Catalyst

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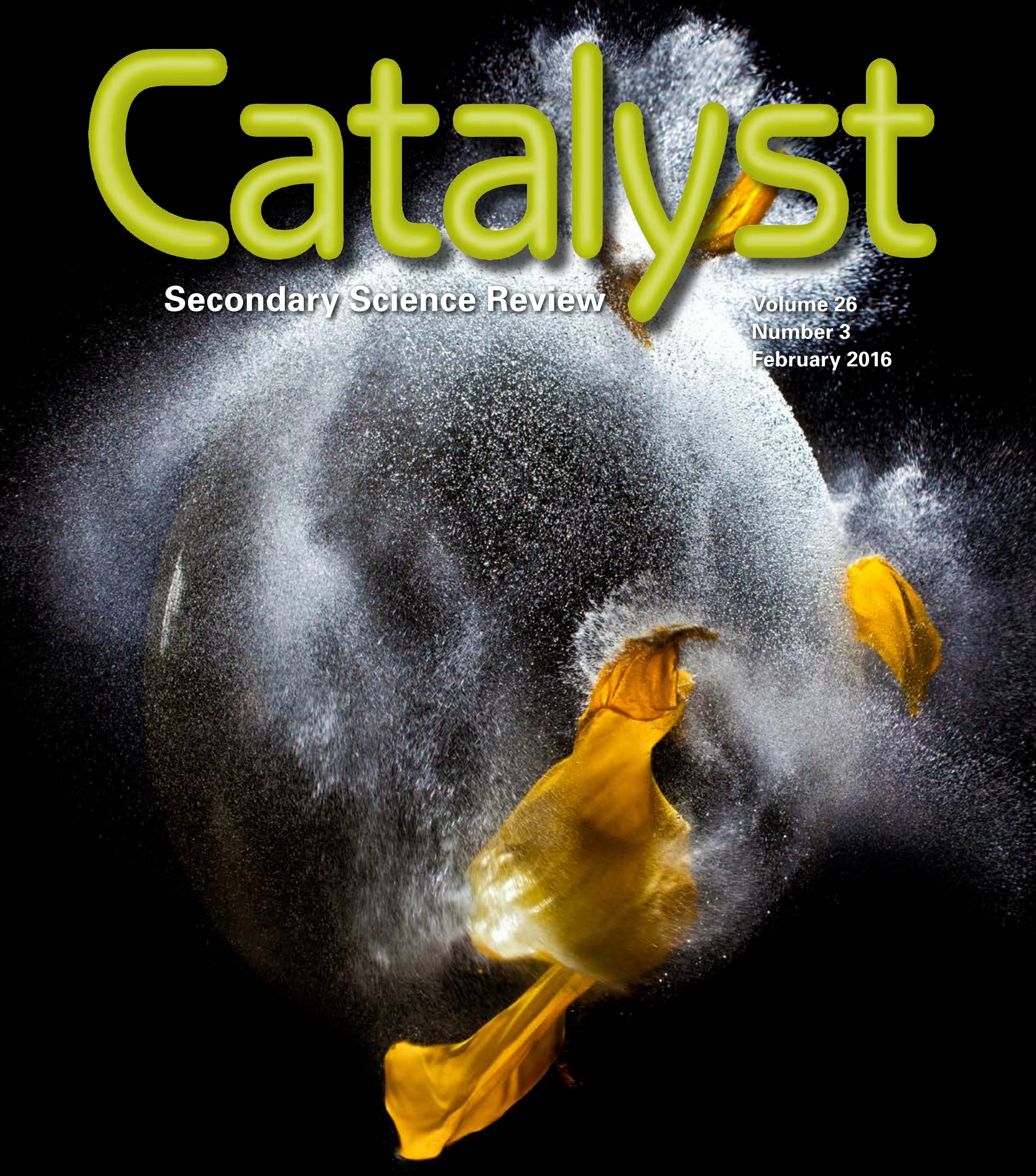

When the balloon bursts

High-speed photography in science and engineering

SEP
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Catalyst

Volume 26 Number 3 February 2016

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The cover image shows a water-filled balloon as it bursts. This high-speed image reveals that the water retains its shape for a fraction of a second as the rubber of the balloon pulls apart under its own tension. (Photo: Gualtiero Boffi/Bigstock)

The surprises of science

One of the fascinations of science is the surprises it can hold. When Gareth Fraser was ten years old, he bought a mask and snorkel. He fell in love with the underwater world and now he leads a research team at Sheffield University looking at how the teeth of fish and mammals develop, with a view to inventing new techniques for dentistry. See the article on pages 17-18.

Advanced scientific techniques can also bring surprises. Our centre spread this month shows a sequence of images of a balloon bursting open, made using a high-speed camera. A well-defined crack widens as the rubber of the balloon pulls itself apart. That's why the rubber of a burst balloon has such neat edges. See Clive Siviour's article on pages 9-13.

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The Catalyst archive

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Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org

Students of La Sainte Union School

Can we save our horse chestnut trees?

Horse chestnut trees were planted in parks and village greens for their attractive shape and beautiful flowers. We noticed there was extensive early browning of the trees in our school grounds, which we found was caused by the horse-chestnut leaf-miner, *Cameraria ohridella* (see CATALYST Volume 25 issue 4, April 2015). Both the horse chestnut tree and the *Cameraria ohridella* moth are invasive species but we consider the moths to be pests because they harm the trees that we chose to plant.

We investigated several possibilities of control: natural predators (parasitoid wasp and blue tit); burning or burying fallen leaves in autumn to destroy the overwintering pupae; pheromone traps that attract and kill male moths. We also considered spraying and root/soil treatment with insecticide.

Most caterpillars eat the leaves from the outside. However leaf miner moth caterpillars live, tunnel and feed between the two layers of the leaf. There can easily be three generations of moths per year. Severely damaged leaves shrivel and turn brown in late summer and fall prematurely.

Adult Cameraria ohridella *moth*

Food web

The horse chestnut leaf (producer) is consumed by the horse chestnut moth larvae (primary consumer), which in turn is predated by the blue tit (secondary consumer). Competing with the blue tits are a number of parasitoid wasps. A parasitoid is an animal that lives inside its host (like a parasite), but always kills its host (like a predator does, but unlike parasites). The parasitoid wasp has a long ovipositor which she uses to insert a single egg through the leaf cuticle into the larva of the moth. The wasp larva feeds within the moth larva, eventually killing it.

By counting the number of the leaf miners in a small section of the tree and then scaling up, we estimated that there were 250 000 – 500 000 leaf miners per tree in July.

Progress of infestation (19th July and 2nd September respectively)

Key words

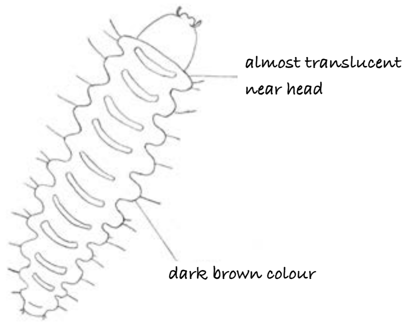
invasive species

food web

insect control

parasitoid

Brown leaf mines were obvious in July and by early September there was substantial browning of the leaves. The leaf miners (caterpillars) are small, with an obvious mouth part and deep indented segments. Mining gives them some protection from natural enemies and the physical environment.



Leaf-miner larvae are translucent and can be seen when a leaf is held against the light.

Natural control

We investigated the effectiveness of the different types of natural control of the leaf miner, starting with parasitic wasps. Infested leaves were stored in zip-lock bags for two weeks. The Conker Tree Website's insect identification chart was used to record what hatched (CATALYST April 2015).

We found 723 adult *Cameraria ohridella* moths. There were 171 wasps altogether indicating that 171 horse chestnut tree leaf miner larvae were killed by the larvae of the parasitic wasps, so there would have been a total 894 leaf miners on 16 leaves. The rate of parasitism by the wasps was only 19%.

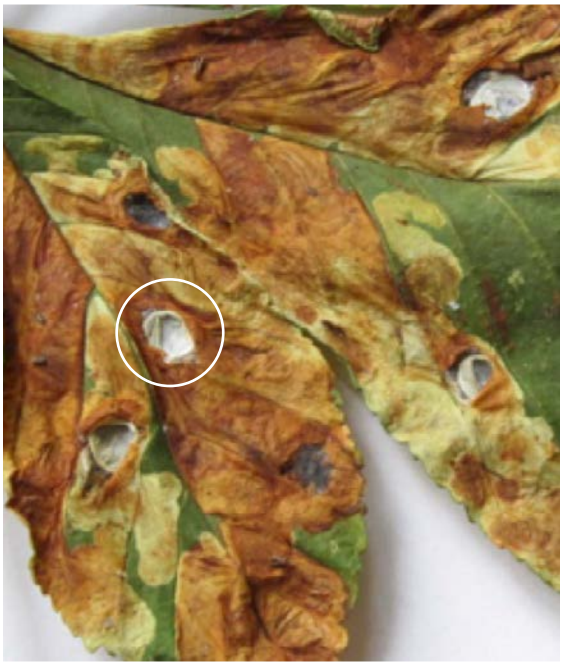
LSU students examine leaves

Natural control by birds

Caterpillars are an important food source for blue tits, which feed them to their young. It's not clear how many leaf miner caterpillars are being eaten by the birds, but if they were to start eating a substantial number it would help the horse chestnut tree.

