Catalyst

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Gene bank

Rice for the future

SEP
Science Enhancement Programme

Gary Skinner

The price of rice

Using genetics to increase crop production

A rice paddy in Thailand

Rice is the most important food crop in the developing world and the staple food of more than half of the world's population. These people are very vulnerable, therefore, to a rise in the price of rice. If you eat a few kilograms of rice a year, then even a doubling in price will have little effect. But, if you were already spending more than half of your income on rice, then a doubling in price would be devastating. In the most rice-dependent regions people eat over 100 kg per year, a phenomenal amount.

A Cambodian family eat rice for lunch.

Key words

photosynthesis

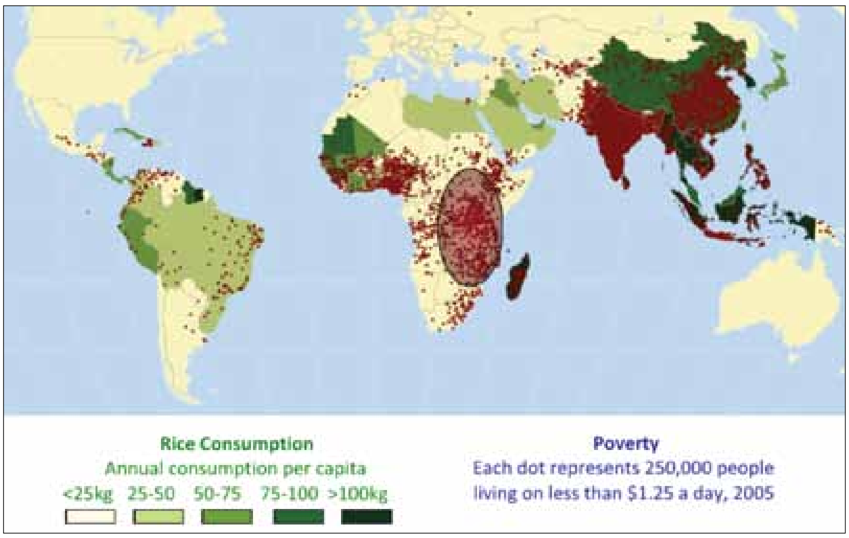
plant genetics

food crops

food chains

More than 3.3 billion people depend on rice for more than 20% of their calories and one fifth of the world's population depends on rice cultivation for their livelihoods.

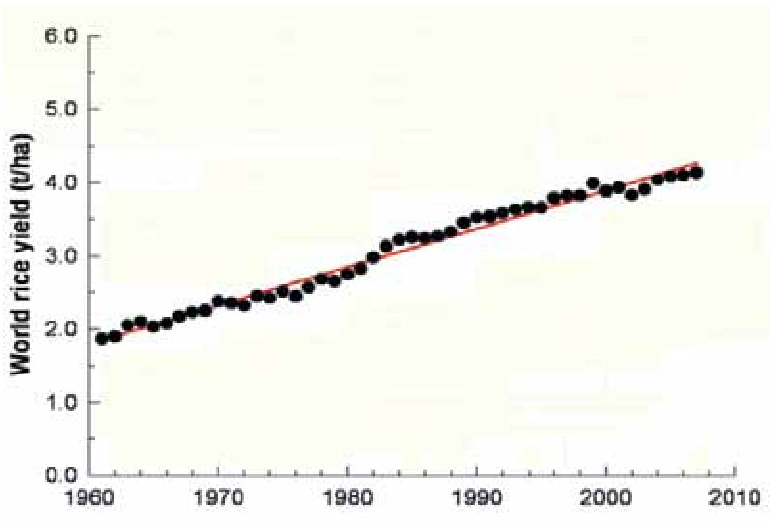
Rice has twice the value of production in the developing world of any other food crop: more than \$150 billion per year. Nearly 560 million people living on less than US\$1.25 per day are in rice-producing areas, far more than for any other crop. Rice has been, and will be, essential for the future, especially in Asia. In the 1960s many Asian countries were thought of as failing states and Western politicians agreed there was little that could be done, there would be major famine and that was that. There were those, however, who felt otherwise.



The people who eat the most rice are amongst poorest in the world living on less than \$1.25 per day. The oval area over East Africa represents an area where there is little data on rice consumption, but it is known to be high.

The Green Revolution

Through research, improving the crop, and better management techniques, yields went from 1.5 tonnes per hectare in the 60s to over 4 tonnes per hectare now.

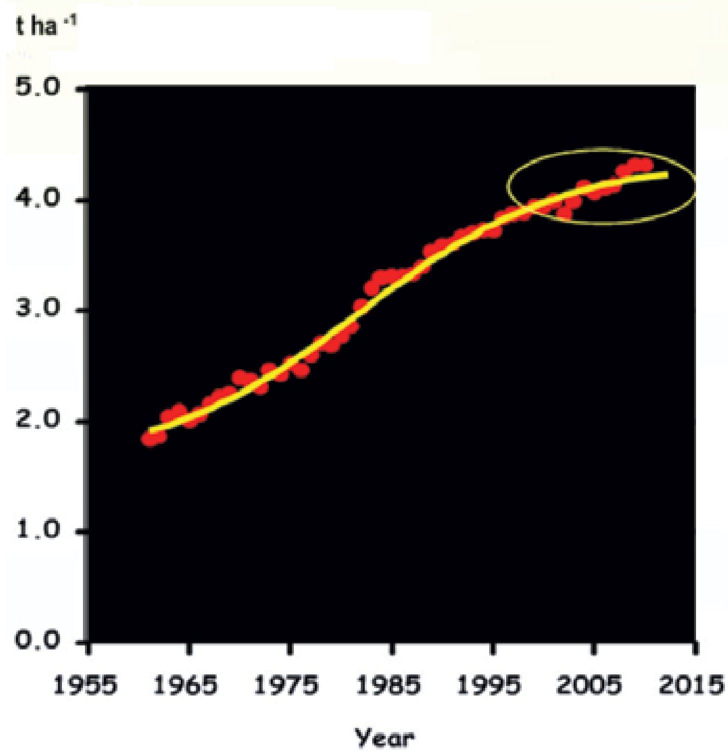


The trend in rice yields over the last 50 years

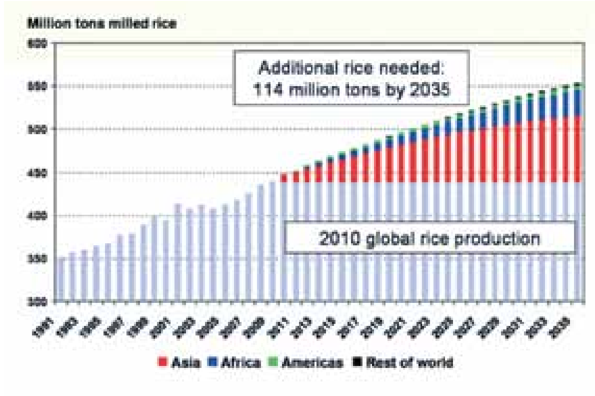
A hectare is an area of 10 000 m^2, or about 2.4 acres.

The consequent fall in the price of rice (from an average of $1000 per tonne to a 2002 low of $200) is probably at the root of the so-called economic miracle in Asia over the last 50 years.

However, there are three problems. First, the growth trend is flattening in the face of further population growth and therefore demands for more rice.



The worrying recent (since 1995) trend in rice production



World rice production will need to increase to meet rising population.

Second, the changes to climate that global warming is likely to bring. Thirdly, land and water are moving away from rice. The mayor of Manila would sooner release water from reservoirs to urban dwellers in a drought than to rice paddies. All the land suitable for rice is already being used.

A second, science-based, green revolution is needed to sustain growth in yield in the face of climate change.

Science to the rescue?

Rice is extremely genetically diverse. The International Rice Research Institute (IRRI) has over 110 000 different varieties, all now stored in the Svalbard Seed Bank in Norway. This could be vital for future research, as could the 20 species of wild rice in the genus Oryza that still exist.

One issue that has already been addressed is the problem of flooding. Rice is cultivated in a paddy, a flooded field, and it thrives in these conditions. However, it will not withstand complete submersion, it only likes its feet wet! Much rice is grown in deltas, which already suffer from floods and will do more so as sea levels rise. In 1978 an Indian rice variety (FR13A) was discovered which showed flood tolerance, but it gave a very poor yield of very poor quality grain. After over twenty years of experimentation, and with new tools from rice genome sequencing work, cultivated strains of rice were rendered flood-tolerant.

A trial of rice plants which have had a flood resistant gene called Sub 1 added to them. Plots with a yellow label have plants with the Sub 1 gene, while white labels indicate the same varieties without Sub 1. The paddy is shown some days after the rice had been immersed in water for over 2 weeks.

The variety (called Swarma_Sub1) is now being distributed to over a million farmers and it will change the lives of tens of millions as a result.

A farmer in Uttar Pradesh state, Eastern India with his badly flooded rice crop in July. Some months later the crop has recovered and he has a good yield. Traditional varieties would simply fail after such flooding.

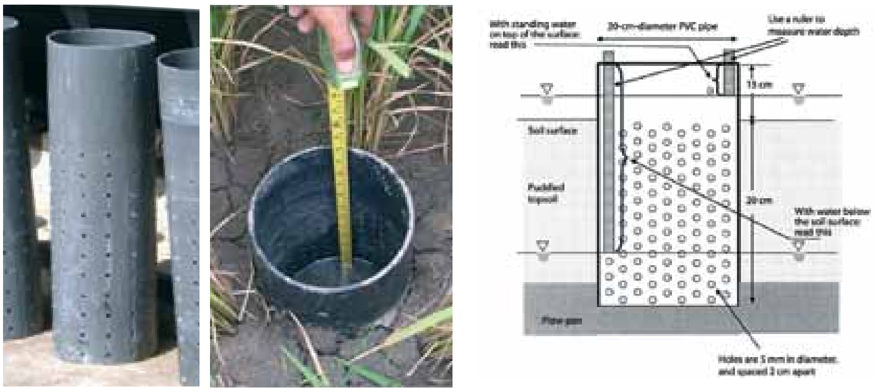
Similar work is also being done on salinity, temperature and drought tolerance, all using the rice genome sequencing work that went earlier.

Sustainability

So, the future of rice as a staple food seems assured. But, most of the world's rice is grown in intensive irrigated systems where two vital factors are large water supplies and the use of fertiliser. Is this system itself sustainable; that is, can it go on into the future as it is now?

IRRI set up experiments, starting in 1963, in which the land has been intensively cropped, more so than anywhere in the world. Yields have remained as high as can be expected. In fact, it was shown that the fields would go along very well even without fertiliser!

