Catalyst

Secondary Science Review

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Beneath our feet

The importance of soil

Science Enhancement Programme

Volume 26 Number 4 April 2016

The cover image shows a ploughed field in southern Germany. The importance of soil as a vital resource which is in danger was highlighted during the UN International Year of Soils, 2015. (Photo: Andreas Krappweis)

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Where will science take you?

When you study science at school, you may think of it as being divided into Physics, Chemistry and Biology. Those three major divisions are a convenient way of thinking of the different parts of science but. In practice, most people who are engaged in scientific research or in developing applications of science have different specialisms. For example, a soil scientist (see the article on pp1-3) must know about the chemistry of soils and the physics of how soils behave. They must also know about the behaviour of organisms that live in soil and about the plants that grow from it.

In the article on pp9-12, Suzy Moody describes new ways of finding out about how fungi attack trees. Her team must understand how to do chemical analyses as well as DNA analysis of material taken from trees. They must be able to identify different fungi and know about their growth habits.

As Jay Culligan emphasises (pp14-16), it's important to find an area of science which interests you develop your skills and understanding if you want to make a career in it.

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Stefania Hartley

Dust to dust? The importance of soil

"The nation that destroys its soil, destroys itself," said Franklin D. Roosevelt (President of the USA), February 1937.

Dark clouds roll over the land at one hundred miles per hour, engulfing and smothering everything on their path. They don't carry the much awaited rain, but choking dust. Not the ash spewed out of a volcano, or the particulate belched out of industrial and car exhausts; this dust is the farmland, crumbling away.

A giant dust storm threatens to engulf a village in the American Dust Bowl disaster of the 1930s.

Key words

soil

erosion

water storage

food security

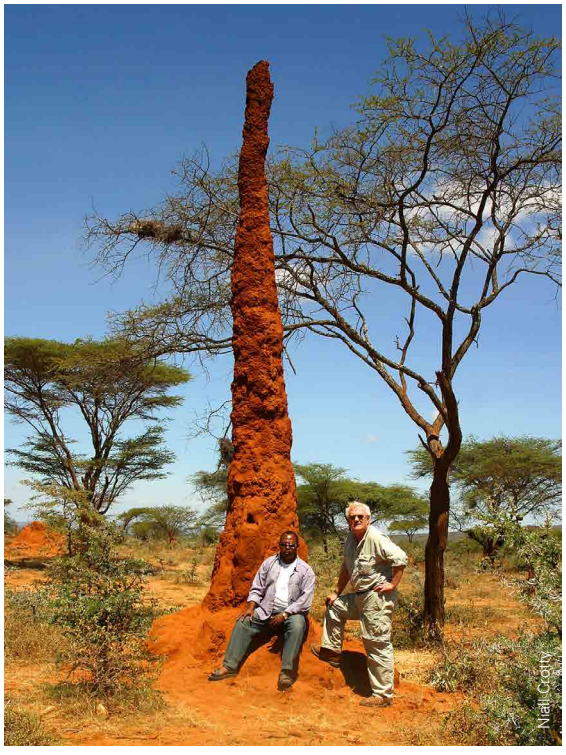
It's 1935 in the Great Plains of the United States, the area newly named 'The Dust Bowl'. Poor understanding of the Plains' ecology has led the authorities to assign to farmers as cropland these drought-prone, wind-swept prairies. Poor soil management (deep-ploughing and fallowing) followed by a few years of droughts have turned the unprotected topsoil into dust. Unprecedented dust storms ('black blizzards') are now ravaging the land and depositing tonnes of earth as far away as Chicago and New York. Entire communities are plunged into destitution, populations are displaced. From this ecological, economic and human disaster, the first legislation for the protection of soil, the Soil Conservation Act, is born.

Even now, few countries have passed legislation for the sustainable management of soil and, every year, 75 billion tonnes of crop soil worldwide are lost to wind and water erosion.

What is soil?

Soil is made, on average, of 5% organic matter (dead plant and animal material), 25% air, 25% water, and 45% mineral material (rock, sand, silt, clay). But soil is constantly changing: different proportions of air and water fill the pores between the solid grains, chemical reactions happen between its minerals components and within the millions of organisms that live in it all the time.

The formation of one cubic centimetre of new soil can take hundreds to thousands of years, thus making soil effectively a non-renewable resource. New soil is formed when 'parent' rock is exposed either by volcanic eruption, by uplift of the sea bed or by weathering (caused by wind, rain, ice or changing temperatures). Parent rock can also be deposited from elsewhere as gravel, sand or sediments of different sizes. The size of the particles will give the soil a different texture: sandy soils feels coarse and gritty; silty soils feel silky; clay soils feel sticky. Plant roots then bind the soil particles and split the rocks, while animals burrow into the soil, mix it and deposit faeces. Faeces and dead plants and animals are decomposed by fungi and bacteria which release their nutrients for new plant colonisers. This creates successions of plant, animal and microbial communities which are affected by and affect the evolving soil.



Termites build their homes from particles of soil – this spectacular mound is in southern Ethiopia.

Why should we care about soil?

We trample it, we cover over it, we call it 'dirt'. With a few pricey exceptions (beauty mud masks, for example), we don't value the soil under our feet. Still, everything we need in order to survive (food, clothing, shelter and water) comes from soil. 'Soil security' is increasingly being spoken about, because soil is unequally distributed across nations and provides us with a crucial range of services:

- Building materials. From peat to sand, from clay and gravel to the ancient Romans' fantastic *pozzolana*, most building materials come from soil.
- Food, animal feed, fibres, fuel and medicinal products. With the exception of hydroponic cultures, all crops are grown on soil. Soil provides plants with anchorage, water, oxygen, trace elements and symbiotic microorganisms which facilitate the absorption of micronutrients by plant roots. Food grown on soil which lacks micronutrients which are indispensable to human health (e.g. iodine, copper, lithium, magnesium, iron and zinc), will foster malnutrition, especially in those cases where the trace elements are essential for humans but not for plant growth (like selenium and iodine). Soil also buffers plant roots from temperature fluctuations.
- Water storage and purification. Un-compacted, healthy soils prevent flooding by allowing water to infiltrate and percolate instead of running off. Some soils can store in excess

Cultivation terraces, such as these in Puglia, Italy, retain rainwater and prevent soil erosion, allowing crops to be grown on steep hillsides.

of 400 mm of rainfall in their first meter of depth. Contaminants and pathogens are filtered out of the water during percolation, and microorganisms like *Enterobacter cloacae* can remove pollutants like selenium.

- Carbon storage. Soil organic matter stores more organic carbon than global vegetation and atmosphere combined. Soil is a key player in the global carbon cycle. Scientists are worried that, with global warming, increased activity of the microbial community in permafrost could release large quantities of the tundra's soil carbon. In an experiment, after only 1.5 years of warming, scientists observed a 38% increase in tundra microbial respiration.
- Disease protection through a diverse ecosystem. Soils host a quarter of our planet's biodiversity, most of which is as yet unstudied. Healthy soil contains millions of organisms including vertebrates, earthworms, nematodes, mites, insects, fungi, bacteria and actinomycetes. Few species occur in most soils, most species being limited to specific soil type or regions. Earthworms and termites increase crop productivity, symbiotic soil microbes increase plant nutrient uptake, fungi promote plant stress tolerance.

Most soil organisms pose no risk to human health and actually compete with the small minority or microorganisms which are pests, parasites or pathogens such as *Bacillus anthracis,* the agent of anthrax, *E.coli, Clostridium tetani* and parasitic nematodes. Ploughing and excessive fertilizer application decrease soil biodiversity and, as a consequence, protection against disease. Studies have shown that our immune system needs to be exposed to soil microorganisms in order to develop tolerance against allergies and scientists are looking at soil microbiota as a yet-untapped source of potential antibiotics and medicines (see Catalyst article on Teixobactin, Oct 2015).

The health of our soils

Every year 75 billion tonnes of crop soil are lost worldwide due to wind and water erosion and unsustainable agricultural practices. Current estimates put the percentage of global soil classified as moderately to highly degraded at 33%. The major causes of degradation are erosion, salination, compaction, acidification, loss of organic matter, soil sealing, chemical pollution and nutrient depletion. In the UK alone, the total cost of soil degradation is estimated at about £300 million per year.

The effects of the mismanagement of soil are felt far beyond the site of the disturbance: soil erosion by water and wind contributes to dust storms and the dispersal of soil microorganisms and pathogens for miles; the release of carbon from soil affects the planet's climate; the run-off and leaching of nutrients affects aquatic systems.

Considering the role played by soil in food security, climate change, human health, poverty alleviation and sustainable development, it is no surprise that the United Nations General Assembly declared 2015 the International Year of Soils with the purpose of raising awareness about this neglected resource. Understanding and appreciating the many services provided by the stuff under our feet is a first step towards using it responsibly.

Stefania Hartley is a science teacher living in Singapore.

Actions to protect soil

- Prevent soil pollution.
- Avoid sealing the soil (covering it with impermeable material).
- Avoid compacting the soil.
- Reduce tillage to increase carbon storage in soil.
- Include cover crops to prevent erosion.
- Increase crop rotation to expand soil biodiversity.
- Prevent water erosion by practising terraced and contour farming (planting crops following the contour of the landscape).

2015 International Year of Soils

Look here!

