CATALYST

Edition 31

In this issue:

Welcome

Welcome to another edition of Catalyst - aimed at young people, we're proud to bring you cutting edge research that sparks debate.

This edition we've got articles on: Dr Emily Grossman inspiring the future generation as a science communicator, reducing waste through green chemistry, the story behind genetics, climate change, saving lives through transplants, how we find out whether we are alone in the universe and antimatter.

We hope you enjoy this edition. If you have any ideas for future topics you'd like to see covered get in touch via our email: **catalyst@stem.org.uk.**

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Career journey with
Dr Emily Grossman

Q Introduce yourself – what is your name, place of work and job title?

A Hi, I'm Dr Emily Grossman and I'm a science communicator - I work as a science broadcaster, writer, educator and trainer.

Q What did you want to be when you were little?

A I really couldn't choose between wanting to be a scientist or an actress. I had no idea that one day I might be able to combine the two, as a science communicator!

Q What is the main focus of your work?

A I explain science for a range of TV and radio programmes, I give motivational and inspirational talks in schools, universities and at public events across the UK and abroad, and I write fun books and articles about science. I also help other scientists to communicate effectively about their work. You might have seen me as a resident science expert on Sky One's fact-based celebrity panel show 'Duck Quacks Don't Echo', or on ITV's 'The Alan Titchmarsh Show'.

Through my work I aim to make science exciting and accessible, by explaining complex concepts in a fun and engaging way. I also hope to change the perception of what it is to be a scientist, to raise awareness as to the value of emotions in science, and to inspire more young people, especially girls, to study STEM subjects.

Q How does your work affect our lives or society?

A There are so many huge problems in the world that need to be solved, from antibiotic resistance to climate change, and we urgently need more scientists, mathematicians and engineers to do so. However, the trouble is that many young people, especially girls, simply don't see a place for themselves in STEM careers. Girls often tell me that even though they enjoy STEM subjects and are good at them, they worry that they're not good enough, or that science is just "not for people like me". Through my work I hope to play a role in changing this, by encouraging more young people not to give up on their passions, no matter what anyone else says, and by demonstrating to them that people just like them can be happy and successful in STEM careers.

Q Talk us through an average work day...

A Every day is different! This week, on Monday I'm giving a talk for secondary school students in Cambridge, called 'Lies, damned lies and newspapers', on the use and abuse of statistics in the media. On Tuesday I am meeting with an event organiser about doing some interactive 'Dr Emily's weird and wonderful science facts' shows across the West Midlands. On Wednesday I'm chatting to a children's book publisher to discuss some ideas. On Thursday I'm filming an interview for the BBC on women's fertility and my decision to freeze my eggs. On Friday I'm giving a talk at Cardiff University called 'Too sensitive for science?' on my career and the challenges I've faced as a woman in STEM. On Saturday I'm super excited to be giving a talk at a maths event in Bristol alongside my childhood hero Johnny Ball and then later that night I'm flying to Bangkok for ten days to run a series of training sessions for research scientists at various universities, on communication skills and working with the media. And somewhere in between all of that I'm supposed to be working on my current book – a fun quiz book for kids on weird science facts!

Q What's the best thing about your job?

A I love the fact that every day is different, that I have lots of different projects on the go, and that I never know what I'm going to be doing next. But the most rewarding part is that I get the opportunity to engage with and inspire so many different types of people. I regularly get emails from people who are excited about a science topic they have heard me speak about at an event or on TV, or who have been inspired by hearing me share my personal story. They thank me and sometimes they tell me that they have decided that they want to be a scientist, or that they now feel confident enough to pursue their dreams. It makes me feel all warm and fuzzy inside!

"I aim to make science exciting and accessible, by explaining complex concepts in a fun and engaging way"

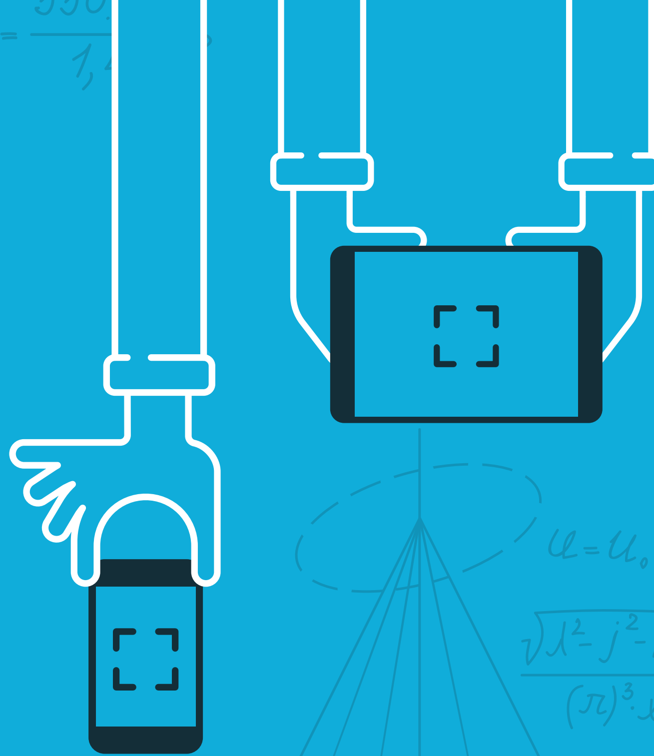
Q When and why you did you decide to follow your profession?

A Having attained a first-class degree in natural sciences from Cambridge University and a PhD in cancer research, I then decided I wanted to go to drama school to pursue my other passion, theatre. I spent the next eight years working as an actress and singer in plays and musicals across the UK, and working part-time as a maths and science teacher in between acting jobs. The theatre world was rewarding but tough, and whilst I had a lot of great jobs I also had a lot of knock-backs, and eventually I decided it was time to leave the business. A few years later, in 2013, I heard about a scheme called BBC Expert Women. The BBC were looking for women who had expertise in areas such as science, and who liked communicating; they were offering a day of media training. By this point in time I had really lost my confidence, so I nearly didn't apply for the scheme, but luckily my friends and family persuaded me to... and I was shocked and delighted to get a place. That training day launched my career as a science communicator.

Q What sort of personality or passions do you need to have to pursue your career?

A You definitely need curiosity. My favourite word is 'why' – I'm constantly asking questions... and driving everyone mad! Science is about solving problems and understanding the world around us.

As a science communicator it also helps if, like me, you love expressing yourself, and explaining things to other people. And as a motivational speaker it's about caring deeply about inspiring others to fulfil their potential and to be the best they can be. After three careers in which I felt that I didn't quite fit in (as a scientist, actress and teacher), I've finally found that science communication is the perfect fit for me.



"My favourite word is 'why' – I'm constantly asking questions... and driving everyone mad!"