But what about water? It takes 500 litres of water to grow a bowl of rice but can it grow on less? Work has been done on this because water is becoming more and more scarce. Scientists have shown that the amount of water around the rice can be managed such that the irrigation requirement can be cut in half and the rice will grow just as well. The key is to make sure that farmers have a simple way to know when to irrigate and only do it when it is needed. The method used is called, in the Far East where the 'magic pipe' technique is being applied.



A magic pipe is a simple device which allows famers to irrigate rice only when it is needed, saving about 50% over traditional paddy field methods.

C3	C4	CAM
C3 because CO_2 is first incorporated into a 3-carbon compound.	Called C4 because the CO_2 is first incorporated into a 4-carbon compound.	Called Crassulacean Acid Metabolism (CAM) after the plant family in which it was first found (Crassulaceae) and because the CO_2 is stored as an acid before use.
Stomata open during day.	Stomata are open during the day.	Stomata open at night (when evaporation rates lower).
RUBISCO, the major photosynthesis enzyme, is also involved in the uptake of CO_2.	Uses PEP Carboxylase for uptake of CO_2 so CO_2 is be taken in very quickly, and delivered to RUBISCO. Photosynthesis takes place in inner cells (requires special anatomy called Kranz Anatomy).	The CO_2 is converted to an acid and stored during the night. During the day, acid is broken down and the CO_2 is released to RUBISCO for photosynthesis.
More efficient than C4 and CAM when cool and moist.	Photosynthesizes faster than C3 plants under high light/high temperatures because CO_2 is delivered directly to RUBISCO, not allowing it to grab oxygen and undergo photorespiration. Has better water use efficiency because PEP carboxylase brings in CO_2 faster and so does not need to keep stomata open as much (less water lost by transpiration) for the same amount of CO_2 gain for photosynthesis.	Better water use efficiency than C3 plants under arid conditions due to opening stomata at night when transpiration rates are lower (no sunlight, lower temperatures, lower wind speeds, etc.).

Three kinds of photosynthesis

There are in fact three kinds of photosynthesis, C3, C4 and CAM. Most plants are C3.

Plant science at work

Plants are at the base of all food chains, including those with humans. For half the world's population, the plant is rice. So plant science, and especially rice science, is one of the best ways to have an effect on people's lives as a scientist today. New projects include efforts to convert rice, a relatively inefficient C3 plant, into a much more efficient C4 plant (see Box) and to more fully sequence the rice genome. As Bob Zeigler, director of IRRI, puts it:

"By addressing the challenges of the very poorest people we are also addressing climate change issues of the future. You can do great science, you can make a huge difference to millions of people's lives, you can have a very satisfying career and you can make politicians very happy!"

Written by Gary Skinner, *based on a lecture by* Bob Zeigler, *Director of IRRI and delivered at the 2011 Gatsby Summer School at York University.*

Anne Chadwick

What causes the Aurora?

These giant curtains of light in the night sky are the aurora borealis.

Key words
aurora
magnetic field
spacecraft
solar wind

At night, around the Arctic and Antarctic circles, a spectacular light show fills the sky. These constantly moving curtains of light are the aurora borealis (in the northern hemisphere) and the aurora australis (in the southern hemisphere). Through the centuries, many cultures and civilisations have observed and recorded the aurora, one of the most beautiful natural phenomena on planet Earth.

***Anne Chadwick** describes how the aurora is created and how scientists are using spacecraft to unravel some of its remaining mysteries.*

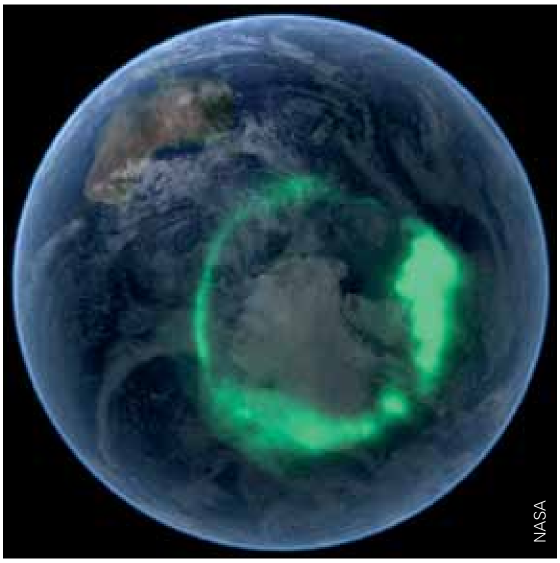
What do we know about the Aurora?

The most common colour of the aurora is green. However, the aurora can appear as a variety of colours. Views from space confirm that the auroras reach round the Earth at high latitudes in regions known as auroral ovals, centred on the Earth's magnetic poles.

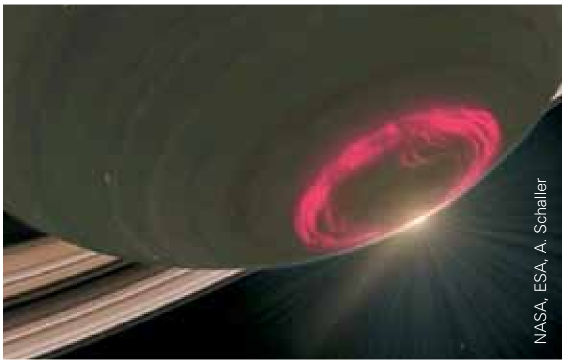
If there are low levels of solar activity, then the size of the auroral oval is fairly constant, and it is usually visible from the ground in Canada, Scandinavia and northern Russia for example.

The aurora moves to lower latitudes (towards the Equator) when the Earth's magnetic field is engulfed by a storm of particles and energy from the Sun. During a large geomagnetic storm, it may be possible to see the aurora in the United Kingdom.

Aurora is the Latin word for dawn. The plural in English is either auroras or aurorae.



The auroral oval of the aurora australis



Other planets with magnetic fields also have auroras, for example Saturn (pictured) and Jupiter.

Earth's magnetic field

The Earth has a strong magnetic field due to electric currents flowing in its hot interior. The electric currents exist in the molten metal outer core which has a temperature of more than 5000°C.

The Earth's magnetic field can be detected with a simple magnetic compass. In the UK, the compass points north, and also downwards into the ground at an angle. This is because the Earth's magnetic field is similar to that of a bar magnet, a simple dipole. The north magnetic pole is not in exactly the same place as the north geographic pole, and is slowly moving from northern Canada towards Russia.

The Earth's magnetic field is stable on timescales of hundreds of thousands of years, but the north and south poles have swapped places many times in its history.

The solar wind and Earth's magnetic field

The Sun's atmosphere – the corona – is so hot that its constituent particles 'boil off' into space, in a continuous stream known as the **solar wind**. This supersonic gale of ions and electrons blows away from the Sun typically at 450 km/s (1 million miles per hour!), but it can gust up to even higher speeds, perhaps 1000 km/s. Under normal circumstances, it takes 3-4 days for the solar wind to travel from the Sun to the Earth.

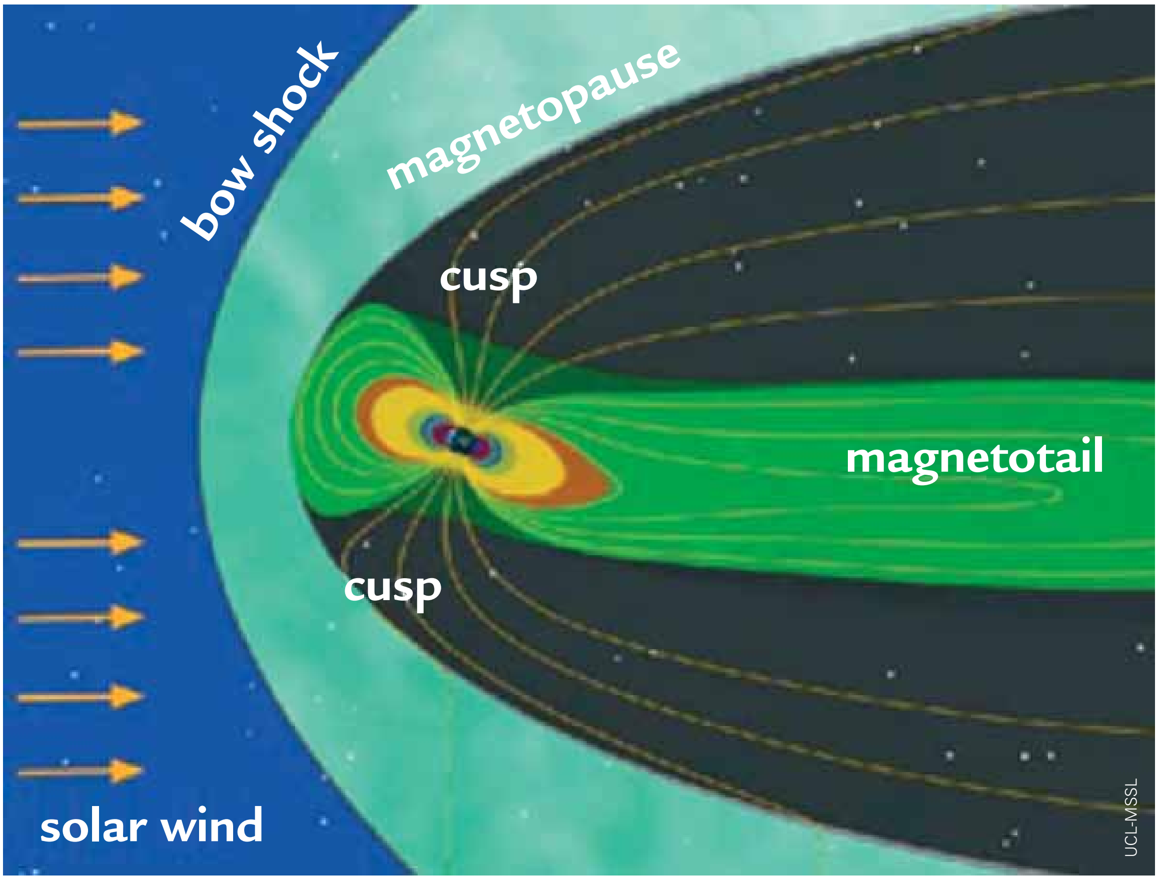
About 50 000 tons of solar wind flows past the Earth every day, carrying as much energy as humans use worldwide on Earth. The flow rate of the solar wind past the Earth is one hundred million billion times greater than the Amazon river!

The Earth's magnetic field extends into space and forms a protective bubble called the magnetosphere. Acting like a shield, it deflects the solar wind so that it passes around the Earth. The magnetosphere is largely invisible, and so it must be measured locally by satellites.