2015 Year of Soils:
http://www.fao.org/soils-2015/about/en/

Take the soil quiz:
http://www.fao.org/soils-2015/news/news-detail/en/c/317128/

British Society of Soil Science: http://soils.org.uk/

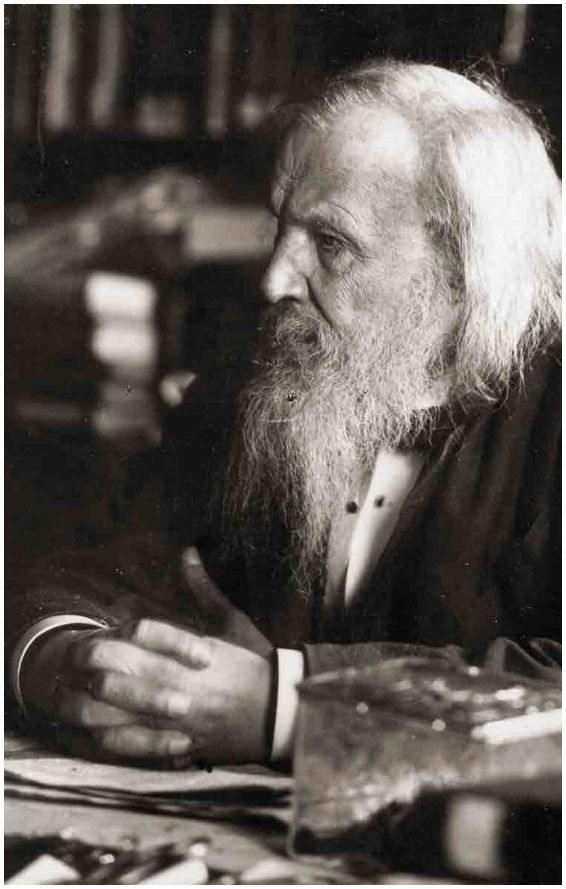
Become a soil scientist:
http://soils.org.uk/what-soil-scientist-0

Global Soil Biodiversity Initiative:
https://globalsoilbiodiversity.org/

Soil Science Society of America The Year of Soils videos:
http://bit.ly/1DmbcMN

Vicky Wong

Dimitri Mendeleev
and the periodic pattern



Dimitri Mendeleev

In 1863 there were 56 known elements and new elements were being discovered at the rate of about one per year. There were several attempts to bring some sort of order to the elements, but Mendeleev was one of the few who realised that not all the elements had been discovered and so left spaces for them in his table. He put the elements in order by atomic weight and by the patterns in their properties. He assumed that they must go in order of mass, but if they seemed to fit better elsewhere by their properties he moved them, and presumed that others had made mistakes in their calculation of atomic mass.

The modern periodic table is not arranged by atomic mass but by atomic number and many of the atomic masses that Mendeleev assumed were wrong were in fact correct. Atomic number is the number of protons in the atom but when Mendeleev put his table together not all chemists even agreed that atoms existed and they had not discovered protons or the atomic number. Usually putting the elements in sequence by mass gives the same order as by atomic number, but there are a few examples where this is not the case. But ignoring the mass where it did not quite fit the pattern allowed Mendeleev to build up his periodic table into something that was useful to chemists rather than just an interesting list.

Reihen	Gruppo I. — R^1O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=86	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev's periodic table of 1871; note the spaces under aluminium (Al) and silicon (Si) with Mendeleev's predicted atomic masses of 68 and 72.

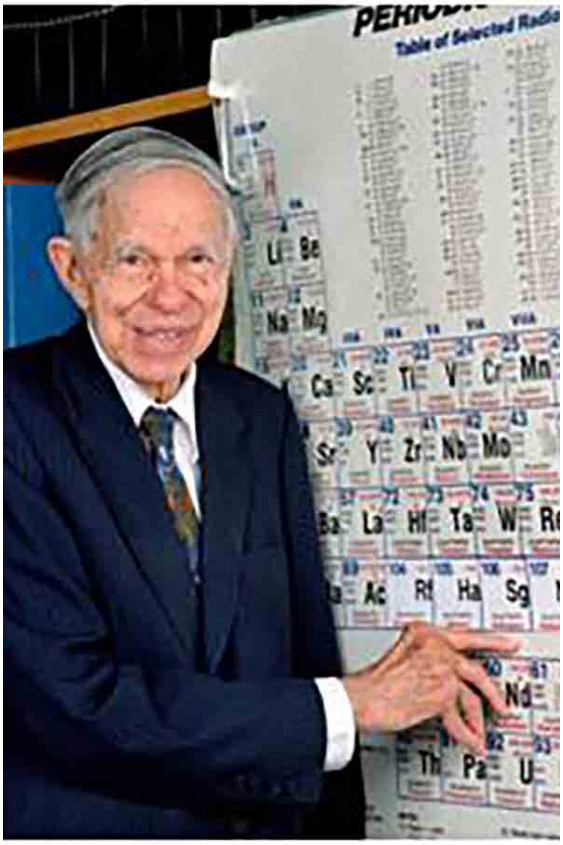
Patterns that predict

Mendeleev's real genius was in realising the predictive power of the periodic table. He used the patterns in the properties of known elements to predict the properties of several undiscovered elements. Within 15 years of him making these predictions public, three of the elements had been identified and their properties shown to match those he had predicted.

The first of these Mendeleev had called eka-Aluminium as it was the one after Aluminium. It was identified in 1875 by the Frenchman Paul de Boisbaudran who called it Gallium. Mendeleev was justifiably pleased when its properties were shown to be very similar to those he had predicted. However, de Boisbaudran gave the value for the density as 4.9 g/cm^3 and this was quite different to the 6.0 g/cm^3 Mendeleev was expecting. He got the Frenchman to check and de Boisbaudran found that the value should have been 5.9 g/cm^3 which was far closer to Mendeleev's prediction.

Creating elements

After Mendeleev's death, scientists began not just discovering but creating elements by fusing atoms together. A whole new section of the periodic table was opening up for these really heavy elements which had not been present in Mendeleev's lifetime. Most only exist for fractions of a second before radioactive decay sees them transform into something else.



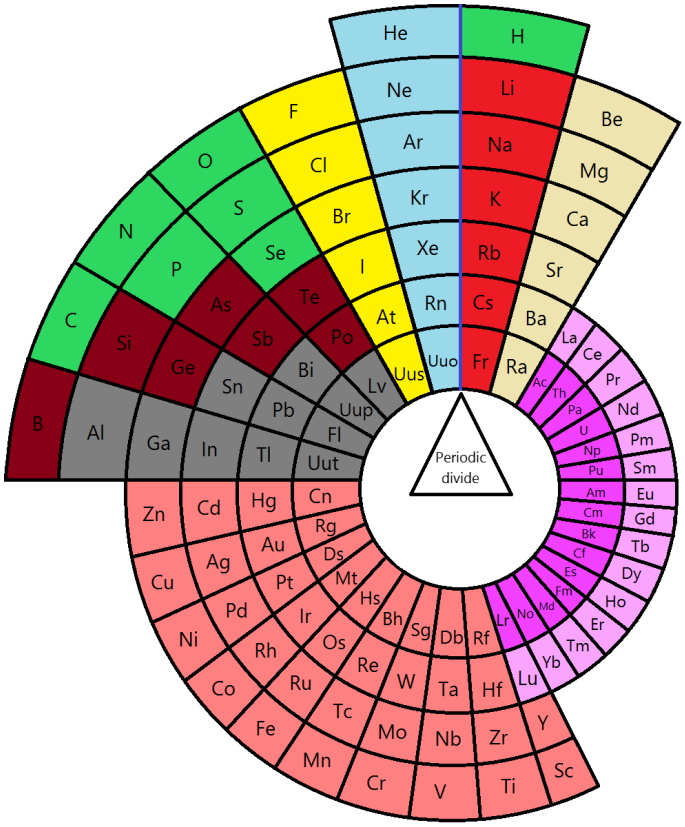
Glenn Seaborg pointing to the element named after him on the periodic table. He is the only person to have an element named after them while still alive.

Element number 106 is Seaborgium (Sg) which was first made in the 1970s. The short lifetime of the atoms made finding out about the chemistry very difficult, but the properties were predicted using the periodic table. Sg was expected to be similar to the elements above it (molybdenum (Mo) and tungsten (W)) and to:

- have a valency of 6
- react with oxygen and chlorine to form an oxychloride with the formulae SgO_2Cl_2
- form negatively charged complex ions.

In the late 1990s researchers were able to produce Seaborgium at the rate of one atom an hour and using fewer than 10 atoms showed that the predictions made using Mendeleev's periodic table were once again correct. Mendeleev would certainly have been pleased, but perhaps not very surprised.

Vicky Wong is Chemistry editor of Catalyst



The information in the periodic table does not have to be shown in the traditional block system and other forms have been devised such as this circular periodic table.

Look here!

The previous issue of Catalyst (Vol 26 issue 3) had another article on discovering new elements:

http://tinyurl.com/jydblgs

Catia Costa

Mahado Ismail

Shelley Watkinson

Fingerprints – beyond identity

Key words

fingerprints

chemical analysis

drug testing

forensic science

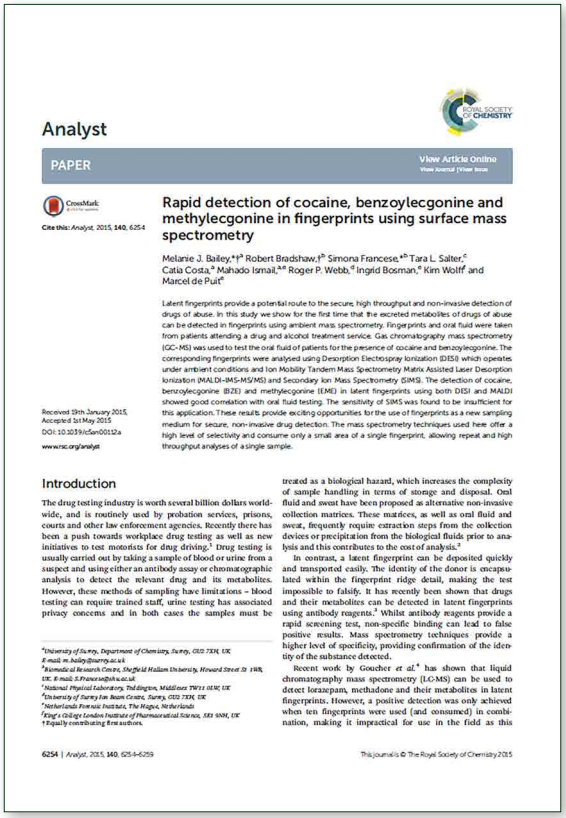
We all know that fingerprints can be used for the identification of people involved in crimes; but what if you could learn more than just a person's identity from their fingerprint? In this article, three postgraduate students from the University of Surrey describe what can be achieved today and what may be possible in the future.