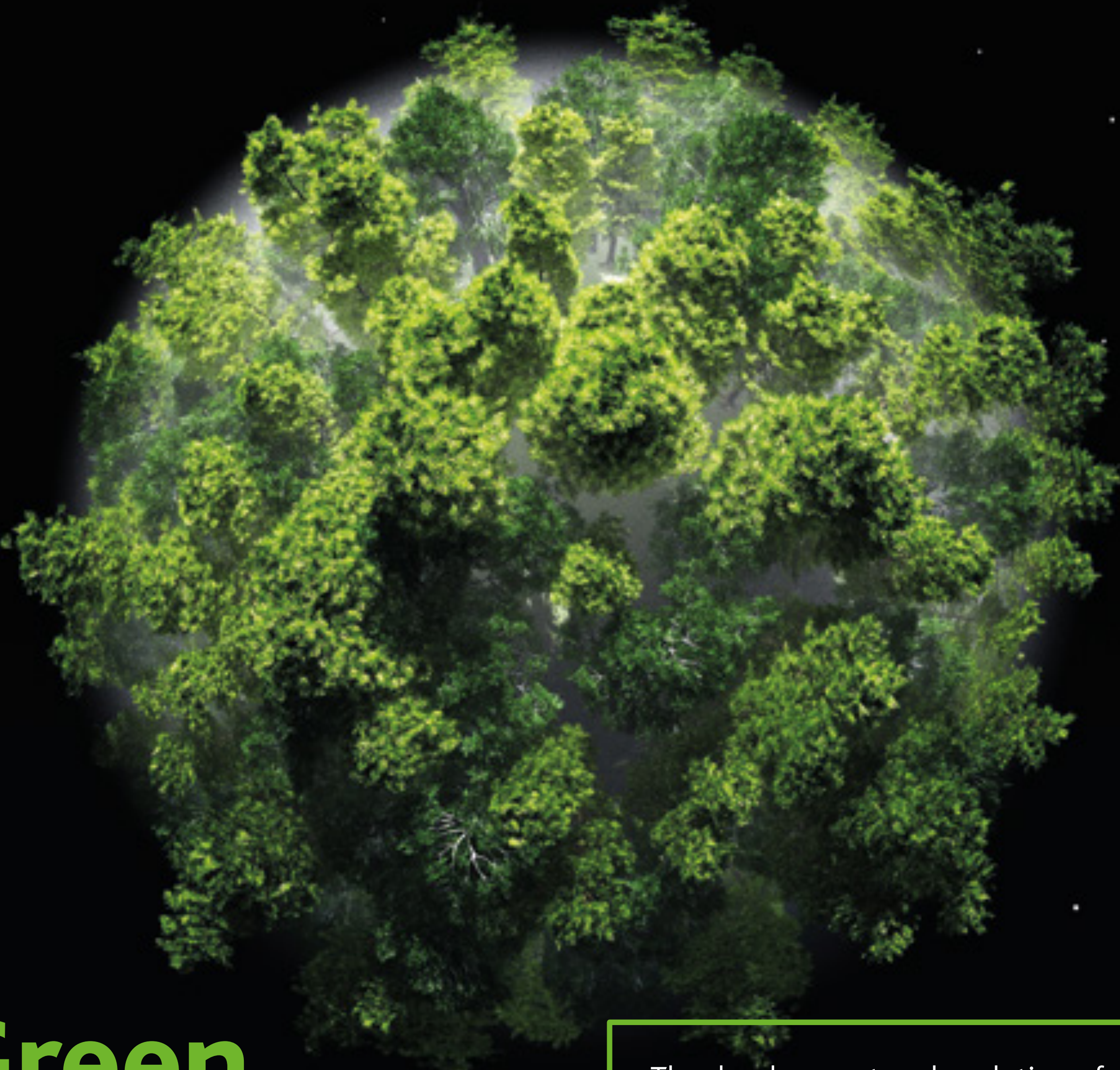
It also helps to be motivated, disciplined and determined, and to be good at using your initiative and at self-promotion. Don't worry if you haven't got bags of confidence though; people can be surprised that I'm actually quite an introvert, and that I often worry about what people think of me or that I'm not good enough. But I've learnt to just keep going, to follow my passions, and to ask for support when I need it.

Q Do you have any career highlights?

A Most definitely my proudest moment so far has been delivering a TEDx talk at UCL called 'Why science needs people who cry'. It was my response to a barrage of horrible misogynistic abuse I received on social media a few years ago, shortly after I appeared on a debate on Sky News about sexism in science. During the debate I spoke of my work in encouraging women to be scientists, and said that it's okay for female scientists to cry – and that in fact we should be encouraging more men to cry! The backlash I received on social media after the debate really shocked me, and I decided I wanted to speak out against it, and to do what I can to change the out-dated stereotype that all scientists are cold, unemotional... and male. A stereotype that is not only wrong, but that prevents many young people from seeing a place for themselves in STEM careers.

www.emilygrossman.co.uk

@DrEmilyGrossman



Green chemistry

is key to reducing waste and improving sustainability

By Alex Bissember
Senior Lecturer in Chemistry, School of Physical Sciences, University of Tasmania

The development and evolution of the chemical industry is directly responsible for many of the technological advancements that have emerged since the late 19th century.

However, it was not until the 1980s that the environment became a priority for the chemical industry. This was prompted largely by stricter environmental regulations and a need to address the sector's poor reputation, particularly due to pollution and industrial accidents.

But the industry is now rapidly improving, and this changing mindset has provided the backdrop for the emergence of green chemistry.

What is green chemistry?

Sustainability is becoming increasingly important in almost every industry and chemistry is no different.

Green chemistry aims to minimise the environmental impact of the chemical industry. This includes shifting away from oil to renewable sources where possible.

Green chemistry also prioritises safety, improving energy efficiency and, most importantly, minimising and (ideally) eliminating toxic waste from the very beginning.

Important examples of green chemistry include: phasing out the use of chlorofluorocarbons (CFCs) in refrigerants, which have played a role in creating the ozone hole; developing more efficient ways of making pharmaceuticals, including the well-known painkiller ibuprofen and chemotherapy drug Taxol; and developing cheaper, more efficient solar cells.

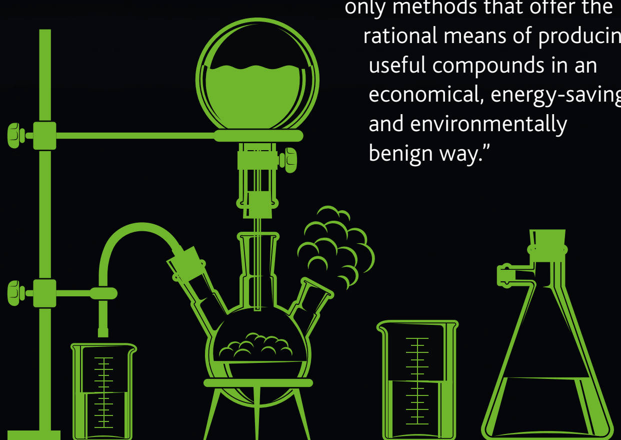
The need to adapt

Making chemical compounds, particularly organic molecules (composed predominantly of carbon and hydrogen atoms), is the basis of vast multinational industries from perfumes to plastics, farming to fabric, and dyes to drugs.

In a perfect world, these would be prepared from inexpensive, renewable sources in one practical, efficient, safe and environmentally benign chemical reaction. Unfortunately, with the exception of the chemical processes found in nature, the majority of chemical processes are not completely efficient, require multiple reaction steps and generate hazardous byproducts.

While in the past traditional waste management strategies focused only on the disposal of toxic byproducts, today efforts have shifted to eliminating waste from the outset by making chemical reactions more efficient.

This adjustment has, in part, led to the advent of more sophisticated and effective catalytic reactions, which reduce the amount of waste. The 2001 Chemistry Nobel Laureate Ryoji Noyori stressed that catalytic processes represent "the only methods that offer the rational means of producing useful compounds in an economical, energy-saving and environmentally benign way."



A secret to cleaner chemistry

Catalysts are substances that accelerate reactions, typically by enabling chemical bonds to be broken and/or formed without being consumed in the process. Not only do they speed up reactions, but they can also facilitate chemical transformations that might not otherwise occur.