The solar wind pressure changes the shape of the Earth's magnetosphere, squashing it on the Sun-side and making a tail on the other side, like a wind-sock. At its closest point, on the side that faces the Sun, the edge of the magnetosphere is approximately 70 000 km away from you. On the side of Earth facing away from the Sun, it has been measured at least 25 times further away. In fact, no-one really knows how long this magnetotail is! The Moon's orbit passes through the magnetotail.

Most of the time, the solar wind cannot penetrate the Earth's magnetic field.. The bubble of the magnetosphere usually does a good job of protecting us from dangerous solar particles, but violent events on the Sun can break down the magnetosphere's protection. Coronal mass ejections, solar flares and solar energetic particles can cause severe space weather in the Earth's magnetosphere.

The Sun's activity follows an 11-year cycle. In the last few years, the Sun has been very quiet. However, the Sun's activity is increasing, with the next maximum due in 2013. We can expect more severe space weather as the Sun becomes more active.



The Earth's magnetosphere protects us from the solar wind

How the auroras are made

The auroral light emission occurs at roughly 100 km altitude, within the Earth's upper atmosphere, called the ionosphere. Energetic electrons crash down into the very thin air in the ionosphere and hit air particles (molecules and atoms), which become excited before releasing the energy they have gained.

Green and red auroras are both due to energy released as light from excited (energised) atomic oxygen ions. Blue light comes from singly charged nitrogen molecules.

Excited oxygen ions release energy as red light relatively slowly. If an excited ion collides with another atom or molecule, its excess energy will be shared and so no red light will be released. In the rarefied air between 100-200 km altitude molecules are far apart, collisions are rare and so this red light is more likely to be emitted. Green light is released much faster by oxygen, and at altitudes below 100 km where air is denser, there is sufficient time for this to be released before collisions happen. Hence red is often seen above green in the sky in an aurora.

The energy of the electrons that hit the air particles is also important. Less energetic electrons do not reach so deeply into the atmosphere and make high altitude red aurora. The most common energies produce green aurora. Occasionally, very energetic electrons produce a red aurora below the green aurora, down to 80 km.

The Cluster Mission

What causes the strange shapes and motion of the aurora? The answer to this may become clearer once the process that accelerates the electrons in the first place is better understood. Observations made by the European Space Agency's 'Cluster' Mission can help to provide answers.

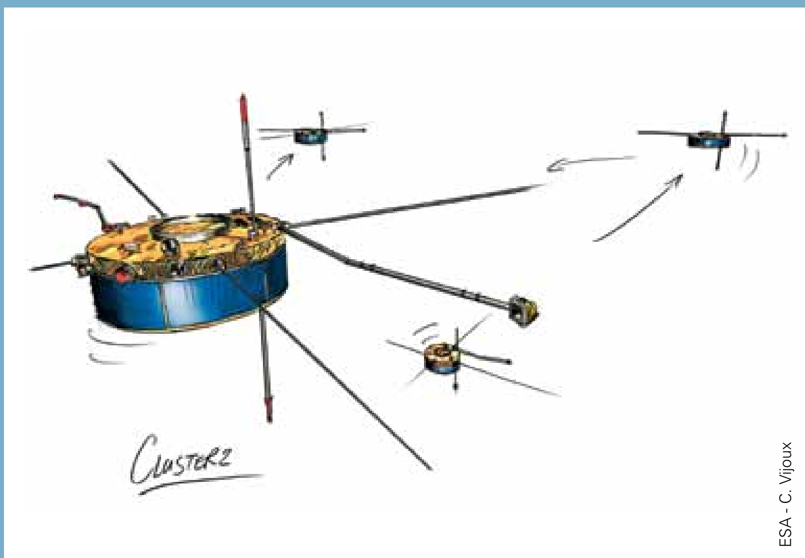
Cluster is a European Space Agency mission that investigates the Earth's magnetic environment and its interaction with the solar wind. Cluster consists of four satellites flying in formation through the Earth's magnetosphere and into the solar wind. Why four spacecraft? The four Cluster spacecraft fly in formation. Together, they can discover things that one spacecraft cannot.

One satellite can tell you about the magnetosphere at a single point. However, we need a three dimensional view to answer the big questions, like how the particles that create the aurora are accelerated. To get a 3D view, you need more satellites. The simplest 3D object is a tetrahedron (a triangular pyramid), so the Cluster mission has four satellites positioned so that they form a tetrahedral, three-dimensional observatory.

We cannot see the magnetosphere, so Cluster uses 11 scientific instruments on each spacecraft to 'touch', 'taste' and 'hear'. Cluster measures magnetic and electric fields, the solar wind and the ions and electrons in the magnetosphere.

Introducing the four spacecraft

The Cluster satellites were launched in the year 2000. More than 10 years after launch they are still making new and exciting scientific discoveries, travelling to different parts of the magnetosphere such as the auroral regions. In the next few years Cluster will complete a full set of observations over a whole cycle of solar activity.



This artist's impression of the Cluster satellites shows the long wire booms carrying instruments which make measurements of magnetic and electric fields in space.

Each Cluster spacecraft is 3m across and 1.3m high, with mass of 530 kg excluding fuel.

650 kg of fuel was originally carried, mainly for reaching the proper orbit. The remainder is needed to adjust the distance between the spacecraft at times through the mission.

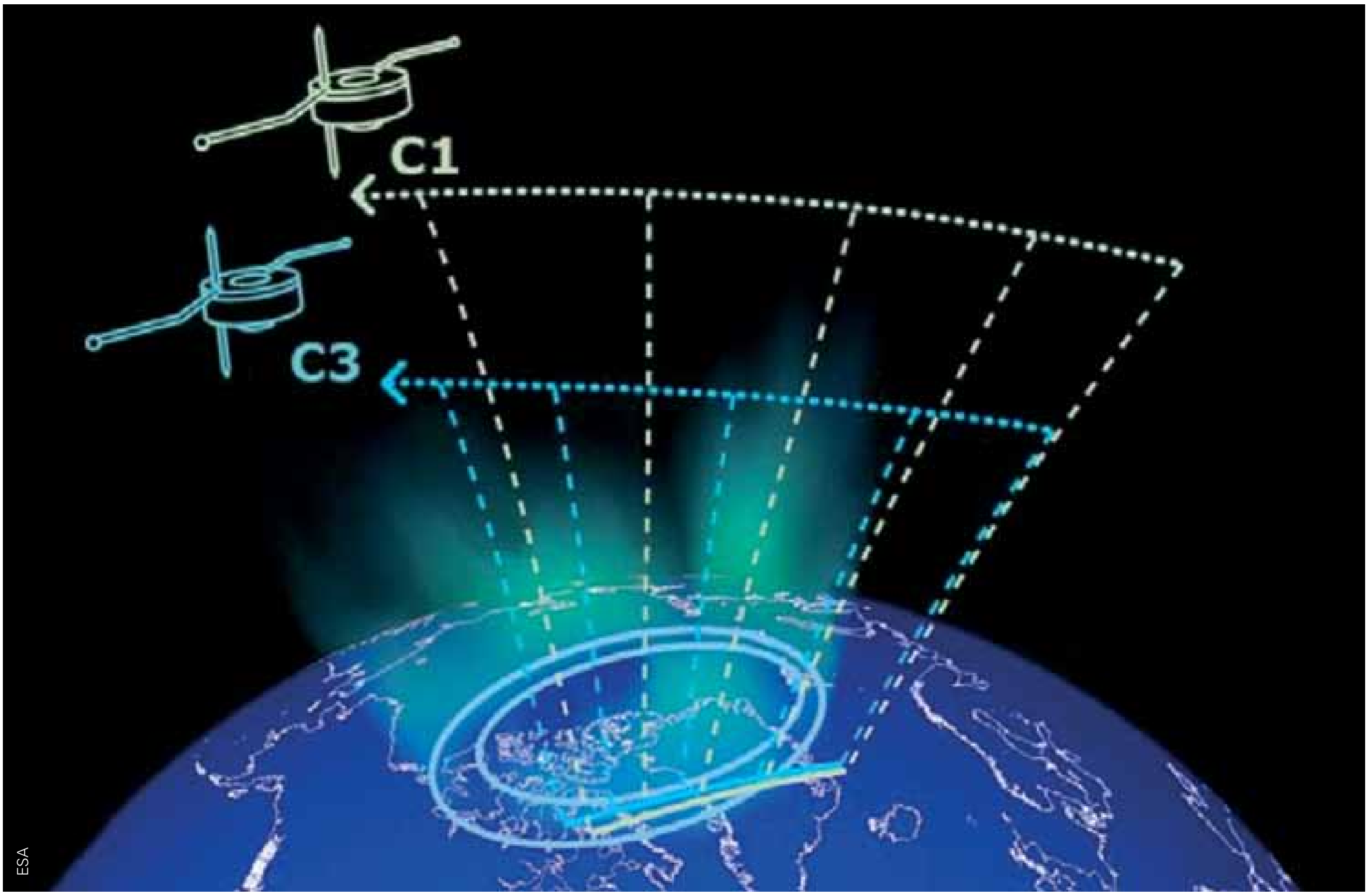
Power is provided by solar arrays, with batteries to provide power during eclipses.

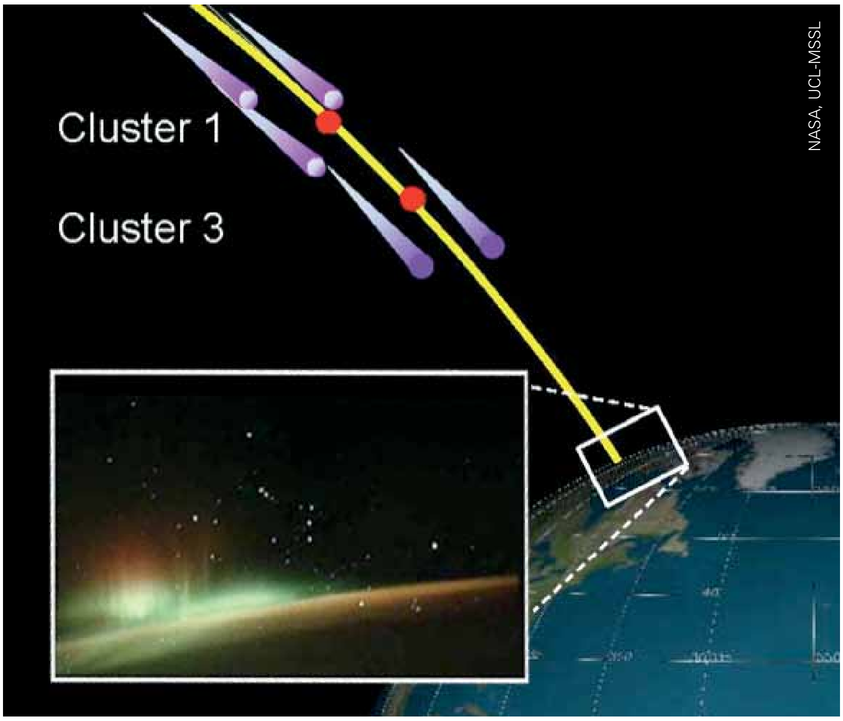
The spacecraft spin once every 4 seconds (15 revolutions per minute).