When a person touches a surface, they leave behind a fingerprint. This fingerprint is a result of sweat excreted from the skin. The material from sweat that is left behind can be referred to as fingerprint residue. Fingerprint residue contains materials from substances ingested (foods or drinks), illegal substances taken (for example cocaine or heroin), nicotine from smoking, and natural components such as amino acids and fatty acids, just to name a few. Due to the numerous compounds found in fingerprint residues, it is possible to determine personal habits (drug use) and maybe even determine the age, gender or diet of an individual. This can be useful to police because a fingerprint gives no useful information if it is smudged or if the offender is not on the fingerprint database. Also, it is thought that fingerprints can be used to assess the medical condition of an individual and this may one day be useful in medical diagnostics.

In our research at the University of Surrey we are exploring the use of fingerprints for more than just identity. By surveying the surface chemistry of a fingerprint, it is possible to gain a wealth of new information.

Drug testing using fingerprints

The chemical analysis of fingerprints is a new and interesting field in the areas of analytical and forensic science. One of the key areas being investigated is the possibility of using fingerprint residues for drug testing purposes. Fingerprints can offer advantages over other biological fluids (e.g. blood, urine and saliva) as they are easy to collect. Furthermore, because a fingerprint can be used to identify an individual, the test is difficult to falsify and there is a lower chance of mixing up samples.



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Rapid detection of cocaine, benzoylecgonine and methylecgonine in fingerprints using surface mass spectrometry

Melanie J. Bailey,*†[a] Robert Bradshaw,†[b] Simona Francese,*[b] Tara L. Salter,[c] Catia Costa,[a] Mahado Ismail,[a,e] Roger P. Webb,[d] Ingrid Bosman,[e] Kim Wolff[e] and Marcel de Puit[e]

Latent fingerprints provide a potential route to the secure, high throughput and non-invasive detection of drugs of abuse. In this study we show for the first time that the excreted metabolites of drugs of abuse can be detected in fingerprints using ambient mass spectrometry. Fingerprints and oral fluid were taken from patients attending a drug and alcohol treatment service. Gas chromatography mass spectrometry (GC–MS) was used to test the oral fluid of patients for the presence of cocaine and benzoylecgonine. The corresponding fingerprints were analysed using Desorption Electrospray Ionization (DESI) which operates under ambient conditions and Ion Mobility Tandem Mass Spectrometry Matrix Assisted Laser Desorption Ionization (MALDI-IMS-MS/MS) and Secondary Ion Mass Spectrometry (SIMS). The detection of cocaine, benzoylecgonine (BZE) and methylecgonine (EME) in latent fingerprints using both DESI and MALDI showed good correlation with oral fluid testing. The sensitivity of SIMS was found to be insufficient for this application. These results provide exciting opportunities for the use of fingerprints as a new sampling medium for secure, non-invasive drug detection. The mass spectrometry techniques used here offer a high level of selectivity and consume only a small area of a single fingerprint, allowing repeat and high throughput analyses of a single sample.

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www.rsc.org/analyst

Introduction

The drug testing industry is worth several billion dollars worldwide, and is routinely used by probation services, prisons, courts and other law enforcement agencies. Recently there has been a push towards workplace drug testing as well as new initiatives to test motorists for drug driving.[1] Drug testing is usually carried out by taking a sample of blood or urine from a suspect and using either an antibody assay or chromatographic analysis to detect the relevant drug and its metabolites. However, these methods of sampling have limitations – blood testing can require trained staff, urine testing has associated privacy concerns and in both cases the samples must be treated as a biological hazard, which increases the complexity of sample handling in terms of storage and disposal. Oral fluid and sweat have been proposed as alternative non-invasive collection matrices. These matrices, as well as oral fluid and sweat, frequently require extraction steps from the collection devices or precipitation from the biological fluids prior to analysis and this contributes to the cost of analysis.[2]

In contrast, a latent fingerprint can be deposited quickly and transported easily. The identity of the donor is encapsulated within the fingerprint ridge detail, making the test impossible to falsify. It has recently been shown that drugs and their metabolites can be detected in latent fingerprints using antibody reagents.[3] Whilst antibody reagents provide a rapid screening test, non-specific binding can lead to false positive results. Mass spectrometry techniques provide a higher level of specificity, providing confirmation of the identity of the substance detected.

Recent work by Goucher *et al.*[4] has shown that liquid chromatography mass spectrometry (LC-MS) can be used to detect lorazepam, methadone and their metabolites in latent fingerprints. However, a positive detection was only achieved when ten fingerprints were used (and consumed) in combination, making it impractical for use in the field as this

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Figure 1 *This scientific paper, published by the Royal Society of Chemistry in its journal Analyst, describes how cocaine and two of its metabolites can be detected in a fingerprint. It has 10 authors from 6 collaborating scientific institutions.*

A recent article published by our supervisor, Dr Melanie Bailey and her colleagues (***Figure 1***), describes how desorption electrospray ionisation – mass spectrometry (DESI-MS, ***Figure 2***) enabled the detection of cocaine and its metabolites in fingerprints of individuals attending a drug treatment service for their drug dependency. DESI-MS uses a beam of charged solvent (a mixture of water and methanol to which a voltage is applied) to strike a small area of the sample, thus causing molecules from the sample to desorb (lift off). It also causes ionisation of the target molecules. The ionised molecules (positively charged, in this case) are then sucked into an instrument called a mass spectrometer, which measures their mass. DESI-MS allows a fingerprint to be analysed in air and can be carried out in under two minutes.

Although the detection of the parent drug (cocaine, in this case) in a fingerprint is important, it does not prove that the person took the drug, as it could be present by contact with a contaminated surface (e.g. a bank note). The detection of the metabolites (molecules resulting from the breakdown of the drugs by the body) will give a better indication of whether the person ingested the drug. The results obtained using this method were corroborated by analysis of saliva collected from the same individuals, which showed a very good correlation. A positive result for cocaine in saliva was matched by a positive result in fingerprint.

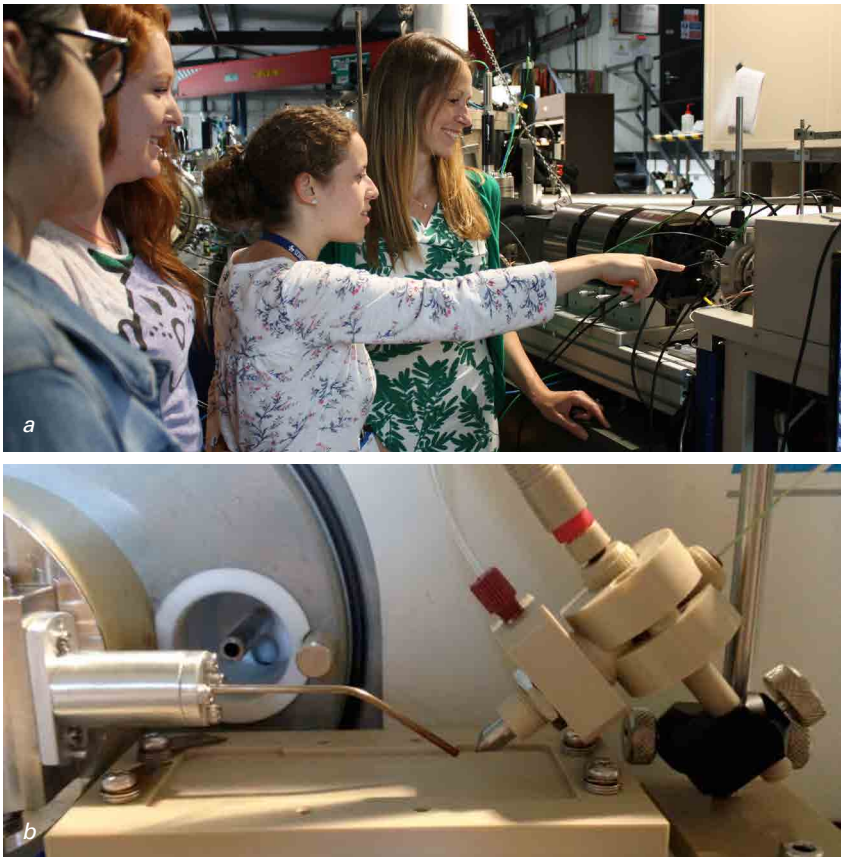


Figure 2 *a The desorption electrospray ionisation – mass spectrometry (DESI-MS) instrument available at the University of Surrey; b The DESI spray head (right) produces a beam of charged solvent which is directed at the sample, causing desorption and ionisation of molecules. The stainless steel capillary (left) extracts the ionised molecules onto the mass spectrometer for mass measurement.*

Overlapping fingerprints and inks on documents

Using available technology, forensic investigators are not able to distinguish whether a fingerprint is above or below a layer of ink on a document. This can have implications in cases where a suspect claims to have handled the document before any text was written. If, however, forensic investigators could determine the chronology of deposition of fingerprints and inks on a document, the evidential value of the questioned document would be increased.

Research carried out at the University of Surrey explored the potential use of secondary ion mass spectrometry (SIMS) for determining the deposition sequence of overlapping fingerprints and inks on paper. Secondary ion mass spectrometry (SIMS) is a technique that is used for surface analysis (***Figure 3***). It only looks at the first few monolayers of the sample surface and therefore does not visibly change the sample making it suitable for document analysis. SIMS is a very sensitive technique and is used for its imaging capabilities as it produces high resolution chemical images. These images show the distribution of molecules on a surface and therefore can determine where the molecules originate from.