In principle, only a very small quantity of a catalyst is needed to generate copious amounts of a product, with reduced levels of waste.

The development of new catalytic reactions is one particularly important area of green chemistry. As well as being more environmentally friendly, these processes are also typically more cost effective.

At least 15 Nobel Prizes have been awarded for catalysis research

Catalysts take many forms, including biological enzymes, small organic molecules, metals, and particles that provide a better surface for reactions to take place. Roughly 90% of industrial chemical processes use catalysts and at least 15 Nobel Prizes have been awarded for catalysis research. This represents a tremendously important and active area of both fundamental and applied research.

Catalysts are substances that accelerate reactions, by enabling chemical bonds to be broken and/or formed.

What's the outlook?

In the past 20 years since green chemistry was established, there have been tremendous advances in the industry. Nevertheless, there remains considerable room for improvement.

The chemical industry faces a number of significant challenges, from reducing its dependence on fossil fuels to playing its part in addressing climate change more generally.

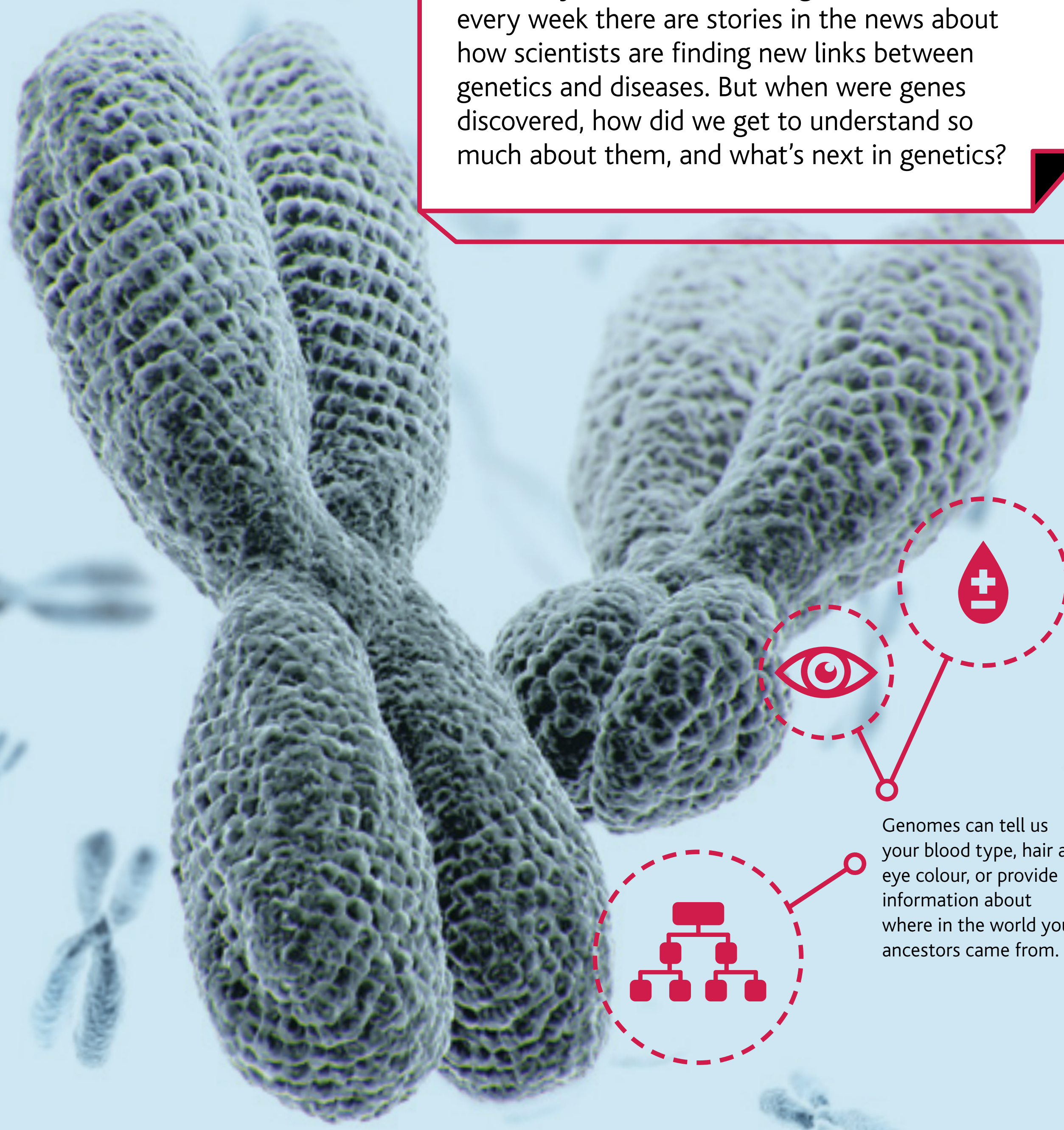
Specific challenges include: capturing and fixing carbon dioxide and other greenhouse gases; developing a greater range of biodegradable plastics; reducing the high levels of waste in pharmaceutical drug manufacture; and improving the efficiency of water-splitting employing visible light photocatalysts.

History suggests that society can develop creative solutions to complex, intractable problems. However, success will most likely require a concerted approach across all areas of science, strong leadership, and a willingness to strategically invest in human capital and value fundamental research.

Unravelling genetics

By Patrick A. Lewis
Associate Professor, University of Reading, School of Pharmacy

Genetics – the study of how characteristics are passed from one generation to the next – is at the heart of much that makes us human, playing a part in what we look like, how tall we are, what colour hair we have, and how our brains develop. The last few decades have seen huge advances in our ability to understand our genes, and almost every week there are stories in the news about how scientists are finding new links between genetics and diseases. But when were genes discovered, how did we get to understand so much about them, and what's next in genetics?

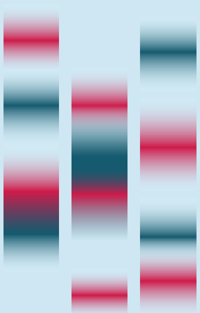


Genomes can tell us your blood type, hair and eye colour, or provide information about where in the world your ancestors came from.

The birth of genetics

The story of the study of genetics starts over 150 years ago at an abbey in Brno (now in the Czech Republic) with a keen gardener called Gregor Mendel. Mendel was interested in the patterns that are passed down through different strains of pea plants, such as flower colour or size. He observed that it was possible to predict how many plants would have a particular characteristic several generations later, laying the foundations for how we understand the simplest form of genetics. This is now called Mendelian genetics, in his honour.

Mendel could observe characteristics being passed down, but it wasn't until researchers working in England in the 1950s discovered a role for a chemical found in all living cells called deoxyribose nucleic acid, or DNA, that we began to understand how this happens. Rosalind Franklin and Maurice Wilkins, structural biologists based at King's College London, were trying understand the three dimensional organisation of DNA and began to piece together what DNA looks like using X-rays passed through purified samples. This information was used by Francis Crick and James Watson, working at the Cavendish laboratories in Cambridge, to generate their famous model of the double helix.



It quickly became clear that DNA acts as a sort of chemical code book, providing every cell with a set of instructions for making the proteins that allow them to function. And what a set of instructions! Inside almost every cell in your body there are around 3 billion base pairs (the building blocks of DNA). The order of these pairs defines the genes for each and every protein in your body.