The majority of the accessible leaves did not have any V-shaped tears indicating bird attack. However a more secluded tree showed these tears (mean = 25; range = 0 – 57) for seven leaves in September.

It was difficult to estimate the contribution that birds were making to control of the numbers of leaf miners because we only looked at a small sample of leaves.



V-shaped tear on a mine indicating predation by birds e.g. blue tit

Pheromone traps

The main component of the sex attractant (pheromone) released by the females has been identified as (E,Z)-8,10-tetradecadienal. We used pheromone traps to catch male moths. This reduces mating and therefore egg laying. We weighed the content of the trap and estimated that 30 000 moths had been captured over a period of two months (8 July - 9 September). This is about a tenth of the number we had estimated on each tree in July after the first generation.

Removing leaf litter

Early in the season (July), we noticed that the browning of the leaves is more prominent at the base of the tree. This is consistent with the moths emerging from fallen leaves and spreading upwards to the lower leaves. We collected leaves from the base of the tree and estimated that there were 100 pupae per leaf.

In the spring there can easily be at least 100 fallen leaves near the tree, each containing 100 pupae. In this case potentially 10 000 moths could emerge and be waiting to infect the tree in early summer. If half of these are females we could expect 150 000 eggs. Furthermore, if we assume that all the eggs from the first generation survived and 150 000 moths hatched, and if half of these are female we would expect 2 250 000 eggs in the second generation.

In reality the number will be smaller because not all pupae, moths or eggs will survive. Nonetheless the number of potential moths is formidable bearing in mind that the calculation is based on just a hundred leaves. By removing the fallen leaves in autumn and early spring, the pupae of *Cameraria ohridella* hibernating in the leaf mines are also removed, and consequently the number of adults emerging in the following spring will be reduced.

Sweeping up leaves

Red or white?

Unlike the common horse chestnut (*Aesculus hippocastanum*), the red-flowering hybrid (*Aesculus* × *carnea*) is very resistant. Leaves of the red flowered horse chestnut tree are glossier, tougher, more crinkled and darker green when compared to the white flowered tree. We cut equal sized strips from the leaves of the two types of trees and compared their masses. We avoided the thick mid vein and any areas with leaf mines. The mass of the red flowered horse chestnut trees was approximately twice that of the white flowered trees regardless of whether we looked at wet (0.35 *vs* 0.19 g/strip) or dry weight (0.14 *vs* 0.06 g/strip) indicating the leaves were thicker or denser.

Leaf mines in leaves of red (left) and white flowered horse chestnut tree (right)

In late summer red flowered trees that were near white flowered trees had short mines. Close examination showed that the caterpillars had died. The caterpillars seem unable to feed successfully on these leaves. It is possible that when the *Aesculus hippocastanum* trees have been decimated, the leaf miner moths may adapt to feed on the *Aesculus carnea*. The present leaf miner problem only became apparent in the 1980s and it is thought *Cameraria ohridella* switched host trees at that time.

Discussion

Unfortunately neither the parasitoid wasps nor the blue tits are able to control the number of leaf miners or their effects on the tree. Without an efficient predator for horse chestnut leaf miner, the tree's future is in jeopardy.

Pheromone traps and insecticides may help, but treatment of 0.5 million trees in this way would be an unsustainable financial burden for the UK. The cost of one pheromone trap treatment per tree per year is about £20. The numbers of moths trapped indicate that this method alone is insufficient.

The control of the leaf miner with chemical products is very difficult since it lives inside the leaf mines during most of its life cycle. Spraying large trees with insecticides is not a viable option in urban areas. One effective chemical control measure is the injection of insecticide imidacloprid ('Admire') in the trunk or soil. However, the cost of systemic soil/root treatment is about £300 per tree per year. This may be more effective than the traps but is not without its problems not least the cost.

A possible solution

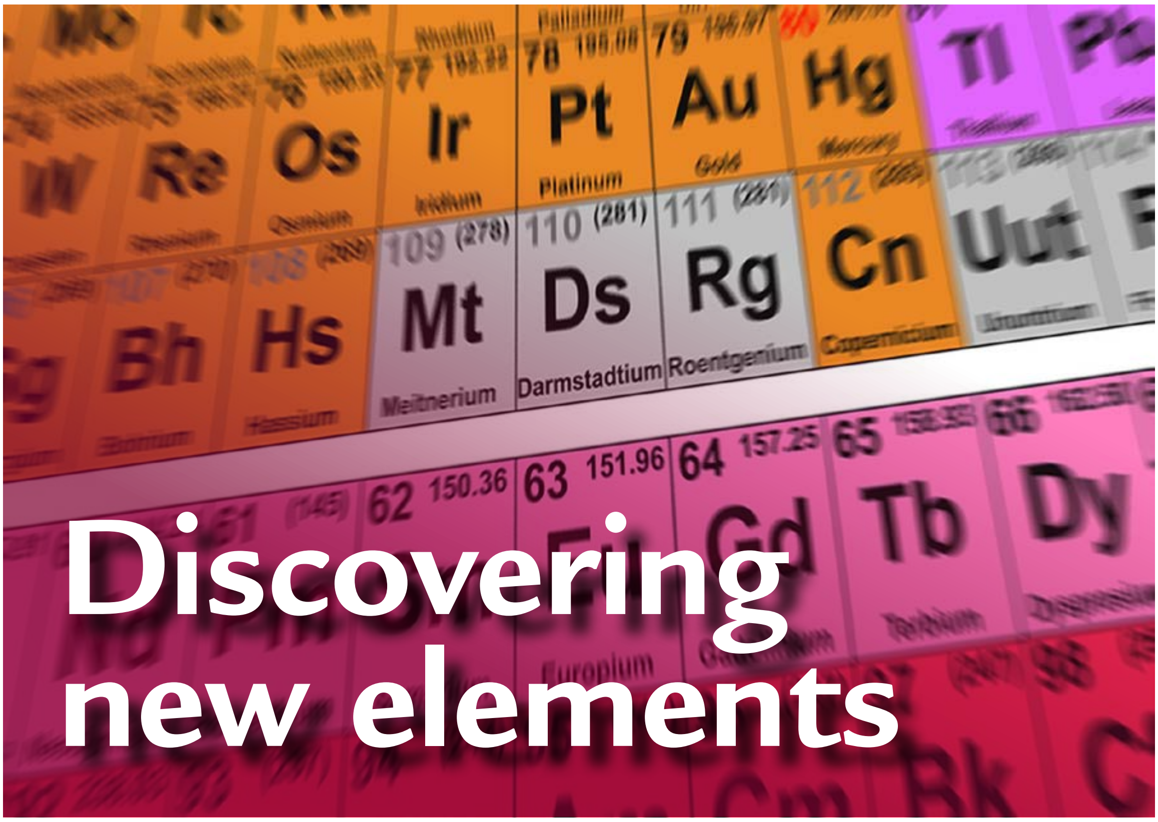
Trees that were planted for their attractiveness are looking withered. The horse chestnut tree has had to contend with bleeding canker as well as leaf miner disease and so is at serious risk. Nurseries have stopped planting horse chestnut saplings. Replacement of horse chestnut trees with other trees will be very costly. We also have the possibility that *Cameraria ohridella* may switch host trees.

The UK could follow Berlin's example where it is considered every citizen's civic duty to participate in the clearing of every single horse chestnut tree leaf. Involving the community in this way may have many social benefits encouraging social interaction, interest and responsibility for the environment.

A poster from Berlin – Save our chestnut trees, stop moths, gather leaves!

Tito Ade-Oguns, Ursula Agyeman-Frempong, Elisabeth Azzopardi, Sharon Bonsu, Ariane Forien, Grace Gannon, Catriona Gilmour, Zoe Hartigan, Oghogho Igbineweka, Dea Loughlin, Mia Oliver, Lara Rosa, Hannah Sullivan and Ellie Themistokleous were Year 10-11 pupils at La Sainte Union Catholic School in Highgate, London, at the time of this research. Their project was funded by a Royal Society Partnership grant and was a winning article in the Young Scientists Journal.

Vicky Wong



Discovering new elements

I cannot imagine many things more exciting than discovering a new element. Perhaps that is because I am a chemist, but the idea that you are seeing an element that no-one has ever seen before is thrilling.

At the very end of 2015, the International Union of Pure and Applied Chemistry (IUPAC), which oversees chemistry around the world, announced that four new elements had been discovered. One of these was by a team from Japan and is the first element to be discovered in Asia. The other three were by a joint team of Russian and American scientists.

These elements have numbers 113, 115, 117 and 118. As they complete the 7th row of the periodic table, if any further elements are discovered then a new period or row will be required.

The elements have yet to be named, but the groups which have been credited with their discovery have the right to suggest the name and symbol. There are rules to naming elements – they have to be inspired by people, places, nature or mythology – but the final decision rests with the International Union of Pure and Applied Chemistry.

Heavier and heavier

The last time new elements were announced was in 2011 – elements 114 and 116. These were subsequently named Flerovium (symbol Fl) for 114 and Livermorium (symbol Lv) for 116.