Two pairs of wire booms, each pair 88m long tip to tip, measure electric fields & plasma waves.

The design life of the spacecraft was 5 years; all the spacecraft still work after more than 10!

The UK plays a leading role in Cluster. Parts of the satellites were built in the UK, while scientists and engineers in the UK built several of the science instruments that are now flying in space. UK scientists and engineers are also responsible for helping to provide the satellites' science operations, and for ensuring that the data they collect is returned safely to Earth and properly stored. UK scientists have led many of Cluster's scientific discoveries.





These pictures show two of the Cluster satellites, C1 and C3 (red dots), flying above the aurora at different heights on a single magnetic field line (yellow). By comparing measurements taken by the two spacecraft, Cluster scientists can understand better the conditions which cause electrons to be accelerated.

What can we discover with Cluster?

Scientists have developed a diverse set of theoretical ideas about what accelerates auroral electrons and thus produces the aurora. Cluster's unique observations will allow the first tests of these ideas.

To test theories about the aurora, it is best to fly satellites above the aurora where they can measure the properties of the electrons that end up creating the aurora.

Cluster will discover where these electrons are accelerated so that they have enough energy to make the aurora. We need at least two spacecraft at different heights on the same magnetic field line to tackle this problem.

When the acceleration region or regions are identified, Cluster can help to tell us what sort of process causes the acceleration there.

To do this, in 2006 the shape of Cluster's orbit was allowed to slowly change, so that the lowest point of the orbit moved closer and closer to Earth. The four Cluster spacecraft are now in exactly the right place to measure electrons just above the aurora.

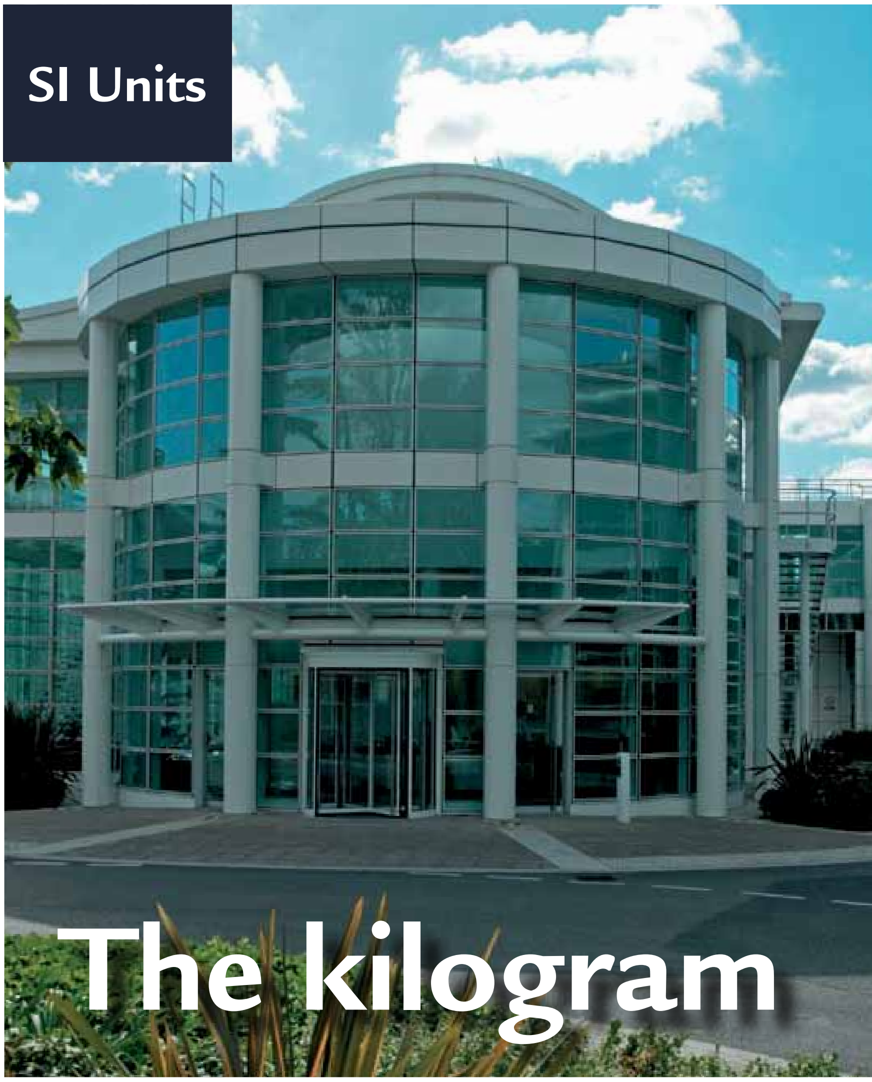
Cluster scientists are using this new data to explore the aurora, and learn how electrons are accelerated into the atmosphere.

Look here!

Is there going to be an aurora near you? To find out, visit: *http://aurorawatch.lancs.ac.uk*

More about the Cluster mission at: *sci.esa.int/cluster*

Ms Anne Chadwick is a space scientist at the Rutherford Appleton laboratory, and has worked on the coordination of science operations on the Cluster mission for 10 years.



The kilogram

The International Prototype Kilogram kept in the International Bureau of Weights and Measures (Bureau international de poids et mesures) in France.

The National Physical Laboratory in Teddington, Surrey, home of the UK's standard measurement service.

What is a kilogram? Two bags of sugar? 1000g? The kilogram is a unit of mass, a measure of how difficult it is to change an object's speed. It is also one of the base units of the SI system (the International System of units).

At the moment, the kilogram is formally defined as being equal in mass to the International Prototype Kilogram (IPK). This was made in Britain in 1879 and is an alloy of 90% platinum and 10% iridium. It is stored in a vault in Paris, France, and is a cylinder roughly the size of a golf ball.

Platinum was chosen because it is unreactive and very dense. The iridium increases its hardness. A consistent kilogram is vital because so many other units are derived from it.

Derived units are calculated by multiplying and dividing the base units. For example, the unit of speed is the metre per second, m/s.

Recently, however, the platinum kilogram was found to have changed in mass by about 50 micrograms. The cause of this is unclear – it could be that gases such as oxygen which were incorporated into the kilogram when it was formed have leached out; it could be that the surface has slightly corroded. It is uncertain if the kilogram has gained or lost weight – in either case it is by about as much as the mass of a grain of sand. This might not sound like much, but it is enough to cause chaos to precise calculations in a range of laboratories and engineering applications.

The seven base units in the SI system

kilogram (for mass)
metre (length)
second (time)
ampere (electric current)
kelvin (temperature)
candela (brightness)
mole (amount of substance)

The kilogram needs to be re-defined by something which is not going to change over time. In late 2011, the General Conference on Weights and Measures agreed to use the Planck constant to calculate the value of the kilogram. The Planck constant relates the energy of a photon (a packet or quantum of eradiation) to its frequency.

The change will not come into effect until 2014, and before then experiments will be conducted to ensure that the Planck constant can give accurate results to within 20 parts per billion.

Most users will not even know that the kilogram has changed, but it will allow the necessary precision for those most accurate calculations.

Vicky Wong is Chemistry editor of CATALYST.

What's in a cell?

A transmission electron microscope in which electron beams go through an ultra-thin specimen. The image is seen through the binoculars or on the screen.

Biologists classify living organisms according to the two-part, five-kingdom system: two parts (Prokarya and Eukarya) with five kingdoms (Plants, Animals, Protoctista, Prokaryota and Fungi). This scheme has gradually changed as we have learned more about the cells of which living organisms are made.

Antonie van Leeuwenhoek was a Dutch microscopist. In 1674, he sent the Royal Society evidence for the existence of single celled organisms. This led to the proposal of the third kingdom, the Protoctista.

Until the 1930s, our understanding of the interior of the cell was limited by the resolving power of the light microscope; this in turn is limited by the wavelength of light. Any object with a diameter smaller than 0.28 micrometres (1 μm = 10^{-6} m or 0.000 001 m) will be blurred or invisible. Things changed with the invention of the electron microscope, which can see objects as small as 1 nanometre (there are 1 000 nm in a micrometre, so a nanometre is 0.000 000 001 m!). This high resolution allows scientists to distinguish between large molecules.

The electron microscope showed clearly that some cells have a nucleus and others do not. This led Copeland in 1938 to propose four kingdoms, with the non-nucleated forms becoming the Prokaryota. Finally, in 1969, Robert Whittaker moved the fungi into a fifth Kingdom.

The electron microscope has revolutionized the way we view cells. Millions of pictures (called electron micrographs) have been taken, often of small parts of cells. The picture on pages 10-11, however, shows two whole cells. They are secretory cells, found in the pancreas and called acinar cells, and they show most of the features that have been revealed as common to cells in the domain Eukarya.

Organelles

A eukaryote cell is one that contains complex structures enclosed in membranes. These structure are referred to as organelles. The full list of organelles found in eukaryotes is :

mitochondria

chloroplasts and other plastids (only in plants and plant-like organisms)