Understanding the structure of DNA immediately raised a huge issue – how do you comprehend such a large instruction manual? It didn't take too long for scientists to figure out how to decipher the code: it is based on a four-letter alphabet, which repeats in three base pairs – forming the words and sentences that provide the instructions for making proteins. But figuring out how to accurately read genomes on a massive scale took a lot longer (and a huge amount of money).

Eventually, molecular biologist Fred Sanger developed a technique, now called Sanger sequencing, which allowed us to peer in to the genome and access the information in all those genes. Sanger initially used it to look at the genomes of very small organisms, such as bacteria, but eventually Sanger sequencing and similar techniques were used to sequence the genomes of much more complicated animals – including humans.

Looking at the instruction manual of life

This has opened a new chapter in the biology of life on earth. Humans are the first organisms to have the ability to look at the instruction manuals that make our cells work, our organs grow, and even provide the canvas which our personalities develop on. And what is more, the rate at which we are learning about our genomes, as well as the genomes of organisms around us, is accelerating at a breathtaking pace.

DNA or deoxyribose nucleic acid is a molecule found in all living cells

Francis Crick and James Watson generated their famous model of the double helix

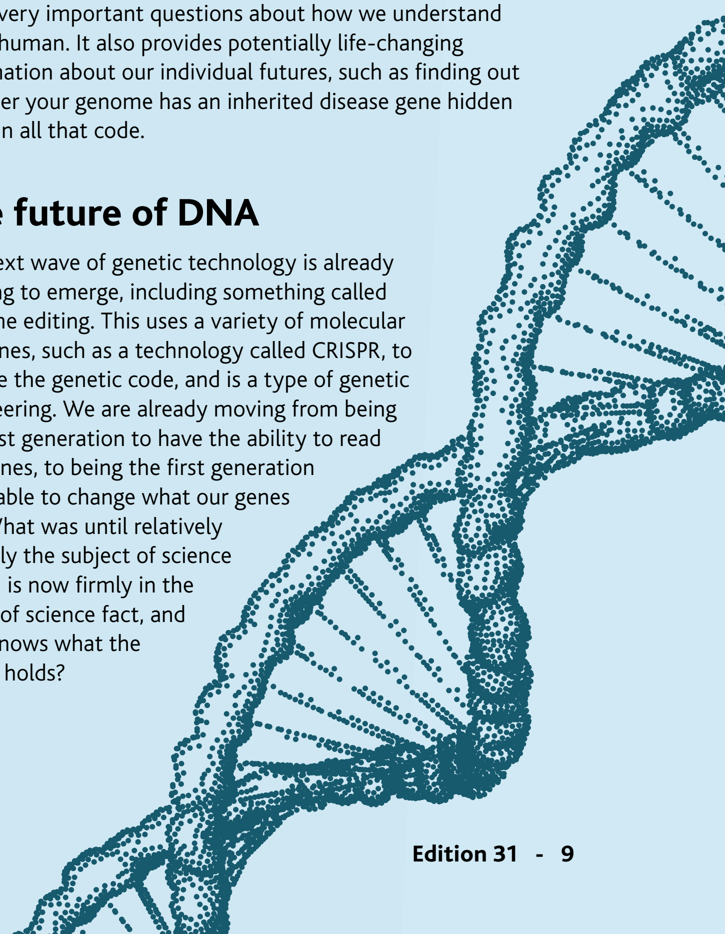
At the start of the century it cost hundreds of millions of pounds and took years of work to sequence the first human genome, now this can be done in a few days and for under £1,000. This is helping us to discover a huge amount about how our genomes and cells work – and also providing massive insights into why cells go wrong and cause disease. Just as importantly, understanding our own genomes can tell us a lot about ourselves as individuals, from providing the genetic details that determine your blood type, hair and eye colour, or provide information about where in the world your ancestors came from, through to information about your genetic risk for some types of disease.

The majority of this information is now available by buying a kit over the internet or over the counter at your local pharmacy, from companies like 23andMe (23 being the number of pairs of chromosomes humans have) – although you do have to be 18 years old to use a 23andMe kit.

This startling explosion in genomics, which has moved from research laboratories onto the high street in a decade, raises some very important questions about how we understand being human. It also provides potentially life-changing information about our individual futures, such as finding out whether your genome has an inherited disease gene hidden away in all that code.

The future of DNA

The next wave of genetic technology is already starting to emerge, including something called genome editing. This uses a variety of molecular machines, such as a technology called CRISPR, to change the genetic code, and is a type of genetic engineering. We are already moving from being the first generation to have the ability to read our genes, to being the first generation to be able to change what our genes say. What was until relatively recently the subject of science fiction is now firmly in the realm of science fact, and who knows what the future holds?



Climate change vs our wildlife

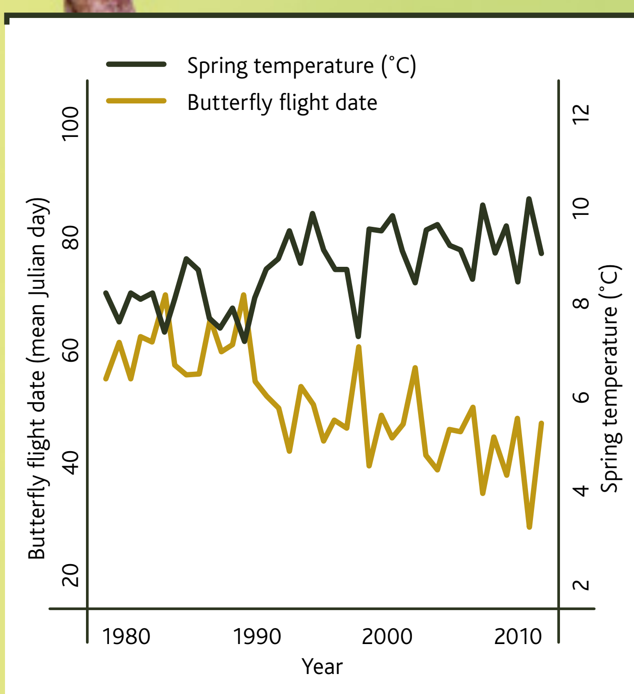
By Tom Oliver
Associate Professor of Landscape Ecology,
University of Reading

The flight date of the Orange-tip butterfly has moved forward by around 19 days since 1980

> With warmer summers and wetter winters predicted in the UK due to climate change, effects on our native species are likely. But is climate change already having an impact on our wildlife?

What we call our 'climate' is simply weather averaged over time. Although weather fluctuates significantly between years, UK temperatures have increased by an average of nearly 1°C since the 1980s. Looking at the last 350 years, nine out of the ten warmest years for the UK have happened in the last three decades.