These super-heavy elements are not naturally occurring so the discovery involves not just finding them but also making them by smashing together atoms of other elements. The Japanese team made element 113 by firing a beam of zinc-70 atoms (zinc atoms with 30 protons and 40 neutrons) at a target made of bismuth-209 (bismuth atoms with 83 protons and 126 neutrons) – both of which are naturally occurring. After thousands of hours of this bombardment they had made enough atoms of element 113 to make a claim about the identity of this new element.

Elements 114 and 116 are named after two Nuclear Physics laboratories, the Flerov lab in Russia and the Lawrence Livermore lab in the USA.

The RIKEN Nishina Centre in Japan is home to this high-energy accelerator which was used to fuse two lighter elements together to create the new element 113.

Like most super heavy elements, element 113 is very unstable and decays to a different element after only the fraction of a second. This means that to prove it has been made requires more than collecting some and putting it into a jar. These new elements are usually identified by looking at the radiation they emit as they decay – the energy and type of that radiation and the nuclides (new nuclei) that are produced.

The Japanese team first claimed to have made this element in 2004 but they had to provide further evidence to prove its existence. Part of the difficulty for the team was that element 113 produced element 111 as it decayed – and element 111 was only verified at the end of 2004. Only known nuclei are permitted as part of the evidence for the existence of a new element. The team went back to the lab and over the past 10 years have gathered sufficient evidence to convince IUPAC that they have indeed made element 113.

The teams credited with the discovery of the other elements have similar stories – the discovery of new elements is not an easy task.

TEMPORARY NAMES

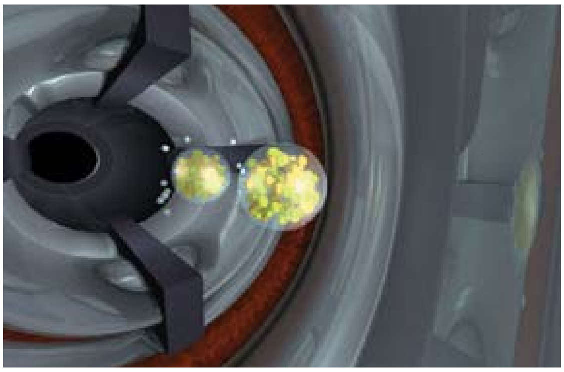
The new elements are given names and symbols based on their atomic numbers.

113 ununtrium Uut

115 ununpentium Uup

117 ununseptium Uus

118 ununoctium Uuo



A computer simulation of a collision between an ion of calcium-43 and an americium-243 target; the particles fused to form an atom of element 115.

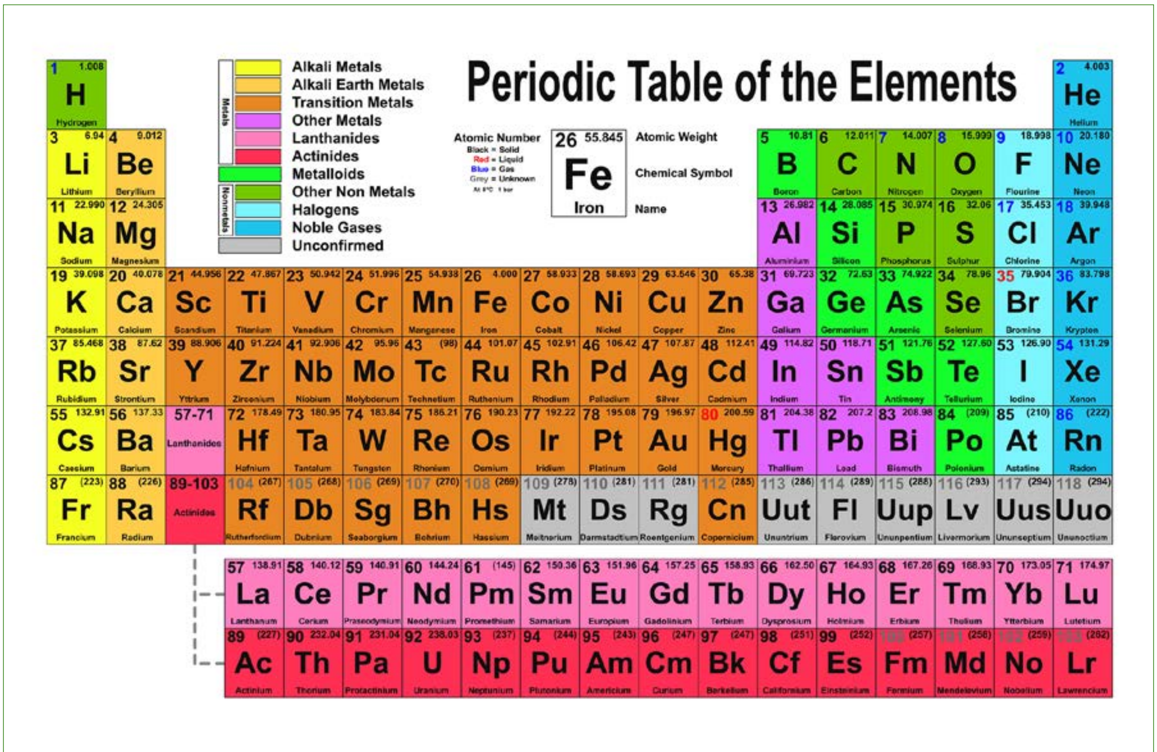
An eighth row?

Researchers are now likely to begin to look for elements beyond the 7th row of the periodic table. To make these elements will be even more challenging as the targets for the bombardment experiments would probably have to be made of super-heavy, short-lived elements themselves. No one has yet claimed to have made an element heavier than 118 and it is not even known if it can be done.

The periodic table may, therefore, be complete – but there is always the possibility that a heavier element may one day be discovered.

Look here!
For a song including all the elements of the periodic table: *http://tinyurl.com/ogqq9jh*

Vicky Wong is chemistry editor of CATALYST.



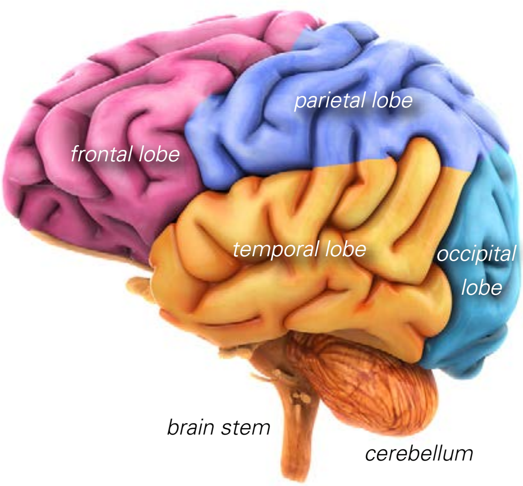
The periodic table showing the most recently discovered elements in grey. The latest elements have temporary names until the new ones are confirmed.

Guy Sutton

The brain and crime

Key words
brain
crime
brain damage
genetics

Are criminals 'born or made'? Does brain damage result in criminal behaviour or do some individuals have a genetic predisposition to crime? Or is criminality more likely to be influenced by social factors? Recent research suggests that the social world influences the activity of our genes, in turn affecting brain function. Neuroscientists are now beginning to explore how the brain might be linked to certain criminal behaviours.



The major regions of the human brain

Brain anatomy and function

The brain controls all thoughts and actions. The two cerebral hemispheres are divided into four lobes.

The frontal lobes, comprising around one third of the brain's hemispheres, are involved in mental and behaviour functions such as thinking, personality and control of emotional expression.

- The temporal lobes are involved in memory, together with hearing, smell, and recognising objects and faces.
- The parietal lobes integrate sensory information.
- The occipital lobe is responsible for vision.

Beneath the surface of the brain, complex brain regions exist such as the limbic system. This includes the two amygdalae; one in each hemisphere and involved in emotion, memory, aggression and fear. The hippocampus curves back from the amygdala in each hemisphere and is involved in emotion and memory.

The damaged brain and altered behaviour

Brain damage could potentially influence behaviour in many ways, for example, by impairing learning or judgement. There is a growing amount of evidence linking brain injury to criminality. Compared with the general population, there is a higher rate of brain damage amongst offenders in custody.

Brain damage in childhood and early adulthood may increase the likelihood of criminal behaviour.

Phineas Gage

In 1848, Phineas Gage, a US construction foreman, was involved in a work-related accident. A three and a half foot long, thirteen pound iron rod was blown into his head, travelling behind his eye and out through the top of his skull, resulting in the loss of much left frontal lobe tissue. Gage survived the accident and his doctor documented his subsequent personality, cognitive and emotional changes. He was recorded as losing his inhibitions, behaving inappropriately and violently, even reportedly molesting his children.