lysosomes

nucleus

rough and smooth endoplasmic reticulum

Golgi body

vacuoles

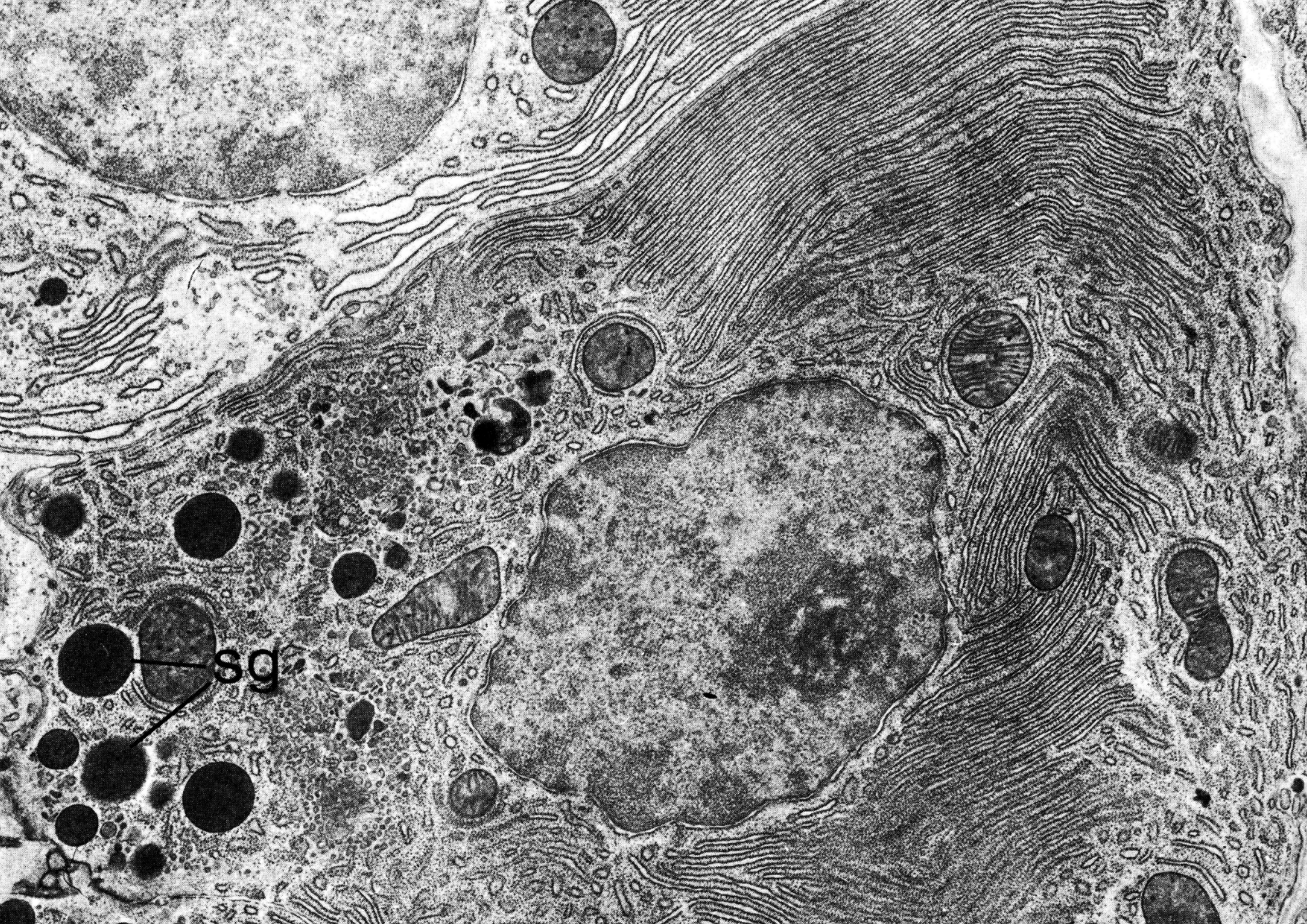
peroxisomes

secretory granules of various kinds

cilia and flagellae (undulipodia)

Most of these organelles are visible in the large picture, although some of them are not very clear (see the labeled diagram on page 13). It should be remembered that a transmission electron micrograph such as this is a picture of a very thin section, and so some things might simply be missed. For example, if you cut many thin slices through a hard-boiled egg, many of them would not contain the yolk. Scientists build up a full picture of a cell by putting together hundreds of such thin slices.

The Big Picture on pages 10-11 shows an electron micrograph of two acinar cells from a pancreas. See page 13 for the key to this image.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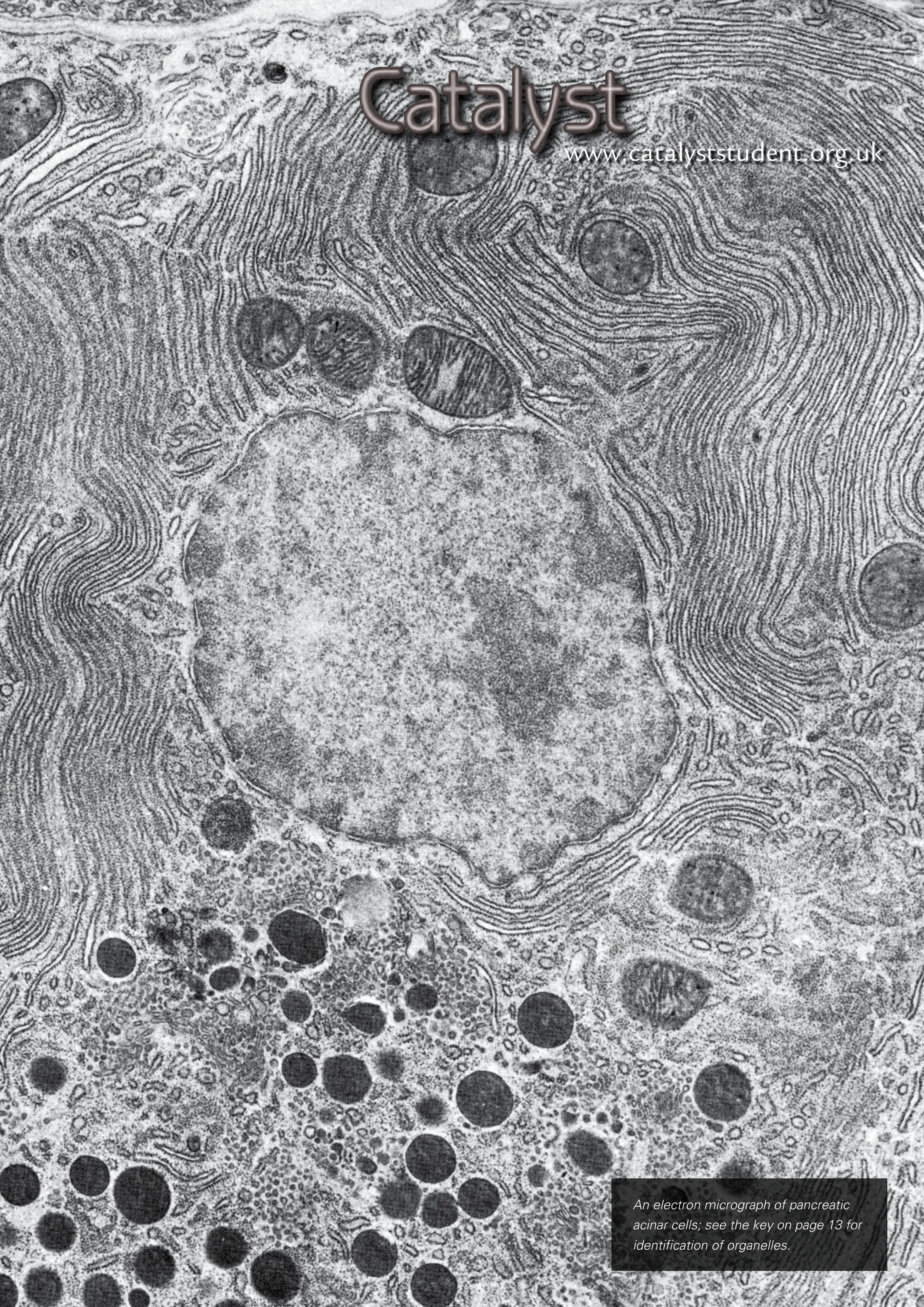


An electron micrograph of pancreatic acinar cells; see the key on page 13 for identification of organelles.

Lynn Margulis

Where did all the organelles come from?

In 1905 the botanist Konstantin Mereschkowski put forward the idea of symbiogenesis, suggesting that large complex cells (like the eukaryotes) evolved from the coming together of less complex ones, like the prokaryotes. This idea was not taken very seriously until it was shown that chloroplasts and mitochondria have their own DNA. By this time, DNA had been shown to be the hereditary material of organisms, so it seemed that these organelles might at one time have been separate bacteria, capable of reproducing themselves.

Then, in 1967, biologist Lynn Margulis published a paper entitled *On the origin of mitosing cells* in which she proposed that at least three of the organelles, the mitochondria, plastids (such as chloroplasts) and the basal bodies of flagellae, were themselves once free-living (prokaryotic) cells, and that they had at some time in the distant past merged with or been engulfed by other cells. Again, it took some considerable time for this set of ideas to be widely accepted but it is now part of accepted wisdom amongst most biologists.

As with all such ideas or theories, its acceptance has been won through the accumulation of evidence for it. Margulis's story is, itself, a triumph of determination over orthodoxy, well summed up by evolutionary biologist Richard Dawkins in 1995 when he said:

"I greatly admire Lynn Margulis's sheer courage and stamina in sticking by the endosymbiosis theory, and carrying it through from being an unorthodoxy to an orthodoxy. I'm referring to the theory that the eukaryotic cell is a symbiotic union of primitive prokaryotic cells. This is one of the great achievements of twentieth-century evolutionary biology, and I greatly admire her for it."

Sadly, Lynn Margulis died in November 2011, but perhaps this will prompt someone to write about the epic struggle she had to have her wild theory, as it was seen at the time, accepted. This, in itself, will be a classic example of how scientific ideas change.

Gary Skinner is Biology editor of CATALYST.

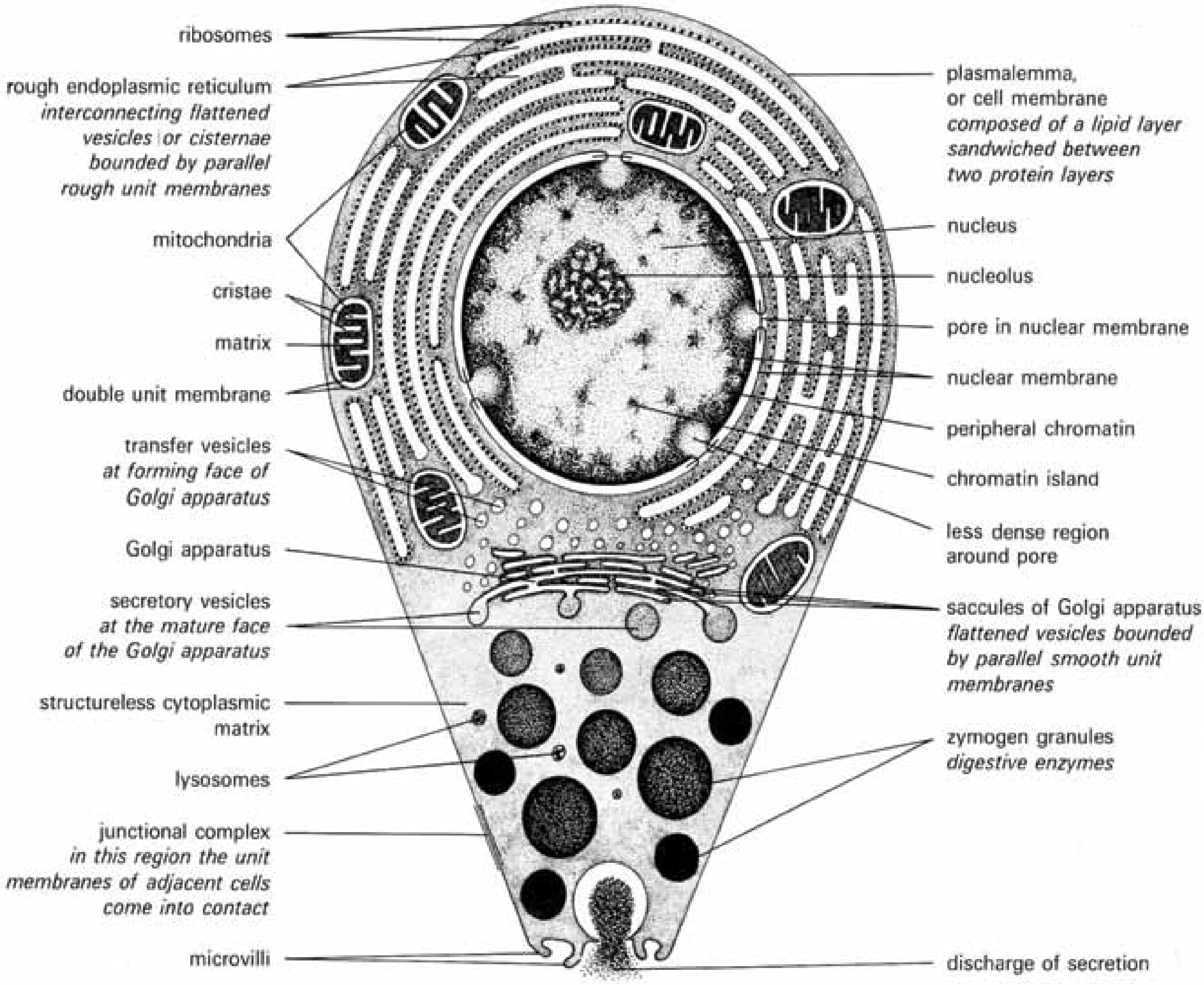
Did some organelles come from bacteria?

