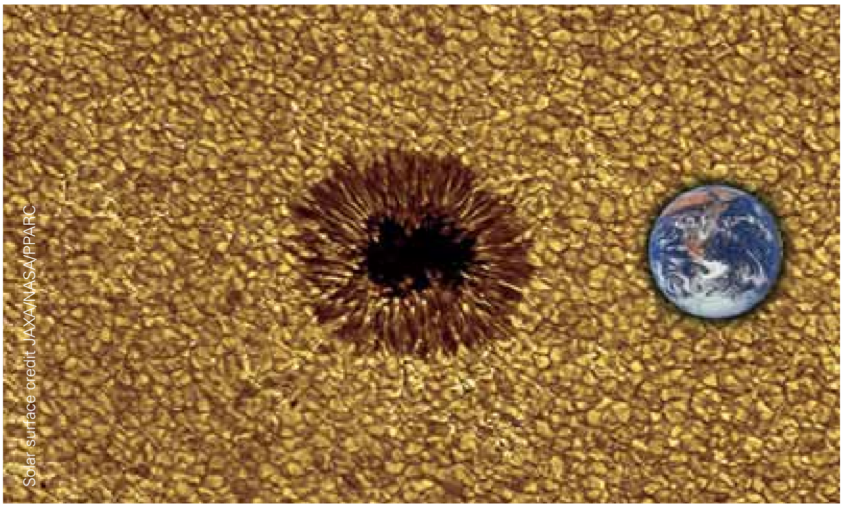
Learning from sunspots

The surface of the Sun – a sunspot as seen by the Japanese Hinode solar observatory.

5800 K is approximately 5500°C. Sunspot temperatures are between 3000 K and 4500 K.

How do you think of the Sun? As a searingly hot ball of glowing gas? That's right, but there is more to it than that. For over two millennia, people have observed darker patches on the Sun's bright surface. These are sunspots.

The Sun's surface is hot, about 5800 K. Sunspots look dark because they are a thousand degrees or so cooler than their surroundings – that means they are still pretty hot. They are regions of strong magnetic activity. The picture at the top of this page shows gases leaping upwards, following the lines of the Sun's magnetic field.



A single sunspot, photographed by the Hinode spacecraft. The granular surface of the Sun arises from convection currents; hot gases well up from below (lighter areas) and cooler gases sink back down (darker areas). The Earth is superimposed for scale.

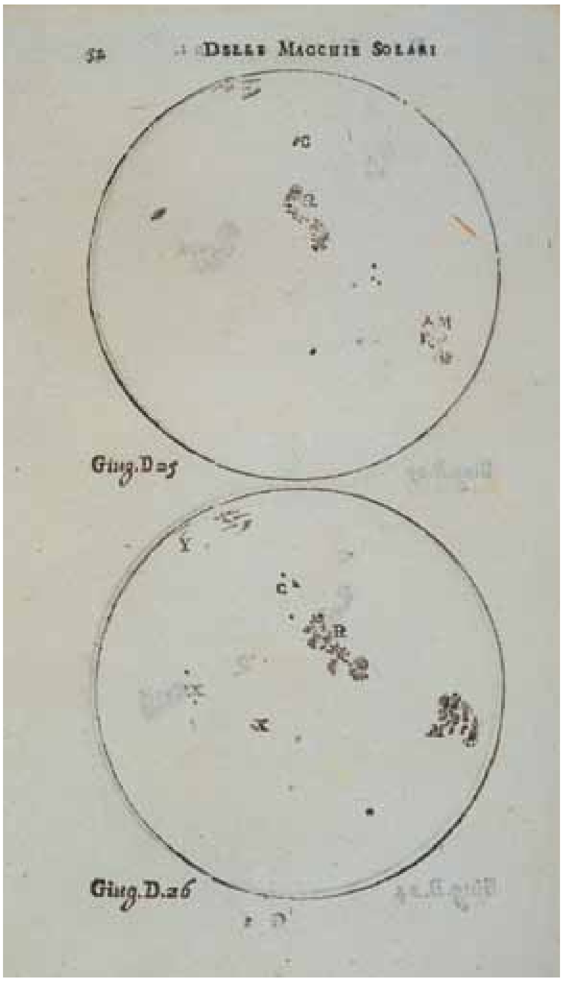
Early observations

Sunspots were recorded by ancient Chinese observers many centuries before they were noted in the west. It's thought that this may have been for a cultural reason. In the west, it was considered that the Sun was a heavenly body and thus must be perfect. Any defects on its surface would be inconsistent with the idea of its perfection.

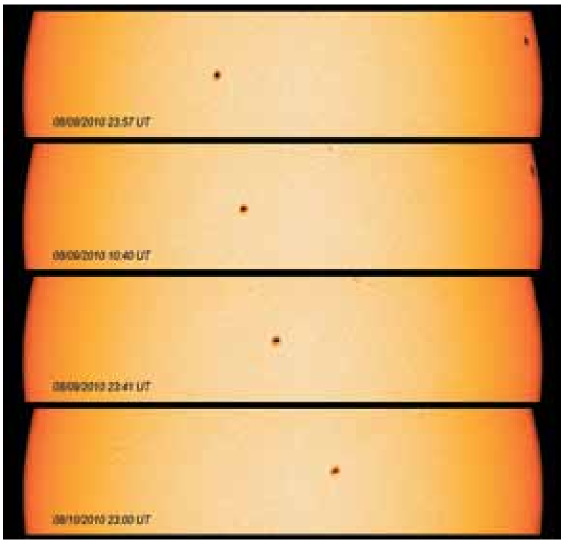
The double picture on the left shows Galileo's drawings of the Sun, made on consecutive days. He got into a hot debate with the German astronomer Christoph Scheiner (pictured on the opposite page) about the nature of sunspots. Scheiner, a devout Jesuit, claimed that the Sun was unspotted and that the apparent spots were, in fact, planets passing in front of the Sun.

Over several days, Galileo noticed that the pattern of spots moved across the Sun's disc. From this he deduced that the Sun is spherical and that it rotates.

Careful observations have since shown that the Sun rotates more rapidly at its equator than at the poles. Its period of rotation is about 25 days at the equator and 35 days at the poles. That's good evidence that the Sun is not a solid object.



Galileo made these drawings on 25 and 26 June 1611. As the Sun rotates, you can see the group of spots gradually coming into view.



In this recent sequence of images, you can see one sunspot moving steadily to the right while another disappears on the right. You can use these images to estimate the rate of rotation of the Sun.

Solar activity

Sunspots give a good guide to the activity of the Sun. You might expect that, since sunspots are cooler than their surroundings, a large number of spots corresponds to a cooler Sun with less energy output. In fact, the opposite is true.

At present, the Sun's face is almost spotless (that's very unusual), and so its energy output is relatively low.

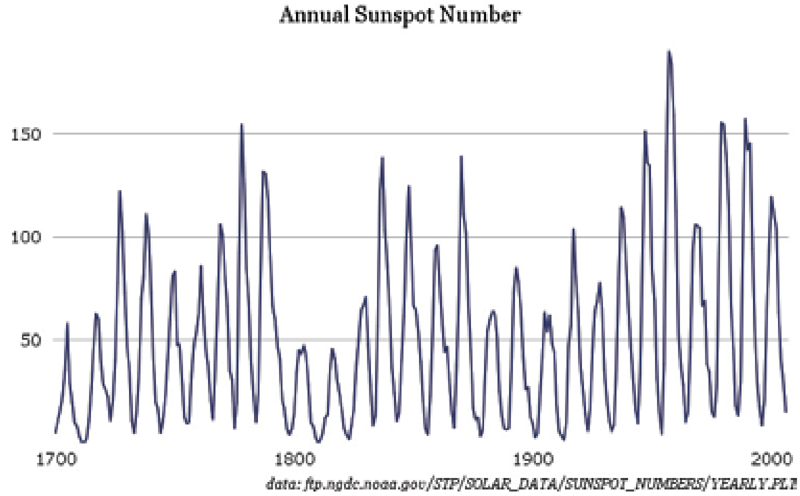
Astronomers have counted and tracked sunspots for over 400 years. This means that we have good data for sunspot numbers and can look for patterns in the data. The graph shows the cyclical pattern in sunspot numbers, with 27 complete cycles in 300 years, giving a period of roughly 11 years.