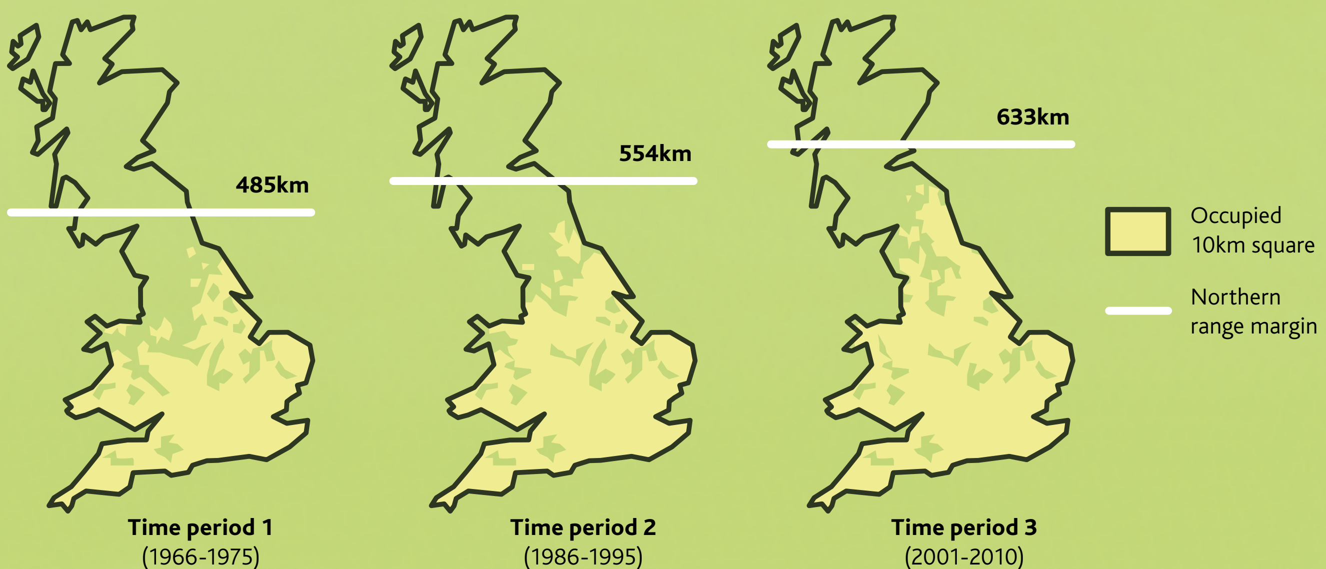
A clear indicator of how climate change is affecting species is the timing of significant biological events – the study of these events is called phenology. As years get warmer, many plants undergo leafing and flowering earlier; frogs spawn earlier and their eggs hatch sooner; and insects emerge from their overwintering stages earlier. One example is the flight date of the Orange-tip butterfly – this is the day when this species of butterfly is most likely to be seen. The flight date correlates closely with spring temperatures and has moved forward by around 19 days since 1980, as you can see from the chart on the right.



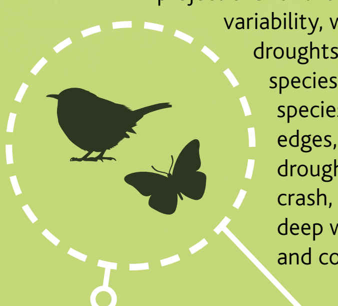
Many species in the UK have traditionally only been found living in the south, due to the colder conditions in the north of the country. As the climate warms, locations in the cooler north become suitable habitats for different species. This means that the most northern point a species can be found shifts further north over time. This is often referred to as a species' geographic range margin. The range of butterflies in the UK has shifted about 25km per decade on average, since the 1960s. Species do not move at a constant rate – in years of favourable weather they may colonise many new locations, and in unfavourable years they might face local extinctions. However, as the climate warms, the northern range margin gradually edges northwards, like the waves of the sea washing in and out as the tide comes in.

Although weather fluctuates between years, UK temperatures have increased by an average of nearly 1°C since the 1980s.

Presence of the Thymelicus sylvestris butterfly



Will events such as droughts, heatwaves, exceptionally cold winters and floods affect our wildlife? Many studies on climate change focus on gradual changes to temperature, because this is easier to study. Extreme weather events are harder to investigate because they are so rare. However, if a species is being closely monitored then we can detect the impact of these extreme events on species' populations. Extremely cold winters are known to cause severe losses in wren populations, for example. Colder winters are expected to become less common with climate warming, so this could be good news for wrens – but future projections for the UK's climate include greater climate variability, which means that heatwaves and droughts will become more frequent. Certain species, such as the Ringlet butterfly, a species that occurs around woodland edges, are very sensitive to drought. In drought years, Ringlet population numbers crash, especially in areas where there is less deep woodland (which tends to be moister and cooler) for the species to take refuge.



Cold winters cause losses in wren populations

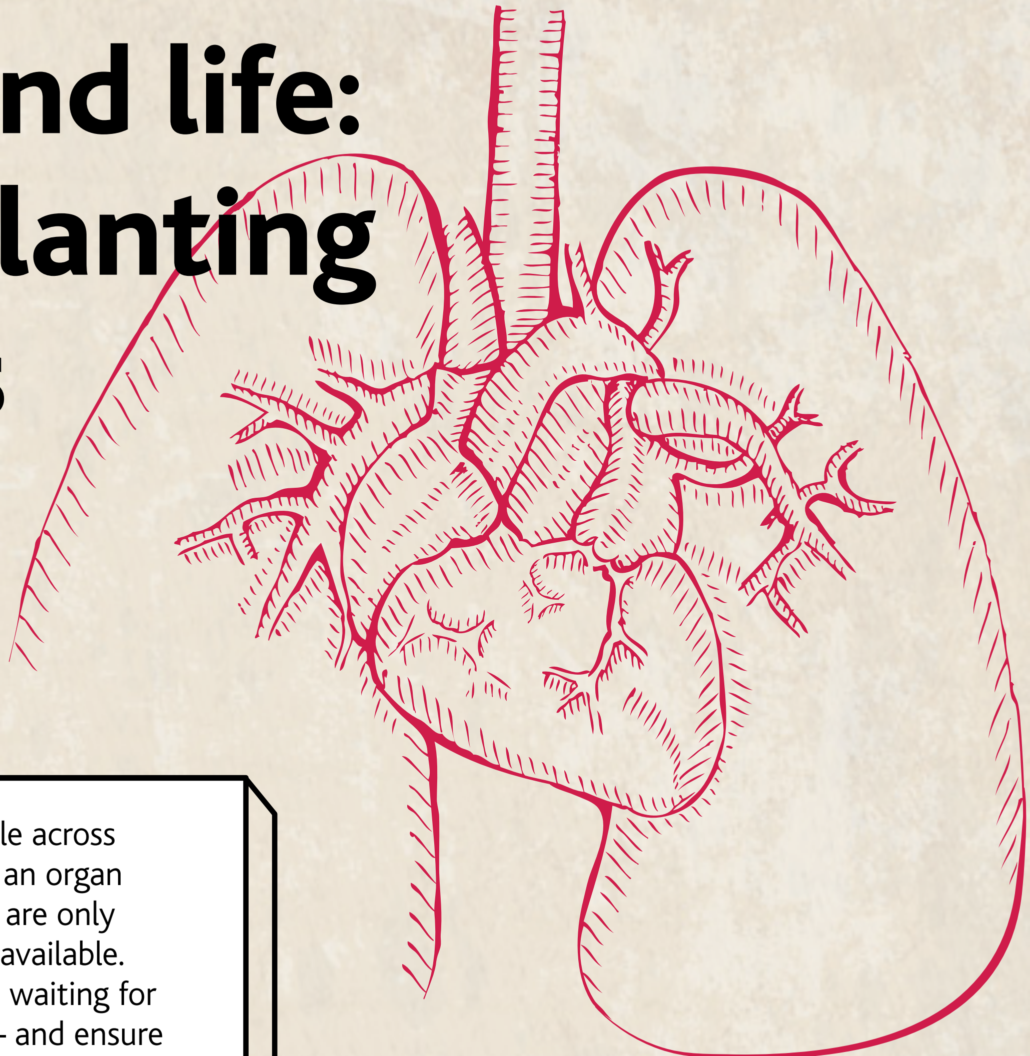
Droughts cause losses in Ringlet populations

With species disappearing in some places, and spreading to new areas in others, the UK is already being affected by climate change. We may see new species coming to the UK as temperatures get warmer. Climate change is causing a change in the balance of species which thrive in warm conditions versus those which survive best under cooler conditions.