Most biologists now believe, as Lynn Margulis did, that mitochondria and plastids were originally free-living bacteria that came to live symbiotically in other cells. Here is some of the evidence for the 'endosymbiont' theory.

Mitochondria and plastids:

- contain DNA that is different from that of the cell nucleus and that is similar to that of bacteria (both in size and circular form);
- are surrounded by two or more membranes, and the innermost of these is similar to a bacterial cell wall;
- are formed only through a process like binary fission seen in bacteria;
- have ribosomes, proteins, enzymes and transport systems similar to those of bacteria;
- are similar in size to bacteria.

This electron micrograph is the same as the larger image shown on pages 10-11. A single acinar cell from the pancreas is outlined in red. You should be able to relate most of the structures in the cell to the drawing of an acinar cell below.



David Sang

They're getting ready for a Zombie invasion

A character from the TV series The Living Dead.

Tins and packets of food, bottles of water, blankets and medicines ... many Californians are storing these items, ready for the zombies to arrive. And they are doing this under government advice. What's going on? Are the zombies – the living dead – really on their way? Or has everyone gone mad?

Key words

earthquake prediction

tectonic plates

seismologist

The true reason is neither of these. California is in an active earthquake zone. The US Government wants people to be ready for the next big shock, but few people have followed the official advice to be prepared for a major quake. So scientists at the Centers for Disease Control, the body responsible for ensuring public health in the US, came up with a new approach.

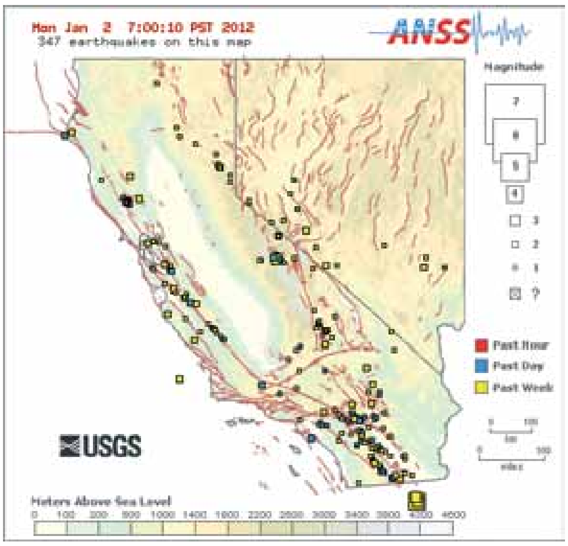
An emergency survival kit, useful in the even of an earthquake, a hurricane of an attack by zombies.

They devised a website warning the citizens of California that a zombie invasion was possible. They recommended preparing a survival kit – food, water, bedding etc. – and many people have followed their advice.

Of course, the survival kit is just what you need if an earthquake strikes, and many more people have now prepared their kit. Of course, most of these people know that there won't be a zombie invasion, but the idea was enough to get them motivated.

Earthquakes in California

California is well-known as a site of earthquakes. The map shows the sites of recent quakes in the state.



Earthquakes recorded in California and (upper right) Nevada during the last week of 2011. The magnitude of each quake is indicated by the size of the square.

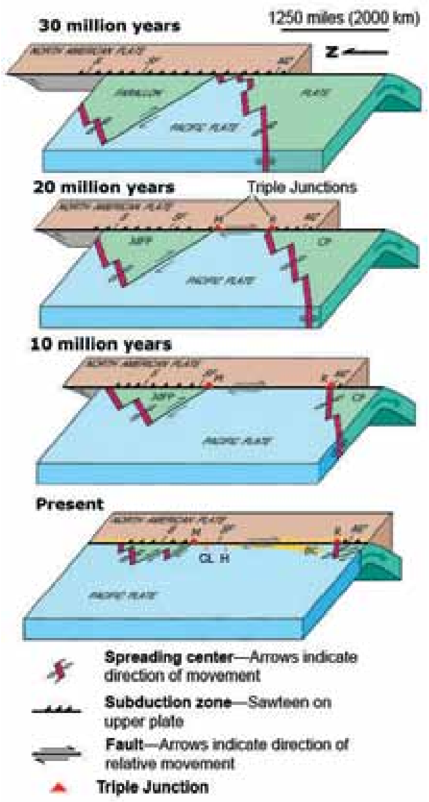
Earthquakes are measured on the the Moment magnitude scale; magnitude 4 is a minor quake while 8 or 9 can be devastating. San Francisco was badly hit by an earthquake in 1906. Its magnitude has been estimated as around 8.0, but modern measuring instruments were not available at that time.

Soldiers among the ruins of San Francisco after the 1906 earthquake. Much of the damage was done by fires which broke out afterwards.

Fault lines

Why does California experience such frequent earthquakes? The answer lies in its situation at a point where tectonic plates meet. The Pacific Plate is pushing towards the northwest so that it is sliding past the North American Plate. At the same time, it is pushing two minor plates down under the North American Plate.

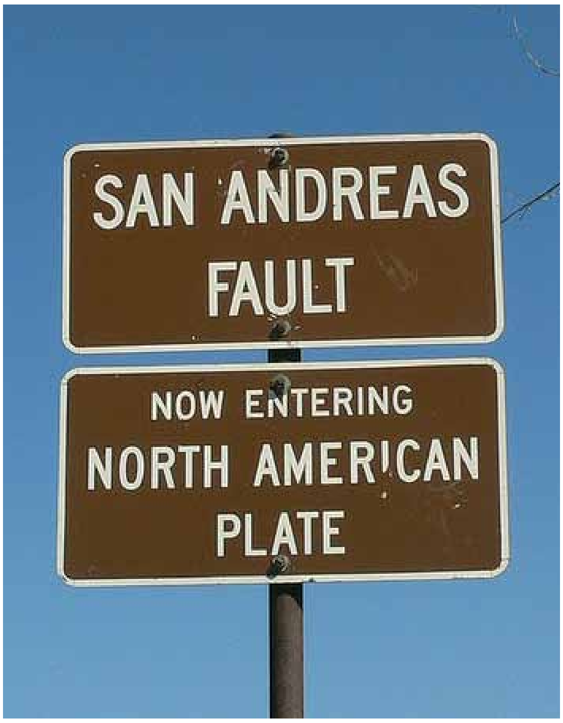
This is a process that takes millions of years. The diagram shows how the plates have moved over a period of 30 million years. You can see that two small plates, the Juan de Fuca and Cocos plates (JdFP and CP), have largely disappeared in this time.



30 million years of Californian plate tectonics.

The San Andreas fault lies along the line where the two large plates meet. As the two plates slide past each other, there are periodic slips along the fault line. Each accompanied by an earthquake. You can see the line of the San Andreas fault on the map; it is shown as a red line running parallel to the coast along the length of California. You can also see that there are many other fault lines in the area.

California is unusual in that it is one of the few places where major fault lines like this can be seen on the earth's surface; most are under the sea. The roadsign shows that, by crossing the fault line, you are travelling from one tectonic plate to another.



A roadsign indicating that you are leaving the Pacific Tectonic Plate.

Predicting earthquakes

In 1989, a segment of the San Andreas fault ruptured, causing major damage in northern California. The magnitude was 6.9 on the the Moment magnitude scale; 63 people were killed and thousands injured. It occurred in a region of the San Andreas fault where pressure was known to be building up. However, it wasn't possible to predict when the quake would happen.

Seismologists (scientists who study earthquakes) are sure that one day, before too long, another major quake will strike California. Unfortunately, it is unlikely that they will be able to give much warning, if any.

As the two tectonic plates rub past one another, pressure builds up in the rocks deep underground. This pressure may be released in a number of small shocks or in one single, giant release of energy, but it is impossible to predict which of these will happen. Often there is no advance warning that a shock is about to occur. That's why it is desirable to be prepared, with a kit of emergency supplies kept in an accessible place in the home.

An official of the US Centers for Disease Control gives out information, encouraging people to be ready for the next big earthquake.

Some psychics claim to be able to predict earthquakes; usually, they announce afterwards that they saw it coming. The US National Earthquake Prediction Evaluation Council asks those who claim to be able to predict earthquakes to give full details, including where, when, how big and how probable the event is. So far, no-one has convinced the council that they have found a reliable way of making such predictions.

Are the zombies coming?

The word zombie comes from a southern African language, and refers to a dead person who has been brought back to life by witchcraft. A zombie has no consciousness but can respond to instructions.

In popular western culture, the idea of the zombie has been popularised by the film *Night of the Living Dead* (1968). Many people have taken part in 'zombie marches' where everyone dresses up as a zombie and parades around town.

A poster for the cult film

Although the idea of the zombie is still an active part of some people's religious lives, no scientist would accept it as an idea worth studying. However, the popular appeal of the zombie is something which might be studied.

David Sang is Physics editor of CATALYST.

Cracks in the Earth's surface in Baja California, part of Mexico, caused by earthquake activity along a fault line.

Look here!

The British Geological Survey (*www.bgs.ac.uk*) has useful information about earthquakes and how they are detected; look at their Discovering Geology pages.