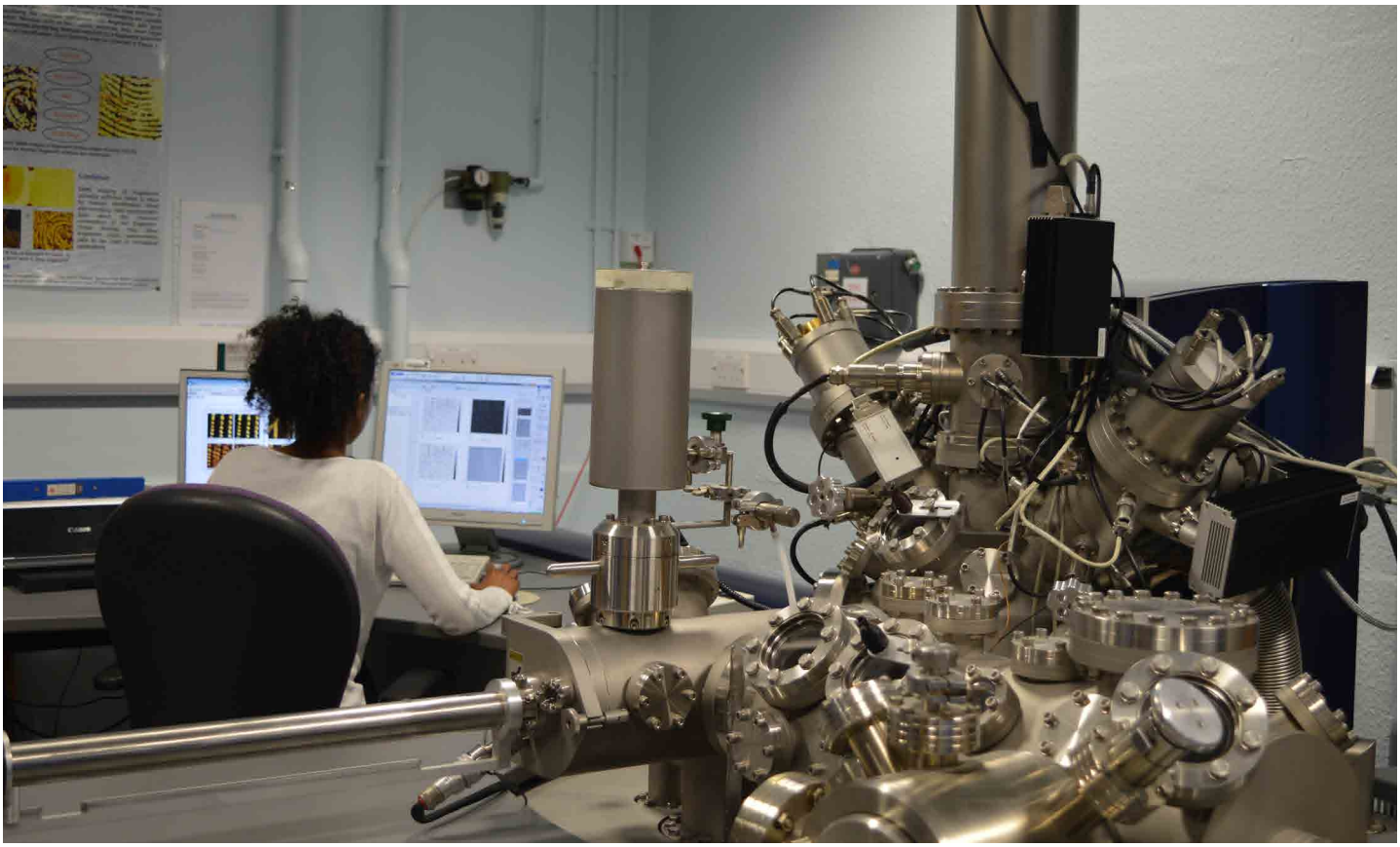


Figure 3 *Surface Analysis Laboratory at the University of Surrey.*

SIMS uses a primary ion beam that is directed onto the sample surface for surface ionisation. This causes a process called sputtering, whereby secondary ions are generated from the sample surface due to the impact of the pulsed primary ion beam. These secondary ions can then be detected using a mass spectrometer.

SIMS has demonstrated that when a fingerprint is deposited over a layer of ink, chemical images from compounds present in fingerprints will allow the observation of fingerprint ridges on top of the ink line (***Figure 4***). When the fingerprint is placed below a layer of ink, the fingerprint signals are masked by the overlapping ink.

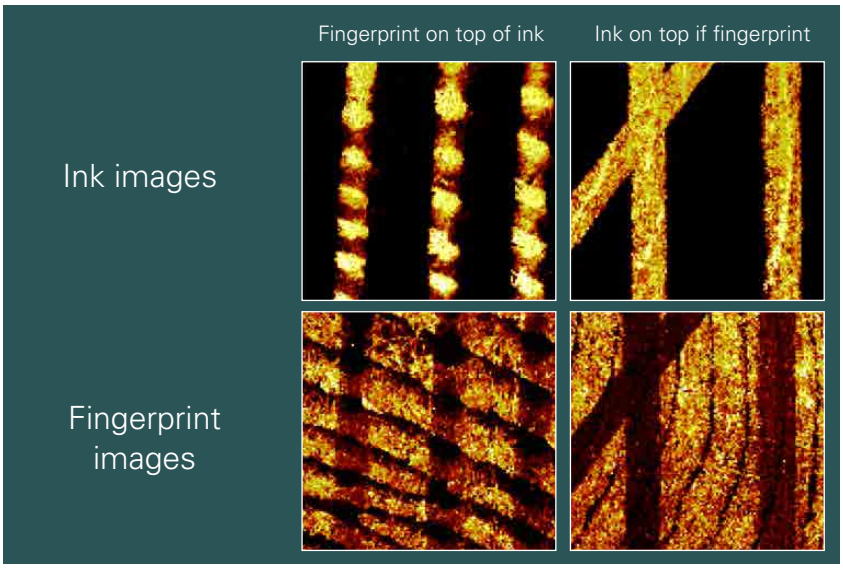


Figure 4 *SIMS ion images of overlapping fingerprints and inks on paper.*

Forensic investigators normally use chemical development reagents to visualise fingerprints on surfaces. A popular chemical developer is ninhydrin, which reacts with amino acids present in fingerprints to produce a purple colour. The SIMS method has also been applied to overlapping fingerprints and laser printed ink on documents after development with either ninhydrin and 1,2-indandione. Similar to images in ***Figure 4***, the chemically developed fingerprints on documents also gave indication of the deposition order. Therefore, this method has shown real-life applicability.

A look forward

Fingerprints can offer more to an investigator then just the identity of an individual. As explained above the analysis of fingerprint residues can be used to detect drugs and metabolites in fingerprints and differentiate between overlapping fingerprints and inks on paper, the use of which is valuable in real world forensic science. Whilst the DESI technique shows great promise for drug testing, it cannot provide any information on how much drug or metabolite is present, and this is currently being investigated. The work on overlapping fingerprints and inks on documents is at a more advanced stage of research and we are working with the Netherlands Forensic Institute on a validation study, which is the final hurdle before it can be adapted in casework.

Catia Costa, Mahado Ismail and Shelley Watkinson are postgraduate students in Dr Melanie Bailey's lab in the Chemistry Department, University of Surrey, UK.

Wood decay fungi

The mystery of a competitive community

Suzy Moody

Suzy Moody

One of nature's most spectacular displays comes from the fungi growing on trees and tree stumps. Fungal fruiting bodies (the mushroom bit) come in every shape, size and colour. Many have weird and wonderful names too – turkey tail fungus, razor strop, witch's butter and scarlet elf cup. Beautiful and strange they may be, but we know remarkably little about how these wood decaying fungal communities become established, or how the different fungi interact. Our focus at Swansea University is primarily on understanding which species colonise the wood (a difficult job as wood is made of lignocellulose and hard to break down) and when. How do the different fungi that we see interact with each other?

Scarlet elf cup on the forest floor

Turkey tail fungus can be found on lots of trees and stumps.

Pattern of decay

The community of fungi growing on dead wood changes over time. Traditionally it is described as a succession with each fungus being out-competed when a new and stronger competitor arrives. For example, primary colonisers are those fungi which are the first saprotrophs to start decaying dead wood. (The branch may die due to a variety of environmental conditions, and wood decay fungi do not wait for the branch to detach from the tree to begin the decay process.) Examples of these include bleeding oak crust (which can also invade other trees) and beech tar crust.

Secondary colonisers are fungi which can out-compete the primary colonisers and utilise more of the partially decayed wood. Turkey tail fungus is a secondary coloniser and has a formidable range of enzymes that can attack the complex structure of wood and break down the lignocellulose.

New approaches

Research being conducted at Swansea University is using pairs of fungal competitors to examine how these interactions occur, which competitors are the more aggressive and how each competition is being fought. Using techniques that look at differences in gene expression and protein production, our research hopes to shed light on why turkey tail fungus is so good at out-competing primary colonisers, and why it in turn is out-competed by competitors such as sulphur tuft fungus. While this laboratory-based work may help our understanding of how fungi interact, it is not the whole story. The reality of decaying wood is a great deal more complex.

A Xylariaceae fungus on a log

Saprotrophs are organisms which feed on dead and decaying things.

The photograph on pages 10-11 shows beechtar fungus and a shelf fungus fruiting on the same piece of branch.

Two different species of fungus growing on a single branch – but are they working together or fighting it out? Research at Swansea University aims to find out.

Catalyst

www.catalyststudent.org.uk

A whole standing beech tree which has been colonised by bleeding oak crust (the white fungus) and dryad's saddle fungus (reddish)

Which fungus?