The graph shows that there are other, longer-term trends in sunspot numbers, indicating that the Sun has long periods of greater and lesser activity

Observing sunspots

It's dangerous to look directly at the Sun. Fortunately, we have a reflex action which makes it impossible to do so. However:

Under no circumstances should you look directly at the Sun, either with the naked eye or with binoculars or a telescope.



Three centuries of sunspot observation – although the Sun's activity is clearly cyclical, there are also long-term variations.

Here is how to observe sunspots safely:

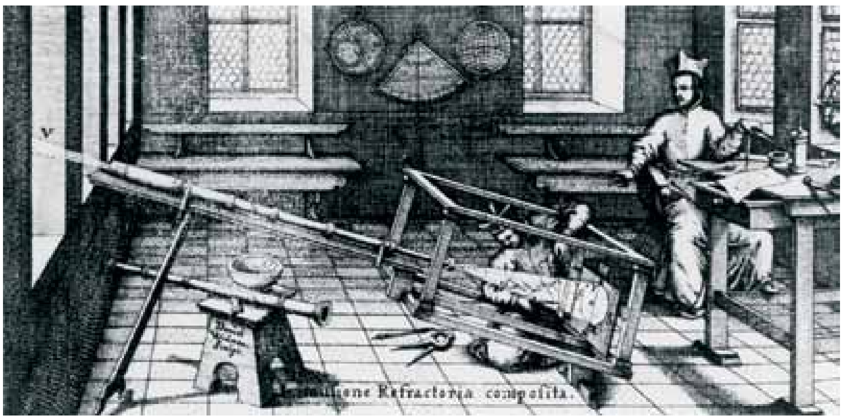
Mount a pair of binoculars (or a telescope) on a tripod. Tip the binoculars so that the larger objective lenses are directed towards the Sun.

Hold a piece of stiff white card a few centimetres behind one of the eyepiece lenses. If your alignment is correct, you should see a bright spot (an image of the Sun) on the screen. Adjust the alignment of the binoculars until you do.

Move the card slowly backwards, away from the binoculars, keeping the spot on card. It should widen into a circular image. You may need to adjust the focus of the binoculars.

The bigger the image of the Sun on the card, the bigger will be the sunspots. However, a bigger image will also be dimmer because the light is spread over a bigger area. To overcome this, mount the card screen in the base of an open-topped cardboard box. Tip the box so that the image on the screen is circular.

You can use this arrangement to track the changing numbers and positions of sunspots over a period of days – weather permitting, of course.



The German astronomer Christoph Scheiner was among the first westerners to study sunspots. Here he and his assistant are using a telescope to observe spots in the way described on this page.

David Sang is Physics editor of CATALYST.

Claire Goncet
Sandra Messenger

Biofuels from waste

Key words
fossil fuel
biofuel
carbon cycle
greenhouse gases

At present, fossil fuels are used to provide most of our global energy requirements. In this article, Claire Goncet and Sandra Messenger describe new efforts to replace fossil fuels with biofuels.

Fossil fuels – such as crude oil, coal and natural gas – power cars and generate heat and electricity. Fossil fuels are a finite resource as they take millions of years to form and the remaining supplies are being used at a greater rate than can be sustained.

When burnt, fossil fuels release carbon dioxide (CO_2) into the atmosphere. This stored form of carbon is released, increasing atmospheric CO_2, adding to greenhouse gases and contributing to climate change. It is therefore essential that alternative energy sources are developed. Biofuels may have a big part to play.

Why are biofuels different from fossil fuels?

Biofuels are different from fossil fuels because they come from recently formed biological material, such as plant biomass, which is renewable. Plants use CO_2 to grow. The CO_2 that is released on burning a biofuel is that used in a plant's life cycle as illustrated in Figure 1, so that there is no net increase in atmospheric CO_2.

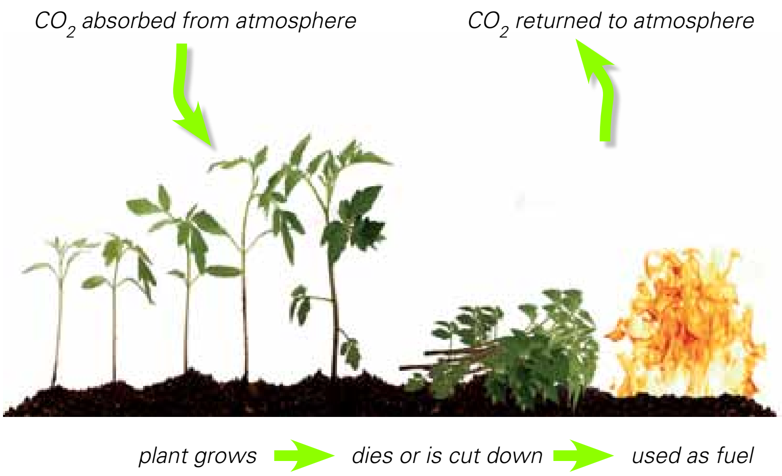


Figure 1 *A plant stores carbon from the atmosphere as it grows, and releases it when it dies or is burned.*

The 'first generation' biofuels focused largely on energy rich crops such as wheat and rape seed oil, and vegetable oils which were processed to create biofuels. The use of these biofuels created a lot of debate and controversy across the world due to issues such as increased food prices as food crops were diverted from the human food chain, increased demand for land, and potential loss of vital habitats.

Microbial bofuels

Interest has now turned to creating biofuels from more sustainable means including the use of industrial biomass waste or by-products, for example the stalks of wheat, corn, and other inedible waste products. This has a number of benefits, both environmental and commercial, including the reduction in waste being sent to landfill. Biofuels can be made from a number of resources. There are many different biofuels including bio-diesel, bioethanol and biobutanol (see Figure 2). Biofuels do not negatively impact on global warming, can reduce waste to landfill, and are often carbon neutral (they do not increase the amount of CO_2 in the atmosphere.)

Current research, including at the Biofuel Research Centre at Edinburgh Napier University, aims to help companies currently sending waste to landfill, and looks at the potential for this waste to be converted into biofuel, and in particular biobutanol, instead.