Phineas Gage, seen holding the tamping iron which passed through his skull. ▼

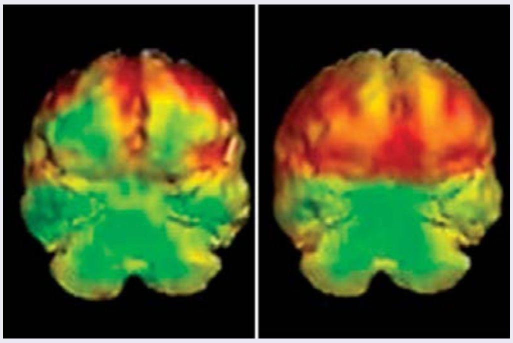
From the collection of Jack and Beverly Wilgus

The skull of Phineas Gage ▶

Donta Page

In Denver, USA, Donta Page was convicted of the brutal murder of Peyton Tuthill in 1999. Subsequent brain scans found decreased brain activity in Page's ventral prefrontal cortex. It was argued that a catalogue of childhood problems, including poor nutrition, parental neglect, physical and sexual abuse and head injuries, together with a family history of mental illness, had left him unable to control his behaviour. On the basis of his brain pathology, Page's death sentence was reduced to life imprisonment.

Donta Page



Scans of Donta Page's brain (left) and a normal brain. The images show decreased activity in Page's pre-frontal cortex.

Frontal lobe damage

This damage typically lowers inhibitions or emotional control, affecting the way we respond to triggers in the environmental.

However the frontal lobe is a complex structure and can be divided into sub-regions. The prefrontal cortex (PFC), for example, is important in judgement, decision-making and impulse control (sometimes described as the 'crowning achievement' of the human brain, it is one of the slowest brain regions to mature). If damage occurs in childhood, problems developing an understanding of moral behaviour can arise; in adulthood, this damage may be associated with an inability to control inappropriate behaviour.

Reduced activity of the PFC has been implicated in aggression and violence, as exemplified by the case of Donta Page.

The orbitofrontal cortex (OFC) is involved in the regulation of social behaviour and, in one infamous case, displacement of this structure in the right hemisphere by a brain tumour was linked with an individual's 'acquired paedophilia'. After the tumour was surgically removed, behaviour returned to normal. A change in behaviour indicated the tumour had regrown. When it was removed for a second time, behaviour once again returned to normal.

Limbic region damage

Damage to the amygdala and alterations to its function have been linked to aggressive behaviour. For example, epilepsy, localised to the amygdala, may be associated with episodes of aggression in some patients. Brain tumours affecting limbic system function have also been linked to aggressive behaviour, and even to murder such as in the case of Charles Whitman.

Charles Whitman

Charles Whitman was an engineering student at the University of Texas. In 1966 he killed 16 people, including his wife and mother. During the post-mortem examination of his brain a tumour was found near to the right amygdala, which some scientists think might have led to Whitman's inability to control his emotions and actions.

Charles Whitman

In studies of otherwise untreatable aggression, the surgical removal of the amygdala on both sides of the brain is reported to have resulted in moderate to excellent improvement of aggressive in about 75% of patients. There is even evidence to suggest that amygdala dysfunction may also lead to poor fear conditioning which may predispose an individual to crime. One study reported that a failure to form an association between a loud noise and fear at the age of three years appeared to precede criminal activity in adulthood.

Genes and behaviour: nature, nurture or both?

Many researchers over the years have reasoned that criminality may be genetically determined, that there might be a gene or set of genes running in families and predisposing to deviant behaviour.

Behaviours such as impulsivity, which is correlated with antisocial behaviour, appear to be heritable. However, the contribution of any single gene to antisocial and aggressive behaviour is most likely to be very small, with several genetic variants incrementally increasing the risk of antisocial behaviour. Genes interact with clusters of genes, which interact with networks of genes that in turn interact with the environment. Further, when considering the relationship between genes and crime, two important points must be noted. First, when we say that a given behaviour is genetically influenced, this is not to say that it is inevitable or 'determined'. Predisposition is not predestination. Second, when we say that genes influence criminal behaviours, this does not mean that genetics can *explain* why certain individuals commit crime.

A doctor examines a CAT scan of a patient's brain.

Epigenetics is an exciting new development in our understanding of how the environment is involved in the expression of genes and linked to antisocial behaviours. The term is used to describe how environmental factors such as stress, diet and drugs can 'switch on' (express) and 'switch off' (silence) genes. Scientists are trying to understand how early life experiences can alter gene expression patterns in the developing brain, altering development and function of areas such as the hippocampus and frontal lobes. It is possible that there will come a time when, as part of an offender's defence, their legal team argues absence of parental interaction and moral teaching has altered gene expression leading to frontal lobe impairment and an inability to control behaviour?

What can we conclude?

Criminal behaviours and their causes are diverse, leading some philosophers and scientists to comment that it is unlikely we will ever find a brain 'signature'. However, certain types of traumatic brain injury seem to increase the risk of offending behaviour and there is increasing evidence that brain tumours, epilepsy, levels of chemical neurotransmitters in the brain and many other biological factors can increase antisocial behaviour and criminality.

Human behaviours are complex in their origins, arising from an interaction of genes, environment, developmental history, and the evolutionary processes which have shaped brain structure and function. In the years to come, we will inevitably learn more about how these factors interact, influencing criminal behaviours, but at present we must be careful not to misinterpret our limited findings and make generalisations about criminal behaviour without supporting evidence.

Dr Guy Sutton is Director of Medical Biology Interactive and Honorary (Consultant) Assistant Professor at University of Nottingham Medical School.

Clive Siviour

Freezing the moment
High speed photography

Key words
photography
pixels
memory
resolution

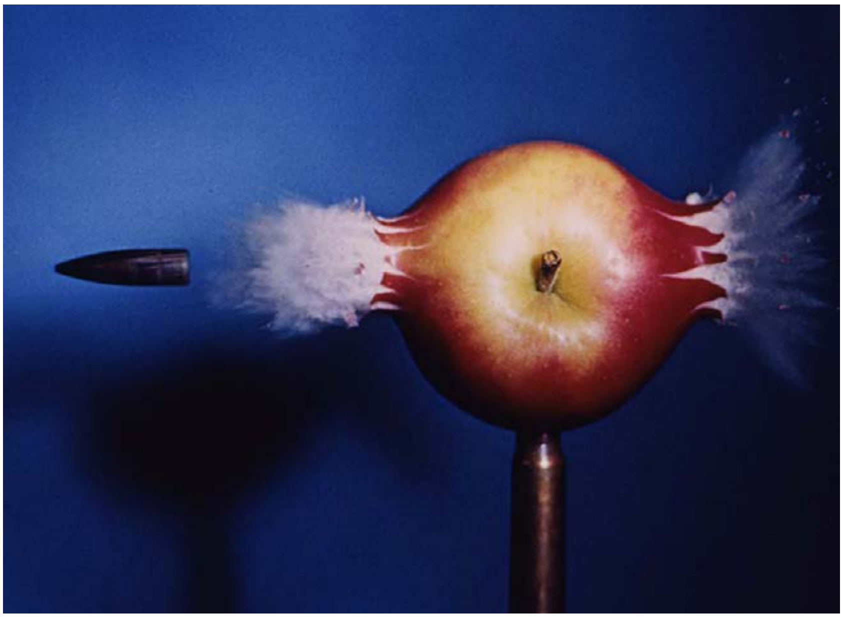
Many of us use photography to keep memories of an event: a holiday, a wedding or a party. This is also true in science and industry. But what if we need to understand a process that happens very quickly?

High speed photography allows us to freeze rapid events and extract direct visual information. In this article, we will explore the technology that allows us to take pictures at speeds up to 300 *million* pictures per second, and how this technology is used by scientists and engineers.

Milliseconds, microseconds

Many phones can record video at speeds of up to 60 frames per second. If you play this video back more slowly, you can often see movement that could not be observed with the naked eye. Just as a microscope allows us to see smaller objects, high speed photography allows us to see shorter times. A normal video sees down to about 0.1 s, but in industry, events might last 1 millisecond (ms) or even 1 microsecond (μs). Something faster is required.

A simple way to freeze a very rapid event is to use a short flash. The light from a typical flash lasts 1 or 2 ms, but, by discharging a capacitor rapidly across a small gap, it is possible to produce bright sparks lasting 1 μs or less. This allows us to take single pictures such as the bullet. Taking a sequence of images requires more expense and sophistication. It is necessary to process a lot of information very quickly. Here will will see the methods used by three types of modern digital cameras.



A bullet penetrating an apple at 840 m/s, an image taken in 1963 using a sub-microsecond flash by Harold Egerton. Egerton (1903-1990) was a pioneer of high speed photography; he worked at MIT.