The assessment of which species are present has always been done visually, using the presence of fungal fruiting bodies. This is beginning to change as molecular techniques are brought into the field of microbial ecology. Anna Rawlings, a PhD student at Swansea University, is studying the colonisation of tree branches before they ever reach the forest floor. To try to determine the community structure and function of early colonisation and the role of the primary coloniser, she is using molecular methods such as DNA extraction and sequencing to determine which species are present, rather than relying on the presence of fruiting bodies.

The results so far suggest that far from mushrooms telling us everything, there can be many other species of fungi present in the wood which are not producing mushrooms. Indeed, it may be that far from one species dominating a section of wood, complex communities of different fungi are present from early on in the invasion process. As can be seen in the photo above, two fungi (bleeding oak crust and dryad's saddle) are present in a standing beech tree. Both fungi have already colonised the wood and begun the decay process. What we are interested in is whether that co-existence is a battle or whether there is a degree of tolerance.

Metabolites are small molecules produced during the chemical reactions carried out by living organisms.

A wood slice showing the interaction zones of different fungi

Witches butter on a standing beech tree

A slice of life

Looking at the slice taken through a beech branch, each of the wiggly lines delineates an area colonised by a different fungus (most of which will not produce fruiting bodies and therefore their presence would remain unknown by traditional methods). Clearly, there are many 'individuals' in close proximity. The lines are caused by the fungi putting up chemical barriers to prevent the neighbouring fungi from taking over.

Anna is using protein and metabolite analysis to try to understand the relationships between the different fungi early in the wood colonisation process, to see what the overall function of the community is and whether communities with different individual members perform in a similar way. It remains to be seen whether these community members are always competing or whether there is also some degree of co-operation. Lignocellulose is extremely tough to break down, and the possibility of co-ordinated degradation by co-operative fungi is certainly something to be considered.

All of the fungi pictured here are involved in wood decay, some as primary colonisers and some in the final stages on the forest floor. How and why they compete and/or co-operate remains something of a mystery.

Suzy Moody is a microbiologist at Swansea University

Make a non-Newtonian fluid

Most liquids behave in ways that we expect: they flow, they splash, they pour, they change their shape to fit their container. Not all liquids behave in this way at all times, however. You can very simply mix up a fluid which behaves in some surprising ways.

This can get messy so you may want to cover where you are working with newspaper and wear an apron and plastic gloves.

You will need:

- 225 g cornflour
- 230 ml water
- A large plastic mixing bowl
- Spoon (optional)
- Small plastic food bag

What you do:

Put the cornflour into the bowl and add the water. Stir together thoroughly using either your hands or a spoon. You can add some food colouring at this point if you wish, but it does make the mixture messier.

Keep mixing until the mixture is smooth and around the consistency of honey, adding a bit more cornflour or water as necessary.

Now try these:

The mixture is great to experiment with; here are a few suggestions:

- Try punching the mixture hard and quickly. Then hit it repeatedly. Most liquids will splash, but this mixture turns hard, resisting your hand. This is because under the force of the punch the water flows away leaving a dense patch of cornflour particles under your fist.
- Contrast this with pushing the mixture slowly. How does the liquid respond differently?
- Put some onto a flat surface and try pushing it with your finger. Can you see the cornflour and liquid begin to separate out again?
- Scoop up some of the mixture and roll it into a ball in your hands. As long as you keep rolling it and applying pressure it will stay in the ball shape. Once you stop it will flow back into the bowl like a liquid.
- Try adding more water or cornflour to change the consistency of the mixture. How does this change the properties?

Disposal: Do not put the fluid down the sink as it can block it. Put it in a bag, tie the top and dispose of in the bin.

Uses: The cornflour slime fluid is described as 'non-Newtonian' because its behaviour depends on how fast you try to move it. It is fun to play around with, but uses have been found for fluids like these too, including in armour.

Vicky Wong is Chemistry editor of Catalyst.

It flows like treacle …

… but you can roll it into a ball.

Dispose of with care.

Look here!
http://www.bbc.co.uk/news/10569761

Jay Culligan

Researching cuttlefish
The clever cephalopods

Cuttlefish on a coral reef

Key words

vision

colour change

convergent evolution

cuttlefish

Biologists investigate animals with lifestyles and abilities that are very different from ours. Creatures such as echolocating bats or animals that can survive in water above 70°C open new perspectives in biology. At the University of Sussex, I am fortunate to be studying one of the most alien creatures on this planet – the cuttlefish. Cuttlefish are cephalopods, like octopus, squid, and nautilus. These creatures could not be more different from humans. They have three hearts and blue blood. They have no bones but capture their prey with elastic limbs equipped with suckers, inject it with venom and eat it with a bird-like beak. But for me their vision and camouflage is most remarkable.

Simplifying the complex world

Cuttlefish may differ from us in just about every possible way, but they do possess one similarity to humans. We look at each other with the same kind of spherical lens eyes. Cephalopods are molluscs, so their common ancestor with humans was most likely a worm-like animal, which was more or less blind, at most able to detect the presence or absence of light. The similarity of the cuttlefish visual system to that of humans arose independently through natural selection. This is what we term convergent evolution. In my laboratory, we investigate how the cuttlefish perceive their world. What are the similarities and differences to human vision?

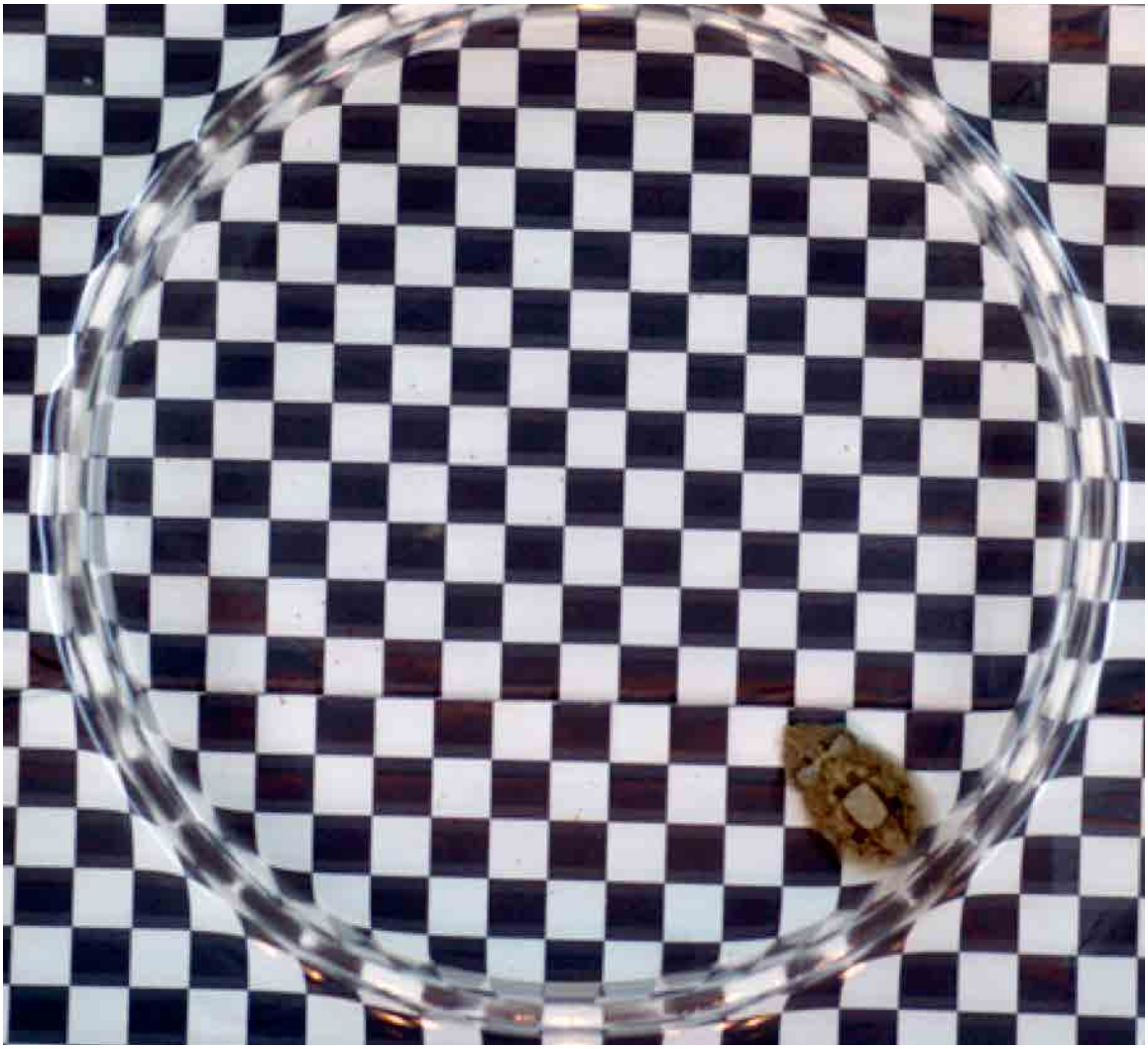


Figure 1
A cuttlefish camouflaging on a checkerboard.

The natural world is a complex scene. Think of a coral reef bed. There's a huge variety of colours and textures. When you add depth, it's easy to see how crazy it is how our brains can interpret these many factors into a 3D image. Trying to understand a visual system with such complexity seems daunting, but like any good scientist, we just need to reduce a visual scene into a smaller number of variables. In the case of cuttlefish, we regularly use checkerboards - see ***Figure 1***. Checkerboards are simple backgrounds that vary in only two variables: size and contrast. We can scale the size or alter the contrast between the checkers and tease out how they respond to the scene.

Alternatively, we may also use image statistics. The combination of simpler variables can get exponentially difficult as you increase the number of variables. Even more difficult is understanding complex patterns and textures. To understand complex natural scenery, we need a way to look way to represent a natural scene more easily. In this way, we can use digital images from a camera. Just like a computer screen, the image is made up of hundreds or thousands of pixels. Each pixel is represented by colour values of red, green, and blue.