So, what can we do? Should we protect species that have typically lived in the UK, as their habitats disappear? Conservationists have previously focused on helping the species that had been present in recent history, but now climate change is forcing them to look hard at their conservation strategies.

We could attempt to help species persist by providing a range of microclimates, especially cooler, wetter areas to offer refuges in hot years. We could also try to help species to shift their ranges by creating new habitats, such as creating new woods and forests, as well as planting hedgerows and field margins in landscapes. This may allow new species to arrive and replace those that are likely to disappear.

A second life: transplanting organs



By Stefania Hartley
Freelance writer, Gloucestershire

More than 6,500 people across the UK are waiting for an organ transplant – and there are only a few hundred donors available. How do we help those waiting for a life-changing organ – and ensure that the process stays safe?

The ability to transplant human organs is one of the biggest medical advances in the last century. Organ transplantation has become increasingly successful, as we continue to develop new drugs and improve surgical techniques. In the UK, the success rate one year after surgery for adult kidney transplants is 98% for organs from living donors and 94% for organs from deceased donors.

As transplantations become safer and more successful, they become the therapeutic option of choice. But the number of donor organs is limiting the number of transplantations. Every day more patients are added to the transplant list, and much fewer are removed after receiving one. This makes waiting lists longer and longer. In the UK, between 1 April 2009 and 31 March 2013 the median waiting time for an adult kidney transplant was 944 days.

To help this situation, scientists are turning to organs which wouldn't have been considered suitable for transplantation in the past. They are also looking at ways of monitoring and improving these organs' quality, in a bid to increase the number of donor organs available.

As of 2011, the oldest recorded organ donor in the UK was 84 years old. The oldest ever recorded cornea donor was 104 years old.

Types of transplantations

From a genetic point of view, transplants can be classified as:

Autograft: using tissue from a patient's own body (eg if someone has severe burns, they might have a skin graft from somewhere else on their body).

Allograft or allotransplantation: a tissue or organ transplant from one animal to another of the same species (usually from one human to another human).

Xenograft or xenotransplantation: a transplant using tissue or organs from a different species, such as a pig. The success rate for this type of transplant is very poor.

Organs used in transplants

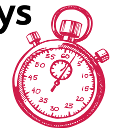
Organs that are normally transplanted are:

- kidneys
- liver
- heart
- pancreas
- lungs
- thymus
- small intestine

The first three of these are the most commonly transplanted organs. Tissues can also be transplanted – such as the cornea (the transparent sheet at the front of the eye), as well as muscles, bones, tendons and ligaments. This type of transplant is much more common than organ transplantation. This is because tissue is much easier to recover than an organ and can be kept ready for a transplant for a long time – sometimes up to five years. A whole organ is more difficult to recover and needs to be transplanted into another person quickly.

A heart can be preserved for up to six hours. Kidneys can last 40–50 hours

(but earlier transplant is preferable).



Choosing healthy organs

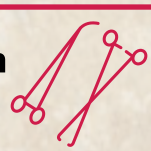
Only the kidney, liver and small intestine can come from a living donor, so most of the organs for transplantation come from someone who has died. Doctors have to be careful to make sure the tissue and organs they use in transplants are healthy, so they look carefully at donors to make sure they don't have any diseases they could pass on. This means few people are chosen as safe donors.

In the past, most donations came from dead donors who were considered 'brain-dead' – these patients' brains have no activity, and their body is kept functioning using machines, such as ventilators, to help them breathe. This is now quite rare – and most organs now come from people who have died of cardio-pulmonary arrest (those whose hearts have stopped). In these cases, the organs might have been damaged by a lack of blood circulation, when the donor's heart stopped. Scientists and doctors are investigating ways to prevent, identify and, eventually, repair the damage suffered by these organs.

The small number of donors means that scientists are now considering a wider range of organs for transplantation, such as organs from older donors, and from people who have died from different causes than the ones above.

In the UK, lungs from donors who smoked at some stage in their lives are used for transplantation. Statistics show that those who receive donated lungs from someone who has smoked have a longer survival time than if they wait a long time for a lung from a non-smoker.

The liver is the only organ which can regrow if cut



Preserving donated organs

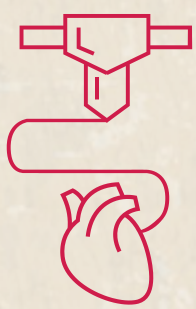
Organs need to be moved quickly into a new body, and need to be preserved until a surgeon can place them into a patient. They are kept at low temperatures, which reduces the organ's need for oxygen, but being cold and deprived of oxygen can damage the organ.

Before the 1960s, donor organs were perfused, or filled, with either diluted blood or blood mixed with an anticoagulant (stops the blood from clotting). However, this process caused problems when the organs were implanted into a patient. So scientists invented synthetic solutions that could be used instead. In 1969 blood was replaced in organ preservation by synthetic solutions (mixtures containing solutions of electrolytes and vitamins), kept at low temperatures.

Collins' solution, one of these synthetic mixtures, was particularly successful, and helped to preserve kidneys for long enough (between 24–36 hours) to find matches for the donated organ and transport it to the patient.

When a donor dies, the body is injected with a chilled solution from the nearest major artery or vein to flush out the blood and cool the organ to 10–15°C. In a method called Static Cold Storage (SCS), the organs are removed and immersed in a fresh batch of solution, double-bagged in ice and transported to a transplant centre. With dynamic methods like Hypothermic Machine Perfusion (HMP), after removal, the organs are attached to a machine which continuously pumps the preserving solution through the organ. This method also helps by providing oxygen to the organs.

For liver transplants, scientists have developed a machine that keeps the liver warm and alive, pumping through warm blood with oxygen, insulin and nutrients as if it was still in the body. The liver in this 'artificial womb' can produce bile and even become healthier than when it was in the body. Before a transplant, surgeons have to decide if a liver is healthy enough to be transplanted into a new patient. A mistake would be fatal for the patient, so they err on the side of caution. But this machine monitors the liver's output and health and allows surgeons to make well-informed choices.



A promising new technique, 3D bioprinting, uses materials similar to the scaffolding outside our cells (like special gelatines), together with live human cells and nutrients, to 3D print tissues or organs. At the moment this technique (part of 'regenerative medicine') is used to create model organs to test new drugs but, in future, it could become a source of organs for transplantation. If the patient's own stem cells were used to produce the organ, the problem of rejection (when the person's immune system doesn't recognise the transplanted organ and attacks it) would be minimised. In years to come this could change the life of millions of people and their families. Right now, joining the donor register is still the best you and I can do to save or improve somebody else's life, and to give our organs a second life.

To find out more about organ transplantation in the UK visit: www.organdonation.nhs.uk

Looking for life in our solar system

By Andrew Coates
Mullard Space Science Laboratory,
University College London

Are we alone in the universe? This is one of the key scientific questions facing humankind. We know of only one place – our Earth – where life exists. The 'habitable zone' may have included Mars 3.8 billion years ago, when life was starting on Earth, so Mars is a good place to look. The ExoMars 2020 rover will be the first to drill up to two metres under the harsh surface and may be the first mission to find biomarkers.