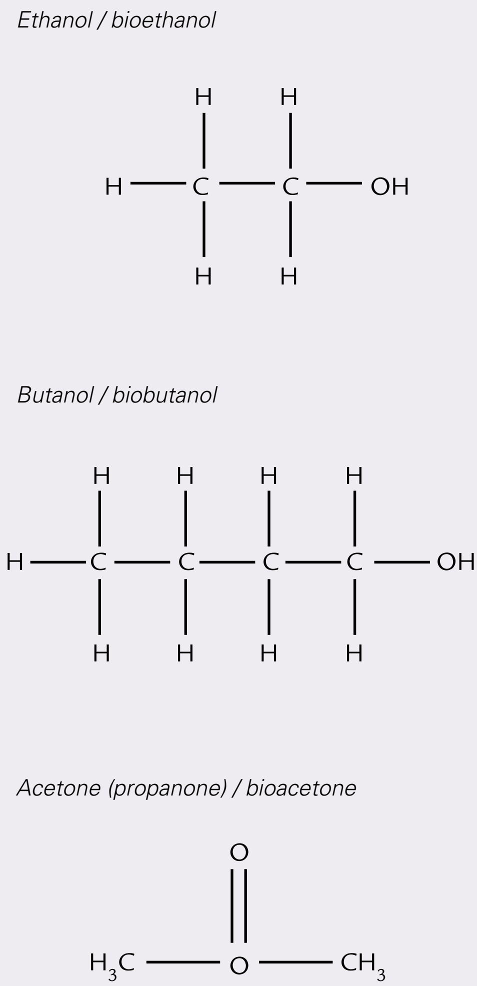


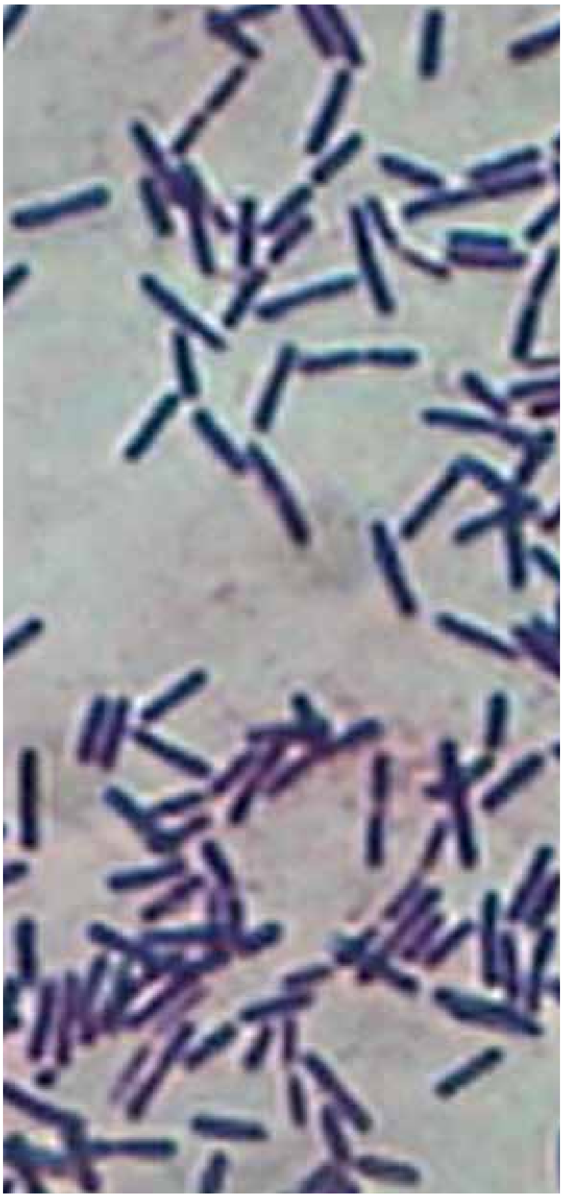
Figure 2 *Molecular structures of three biofuels*

Discovery of biobutanol

In 1915 Chaim Weizmann isolated the bacterium *Clostridium acetobutylicum*. It produced high levels of bioacetone, biobutanol and bioethanol under anaerobic (oxygen-free) conditions. When it was grown on maize mash and potato it was found that these valuable chemicals were produced through fermentation. This fermentation process was exploited on an industrial scale during the First World War to supply chemicals needed for explosives. The availability of cheap petrochemicals led to the decline of this process on an industrial scale. Today fermentation is once again being developed for industrial scale biofuel production.

Biofuels produced by microbial action

Biofuels can be made by combining a waste by-product with a microbe such as Clostridium acetobuylicum. Figure 3 shows an overview of the different types of biofuels that are being developed with the use of microbes.



Clostridium bacteria – each is about 10 μm in length.

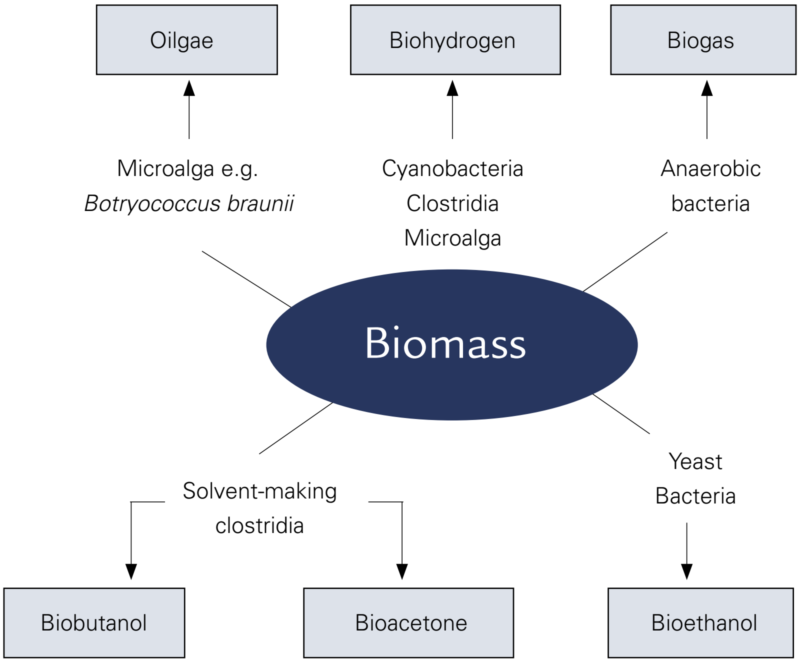


Figure 3 *Many different biofuels can be made using the action of bacteria on organic matter.*

Biobutanol is emerging as an important biofuel for the transport industry as it has more advantageous chemical properties than bioethanol (see Table). Biobutanol, unlike bioethanol, does not need to be blended with petrol, and can also be transported in existing pipelines.

Biobutanol can be used immediately as a substitute for petrol in the transport industry with no costly modifications or changes to the infrastructure of fuel transportation.

	Fuel type		
	Bioethanol	Biobutanol	Petrol
Energy content (megajoule / litre MJ/l)	21	29	33
Use as transport fuel	Engine modification required for higher than 15 – 20% blends with petrol.	Can be used in existing engines. Can be blended at any ratio with petrol or diesel.	Currently the predominant fuel used in vehicles.
Transportation	Rail, barge, truck	Existing pipelines	Pipelines

Table *Comparison of petrol, biobutanol and bioethanol*

Future research in microbial biobutanol production

Although current research has demonstrated that biobutanol from industrial biomass can feasibly produce biofuel, there is a need for continuing and future research.

Current research is focusing on identifying a wide range of waste products which can be converted to biofuel and developing ideal fermentation methods. There are many areas of research aimed at increasing the yields of bioethanol, biobutanol and bioacetone. Improved processes will lead to cheaper products. BP and DuPont plan to have a commercial plant by 2013.

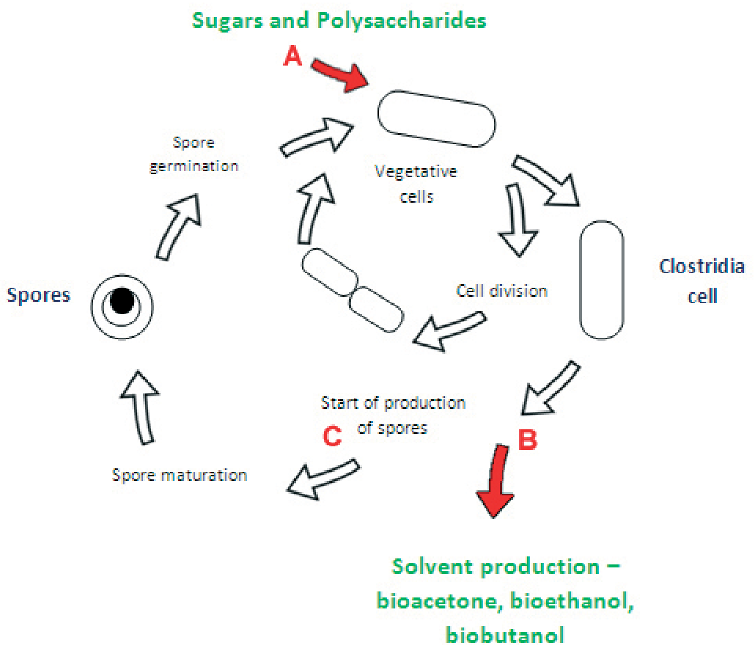


Figure 4 The lifecycle of Clostridia bacteria.

Figure 4 shows the lifecycle of Clostridia. Scientists are targeting the points shown as A, B and C in their efforts to increase yields.