Think of an image as a giant matrix. We can use various algorithms and statistics to alter these values to understand more complex relationships in the natural environment and how the visual system interprets it. After altering the image, we can present it to the cuttlefish and see how they respond For example, if you refer to ***Figure 2***, you see three textures in their original state and phase randomized. When the phase information is randomized, the detailed information, such as well defined edges, for object recognition disappears and the images appear cloudy.

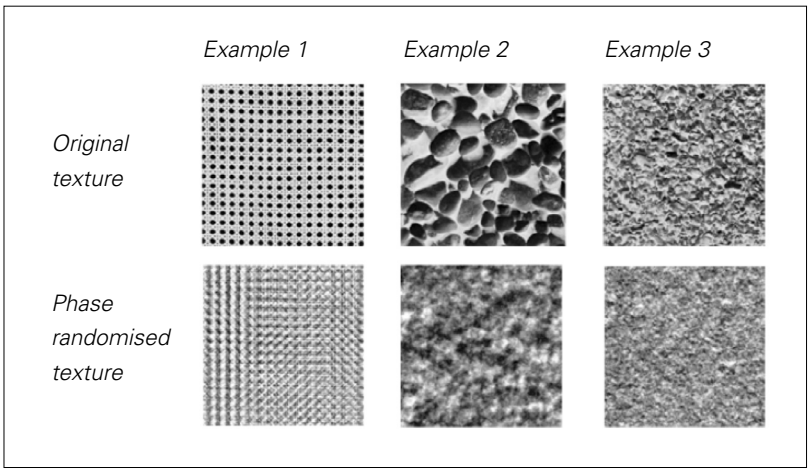


Figure 2 *An example of using image statistics to alter an image. The top row shows the original image and the second row demonstrates how randomizing the phase of an image can distort the edges in an image making it blurry.*

I just want to blend in

When we examine human vision, we are able to ask the person in question what they see; we have the opportunity for a verbal response. Unfortunately, we are unable to ask the cuttlefish this question. You're more likely to be inked at. Instead, we can use another aspect of cuttlefish biology to tease out the answers to these questions. We achieve this through investigating their rapid adaptive camouflage.

Cuttlefish are the camouflage masters of the world. They are unrivalled in the animal kingdom. They are capable of altering the colour, pattern, and texture of their whole bodies in under a second! This remarkable capability is due to the fact that the cuttlefish's skin is directly connected to their brain. The skin is under the control of motor neurons. The nerve signals control muscles, known as chromatophores, which contract and expand to form the myriad stripes, spots, and other pattern formations on the skin. This is akin to the motor neurons in human facial expression. A cuttlefish can switch its whole body colour at the same speed at which a human can smile or frown.

We can use this camouflage system as a behavioural output to understand how they see the world. The information from the environment comes into the eyes, into the brain, and directly to the skin – see ***Figure 3***. More importantly, we can utilise these camouflage masters to understand other visual systems, including that of humans. Any animal that has a visual predator requires camouflage. It's important to prevent being eaten and to hunt effectively. We can investigate the similarities between the camouflage patterns and the environment to understand what makes them blend in so well. Even better, we can fine-tune our analyses to the specific visual capabilities of a range of predators to do this. In essence, we can attempt to understand how other animals view the world.

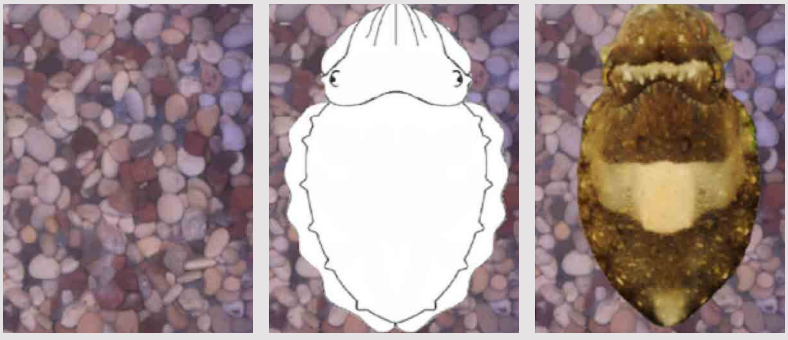


Figure 3 *A cuttlefish will select a pattern by examining elements in the background and choosing the camouflage pattern best suited to that environment.*

Vision, ecology, and beyond

What we learn from cuttlefish vision and camouflage extends well beyond human vision and perception. Our research easily extends into the wider concepts around evolution and ecology. For example, the camouflage of an animal is intrinsically tied to the ecology of the animal. The colourful coral reefs in the Great Barrier Reef allow the giant Australian cuttlefish (*Sepia apama*) to exhibit a whole rainbow of colours and patterns, both beautiful to behold and effective camouflage for the environment. In contrast, the species I study, the common cuttlefish (*Sepia officinalis,* see ***Figure 4***), lives in the English Channel. Lacking coral reefs, these cuttlefish's camouflage relies on more earthy tones, such as brown, black, white, and tan. The environment plays a crucial role in the development of not only vision, but also the way animals look.

Figure 4 *The common cuttlefish – you may have seen bones from this species lying on beaches around the UK.*

I highly recommend any student interested in biology or other science fields to find a concept that fills them with passion and awe. My own attachment to cuttlefish lies within their rapid colour changing capabilities. It still seems like magic to me as their patterns shift instantly. Find your passion and talk to researchers in the field about how to get involved. There are many internships, work placements, or volunteer positions in research labs. If those are not immediately available, build on your skill sets as a researcher to be competitive.

Growing up in the middle of the United States, I lived hours away from the ocean. I never even saw the ocean until my young teens. The passion I had allowed me to find what necessary skills were needed to pursue my goals. I worked on many other animal systems until I could develop the skills and knowledge to do what I do today. I hope you find your passion too.

Jay Culligan is a research student in the School of Biological Science at the University of Sussex, UK. He has a BA degree from the University of Indiana, USA.

Look here!

Some remarkable films of cuttlefish changing their shape and colouration at high speed:

https://www.youtube.com/watch?v=h5CYvgYVqQ0

https://www.youtube.com/watch?v=WhYD-ylPAZo

Benedict Jones
Lisa DeBruine
Rachael Jack
Philippe Schyns

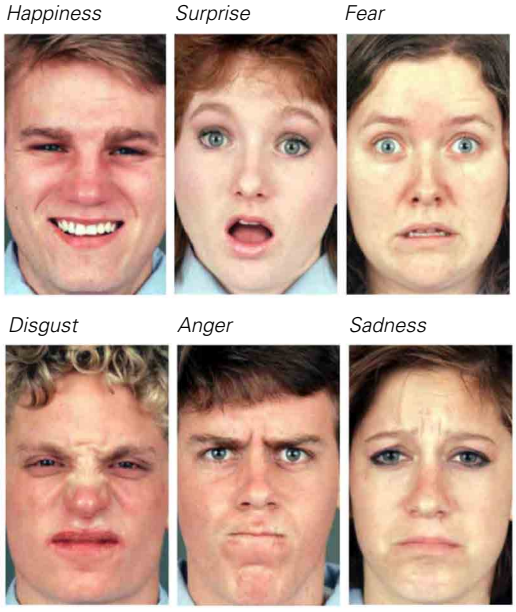
Face facts

How culture and hormones shape our responses to faces

The human face contains a wealth of information. For example, faces contain information about a person's sex, age, health and emotional state. Our research at the University of Glasgow's Institute of Neuroscience and Psychology investigates Charles Darwin's universality hypothesis and Konrad Lorenz's 'baby face' hypothesis. It shows that people form strong first impressions based on facial characteristics and that these impressions are influenced by both cultural and biological factors.

Contradicting the universality hypothesis

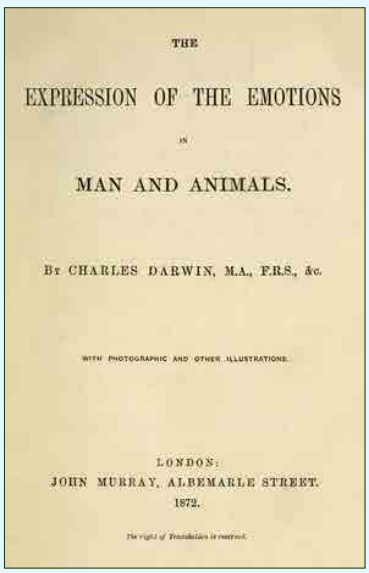
Darwin suggested that the way people express emotions through facial expressions is the same in all cultures – see ***Box 1***. In the 1970s Eckman and Friesen suggested that there are six basic expressions of human emotions (happiness, sadness, surprise, fear, disgust and anger).



Facial expressions of six basic emotions

Our work shows that people in different cultures use different facial expressions to communicate emotions. To demonstrate this, we developed a platform called the Generative Face Grammar that can display different combinations of facial movements, such as a wrinkled nose or wide opened eyes, on different face identities. We then asked people from different cultures to look at these different combinations of face movements and identify those that accurately represent different emotions (e.g., disgust, fear). By doing so, we can find the specific patterns of face movements that communicate emotions to people in different cultures.

Key words
faces
emotions
perception
hormones


THE
EXPRESSION OF THE EMOTIONS
IN
MAN AND ANIMALS.
By CHARLES DARWIN, M.A., F.R.S., &c.
WITH PHOTOGRAPHIC AND OTHER ILLUSTRATIONS.
LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1872.

Box 1: The universality principle

In 1872 Charles Darwin proposed the universality hypothesis in his book *The Expression of the Emotions in Man and Animals*. He suggested:

- that facial expressions of emotion are culturally universal;
- that these are conveyed using the same facial movements across all cultures.

He argued that these facial changes originally served a physiologically adaptive function in response to a change in the sensory environment. For example, if a person is subjected to a fear stimulus then the widening of the eyes will allow more light to enter and thus increase the ability to see clearly. This would help them to respond to a fear situation, such as being attacked by a predator.