Mars was formed 4.5 billion years ago

The surface is dry and cold, changing from 10°C on a warm day to -100 to -120°C every night

But now, following missions like Cassini, we are redefining the 'habitable zone' to include 'habitable conditions'. This opens up outer solar system moons like Europa and Ganymede around Jupiter, and Enceladus and Titan around Saturn, as possibilities for life now. So, what are the prospects for life in our solar system, and what can missions like ExoMars 2020, Cassini and JUICE (Jupiter Icy Moons Explorer) tell us about habitability?

The 'habitable zone' is the region where a terrestrial mass planet, with favourable atmospheric conditions, can sustain liquid water on its surface. Water is important as one of the four ingredients for life 'as we know it', the others being the right chemistry (involving the elements carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur), a source of heat, and enough time for life to develop. We don't know exactly how life on Earth started, but in the last 40 years we have found that extreme forms of life can thrive near hydrothermal vents, such as 'black smokers', broadening the possibilities for the search elsewhere.

Mars

Mars is the first place to look. 3.8 billion years ago, some 800 million years after its formation, Mars was a very different place to now in three ways.

First, Mars had surface water, initially found as outflow channels seen by orbiters. Now, we have direct evidence from clays or phyllosilicates mapped on the surface from Mars Express, and from water-rich minerals found by the recent rovers Opportunity and Curiosity. The Mars climate must have been very different then, with a thick atmosphere, a water cycle with clouds and lakes, and probably a blue sky.

Second, Mars had a global magnetic field, as seen from crustal fields in the heavily cratered, 3.8 billion-year-old southern highlands, detected by the Mars Global Surveyor mission in 1999–2000. This would have shielded any emergent life from galactic and solar energetic particles, and protected the early Mars atmosphere from the solar wind, providing a similar protective cradle for life to our magnetic field on Earth.

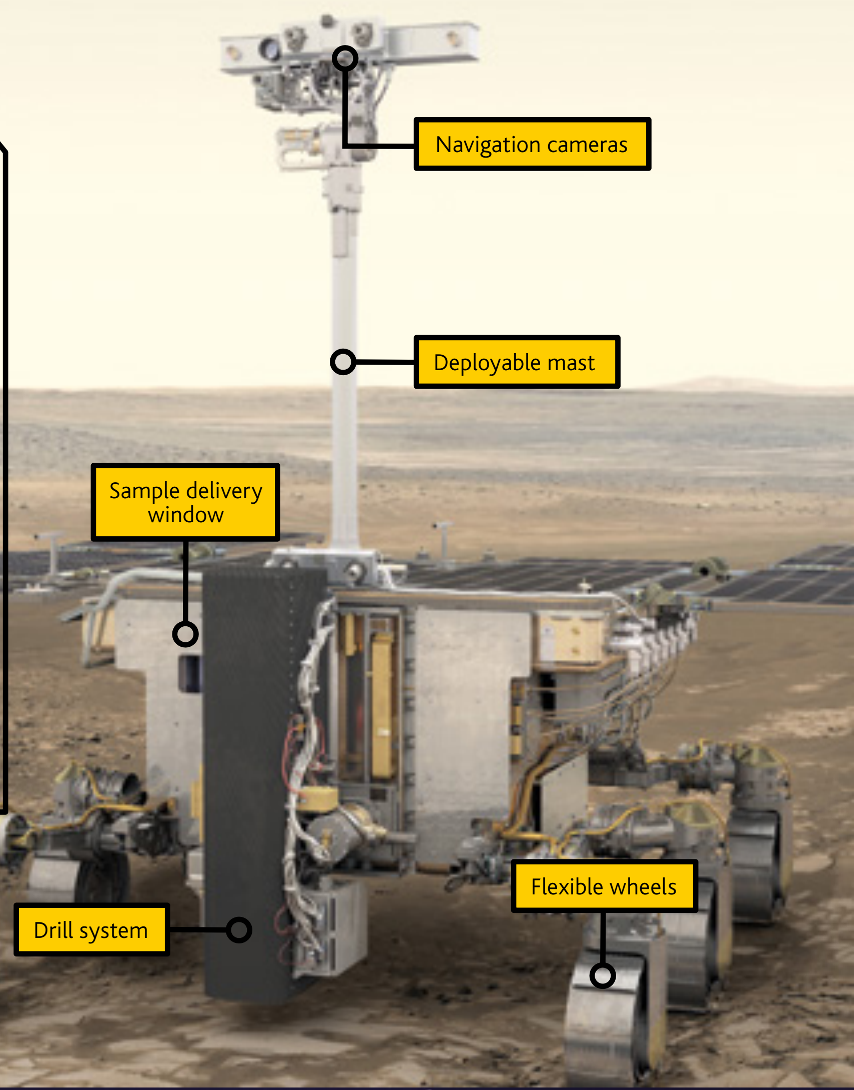
Third, and completing the water cycle, Mars had volcanism. This is seen from structures like Olympus Mons, the largest volcano in the solar system at 600km diameter and 27km high, three times the height of Mount Everest – but now extinct.

Mars is very different now, with extinct volcanoes, no global magnetic field and a thin CO2-rich atmosphere, now about 1% of Earth's atmospheric pressure. This was stripped away by the solar wind over 3.8 billion years. The surface is dry and cold, changing from 10°C on a warm day to -100 to -120°C every night. Probably the large collision 3.8 billion years ago, which caused the large Hellas basin, snuffed out the magnetic field. But 3.8–4 billion years ago is also when life started on Earth, and the right conditions were there at that time for life on Mars to start too. We just need to find it. We might, with the ExoMars 2020 rover. The atmosphere of Mars now is harsh for life: it is highly oxidising, and the thin atmosphere means that ultraviolet and cosmic rays flood the surface. This is why we will dig deep with ExoMars – we need to get below 1mm for the UV, 1m for the oxidants and 1.5m for the cosmic radiation. Hence the 2m drill.

The rover payload includes context instruments:

- a PanCam, which gives geological and atmospheric context
- an infrared spectrometer for geology
- a close-up imager to image the drill sample more closely
- a subsurface radar to look for outcrop rocks under the surface and water ice
- a neutron detector to look for subsurface water
- a tiny visible and infrared imager in the drill tip for local context for the sample

The sample will be ingested into the Analytical Drawer and looked at with three instruments – a visible-infrared spectrometer for minerals, a Raman spectrometer for fluorescence studies of minerals and biomarkers, and a gas chromatograph mass spectrometer instrument to look for chemical traces of life.



Moons

Jupiter's moons – Europa, and perhaps Ganymede – may be habitable now. We know from Galileo that there are subsurface oceans beneath the icy crusts, and Europa's ocean floor is in contact with silicates, increasing the chances of life there. At Ganymede, the ocean floor touches ice, but it has a magnetic field to protect it from Jupiter's harsh radiation belts. ESA's JUICE mission launches in 2022, reaches Jupiter in 2030, and will study both these moons before orbiting Ganymede in 2032. With NASA's Europa Clipper mission, this will tell us more about Europa's oceans, and will explore habitability there.