Seven billion – and counting

Gary Skinner

On the 31st of October, the United Nations (UN) designated little Danica May Camacho, born in the Philippines and weighing 5.5 lbs (2.5 kg), as the world's seven billionth human.

In this article, ***Gary Skinner*** *considers the possible future for Danica May and her fellow citizens of planet Earth, and wonders whether human activity may lead to a mass extinction event comparable to those in the distant past.*

Key words
population
human impact
mass extinction

Declared the world's 7 billionth human by the UN, Danica May Camacho lies in her mothers arms in a hospital in Manila, Philippines on 31st October 2011. She received a cake decorated with '7B Philippines' and a voucher for some free shoes.

But with a daily birth rate of over 350 000 – 4 per second - it is impossible to be sure she was '7B'. Indeed, when the UN secretary Kofi Annan visited Fatima Nevic in Sarajevo on 12th October 1999 to proclaim her newly born little boy as the 6 billionth human, it is now thought 6 billion had actually been passed more than a year earlier. However, this symbolic event was designed to focus attention on the growth of world population and the same is true now.

With those 350 000 births but only about 155 000 deaths, the population is growing at over 200 000 per day, or about 73 million a year, more than the entire UK population. But is there really a 'population problem'? How many people can the Earth support?

Human impact

It should be appreciated that there is more to the extent of the pressure people put on the Earth's resources than just numbers. Some people consume more than others; on average, people consume more today than in the past. We also must consider affluence (how much money each of us has) and technology. These constitute the main forces driving consumption. So, human impact I equals population P times affluence A times technology T, or

$$\textbf{human impact index } I = P \times A \times T$$

GDP (Gross Domestic Product) is a good measure of affluence and the number of patent applications is a measure of technology. The table on the next page shows the data for the years 1900 and 2011. In this time interval, the world population increased by a factor of 4 but the human impact index increased more than 1400 times.

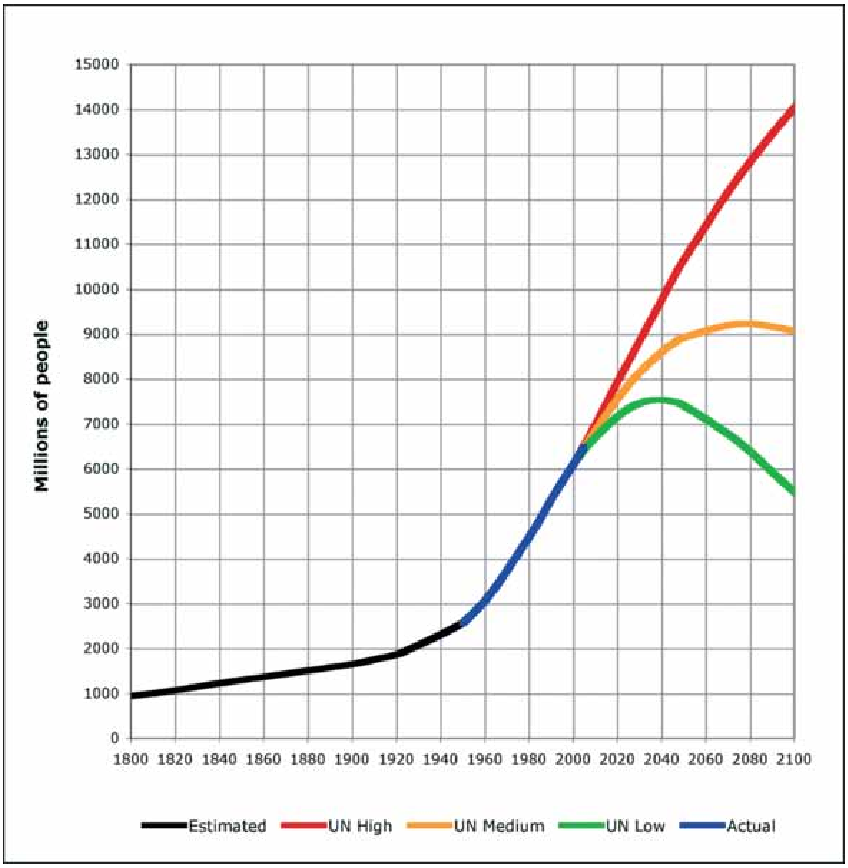
On the other hand, much of the technology and the use to which affluence is put may help with the challenge of coping with the increase in population. As discussed in the article on pages 1-3 of this issue, world rice yield per hectare has been quadrupled in the last fifty years due to improvements in farming technology of all kinds.

Year	1900	2011
World population	1.8 billion	7 billion
GDP (at today's prices)	$2 trillion	$55 trillion
Patent applications	141 000	1 900 000
Human impact index	507 600	731 500 000

How has the human impact index increased since 1900?

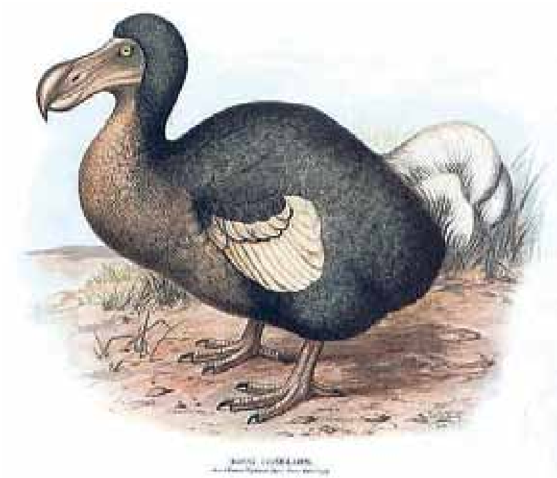
What of the future?

The UN constantly revises and refines its estimates for population statistics. The highest estimate suggests there may be 14 billion people alive by 2100, but the lowest predicts a decrease, back to 6 billion. GDP is expected to double by 2020 but after that it is hard to be at all sure, and who knows about what new technology will arrive! It is certain, though, that the impact will increase for many more decades yet, as population growth in the medium term and the desire by all to be better off are virtually unstoppable forces.

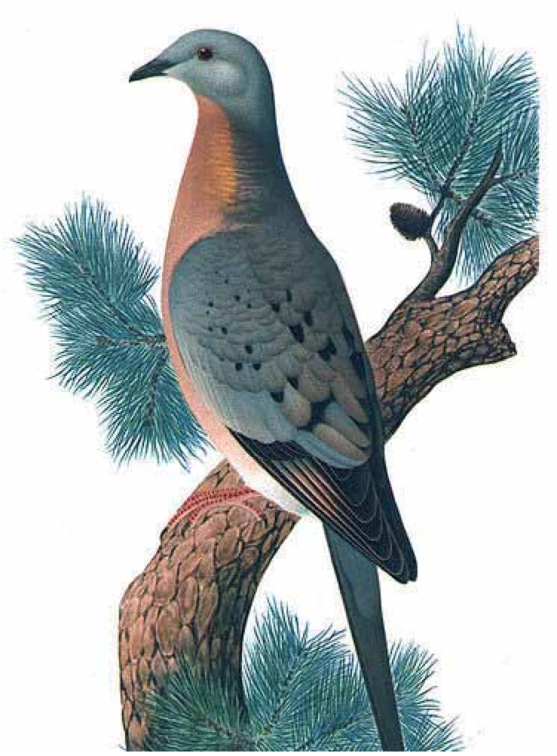


There are many uncertainties in estimating human population changes over the next century, as shown in this graph derived from a UN report.

Will thousands of today's species like the gorilla go the way of the dodo and the passenger pigeon and be labeled 'cause of extinction - Homo sapiens'? Then, all we will have left will be paintings and stuffed animals, like the famous Guy the Gorilla from London Zoo, who died in 1978.



The dodo



The passenger pigeon

Guy the Gorilla

Some believe that the human impact is already as significant as major events of the past, like those that led to the extinction of the dinosaurs 65 million years ago (the so-called K-T or end-Cretaceous event, probably caused by a meteorite) or the largest extinction event of all, the Permian-Triassic or end-Permian event (sometimes simply called the Great Dying) which wiped out 96% of all marine species and 70% of those on land 250 million years ago.

Such events have left traces in the rocks, studied by scientist called stratigraphers. Suggestions for the causes of these events usually involve at least some catastrophic events (see the chart opposite). Five such major extinctions are known to have occurred in the last 500 million years.

Many believe that we are now in the middle of a sixth such extinction and the cause is human beings, through their numbers and their desire for goods, travel and so forth. Nobel prize winning chemist Paul Crutzen has coined the term Anthropocene to describe this new geological age, or epoch, marking the end of the Holocene which started at the end of the last ice age 11 500 years ago. It will be millennia before future stratigraphers will see the traces of the Anthropocene in the rocks. However, more and more present day scientists are convinced that they will identify an 'end-Holocene event', and put it all down to *Homo sapiens*.

Gary Skinner is Biology editor of Catalyst.

Name of event and when	Effect on life	Possible causes
End-Ordovician, 440 mya (mya = millions of years ago)	Nearly 60% of genera, ranking second to end-Permian.	Possibly a super-continent (Gondwana) drifting over the South Pole leading to massive sea level fall, eliminating many habitats. Some suggest a massive gamma ray burst from a hypernova (exploding star), but there is little evidence for this.
Late Devonian, 360 mya	About 70% of species.	Possibly asteroid impact. A huge increase in plants, so-called greening of the Earth, may have removed carbon dioxide leading to very significant cooling.
End-Permian ('the great dying'), 250 mya	96% of marine and 70% of land species lost.	Possibly a sequence of linked events, a massive eruption in Siberia followed by release of carbon dioxide and methane leading to global warming itself leading to removal of oxygen from the oceans.
End-Triassic, 205 mya	Over 50% of genera including large amphibians lost, allowing the rise of the dinosaurs.	Not really understood. Climate change? - but this does not explain its suddenness. Asteroid impact? - but no known crater coincides. Massive volcanic eruptions have also been suggested.
End-Cretaceous or K-T, 65 mya	75% of all species lost, including non-avian dinosaurs.	Large asteroid hitting Yucatán peninsula, Mexico.
End-Holocene, already under way?	Outcomes unpredictable.	Activities of one dominant species, ***Homo sapiens***?

Mass extinctions of the past

Scientists have gradually gathered evidence of past mass extinctions, when large numbers of plant and animal species have been wiped out. This evidence comes from the fossil record. It's harder to explain why these extinctions occurred – they may have arisen from external causes (such as a collision with an asteroid), or from changes on Earth itself.

An artist's impression of an asteroid speeding towards the Earth. Such asteroid impacts may have had a hand in some of the five major extinction events of the geological past.

A fossil trilobite, a marine arthropod, from Canada. All species of trilobite disappeared in the end-Permian extinction, 250 million years ago.