He further suggested that people from different cultures should produce and perceive facial expressions of emotion in the same way because they retain some of these physiologically adaptive muscle movements. These socially perceived facial changes, he concluded, are therefore biologically hard-wired.

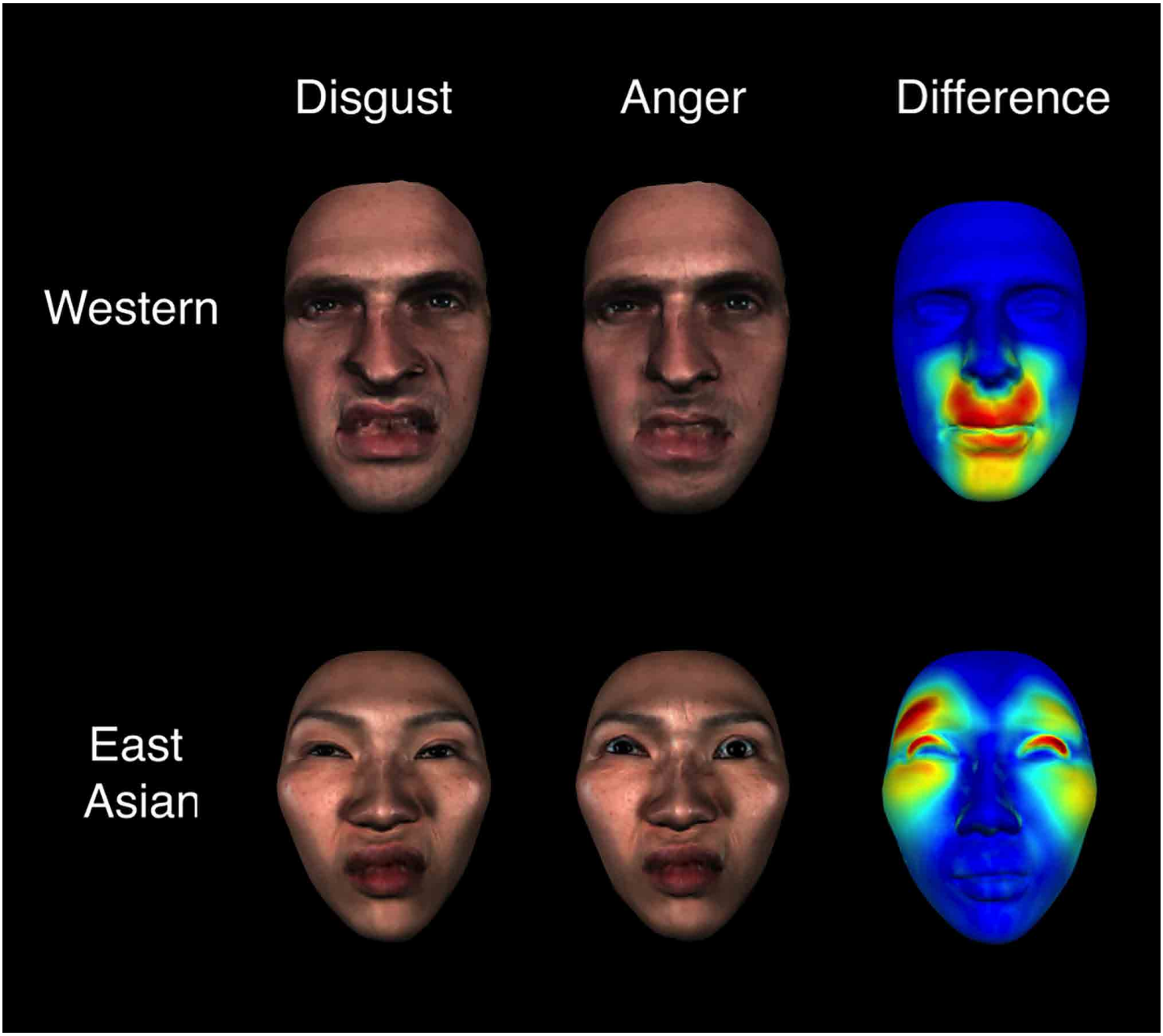


Figure 1 *Cultural differences in emotion signalling with the face. In Western facial expressions of disgust and anger, the mouth varies most (see color-coded difference map where blue represents the least difference and red the most across cultures). In the top row of faces, try covering up the eyes, and then the mouth to see the difference between disgust and anger. In contrast, in East Asian facial expressions of disgust and anger, the eyes vary the most. Again, try covering up the eyes, and then the mouth to see the difference between disgust and anger. For example, note the narrowed eyes in disgust compared to eye whites in anger.*

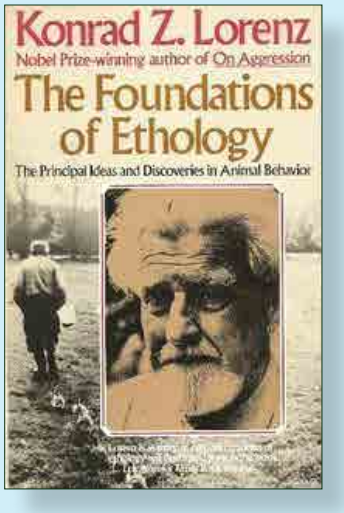
Analysis of the facial expression patterns revealed clear cultural differences. For example, we discovered that East Asians are more likely than Westerners to indicate that the eyes are used to communicate emotion (see ***Figure 1***). Our results therefore dispute the notion that facial expressions are universal across all cultures and are hard-wired. Rather, our results suggest that facial expressions have evolved culturally so that emotions are communicated by different expressions in different cultures.

This cultural difference in emotion signalling with the eyes could explain why the eyes are particularly prominent in East Asian emoticons. For example, East Asian emoticons tend to vary in the eye region, using ^.^ for happy and ;_; for sad. By contrast, Western emoticons tend to vary in the mouth region, using :) for happy and :(for sad.

Hormonal effects involved in the response of women to 'cuteness' in infant faces

While our work on emotional signals typically investigates how people use information in adults' faces, some of our other work investigates responses to infants' facial characteristics. In the 1940s, the ethologist Konrad Lorenz suggested that characteristics in infants that appear 'cute' to adults are important triggers for caregiving responses – see ***Box 2***.

Box 2: The 'baby face' hypothesis

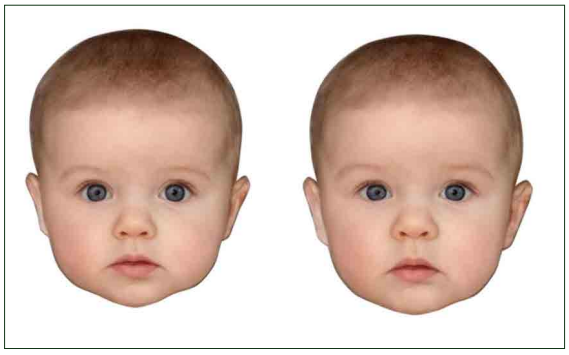


Konrad Lorenz suggested that infant cues encourage a caregiving response in adults. This was particularly so for an infant's facial features. Adults report being more willing to care for infants with facial cues that are perceived as 'cute'. They also form stronger bonds with such infants.

Brain imaging techniques show that when women are shown cute images of infants there is a greater amount of brain activity in regions which process rewards.

Women's hormone levels appear to be related to the level of reward that is experienced when viewing infant faces, evidence for a biological influence on the response women show to infant faces perceived as cute.

To investigate this issue, we used a computer graphic technique called prototype-based transforming to vary face shape in images of infant faces. First, we created face prototypes with the average shape of infant faces that people judged to be either particularly high or particularly low on cuteness. We then created high-cuteness and low-cuteness versions of infant faces by adding or subtracting the linear shape differences between these prototypes to or from infant face images.



Examples of an image of an infant face manipulated to increase (left image) and decrease (right image) perceived cuteness using a computer-graphic technique called prototype-based transforming.

Adults were tested using a key-press task where they could control how long they viewed a particular facial image of an infant by repeatedly pressing designated keys on their keyboard. Through this it was possible to record how much effort they were willing to expend to watch different faces.

Women were tested in two ways multiple times over a period of weeks. They were asked to decide how long they wished to look at an image using the keyboard press task and they rated the cuteness of the images of infants to give cuteness perception scores. They also donated samples of saliva to be tested for hormone levels. The research interest was to see, within each woman, how their response to differing levels of cuteness in infant faces was related to their hormone levels.

It was found that women were willing to expend more effort to look at high-cuteness versions of infant faces than low-cuteness versions, suggesting that looking at cute infant faces is rewarding to adults. Our work also showed that this effect was particularly pronounced when the adults' own testosterone levels were high, linking adults' hormone levels directly to their responses to infant facial cues.

In the women tested there was as strong positive effect within each woman showing that reward value of infant faces was greater in test sessions where salivary testosterone levels were high. Also there is evidence that the effect of testosterone on women's motivation to engage in protective behaviors may be more pronounced for cuter infants.

There was no such effect related to estradiol or progesterone. Also, the women did not change their perception of the cuteness of the images.

Previous work has shown that administering testosterone to women increased their response to infant vocalizations in a region of the brain called the thalamocingulate circuit. This brain region is implicated in both reward processing and parental behaviour.

All this suggests a biological control of women's response to cute infants which probably varies with the menstrual cycle and social situations, both of which influence testosterone levels.

Together, findings like these demonstrate how computer graphic techniques can be used to shed light on the cultural and biological factors that influence our responses to faces.

Benedict Jones, Lisa DeBruine, Rachael Jack & Philippe Schyns work in the Institute of Neuroscience and Psychology at the University of Glasgow, UK. *Their research was funded by grants from the Economic and Social Research Council, European Research Council, British Academy, and Biotechnology and Biological Sciences Research Council.*

Look here!