The Cassini-Huygens mission to the Saturn system changed our ideas about habitability. Titan, Saturn's largest moon (radius 2,575 km, second only to Ganymede), orbits at 20 Saturn radii. It is unique, with a thick nitrogen-methane atmosphere like early Earth's. Huygens found that Titan has a methane cycle with lakes and rivers, similar to Earth's water cycle but on a cold, -180°C surface. Cassini found prebiotic chemistry in the upper atmosphere, huge anions up to 14,000amu, which drift through the atmosphere forming haze, and fall to form hydrocarbon dunes on the surface. Titan has a subsurface water ocean, and although too cold for life at present, Titan may emerge as a habitat in 5 billion years when the Sun becomes a red giant.

A major surprise from Cassini was water plumes and a subsurface ocean at Enceladus. This small (radius 252km) moon orbits at only four Saturn radii from the planet, but deflections in the magnetic field revealed an atmosphere near the South Pole. Then, imaging and other data revealed water-rich plumes from 'tiger stripes' on the cold surface and a global water ocean below. Sodium in the plumes suggests a salty ocean, silicates indicate possible hydrothermal vents and recently hydrogen in the plumes indicates habitability.

Titan is Saturn's largest moon

The search begins

The recent and planned solar system missions have revealed evidence for habitability and point the way for further exploration. Mars, Europa and now Enceladus are the major likely targets for life in the solar system beyond Earth. Our own solar system gives us the best chance to look for life elsewhere, and acts as a model as we find more and more extrasolar planetary systems.

Why antimatter matters

By Pete Knapp
CERN, the European organisation for nuclear research

Antimatter. Lasers. Temperatures colder than space... These are the things that I work with every day at an experiment called ALPHA at CERN's 'Antimatter Factory' in Geneva, Switzerland. The words alone were enough to make me interested to work here, and the more I found out about the science the more I wanted to know.

Antimatter is very similar to the 'normal' matter that everything is made of. The charge, among other things, are switched, which means the antiproton has a negative charge and the antielectron, or 'positron', has a positive charge. When matter and antimatter come into contact they annihilate – disappearing in a flash of energy. According to our best understanding of the Universe, the Big Bang should have created equal amounts of matter and antimatter. So why is there far more matter than antimatter in the Universe? And why does anything exist at all?! This is the question that we are aiming to answer.

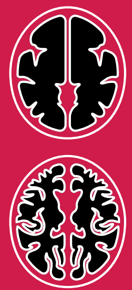
Where do the antiprotons and positrons come from? Around one antiproton is produced for every billion protons that are fired at near light-speed into iridium metal. We steer them around an airless ring using strong magnetic fields, and electric fields slow them down to about 10% of the speed of light so we can work with them. Our positrons come from 50 grains of radioactive sodium, each one about the size of a salt grain, which continuously spit them out. These grains cost around $50,000 and last for around five years when they have to be replaced. A small fraction of the potassium atoms found in bananas emit positrons by radioactive decay, around one every 75 minutes, which is unfortunately too low to run the experiment on them; we need over 400 million per second.

Bananas emit one positron every 75 minutes

A human hair is about a million atoms wide

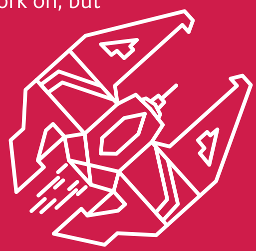
Once we have the antiprotons and positrons, we slowly merge them together in a trap partly funded by Carlsberg, the Danish beer company. This means that if your parents buy this beer they are funding probably the best antimatter experiment in the world! The antiprotons and positrons bind together in a special atom trap to form antihydrogen. In a single run, we can make around 30 antiatoms, which is an astonishingly low number considering a human hair is about a million atoms wide. This also makes antihydrogen the most expensive material to make, at around $760,000,000,000,000,000,000 per gram! They also have no charge, and holding on to things without charge is very tricky. Thankfully, these antiatoms can become like tiny bar magnets when they are in a magnetic field, due to having something called a 'permanent magnetic dipole moment'. The magnetic coils need to be about 3,000 times stronger than a fridge magnet and require a high current to achieve this. The electrical resistance disappears when they are kept below -222˚C, achieved by pumping liquid helium around them. This helium is a precious resource and it is 'on loan' from Russia. The temperature inside this trap is kept even colder, to around 5 degrees above absolute zero, or -268.15˚C, and this helps to make antihydrogen that is colder than space! This incredibly low temperature is required to stop the antihydrogen atoms bouncing around too much and leaving our magnetic trap. Once they are held in place, precisely-tuned lasers are fired into them to see if they react in the same way as normal hydrogen does. If they act differently, this may help to explain why there is none of it in the Universe.

A future experiment, which started construction in January 2018, aims to test how antimatter reacts to gravity. The idea is to suspend it in a £10 million vertical pipe – flipping our current experiment on its head – and 'drop' it to see if it falls just like normal matter as Einstein's theories predict... or not. Perhaps it floats, or even falls upwards! Watch this space. Two other experiments, called AEgIS and GBAR, situated in the same building as us, are using other techniques to test the same thing. Despite being next door, it is important for us to both avoid each other's findings so that our conclusions are independent – this is good scientific practice.



How could antimatter be useful? The idea of using it to propel spacecraft, or to annihilate your enemies may well be in the far distant future, but it has already found its uses in medicine. The PET scanners in hospitals use positron annihilations to image your internal organs to find tumours, and proton-antiproton annihilations are currently being investigated by the Antiproton Cell Experiment (ACE) to treat cancers.

Something very attractive about this type of work is that it is not driven by profit or appeasing shareholders. The experimentation is done out of pure curiosity, plain and simple. Everybody in the group has their own project to work on, but there is also an open playing field for exploration into new physics. Maybe, if you work in the field of antimatter, you could be the inventor of the antimatter engines that power the Enterprise...



At the age of 32 I have had three varied jobs: a professional drummer, a teacher and now a scientist, and having a degree in mathematics helped a lot.

My route into this field was not ordinary, and it is amazing where life's twists and turns can lead you.

Firstly, some words of advice for someone who may be worried about their university options: if you take a degree, take a general one to open doors. You can change jobs every five years and have eight different jobs before retirement. At the age of 32 I have had three varied jobs: a professional drummer, a teacher and now a scientist, and having a degree in mathematics helped a lot.

Maths was difficult for me at school. It took a couple of great teachers to bring me back into it and I read Mathematics with Astronomy at Southampton University. By treating it as a 9-to-5, Monday-to-Friday job I was able to walk out with a first-class degree, which has proved to be incredibly useful in doing what I wanted to do afterwards.

My first job after university, however, was working as a street sweeper for the local council. Alongside this I was a drummer in a band, and with a recording studio we built on a chicken farm we recorded our own music and other bands' music for four years. This is not classic 'CV material', but having a good degree gave me the freedom to try something I really wanted to do (not the street sweeping).

I trained to become a teacher and taught at a British school in Beijing for three years. Working abroad gave me many opportunities to see different parts of the world and I grew to appreciate the intricacies of societies and politics that make the world how it is.

As a teacher on a training course at CERN, I spoke with someone about how to work there, and he suggested I applied to the universities that collaborate with the CERN-based experiments. This is exactly what I did. I applied for a Masters of Research at Swansea University to work on a project based at CERN and now I work at the leading edge of scientific research, and am enjoying every moment of it.

So, my general message is that doing what you enjoy is important, but as you get older and your interests change it is worth having something solid to fall back on. Choosing a degree can be daunting, and it's fine if you don't have a clear picture about what you want to do when you're at school.

In the words of Baz Luhrmann,

"Don't feel guilty if you don't know what to do with your life. The most interesting people I know didn't know at 22 what they wanted to do with their lives, some of the most interesting 40-year-olds I know still don't."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