Point A Biomass utilisation

Clostridia rely on the uptake of nutrients from their immediate environment to complete their life cycle. Clostridia typically exist in areas of plant decay and have the natural ability to use a wide range of sugars from a range of biomass resources. Research is required into the full spectrum of waste, sugars and polysaccharides that *Clostridia* can use to assess which biomass streams the microbes can break down naturally with their own enzymes. There is also potential to genetically modify the microbes to enable them to break down and use alternative energy sources. At present, additional enzymes need to be added to produce biobutanol. If this were not the case, the industrial costs of biobutanol production would decrease.

A continuous process is one which runs without interruption. A batch process is stopped and started again frequently, to extract the product.

Point B Solvent tolerance and specific solvent production

An additional approach to maintaining continuous solvent output is to increase the levels of bioacetone, biobutanol and bioethanol which *Clostridia* can tolerate. By understanding the solvent biochemical pathways it may be possible to encourage the production of biobutanol rather than bioacetone and bioethanol. This could increase the level of this desirable solvent.

Point C Solvent-producing strains that do not form spores

When the environment becomes too harsh for the *Clostridia* cells to handle they produce spores. There is a point where solvent production

A laboratory fermenter for experiments using bacteria.

(biobutanol, bioethanol and bioacetone) makes the environment unfavourable for cells to live, and this induces spores to form. When this happens, biobutanol production stops. In order to prevent this, industrial biobutanol fermentations in the past have been done in batches. By modifying the ability to produce spores without reducing solvent production, a continuous process could be achieved. This would increase production and therefore increase income. A continuous process is usually more profitable than a batch process.

Oxygen tolerant strains

Clostridia are not able to tolerate oxygen; currently fermentations must be oxygen free making the process more difficult to handle. Research into the development of oxygen tolerant species is needed.

Dr Sandra Messenger and Claire Goncet work in the Biofuel Research Centre at Edinburgh Napier University. Sandra is a research fellow and has a PhD in plant carbohydrate biochemistry. Claire is the Marketing Officer and has a degree in English and experience in marketing both in the UK and internationally.

Look here!

For a previous Catalyst article about biofuels, see: *http://www.sep.org.uk/catalyst/articles/catalyst_17_1_297.pdf*

Researchers at Edinburgh Napier University have developed a biofuel from the waste produced in whisky production. Watch this video: *http://www.napier.ac.uk/randkt/Pages/BiofuelsVideo.aspx*

Antibiotics on a plate

Over sixty years ago, a Russian soil scientist called Selman Waksman discovered that soil bacteria belonging to the Streptomyces *genus produce some very useful compounds. He isolated a species that produced streptomycin, which became the world's first anti-tuberculosis antibiotic. Suzy Moody of Swansea University describes how this work continues today.*

Scientists have made great progress since Waksman's time. Many other Streptomyces species have been isolated and their ability to make antibiotics, antifungals and even drugs to lower human blood cholesterol has been exploited. The centre spread picture (next page) is of Streptomyces coelicolor, which produces five different antibiotics. Some of the antibiotics are pigmented. These colonies have produced actinorhodin, which is blue and gives the species its name (coelicolor means heavenly colour or sky-coloured in Latin). The medium it was grown on (the agar in the plate) was originally very pale yellow, but the bacteria produce a red antibiotic called undecylprodigiosin that has diffused out and turned the whole plate pink. Beautiful, isn't it?

Knocking out genes

These colonies have been genetically modified. We have knocked out (or disabled) the gene for one of the other antibiotics, albaflavenone. We call this a knockout mutant, and these play a very important role in many areas of biology. Often, it is only by taking away a gene that you can work out exactly what it does. With bacteria such as Streptomyces, a knockout mutant may have a different morphology (it may look different) to the original bacteria, so taking photos of them is useful – see Image 1. Streptomyces, like many other bacteria, will look different depending on what medium you grow it on too. It might sound complicated, but it makes lab work interesting!

The albaflavenone mutant looks the same as the original. But if you look at the close up photo, you will notice that the colonies are similar but not identical. This can suggest that the mutant is unstable (although that does not seem to be the case with this one). Image 2 shows just how different the same bacteria look on different media – although the bacteria will grow well on it, they do not produce any antibiotics. So when new species are found, or new mutants made, it is important to know what they look like and how they behave, on a variety of media.

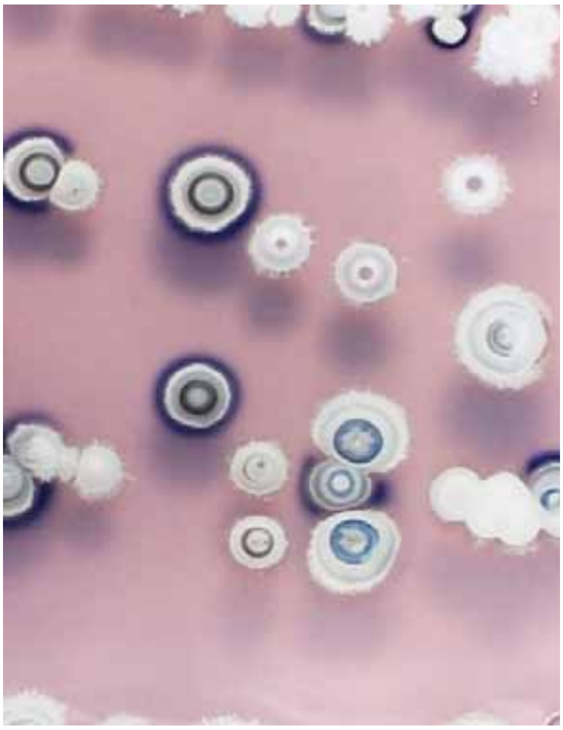


Image 1 Close-up of Streptomyces *colonies with differing morphologies. You can see that the colonies grow on the surface of the transparent medium; the red antibiotic they produce diffuses into the medium.*

Image 2 These colonies of S. Coelicolor are growing on a different medium to that shown in Image 1. This medium doesn't support antibiotic production.

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A knockout mutant of Streptomyces coelicolor growing on an agar plate; the pink colour shows that an antibiotic has been produced by the bacteria.

Photo: Suzy Moody

How streptomycetes grow

Streptomyces are unusual bacteria as they have three distinct life stages. While most bacteria grow as rods or cocci (spheres), streptomycetes grow as long branching filaments called vegetative mycelia. When the colony is mature, aerial hyphae (stalks) grow up from the mycelia, and spores are made at the end of each hypha. Some species grow spores in curled chains, so they end up looking a bit like a twister lolly. Images 3 and 4 are taken down a microscope, and show the mycelial growth. Antibiotic production is associated with a mature colony, that is one producing aerial hyphae and spores. The big question is: why do these bacteria produce antibiotics in the first place?

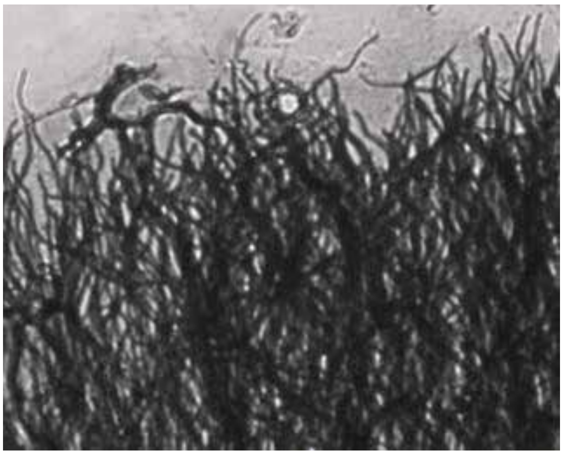


Image 3 A microscope image of dense mycelial growth

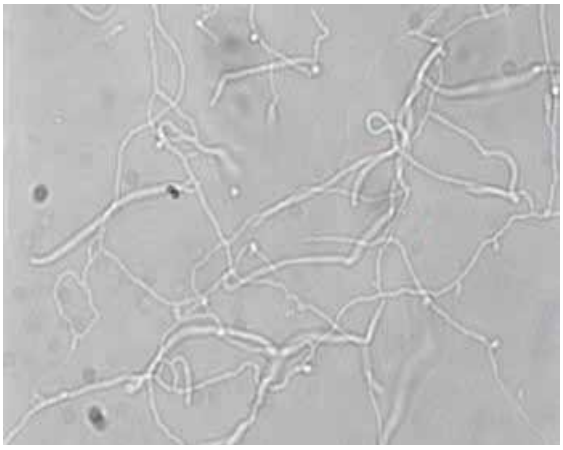


Image 4 When the sample in Image 3 is diluted a little, vegetative mycelia with branching chains can be seen

Why antibiotics?