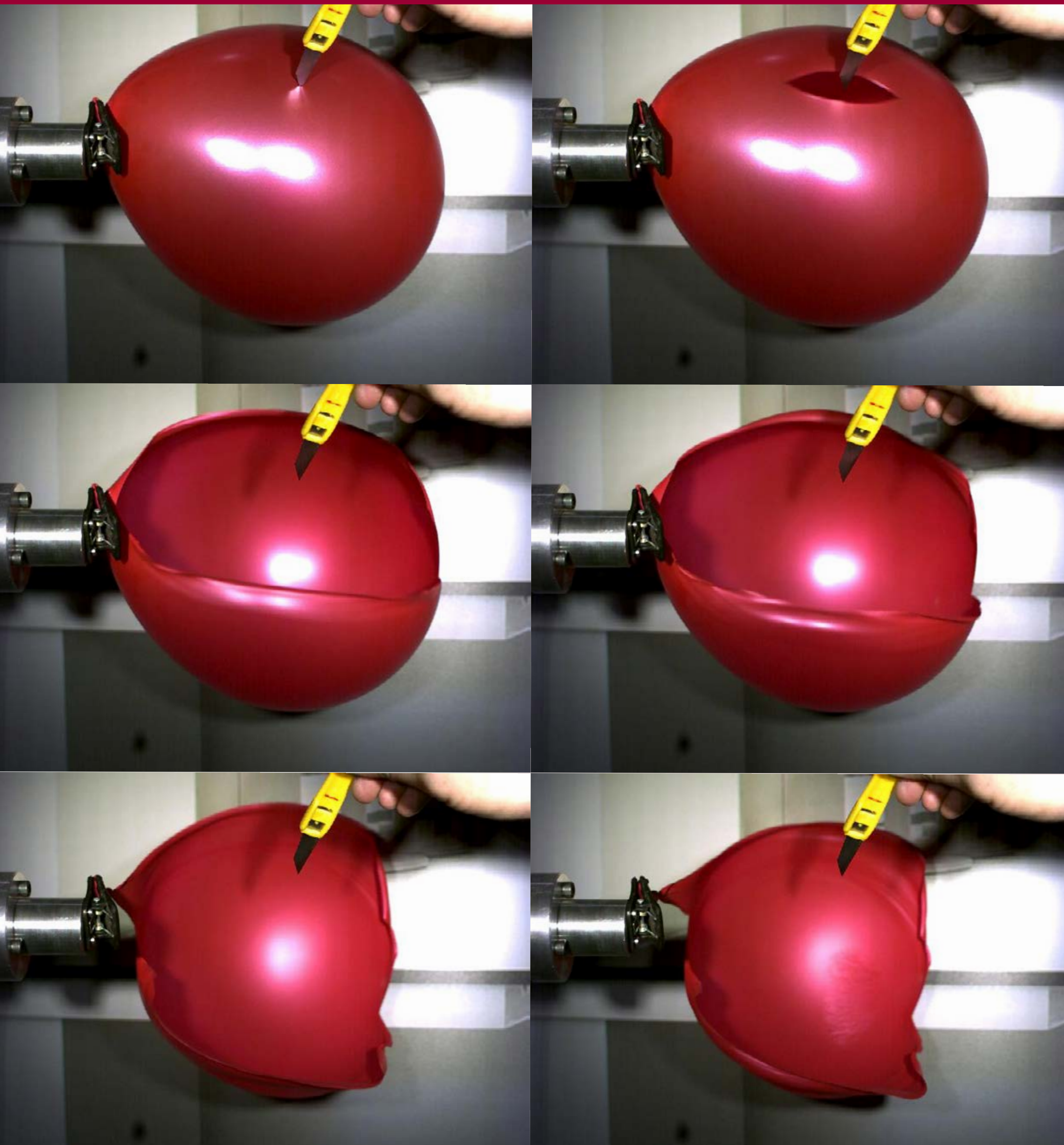
More sensors

To go very fast, the solution is to have not one sensor but multiple sensors. The incoming light is divided by a beam-splitter to illuminate all the sensors at once. The camera's electronics are programmed to activate each sensor in turn, which can be done *very* quickly. These cameras are capable of taking pictures at speeds of 300 *million* frames per second. Light moves only 1 m between images at this speed! However, typical cameras only have 16 sensors: only 16 images can be obtained at this speed.

Numbers large and small

1 millisecond is a thousandth of a second or 0.001 seconds; 1 microsecond is a millionth of a second, 0.000 001 seconds.

1 gigapixel is 1 billion (10^9) pixels; 1 terapixel is one trillion (10^{12}) pixels.



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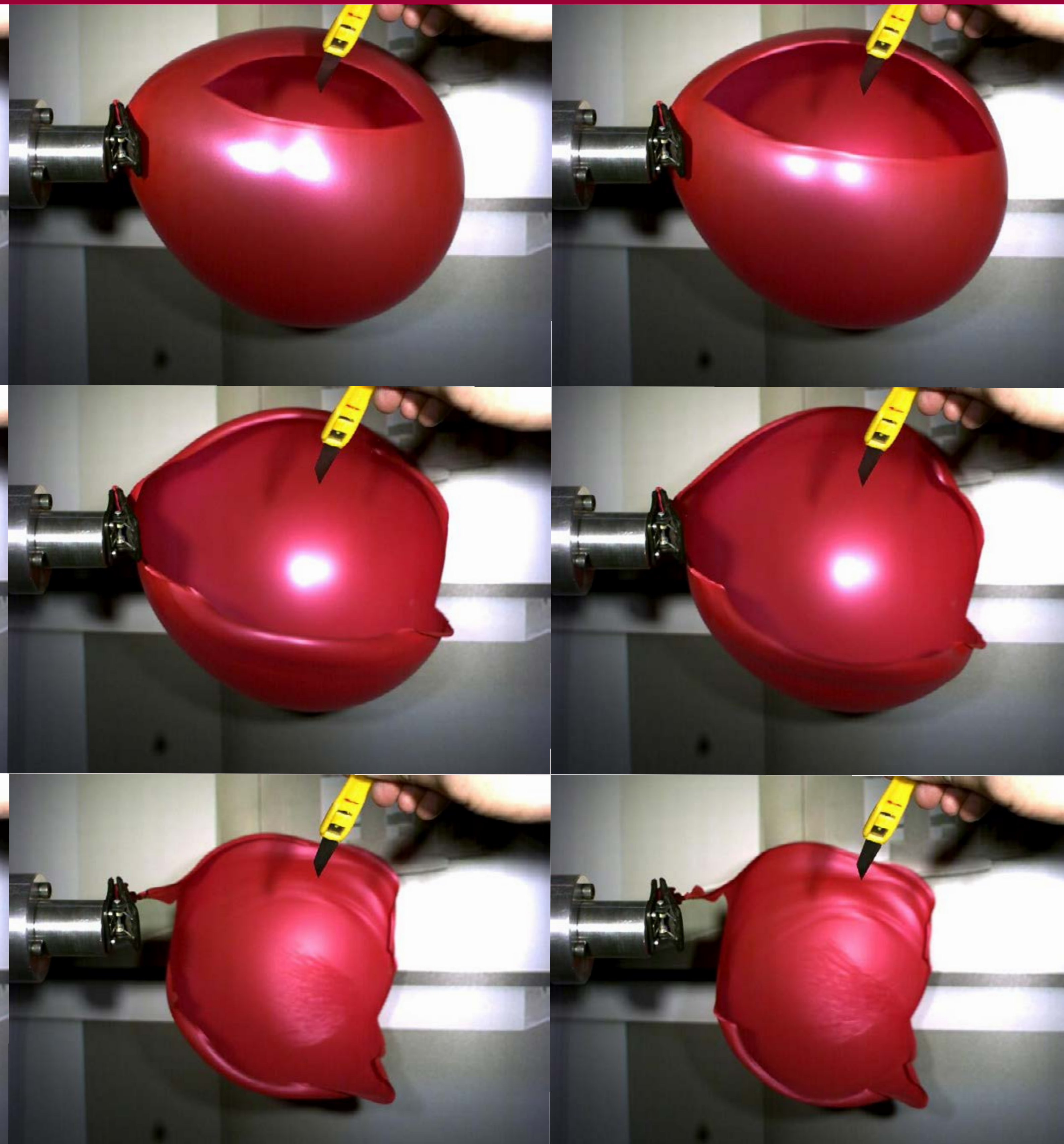
A balloon bursts – a linear crack extends as the tension in the rubber pulls the balloon open. Consecutive images are 0.40 ms apart.