You can experiment with some of the computer graphic techniques we use, manipulate images of your own face, and create your own prototype celebrity faces at *http://facefacts.scot/catalyst*.

Try this

Chemical reaction biscuits

All cooking involves chemical reactions but you are not normally aware of them happening. There is an obvious thermal decomposition reaction which takes place in the middle of this recipe – and you get fabulous ginger biscuits at the end.

You will need:

120g butter or margarine
120g self-raising flour
120g oats
120g granulated sugar
1 rounded teaspoon ground ginger
1 level teaspoon bicarbonate of soda
½ level teaspoon salt
1 tablespoon milk
1 tablespoon golden syrup
Mixing bowl
Wooden spoon
2 teaspoons
Small bowl or cup
Saucepan
Baking sheet lined with baking paper
Oven pre-heated to 180°C
Wire cooling rack

What you do:

Mix the oats, flour, sugar, salt and ginger in a mixing bowl. Melt the butter (or margarine) and syrup in a pan. Dissolve the bicarbonate of soda in milk and pour it into the pan, stir briefly. Look for the chemical reaction.

Pour the wet ingredients into the dry ingredients and mix well. Place 1 teaspoon of the mixture in small balls onto the baking sheet. Flatten slightly with a fork. Bake for about 7-8 minutes at 180°C and then cool on a wire rack.Makes about 26.

What's the reaction?

Bicarbonate of soda is sodium hydrogen carbonate, chemical formula $NaHCO_3$. When this is added to the hot butter and syrup mixture it decomposes, producing carbon dioxide, water and sodium carbonate. You can see the gas being produced as the mixture foams and produces lots of bubbles.

$2NaHCO_3 \rightarrow CO_2 + Na_2CO_3 + H_2O$

Vicky Wong is Chemistry editor of Catalyst.

Look here!

The same chemical reaction can also be used to make cinder toffee or honeycomb. For details see this Catalyst article: *https://www.stem.org.uk/system/files/elibrary-resources/legacy_files_migrated/31929-catalyst_24_3_579.pdf*

David Sang

Gravitational waves
Detected at last!

Henze NASA

On September 14, 2015, scientists working at the LIGO laboratory detected gravitational waves for the first time. So, what are gravitational waves and how are they detected?

Einstein's prediction

Albert Einstein published his General Theory of Relativity in 1916. He suggested that we should picture masses as causing distortions of the fabric of space. When large masses interact, gravitational waves will ripple out into space, rather like electromagnetic waves.

LIGO is the Laser Interferometer Gravitational Wave Observatory – here you can see the two long arms of the interferometer, at 90° to each other, used to detect ripples in space.

A weak force

Although gravity is an important force on the astronomical scale, it is the weakest of the four forces of nature. This means that, although gravitational waves transfer energy, their effects will be vey weak and difficult to detect.

Scientists realised that the collision of two black holes could produce relatively strong gravitational waves. They made computer simulations of such an event so that they would know the pattern of waves that they might expect.

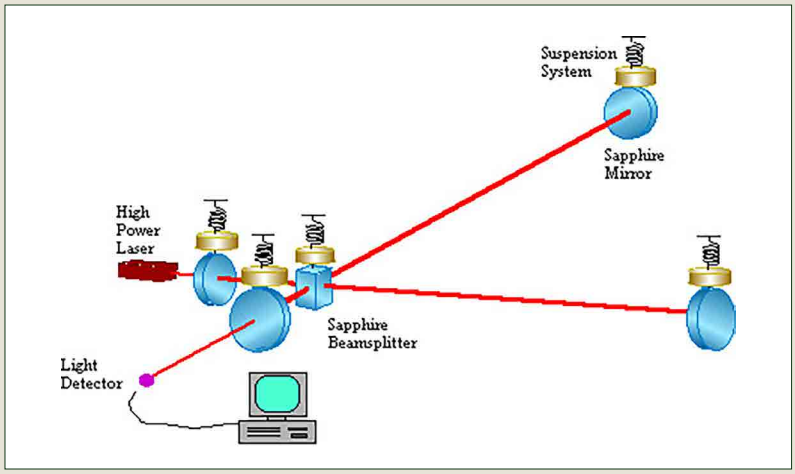
Tiny signals

In practice, it has proved enormously difficult to isolate the vibrations of gravitational waves from all the other vibrations which reach the laboratory. Traffic noise, the hum of mains electrical equipment, even the crash of a distant falling tree could be far stronger than the effect that being sought. That's why it has taken a century from Einstein's prediction to the first detection of gravitational waves.

A computer simulation of the production of gravitational waves as two black holes merge

Detection with light

The LIGO observatory uses a laser interferometer to detect the slight distortions in space which occur as a gravitational wave passes the Earth.



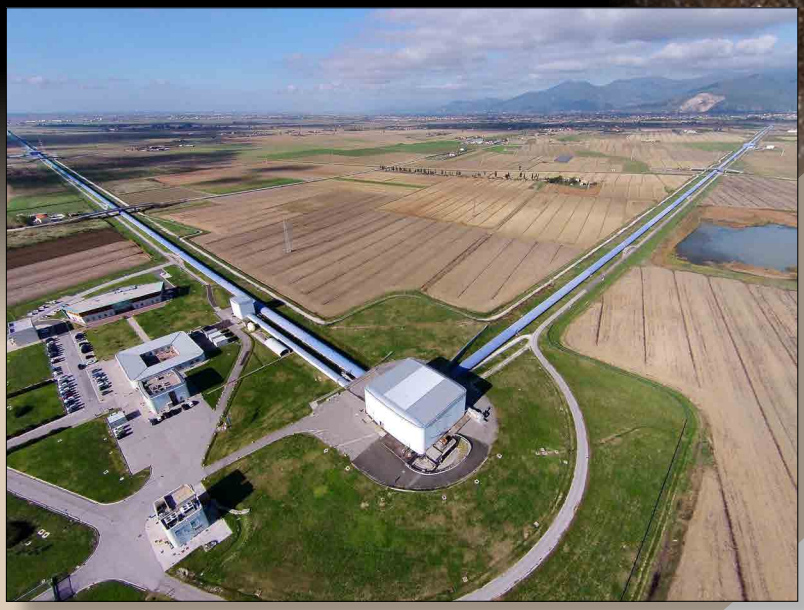
A powerful laser sends a beam of light into a beam splitter. Each half of the beam then travels along a 4 km arm of the interferometer. At the end it reflects back from a heavy mass.

The beams are recombined by the beam splitter.
If they have travelled exactly the same distance they will arrive at the detector exactly in step with each other. This gives constructive interference and a strong signal.

However, if one of the two arms has been lengthened or shortened by the passage of a gravitational wave, one beam will have travelled slightly further than the other and the waves will be out of step, causing destructive interference.

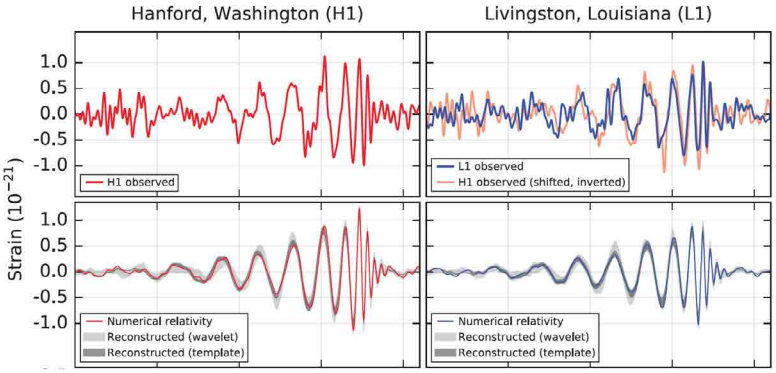
Detecting a cosmic collision

The LIGO lab detected gravitational ripples produced when two black holes with masses of 29 and 36 solar masses collided 1.2 billion years ago. The waves have been spreading out through space ever since so that they were very weak as they passed Earth.



Europe has a gravitational wave lab near Pisa, Italy. You can see the two long arms of the interferometer.

Gravitational wave observatories are likely to be built in space. Here, the European Space Agency's LISA Pathfinder spacecraft is being prepared for launch.



Gravitational vibrations detected by LIGO. In fact, there are two labs at opposite ends of the USA; the graph at top left is from the lab at Hanford in Washington state. Upper right is the graph from the lab at Livingston, Louisiana (blue), compared with the Hanbury graph. The lower graphs are the patterns predicted by computer simulations.

Publishing the results: more than 1000 authors were credited when the LIGO results were published.

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Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

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On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

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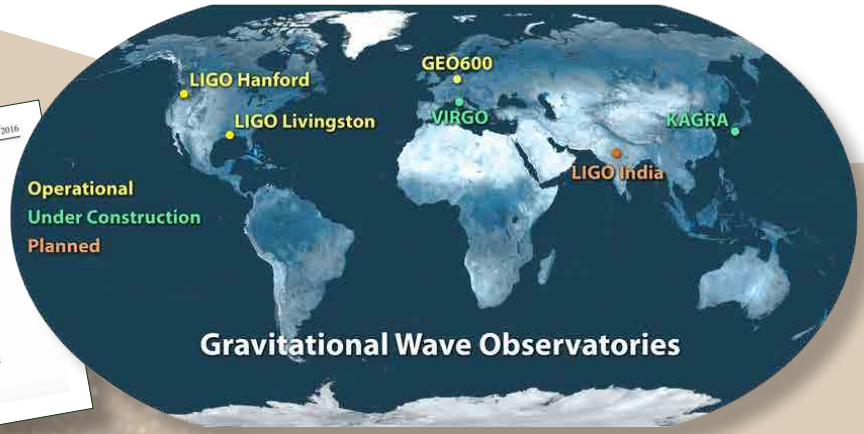

In future, with observatories around the world, it will be easier to tell the direction of travel of gravitational waves.