It has long been thought that the main reason for antibiotic production is to give the producing bacteria a competitive advantage over their rivals. Soil is a particularly complex chemical and biological environment, with lots of different species of bacteria, fungi, plants and other organisms, all competing for space, nutrients and energy. Streptomycetes may produce antibiotics to kill off their bacterial competitors, thereby giving them more space and energy with which to grow. This effect can be demonstrated on agar plates.

Image 5 An agar plate showing competition between B. licheniformis and S. coelicolor.

Image 5 shows a mature *S. coelicolor* colony producing antibiotics that are inhibiting the growth of the bacteria on the left side. This is *Bacillus licheniformis*, another common soil microbe. We call the gap caused by the antibiotics a 'zone of inhibition'.

Image 6 Close up of the zone of inhibition

If you look more closely at what is going on, the story gets even more interesting. Image 6 shows the same plate, with the zone of inhibition still very clear even down a microscope. But streptomycetes only produce antibiotics as a mature colony. So when we plated the same two species against each other, but with a young streptomycete colony, we saw a different pattern emerging, as shown in Image 7. Here the *B. licheniformis* at the top, is growing out towards the streptomycete colony with no problem. *Streptomyces coelicolor* hasn't begun its antibacterial warfare yet.

Image 7 B. licheniformis and S. coelicolor growing towards each other

Suzy Moody is a microbiology research student at Swansea University. She loves her streptomycetes and enjoys growing pretty colonies to photograph!

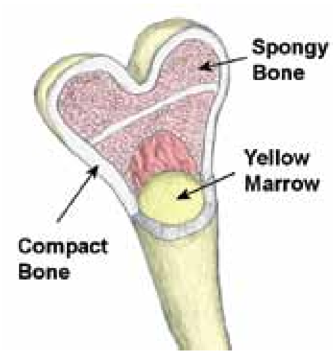
Katherine Staines

Exercise: working it to the bone

Obesity in Britain is on the rise and so we are all encouraged to do regular exercise, not only for our cardiovascular and respiratory health, but also for our general well-being. But what effects does exercise have on our bones, and why is this so important? Katherine Staines reports.

Our bones are alive

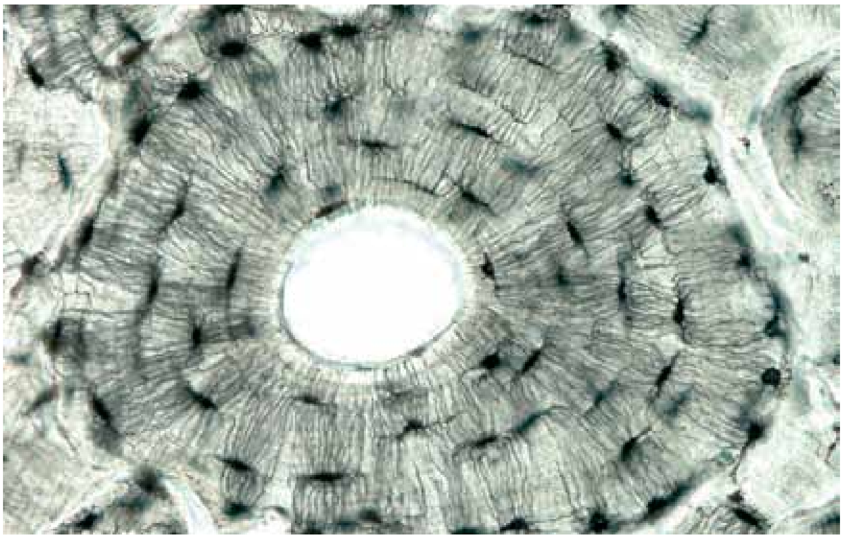
The skeleton is often thought of as dead tissue. However, the opposite is true. Bones are alive and able to respond to the changes they experience when you use them. The structure of bone makes it lightweight but strong and hard so it can support the body and protect its vital organs. It has a honeycomb-like internal structure composed of mineral crystals. These form when calcium and phosphate in bone cells undergo chemical reactions to produce the crystals that grow in size and make bones rigid.



Bone is a living tissue and its structure makes it lightweight (spongy bone) and yet strong (compact bone).

Bone consists of three cell types; osteoblasts, osteoclasts and osteocytes. Osteoblasts produce new bone while osteoclasts reabsorb bone by secreting enzymes to digest it. These two cell types work together to constantly renew our bones: our entire skeleton is replaced every 10 years. When an osteoblast completely surrounds itself with newly formed bone, it becomes an osteocyte. The structure of an osteocyte is unique – it has long processes that extend throughout a bone. Osteocytes are the most numerous cell type but the least is known about them. This is why this cell is becoming more interesting to research.

Key words
bone
exercise
osteoporosis
osteocyte



Tim Arnett, UCL www.brsoc.org.uk.

Osteocytes are arranged in bone in circular layers like an onion. In the middle is a canal with blood vessels and nerves. There are thousands of connections between the osteocytes sitting next to each other, and between those in the different layers. This has led scientists to believe that the osteocytes communicate with each other, and other bone cells.

Exercise builds your bones

Muscles get bigger and stronger as we use them, and shrink when we don't. Bones act in a similar way – the more you use them by exercising, the more dense and strong they become.

The most beneficial type of exercise for bones is the weight-bearing kind, for example weight-training, hiking, jogging, tennis and dancing. However, these must be done in moderation, especially in children so as not to prevent the longitudinal growth of their bones.

A recent craze in gyms is the vibrating plate. It claims to tone muscle, as well as build bone mass, simply by standing on it. Has the vibrating plate completely ruled out previous research and found a low impact sport that can build bones, or is it all just a clever sales idea? NASA-funded scientists certainly believe in it and have shown that standing on a vibration plate for 10-20 minutes every day could replace bone loss that is seen when astronauts go into space and experience weightlessness. However, more evidence needs to be gathered as this idea remains controversial and prolonged exposure may cause development of other health risks.

Dancing is a form of weight-bearing exercise which helps to build bone.

When we are born, our bodies cannot predict what level of activity we will do in our life – some people will remain as couch potatoes throughout their lives, and some will go on to become Olympic rowers. So, we have different skeletal requirements to which our bones adapt. But how does this happen?

In the 19th Century, Julius Wolff (a German anatomist) stated that a bone will change its mass and internal structure to best meet the mechanical demands placed upon it. Various experiments have explored this idea. One example: in 1977, Henry Jones and colleagues looked at the size of the upper arm in 84 professional tennis players by X-ray. They found that they had up to 35% more bone in their playing arm than their other arm. This clearly shows the effects exercise can have on bones.

Do you think Andy Murray has more bone in his right arm than his left?

So our bones can be thought of as self-regulating; they sense the loads placed upon them and adapt their strength to a level at which the bone can still safely function. So what could be this 'sensor'?

Bone v brain

The brain communicates with the rest of the body by sending impulses through its billions of neurons. Remarkably, it has been suggested that bones also function like this.

The internal structure of your bones is highly organised and its cells form a network. The long processes of the osteocyte make this cell type a candidate for what is equivalent to the neuron in the brain. It may sense the different forces applied to it as we exercise, and relay this information to the rest of the bone. They also have tight junctions (see Box 1) between their processes and the other bone cell types, which could act as a junction similar to a synapse.