The balloon bursts

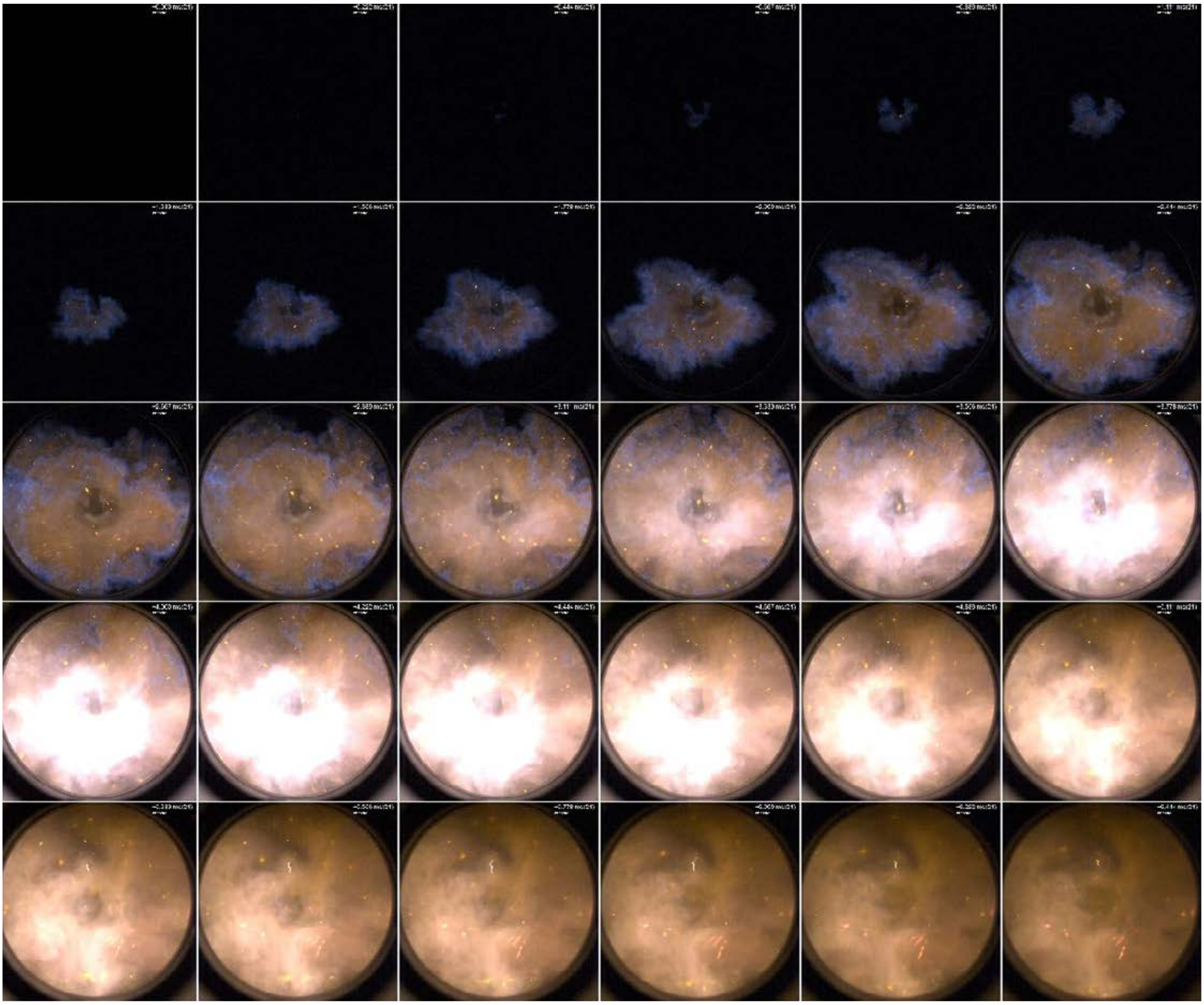
The sequence of images on pages 10-11 shows the bursting of an inflated balloon. The images were taken at 25 000 frames per second using a Photron Fastcam SA-X2. The resolution of each image is 768×576 pixels. We have selected every tenth image in the sequence so that the time interval between images is 0.40 ms. The speed at which the crack grows is determined by the material properties of the rubber combined with the pressure of the air inside the balloon.

A Photron Fastcam SA-X2 high-speed camera

More speed, less resolution

For many applications in industry, film and television, a high speed system similar to a normal video camera may be used. CMOS sensors (those in a standard digital camera) allow rapid data readout, and large pixels of 20 μm or more make the camera very sensitive to light. The data from the sensor must be transferred quickly to external memory. Even with modern electronics and sophisticated sensor design, the maximum readout speed of the camera is about 21 gigapixels per second, limiting the speed of a 1 megapixel image (1024×1024 pixels) to about 20 000 frames per second. To go faster, the image must be made smaller: the resolution decreases with increasing speed. Rates of up to 1 million frames per second are possible, and the duration of the video is limited only by the amount of memory in the camera.

Combustion of ethanol in air. Images taken at 9000 frames per second. Image courtesy of Tim Nicholls, Photron. ▼



On-sensor storage

A solution to the data processing is to store the images *on* the sensor and read them later on. One method to do this is for each pixel to contain an active light sensitive element, the imaging element, accompanied by storage elements. A picture is taken using the imaging elements, and then moved rapidly to the storage elements, so that the imaging elements can be used again. This happens at a rate of 3.5 terapixels per second. Once all the storage elements are filled, the camera can read out the data at a slower speed. Cameras using this technology can curently take images at speeds of 1–5 million frames per second with much higher resolution than high speed video, but are currently limited to a sequence of between 150 and 200 pictures.

Look here!

Further details about the cameras used and more high speed images:

Photron: *www.photron.com*

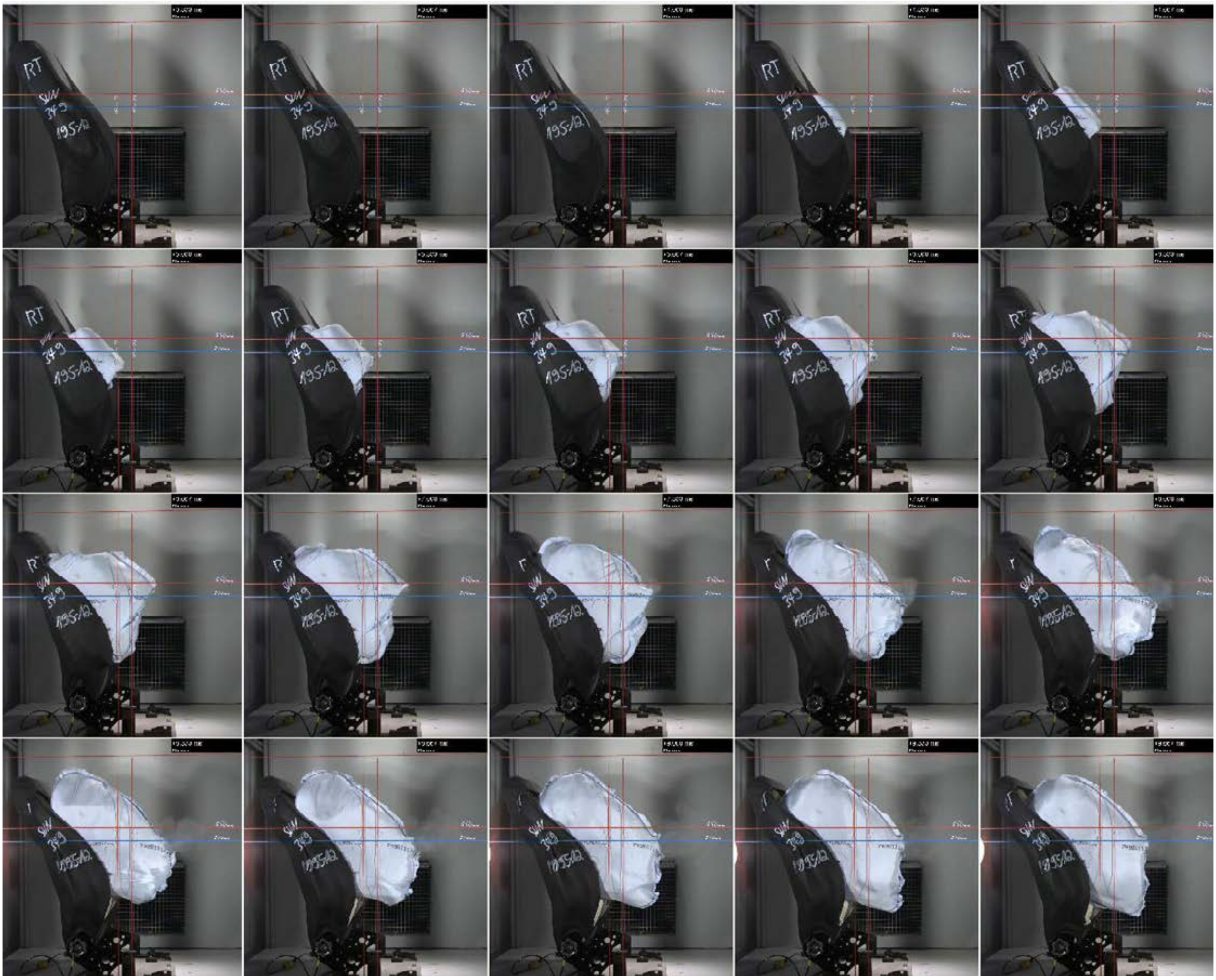
Specialised Imaging: *specialised-imaging.com*

High speed studies

High speed cameras are used extensively in industry and research. Applications include automotive safety and crash testing, ballistics and armour, studies of combustion in engines or industrial processes such as welding, and slow motion photography for film and television. Another important application is the study of biomechanics. Very high speed imaging is required for studies of explosives, for example those used in mining, or dynamic failure of materials such as ceramics and glasses. In my laboratory, we use high speed imaging to understand how materials and structures deform under impact loading, aiding the production of safer cars and aircraft.

Clive Siviour is Associate Professor in Engineering at the University of Oxford. His research interests include the behaviour of materials and structures when they are deformed very rapidly in impacts at speeds up to hundreds of metres per second.

High speed sequence showing inflation of a car's airbag. Images taken at 6000 frames per second. Image courtesy of Tim Nicholls, Photron. ▼



David Marks

Dr John Roberts

Key words
engineering
construction
materials
glass

A clear view from the top

Building the pod for the British Airways i360

The i360 pod under preliminary construction at its manufacturer's base.

The i360 tower rises high above Brighton and the surrounding countryside.

Currently under construction in Brighton is the British Airways i360, the world's tallest moving observation tower. Created by the team behind the London Eye, the i360 has a large glass pod that glides up the 162 m tower. It is a testament to the design skills of our architects, engineers, and contractors that the pod appears so simple and delicate, and that each pod sector fits together perfectly. To achieve this degree of sophisticated simplicity is in truth hugely complex.