Vicky Wong

Marie Curie
A life of discovery

Key words
Marie Curie
radioactivity
radiation
Nobel Prize

Marie Curie in 1903 when she was awarded the Nobel Prize in Physics

Marie Curie won two Nobel Prizes, the only woman to have done so. She is still the only person to have won awards in both Physics and Chemistry. She has both an element in the periodic table and a cancer hospice charity named after her. In this article, ***Vicky Wong*** *looks at her achievements and explains why she is still remembered today, nearly 90 years after she died.*

From Poland to Paris

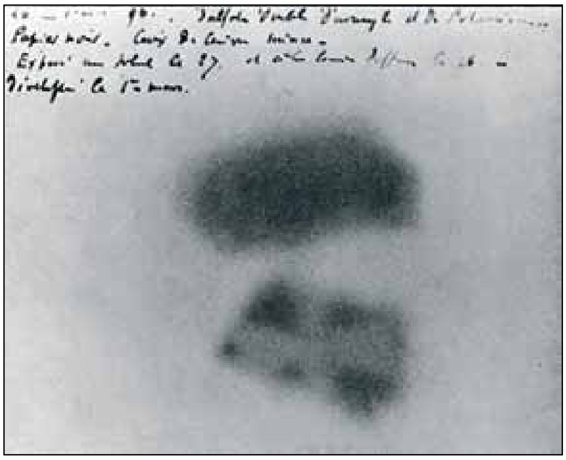
Marie Curie was born in Poland in 1867. Her family were not wealthy. Her parents were both teachers and ensured that she had a good education. However, advanced scientific training was not possible for women in Poland, so she worked as a governess before going to Paris in 1891 aged 24.

Marie had been away from her studies for 6 years. She wrote:

'It was like a new world opened to me, the world of science, which I was at last permitted to know in all liberty.'

After two years she took her degree in Physics with the highest marks of any candidate and the following year came second in a degree in mathematics. During this time, she met physicist Pierre Curie. He was 8 years older and already had an international reputation; they married in 1895.

1895 was the year in which X-rays were discovered. A year later, Henri Becquerel discovered that uranium emitted a new type of invisible radiation.



The photographic plate produced by Henri Becquerel to demonstrate the existence of radioactivity

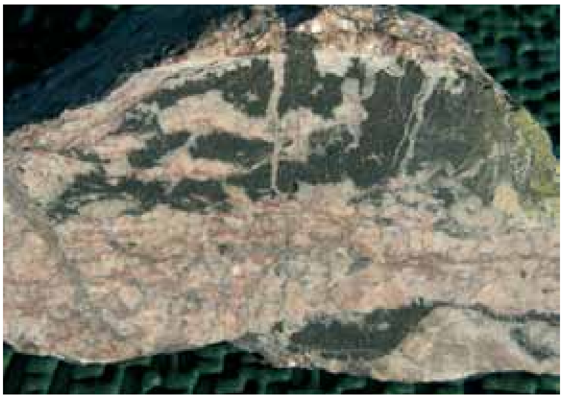
Marie Curie decided to study this, and after only a few days she discovered that the element thorium gives off the same rays as uranium. She called this phenomenon 'radioactivity'.

Marie also discovered that the strength of radiation did not depend on the particular compound that was being studied – it only depended on the amount of uranium or thorium present. Usually, chemical compounds of the same element have very different chemical and physical properties. For example, sodium chloride is table salt; sodium chlorate (I) is bleach. Marie concluded that the ability to radiate did not depend on the arrangement of atoms in a molecule and therefore it must be linked to the atom itself.

Are atoms divisible?

This idea was completely revolutionary and is considered to be her most important contribution to Physics. At the time, atoms were thought to be the smallest unit of matter and indivisible. Marie then found that, of the known elements, only uranium and thorium gave off the radiation.

Marie's next idea was to study pitchblende, a natural ore that contains uranium and thorium. This was a brilliant idea; she found that pitchblende was four to five times as radioactive as expected from the amount of uranium present. She hypothesised that a new element was in the ore which was even more active than uranium.



A uranium ore showing pitchblende (black) and dolomite (red).

By 1898, she and Pierre had evidence for the existence of two new elements that they suggested be called polonium, after Marie's native country, and radium. In order to be certain that they had indeed discovered new elements, they needed to produce them in reasonably large amounts and determine their atomic weights. They obtained tonnes of material from the spoil heaps of a mine and set about purifying it.

To do this they needed space. The principal of the school where Pierre worked offered them a large shed. Marie carried out chemical separations, processing 20 kilos of raw material at a time. She wrote:

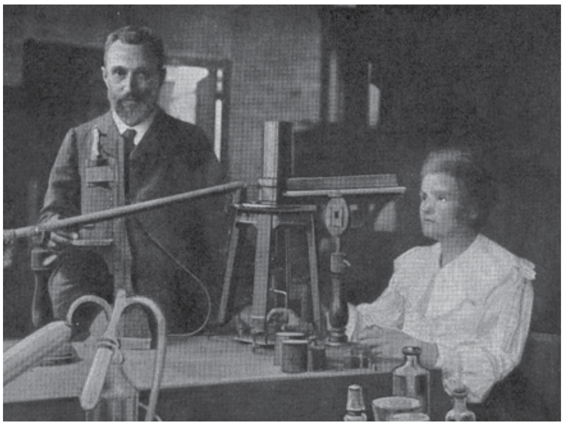
'Sometimes I had to spend a whole day stirring a boiling mass with a heavy iron rod nearly as big as myself.'

The shed was not ideal. A visitor described it as a cross between a stable and a potato shed. Eventually, after thousands of crystallisations, Marie had purified several tonnes of ore to produce 0.1 g of radium chloride. She determined radium's atomic weight as 225. When she presented her findings, the examination committee said that it was the greatest scientific contribution ever made in a doctoral thesis.

Poor health

In 1903 the Curies were jointly awarded the Nobel Prize for Physics with Henri Becquerel for their research into radioactivity. Their health was poor, however. Both were tired and Pierre was in pain from his legs, which shook. Both had scarred hands. Doctors suggested their symptoms were linked to the draughty shed and the long hours they worked, not to the radioactive materials they studied.

Pierre Curie died in 1906 before he ever had a real laboratory to work in. In 1908 Marie was appointed Professor at the Sorbonne University in Paris. There she isolated pure metallic radium.



Pierre and Marie Curie in their laboratory

In 1911 she was awarded the Nobel Prize for Chemistry for her work on radium and polonium.

During the First World War, Marie Curie was actively involved in developing the use of radiation for treating soldiers. She installed radiation equipment in field hospitals, trained young women in simple to use it and taught doctors how to interpret the results. She even drove a radiology van. The radiation she used came from glass tubes containing radon gas, an emitter of gamma radiation, similar to X-rays.

Marie Curie died of leukaemia in 1934. She was truly a pioneer of modern science and blazed a trail along which many women, including her daughter and granddaughter, have followed.

Vicky Wong is Chemistry editor of Catalyst.

The Radium Institute which housed Marie Curie's laboratory from 1914 to 1934. This is now a museum where you can see Marie Curie's laboratory, office and original equipment.

Look here!

For further information on Marie Curie and her work: *http://www.aip.org/history/curie/contents.htm*

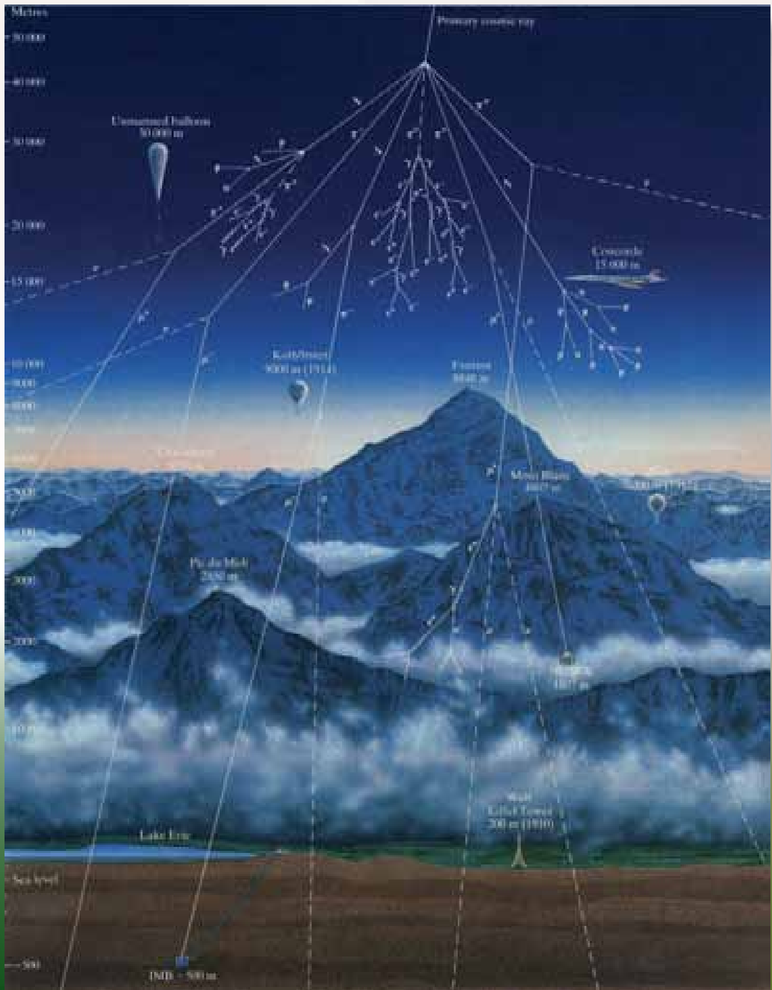
For two silent video clips of Marie Curie: *http://tinyurl.com/cfo7rqy*

Going bananas about radioactivity

Building materials are radioactive. This rock contains dinosaur fossils which are more radioactive than the surrounding rock. Typical dose: 0.35 mSv per year.

Bananas are radioactive. They contain potassium-40, a radioactive isotope that emits beta and gamma radiation. If you eat one banana a day, your annual exposure to radiation will increase by about 0.035 millisieverts (mSv). Other radioactive foodstuffs: kidney beans, brazil nuts, peanut butter and coffee. Typical dose: 0.27 mSv per year.

In a bone scan, the patient is injected with radioactive material. The radiation reveals the state of their bones. Typical dose: 3.5 mSv.



Cosmic rays are radiation from space. They were discovered in 1910 when Theodor Wulff measured more radiation at the top of the Eiffel Tower than at the foot. Typical dose at sea level: 0.25 mSv per year.

Radioactive radon gas seeps up from underground and we breathe it in. Marie Curie drove a mobile clinic which used gamma radiation from radon to X-ray soldier's injuries in WW1. Typical dose: 1.3 mSv per year