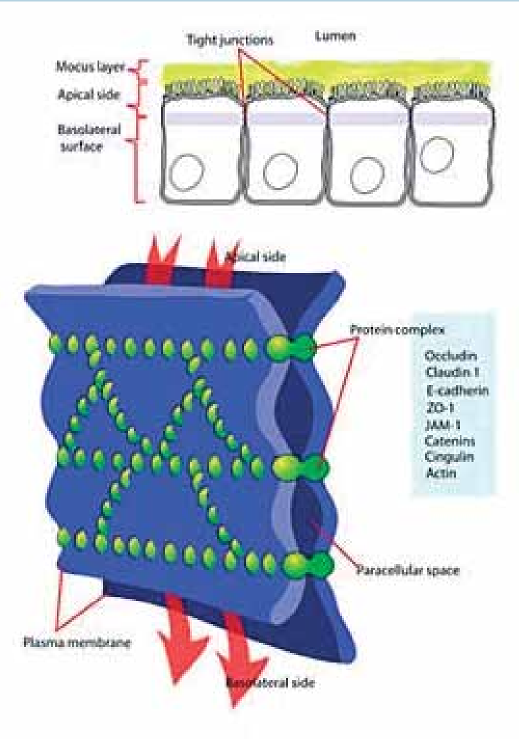
The most abundant chemical that is transported across a synapse in the nervous system is glutamate which is thought to be involved in our learning and memory. Studies have shown that bone cells have glutamate receptors, and function in a similar way to cells in the central nervous system. However this idea is controversial and work continues.

Box 1 Tight Junctions

A tight junction is a point where the membranes of two cells become close together. Proteins, which are embedded in the outer membranes, join together to form strands which span the junction, much like beads on a string.

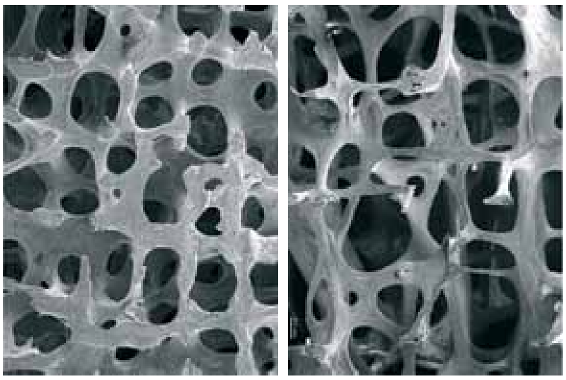
They have two main functions:

- they hold cells together;
- they act as a barrier, preventing the movement of molecules between the two cell, so molecules have to enter the cells by diffusion or active transport.



A tight junction keeps cells together and stops molecules passing between them. The plasma membranes of two cells are kept together by proteins which link together like beads on a string.

Tim Arnett, UCL www.brsoc.org.uk.



This image was taken by an electron microscope. The left hand image is from a healthy person. It has a honeycomb structure which allows it to be lightweight. The right hand image is from someone with osteoporosis. The bone is thinner and has many more holes in it. This means it is more likely to break.

Why should we build our bones?

About 3 million people in the UK have osteoporosis which increases the risk of bones breaking. It is commonly thought to just affect older women but in fact can affect men and women at any age, and is caused by a loss of bone mass. The amount of bone you have increases up until the age of 30 at which it reaches its peak strength and density. After this, bone mass decreases at a gradually, but certain factors such as the menopause can accelerate this. The higher your peak bone mass, the longer it takes for it to fall to potentially dangerous levels.

Exercise is key to determining peak bone mass. Its main benefit is building bone strength and mass but it has other effects. It will assist joints, making them more flexible. However this must be done in moderation as it can put wear and tear on the joints. Exercise also reduces the risk of an injury, and can increase balance and flexibility.

The idea that genetics plays a large part in determining peak bone mass is new and is dominating research into osteoporosis. From looking at family histories and from studying twins (see Box 2), scientists have shown that up to 90% of peak bone mass can be inherited. They have also identified genes that, when mutated (faulty) have been suggested to cause the disease. These include the gene for the vitamin D receptor.

So when is the best time to "invest" in the health of your bones? Well now. Up to 90% of peak bone mass is acquired by age 18 in girls and by age 20 in boys.

Box 2 Twin studies

In the 1870s, Sir Francis Dalton (Darwin's cousin) recognised that twins could be used to study what he called "nature versus nurture".

Twins are unique: identical twins, from one egg split in two, are genetically identical. Non-identical twins (from two eggs and two sperm) only share half of their genes but will be brought up in the same environment.

Similarities between identical twins and non-identical twins are compared, allowing researchers to establish the percentages of a disease which are due to genetics, to a shared environment, and to events that happen to one twin but not the other.

The only department of twin research was set up to study the genetics of osteoporosis. It now has a database of over 10 000 sets of twins and looks at the role genes have in cardiovascular disease, the musculoskeletal system and ageing.

Katherine Staines is a PhD student studying bone development at Edinburgh University.

Jon Purdy

On Screen

Physics and computer games

Key words
forces
collisions
momentum
computers

From calculating the angle that a ball bounces off a wall to modelling the frictional forces on a rally car, physics has always played a part in the development of computer games. In recent years the drive for more realistic environments has resulted in the implementation of some quite advanced physics simulations in computer games software. In this article, Dr Jon Purdy of the University of Hull gives a brief overview of some of the physics used to make computer games and outlines the technical limitations that must be overcome to make the games realistic and appealing.

History

The first video game to really make an impression was the simple tennis simulation *Pong*. Even though this was extremely simple in terms of the game-play and graphics it still relied on some key physics techniques. These were:

- Collision detection – determining when the ball (in this case a square block of a few pixels!) hit the walls or the bat (a short straight line!).
- Reflection – The ball must bounce off the wall at an appropriate angle.

Video games quickly developed and arcade games like *Space Invaders* generated massive amounts of money around the world. Although *Space Invaders* used collision detection it was an arcade game called *Lunar Lander* that introduced more complex physics into mainstream video games.

Lunar Lander is a 2D game in which the player has to land a lunar landing craft on the mountainous surface of the Moon. The player has to use short bursts of rocket power to reduce the landing craft's vertical velocity to a point where it touches down safely. The added complication is that the landing craft has to navigate to a flat landing site and usually has to reduce its horizontal velocity to zero before attempting to land. The simple physics used in games now included:

- Force of gravity – determining the acceleration of the landing craft towards the surface.
- Newton's laws – determining the resultant velocity of the craft when subject to the forces resulting from the rocket firing.
- Resolving forces – determining the component of a force in a particular direction.

Lunar Lander – heading for the landing site

The release of *Doom* in the early 90s popularized games that are played in a 3D environment. This leap into the third dimension required an equivalent leap in the complexity of the programming skills required to make these games. Game programmers now had to have a good working knowledge of some complex mathematical methods such as 3D coordinate systems, matrices and vector algebra.

For a few years the physics was sidelined by the development of the computer graphics that make modern games look so realistic. However even in this process physics was never very far away; the increased levels of realism used the following simulation methods.

- Projections of shadows.
- Reflection and refraction from shiny curved surfaces.
- Modelling of the scattering of light from beneath the surface of materials to make realistic skin tones and to simulate translucent materials like glass and marble.
- Simulations of special effects like explosions, fire and rain.

By the beginning of the 21st century computing power had increased by so much that the production of realistic graphics no longer used all the available processing power. This spare capacity was soon earmarked for the simulation of more realistic physics.

Games hardware

The potential for realistic physics in games greatly increased with the current generation of games consoles. The PS3 and Xbox 360 both use multiple high-powered processors rather than the single processors used in their predecessors. The programs that run on these devices use a technique know as parallel processing, and can produce increases in the speed and complexity of the simulations that the console can cope with. The programmers achieve this by getting the individual processors to perform specific tasks; for example, one processor can deal exclusively with the game program, another can do the graphics and another can be set aside for the physics to make the game more realistic.