The pod design

From the outset, we wanted the pod to have a clear, open space so that up to 200 people would have the freedom to move around and enjoy unimpeded 360 degree views in all directions. Having successfully worked with Poma to create the 32 London Eye capsules, it made complete sense to bring them in to realise the pod design. Ten times bigger than a single London Eye capsule, and 18 metres in diameter, the design of the i360 pod is based on an 'oblate ellipsoid'. In geometrical terms this means a 3-dimensional shape created by revolving an ellipse 360 degrees about its minor axis (with a cylindrical core removed to allow the tower to pass through). In layman's terms this means a shape a bit like a Smartie, but with a vertical hole through the centre.

With up to 200 people free to move around inside the pod on each ride or 'flight', this meant the team had to consider not only how to manage the weight to keep the pod stable as it runs up the 162 m tower, but also how to manage humidity and temperature, bring electricity into a moving structure and integrate the communications, sound and lighting systems into the design of the pod, whilst keeping the design as visually light and free from clutter as possible.

The chassis

The pod is supported on a red-painted chassis which will be hauled up and down the tower on 4 pairs of steel ropes. These ropes run up the outside of the tower in the 4 vertical slots in the tower cladding, and then run over bull wheels near the top of the tower and are attached to a counterweight inside the tower. To lift the pod, a winch in the basement pulls the counterweight down. To lower the pod, the winch slowly releases the counterweight back up inside the tower.

The i360 pod is attached to the two ring beams of this red chassis as it travels up and down the tower.

If you have been able to watch the progress of the build you will have seen that the red-painted chassis actually came over with the tower sections back in June 2015 and was placed over cans 1 and 2 as the tower went up.

A close up look at the chassis reveals 4 masts with a small ring beam at the top and a large ring beam at the bottom. The bottom ring beam supports 24 cantilevered pie-shaped floor sectors of the pod, and the upper ring beam supports 24 glazed superstructure pie-shaped sectors of the pod. The cables connecting to the counterweight inside the tower are attached to the 4 mast sections of the counterweight which also integrates spring-loaded guiding wheels running on the tower, so the pod and chassis travels up and down smoothly on the surface of the tower.

Two electrical 'bus-bar' tracks run up two of the tower slots and transfer mains electricity, via pick-ups on the chassis, into the pod to power air conditioning, heating, and other equipment housed within the pod. Because the pod and chassis are always heavier than the counterweight, we are able to harvest 50% of the power required to lift them through regenerative motors, making a return ride equivalent in energy-usage to a passenger sitting on a bus for a 1.5 mile journey.

Delivering the pod to Brighton

To ease prefabrication and transport, Poma constructed the pod in 24 floor sectors, 24 glazed superstructure sectors and 12 inner wall arc sections. The superstructure sectors consist of double-curved, double-glazed laminated glass assemblies mounted onto a light-weight painted mild steel frame. The floor sectors support a solid floor and house the air conditioning units, communication and safety systems. These systems are concealed from view by mirrored glass on the underside of the pod, which will create convex reflections of the city and its surroundings for people on the boarding platform to see as the pod rises or descends.

Working on the interior of the pod

Constructing the pod

The floor sectors were installed first, supported on temporary rods or hangars. The floor sectors of the pod are supported by 48 trusses, one either side of each sector, which are bolted together and cantilevered from the chassis to support the floor. The temporary hangars were removed once all of the sectors were adjusted to be perfectly level and then bolted together.

Creating the glazed superstructure sectors

Despite the delicate appearance, the superstructure sectors are incredibly robust, weighing slightly less than the weight of the floor sectors. This is because the double-glazed glass assemblies are constructed from two laminated double-curved sheets glued together with an interlayer and separated by a sealed air gap between the two separate glass layers, creating a window assembly that is four layers of glass thick.

Specialist glass maker Sunglass in Italy, who also provided the double-curved glass assemblies for the London Eye capsules (although they are only single glazed), curved the glass at high temperature using their own patented bespoke moulds. The process of heating glass puts the outer surface into compression and the inner surface into tension, effectively creating a stronger 'toughened glass' material. As this form of toughened glass cannot be cut to size, each piece had to be precisely cut to size at the start of the process in order for them to fit together accurately in layers and then be attached to the steel ribs forming the frame for each superstructure sector. Each sector has a rib on each side which matches perfectly with its neighbour so that two adjoining sectors can be bolted together.

Perfect viewing conditions

The external glass surface incorporates a permanent self-cleaning treatment, which means rain water will not stick, but rather it will run off in sheets preserving clear views for visitors even in rainy conditions.

The last segment of the pod is lifted into place.

Look here!

Keep up-to-date with this exciting engineering project:
http://britishairwaysi360.com/latest-news/

David Marks of Marks Barfield Architects is the i360's chairman and architect; Dr John Roberts is chief engineer.

A CGI impression of the pod as it lifts off to rise up the tower.

Jaws of a shark

What can we learn from how shark teeth develop?

***Dr Gareth Fraser** has been interested in marine biology since he was a child. Here he describes how this interest is leading to surprising possibilities in the field of human dentistry.*

I grew up near a Jurassic limestone beach in Wales where often used to collect fossils, and my dad would take us to fish out on the deeps. On our first family holiday away from the UK, to Greece, I learnt to snorkel. I was about ten years old and I walked into a shop and asked if I could buy a mask and snorkel and that was it. I was hooked.

I studied Palaeobiology at Portsmouth. This was great for learning about geology, fossils and past life on Earth. Then, to learn more 'real' biology, I studied for a Master's degree in Genetics at Glasgow.

As an undergraduate I became fascinated with shark teeth and I studied shark biology during my Master's project. The fossil record is incredible in that it preserves lots of hard tissues but especially teeth because they are the hardest biological material. For my PhD, which I did at King's College London, I focused on looking for the genes that control tooth development in mammals and seeing if the same genes worked in fish, suggesting that all teeth were made in the very same way.

Sharks' jaws, each with multiple rows of teeth

The Shark Trust (**www.sharktrust.org**) organises a Great Eggcase Hunt Project where groups of volunteers collect mermaids purses (shark egg cases) that wash up onto beaches. This gives scientists a good understanding of where sharks are breeding and laying their eggs. They also organise fun activities with school groups and the general public to educate people about sharks. Whatever you do, just get stuck in and be inspired by nature!

You can find fossilized shark teeth like these at many sites in the UK.

New teeth for old

Fish, especially sharks, can regenerate replacement sets of teeth throughout life. This is thought to be a very ancient programme. Mammals were probably able to replace their teeth to a greater extent than now but they have lost that ability over evolutionary time. That programme has always been there – sharks represent the most ancient and primitive state, and from there we have arrived at a state of fewer and fewer replacement rounds.

My main focus now is cranio-facial development, using fishes as model organisms. I am also investigating the molecular basis behind tooth regeneration and why fish are able to regenerate teeth continuously throughout life while we only have two sets of teeth. There are a number of cells in the human system that hint that this system can be turned on again in mammals, for example the pockets of cells that form the wisdom teeth late in adolescence. These contain stem cells which, in sharks, are active throughout life. The human adult jaw is thought to contain islands of these cells that could potentially be used for tooth regeneration but which just sit there quietly over time. In some cases, they can become active again and become cysts or tumours that can cause problems. We are trying to isolate these cells to figure out the genetic mechanism that keeps them quiet and how they could be activated to spark a new tooth.

Working with the Dental School at the University of Sheffield we hope that, one day, we can apply our research to help humans who have lost a tooth. At the moment, the only options are implants or dentures; these are invasive, painful and expensive. The idea is to be able to say, "If you need teeth, we can get you your own teeth and they will develop painlessly, just like your second set did." It's going to take a long time – many years – to learn about the human and shark systems and piece together their evolutionary history.

Gareth Fraser swims with sharks (right and top right)

Sharks in the ecosystem

I think sharks are targeted because they are the biggest predators in the ocean. However, current research is starting to reveal more about these animals – where they breed, where they feed, where they migrate to. This allows us to build a story about how sharks are important for the ocean and not the vengeful killers that the movies portray. Sharks are predators – we can't lie about that – but they usually feed on injured or dead animals. If sharks became extinct, the ocean would be put into disequilibrium as things that would normally be preyed on would explode in number – having detrimental effects on the balance of the oceans.

Take the Basking Shark. These are beautiful, graceful creatures but a little bit misunderstood. They are the second largest fish in the water but they are filter feeders, preying on nothing other than plankton. Often when people see basking sharks off the coast of the UK, they think it's a Great White and the tabloids write stories saying, "There's a Great White in the UK!" but it turns out to be a Basking Shark. I think it would be better if they wrote stories of the beauty of the Basking Shark. Using satellite tags, we have recently found that these sharks undergo huge migrations around the world, coming back to feed in the UK in the summertime. It's very impressive!

For anyone hoping to study sharks and marine biology I think the best advice would be to get involved – get out there and get your hands dirty. The problem for children at school is that they're told a lot but they don't do a lot. For me, the key was to be able to go out and do something. There are lots of organisations and conservation groups that work to spread the word about how important sharks are.

Dr Gareth Fraser is a lecturer at the University of Sheffield, UK. Find out more about his work at http://www.fraser-lab.net

Sophie
Harrington

From small seeds to big yields

There are hundreds of different plants that we grow for our food, ranging from staple foods such as rice and wheat to more exotic ones, such as passion fruit. There are so many different plants in the world, it's hardly surprising that there are lots for us to eat! Or is it?