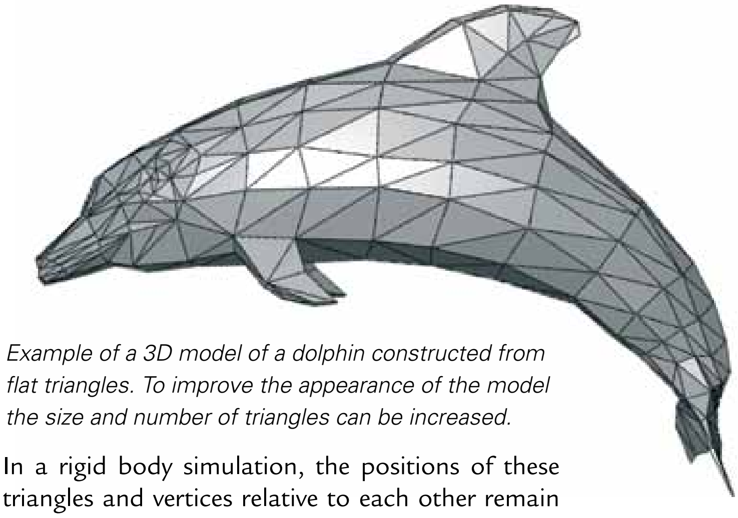
One game that uses the power of these consoles is *Little Big Planet*, developed for Sony's PlayStation 3 by Media Molecule. *Little Big Planet* uses the power of the PS3 to create a soft body world in which the player runs, jumps and swings through different levels, solving many physics based puzzles and challenges along the way. Another example is *Geometry Wars* developed by Blizzard originally for the Xbox 360. This game implements very fast and effective special effects to create a frantic and beautiful game.

Little Big Planet (Media Molecule) A soft body world using the power of the PS3

Soft body modelling

One of the main changes being introduced into games is the use of more soft body modelling. To understand what this means it is useful to first loosely define what a rigid body model is.

Most objects in games are defined by a collection of points in 3D space. These are called vertices and they are connected together by straight lines. These straight lines form polygons, which are in practice almost always triangles – the dolphin pictured is an example.

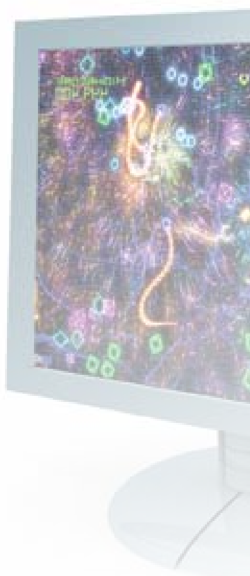


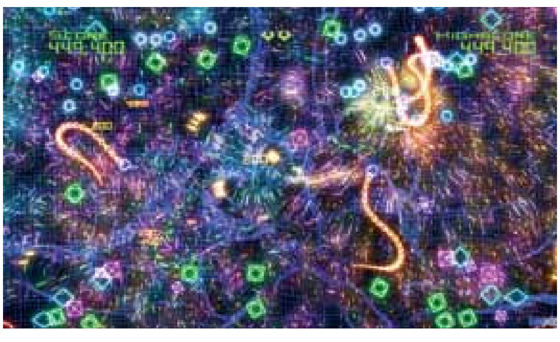
Example of a 3D model of a dolphin constructed from flat triangles. To improve the appearance of the model the size and number of triangles can be increased.

In a rigid body simulation, the positions of these triangles and vertices relative to each other remain fixed. This means that two objects colliding do not bend or break. This approximation falls down when collisions occur between objects we expect to bend and deform, like skin, clothing or liquid. In the Box, we look at two simple examples, a rope and a cloth, to see how such materials can be simulated.

Collisions

Burnout was the first mainstream computer game to perform a real-time simulation of the deformation of the vehicles as they crash. This was pioneered by Andrew Hubbard, the lead physics programmer at Criterion and graduate of the Games Programming MSc at the University of Hull. Andy was given the difficult task of simulating the crash deformations witnessed in real life crash tests. He has to do this real time in the game. Some clips of the material Andy used to work out how to do this and the results he achieved can be downloaded from my website www.jonpurdy.co.uk



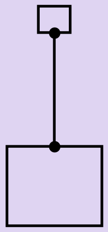


Geometry Wars (Bizarre Creations) A frantic 2D game that uses the power of the Xbox360 to produce some truly stunning particle effects.

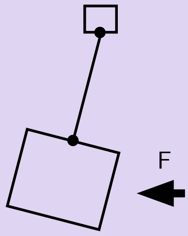
Screenshot of Split Second made by Black Rock Studio. In the game the player can trigger impressive large scale simulations like explosions of buildings and bridges, the collision of airplanes and the derailment of trains and to control the race.

Simulating soft materials

Rope: A rope can be represented simply by a straight line.

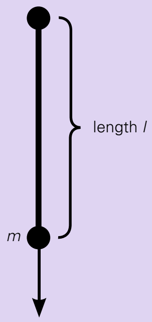


If a straight line is used to model a rope it is simply a case of keeping the distance between the ends of the rope constant



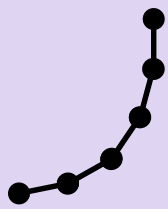
When a force is applied to one end of the rope the simulation must deflect the mass until the forces balance. The rope should follow an arc. If the force is removed the simulation can be performed by a simple damped pendulum calculation.

This doesn't show how a rope bends and sways, or how it coils when it collides with a flat surface like the floor. To simulate this, the rope must be split up into segments with each one treated as a small spring connected to a mass.

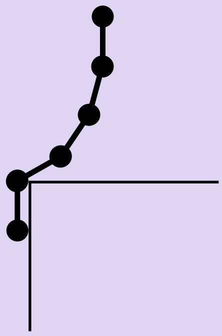


The rope is now constructed of individual elements each made up of a straight line of length l with a small mass m attached to one end. The length and orientation of the segment is determined by the forces on the end of the individual element and the spring constant.

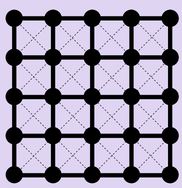
When the individual segments are attached together the force on each element depends on the sections that are attached to it. So the top element has a combined mass of 4m hanging from it.



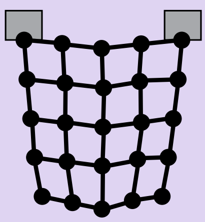
When a horizontal force is applied to the rope the individual position and motion of each element must be calculated to determine a stable position for the entire rope. The overall effect is that the rope can bend and sway realistically. If collision detection is performed on each element the rope will coil or deflect realistically when it touches a surface.



Cloth: Cloth can be simulated using a two dimensional grid of masses joined by springs as shown. Each mss is pulled on by eight springs.



If the corners of the cloth are fixed and the simulation is allowed to run under gravity the material will deform something like as shown. Modern simulations can cope with horizontal forces like wind and can even cope with tears and holes in the fabric. Adding collision detection to the simulation allows real deformable cloths to be added to models. This allows clothing to be ripped and damaged during a game.



A real crash test (above), and a simulation (below).

Andy currently works in Brighton for the Disney-owned studio Black Rock. Their game *Split Second* broke new ground by also introducing a race track that can be altered during the game.

The future – your future?

The simulation of realistic physics is becoming more and more important in the production of computer games and the techniques used to perform these simulations are becoming more complex. The games industry employs specialist physics programmers to produce these realistic simulations and effects and there are jobs for talented and dedicated people in the UK and around the world. To get a job in this demanding industry you need A levels in Physics and Maths and a good degree in Computer Science, Software Engineering or Physics.

Look here!

Follow these links for more about how computer games are devised:

www.pong-story.com
www.havok.com
www.naturalmotion.com
www.jonpurdy.co.uk

Try these Physics games:

Crayon Physics www.crayonphysics.com
World of Goo www.worldofgoo.com

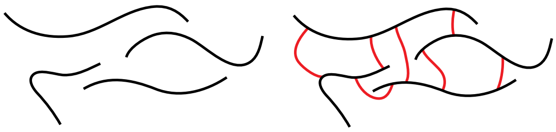
Dr Jon Purdy is in the Department of Computer Science at the University of Hull.

Make your own elastic band

Try this

Rubber latex is a liquid polymer. It is made of long molecules which are all separate. Copydex is a convenient source of rubber latex. (Note that PVA glue will not work in this activity.)

Elastic bands are made by cross-linking the polymers in rubber latex. This changes the properties of the polymer and forms a solid from a liquid. Instead of being separate, cross-linking joins the long molecules together to form a network joined by strong covalent bonds. (See Diagram 1).



uncrosslinked rubber *crosslinked rubber*

Diagram 1 *– cross-linking of polymer chains.*

You will need

Copydex glue

Vinegar

2 small pots – washed out yoghurt pots are ideal

A former – this can be any round, smooth, solid object with a diameter of about 1cm – eg a kitchen implement with a metal handle or a large round pencil. Unpainted wood does not work well.

Remember to ask the owner of any kitchen item before you use it for this experiment.

What you do

Pour some vinegar into one of the pots to a depth of about 5 cm. Fill the other with water to a similar depth.

- Paint about 3 cm of the end of your former with the Copydex, ensuring that you have a smooth, even coating.
- Dip the Copydex-coated former into the vinegar, ensuring that all the Copydex is covered. Rub the bottom of the former on the base of your pot to make a small hole in the Copydex.
- Dip it into water, again ensuring that all the Copydex is coated.
- Allow the Copydex to dry, without it touching anything. This will take at least 5 minutes but it is worth being patient at this stage.
- Carefully roll the rubber coating off the former to make a rubber ring – your rubber band.
- To make a larger rubber band, use a thicker cylinder such as the neck of a glass bottle.

Your rubber band

You will probably have to practise a few times before you can successfully make a rubber band. The technique is fiddly and requires patience.

Over time your rubber band will change colour from white to the more usual brown colour.

Notice the changes in properties from the Copydex to the rubber band. This is due to the change in the structure and bonding of the molecules as shown in Diagram 1.

You could try painting some Copydex onto a bottle or similar and allowing it to dry. You can then peel it off. This solid will not be cross-linked and will have different properties to your rubber band.

Look here!

For more information on rubber and its properties, see: *http://science.howstuffworks.com/rubber.htm*

For more information about molecules and how they change during cross-linking, see: *http://tinyurl.com/2u2z2c2*
(but note that the cross-linking shown on this website is not chemically the same as the cross-linking you are doing)

For a previous Catalyst article about polymers and their uses, see: *http://www.sep.org.uk/catalyst/articles/catalyst_19_1_360.pdf*

Vicky Wong is Chemistry editor of Catalyst. *Thanks to Lynn Nickerson from Didcot Girls' School for her help with this article.*

The many faces of biology

With over 1,400 different university biology courses, how will you ever decide which is the right one for you? Instead of just randomly picking one out of a hat, this article hopes to give you an overview of the other different options available when choosing your higher education pathway. Interviews by Catherine Lichten, Aisling Spain and Katherine Staines.

David MacFie

Physiology, Nutrition and Sports Science at Glasgow University

Why did you decide to do your degree?
I have always been interested in the human body and how it functions, especially in response to exercise. This degree allowed me to combine this with my love of sport.

What was the best thing about your degree?
I really enjoyed having a mix of teaching – Lab work and small group tutorials meant that I wasn't stuck in a lecture theatre everyday.

What advice would you give people interested in your subject?
I always expected to do a job which directly related to my degree. However I soon learnt that this wasn't always the case! I've done Sky telesales, been a tennis coach, and now I am a manager for a orthopaedic device company which provides surgical instruments

What would you do differently if you could?
I would have taken more careers advice both at school and at university

David studied Chemistry, Biology, English Literature and Economics at A-Level

Rudra (speaking) at the Copenhagen climate conference.

Rudra Kapila

Environmental Sciences at Edinburgh University

Rudra studied Biology, Maths, English literature, French and French literature for the International Baccalaureate.

I work in the topical and high profile field of climate change. This means I get to travel to international conferences such as the UN climate conference in Copenhagen. It also means I get to work with people from a variety of disciplines, such as engineers and policy makers, something that I find to be the most enjoyable part of what I do.

Looking back on how I got to where I am, I wouldn't change a thing. I might have studied law, but in all honesty, I have no regrets, as I love the work I do, and I get to study law now as part of my PhD at the University of Edinburgh.

I've always been interested in the natural environment and conservation but at school I also wanted to be a musician, something I still pursue in my free time.

Jo Mendum

Human Anatomy at Strathclyde University

What subjects did you study in the sixth form?
Highers: Maths, English, French, Chemistry, Biology, Physics

How did you choose what to study at university?
The first year of my degree was a general biology degree but then in the second year we got to do modules. I liked the modules relating to human anatomy the most and so opted to do these in my 3rd and 4th years. Law also interested me so I decided to do it part time.

What did you want to be when you were younger - is that what you are doing now?
I always wanted to be a forensic pathologist. However that is not what I do. Now, I work for a clinical trials company. My job is to ensure all the necessary documents meet the requirements of the Authorities and the Ethics Committees and then submit the documents so that the study can be reviewed and approved. I work with countries all over the world to get the studies approved so patients can be enrolled.

What advice would you give someone who is thinking of following a similar career path?
Be prepared to start with the administrative work and build up from there. Also, always try and get some good contacts as many jobs are word of mouth.

Helen Towrie

Molecular and Cell Biology at Stirling University

What A levels/highers did you do?
Biology, Chemistry, Maths, English, History. I also did CSYS Biology and Chemistry.

How did you choose what to study in university?
I didn't really know what I wanted to do but really enjoyed biology so went with a Biology-orientated degree. I also liked Stirling as a place to study.

I never knew for sure what I wanted to be when I grew up and considered everything from mechanical engineering to teaching to working as an agricultural advisor. I got a job after university which involved doing laboratory testing and whilst here, I completed (by distance learning) an MSc in virology from Liverpool John Moores University.

I now work at a large pharmaceutical services company called Quintiles where I set up laboratory testing for global clinical trials. I particularly this job because it gives me a chance to work with people who are based around the world.

The most important thing I have learned is how important it is to put yourself forward for opportunities as they arise; they are all good learning experiences. For instance, I managed a cattle health scheme where I had to present to farmers and vets and it has given me great skills for presenting to clinicians now.

The many faces of biology

Phil Newton

Biochemistry at UCL, London

I really enjoyed doing Biology and Chemistry at A-level and I found biochemistry a more interesting subject than doing either of these on their own.

I am fascinated about how life works, so for me the topic always interested me. Combine this with the excitement of university lifestyle and the whole experience was brilliant.

I am currently studying for a PhD in bone biology at Manchester University. A PhD allows you to be independent and plan your own experiments. I also enjoy the feeling of being on the cutting edge of scientific research.

What would you do differently if you could?
I'd be more proactive in getting a job lined up for after finishing university – I got a 2.1 in my degree and I couldn't get a science job for 6 months.

What advice would you give people interested in your subject?
Science is an amazing field to study because you feel you can achieve anything and make a difference to people's lives. I think if you are motivated by personal reward then science would not be the ideal choice.

Robin Coltman

Pharmacology at Edinburgh University

A-Levels/Highers: English, German, Geography and Music. Returned to college to take Maths, Physics, Chemistry and Biology.

At school I didn't know what I wanted to be but it was always important to me to work. So, after leaving my business degree I worked as a manager in a furniture shop. Ten years later I decided to return to college so that I could go back to university. I chose to study pharmacology as this time round, the most important thing to me was choosing subject that would interest me for 4 years.

My degree has led me onto a PhD in neuroscience which I really enjoy because it's extremely challenging and really pushes the limits of your understanding about a subject which generally means you learn a lot and this I find very rewarding. Outside of university I am a 3rd dan Tae Kwon Do instructor.

Look here!
You can find out more about Biology courses at UK universities on the biology4all website:
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