The truth is, the ancestors of many common foods would be almost unrecognizable to us today. Take corn, also known as maize, a staple food across much of the world.. Unlike the fat, juicy yellow ears of sweet corn we see today, the ancestor of farmed corn (known as teosinte) was a small, hard, and brittle cob of almost inedible seeds. For corn to be used as a food crop, the plant has changed significantly, through a process known as domestication. This process led to a natural increase in traits such as grain size (increasing calories available), grain accessibility, an increased number of grains and the loss of a hard protective coating. The seeds also are no longer "shattered", preventing the grain from being lost on the ground. Instead of being able to spread its own seeds, and reproduce, corn is now reliant on humans to manually propagate it.

Key words
domestication
agriculture
biology
archaeology

Domestication led to a change in corn, including grain size, number, and accessibility increasing yield for early farmers. Teosinte, closely related to the wild ancestor of corn, is seen at the top, with domesticated corn at the bottom, and a hybrid of the two in the middle.

This rainbow of produce has relied on thousands of years of domestication, with the different fruits and vegetables originating all across the globe.

How to feed a city

Early humans originally lived in small groups of hunters and gatherers. These groups were sustainable because of their mobility. They were able to gather all the edible foods in one area before moving on to the next. However, we know that the transition to sedentary societies based around agriculture rather than hunting and gathering required plants and animals that can produce enough food in one place for the whole group.

To develop agriculture, humans had to choose, or select, plants and animals that produced enough yield to sustain a group on the same land throughout the entire year.

Understanding domestication

The process of domestication is of increasing interest to many different scientists, from biologists to archaeologists. There are several main questions that research aims to answer—when and where did domestication happen; and how did it occur?

When and where crops were domesticated describes the spread around the globe of staple crops. For example some crops, such as rice, have been shown to have multiple origins of domestication. That is, humans domesticated wild rice for use as a crop independently in different locations and at different times. This suggests many separate groups of ancient humans were moving towards sedentary, agricultural lifestyles around the same time.

Unlike their wild ancestors, domesticated rice plants retain seed on their stalks. This loss of seed shattering allows humans to harvest the nutritious grains more easily.

To explain how domestication happens there has to be a focus on the genetic changes that led to new phenotypes of plants. For example, the increase in grain size in corn is partly down to the deletion of one particular gene, known as Teosinte Branched (tb1). This gene produces a protein that acts as a transcription factor, regulating the expression of other genes in the plant. In particular, tb1 prevents the growth of lateral branches while promoting the formation of female flowers. These will form corncobs, once seeds are produced. Without the tb1 gene, resources are diverted away from branch formation and into seed formation. This increases yield, making corn a more valuable crop.

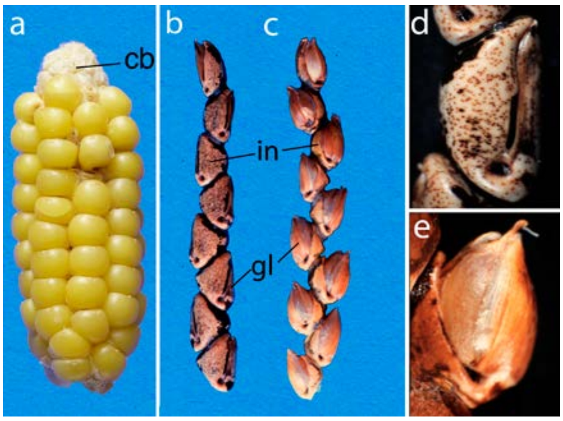
From dirt to DNA

Addressing these questions requires collaboration between scientists with a range of different specialties. Biologists can provide insight into the genetic changes that have taken place in different domesticated crops. Archaeologists on the other side are able to examine evidence from early-domesticated crops, such as ancient seeds found in archaeological sites. Together, these two disciplines can paint a picture of the process of domestication around the globe.

Understanding the spread and timing of corn domestication has relied upon a combination of genetic studies and an accumulation of archaeological data. Until recently, it was thought that corn, like rice, was domesticated several times independently across South America. By studying the genomes of multiple corn and teosinte plants, researchers were able to show that there was only a single domestication event for maize.

This idea seems feasible since it has also been shown that domestication involved small changes to only a few genes. For example, the teosinte glume architecture gene (tga1) changed in such a way as to expose the kernel on the ear so that it was easily accessible for humans to collect as food. Some researchers think this change may have taken only a few years.

At the same time, studies of ancient grains of corn have been used to demonstrate the early presence of domesticated corn, having been found in archaeological sites dating back almost 9 000 years.

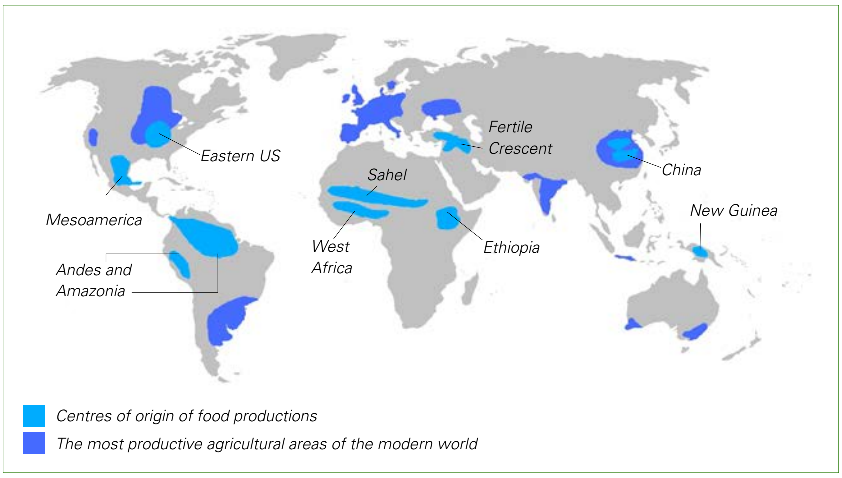


a *Maize ear showing the cob (cb) exposed at top.* *b* *Teosinte ear with the rachis internode (in) and glume (gl) labelled.* *c* *Teosinte ear from a plant with a maize allele of tga1 inserted into it.* *d* *Close-up view of a single teosinte fruitcase.* *e* *Close-up view of a fruitcase from teosinte plant with a maize allele of tga1 introgressed into it.*

Researchers focused on excavating the Xihuatoxtla Shelter in an area of the Balsas Valley in southwestern Mexico. The Xihuatoxtla archaeological site yielded evidence of maize and squash dating back 8 700 years, representing the earliest remains of maize yet discovered.

Studies of rice domestication using genomic data has shown that rice was domesticated multiple times independently. Researchers compared DNA sequences thought to be involved in domestication between different varieties of domesticated rice. The researchers showed that there are at least three different centres of domestication: southern China, Indochina, and central India and Bangladesh. This genetic data corresponds with archaeological data from sediments containing remains such as charred rice plants. Other types of archaeological data that support these conclusions include the presence of rice grains at certain sites or rice husks alongside shards of pottery.

Such a combination of biological and archaeological data is essential in helping scientists delve into the origins of our staple crops. The move from hunter-gatherer societies to sedentary, farming societies relied heavily on the selection of crop varieties with higher yield, amongst other traits. Studying crop domestication doesn't just shed light on the past, but can also help scientists working towards improving our crops today. Understanding the genetic changes needed to increase yield, nutrient content, and all sorts of other traits during domestication can direct research in those areas today.



Key centres of plant and animal domestication are found across the world, though the early centres of agriculture often don't overlap with the most productive agricultural lands today.

Sophie Harrington is a first year PhD student at the John Innes Center in Norwich, studying plant science.

Mercury

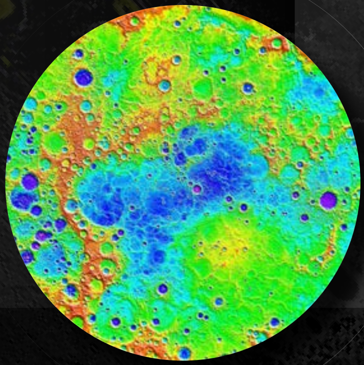
Six views of a planet's surface

Mercury, the planet nearest the Sun, has been visited by two probes. The most recent, Messenger, orbited the planet 4000 times in four years before crashing into its surface on 30 April 2015. Like the maps in an atlas of the Earth, the images below are coloured to highlight different aspects of Mercury's surface.

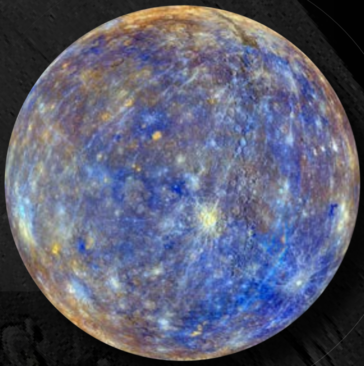
The Mariner spacecraft flew past Mercury in March 1974. This mosaic image shows the planet's southern hemisphere.

The Messenger spacecraft took this view of the whole planet shortly after its second flyby. The colours are as they would be seen by the human eye. It's night-time on the left.

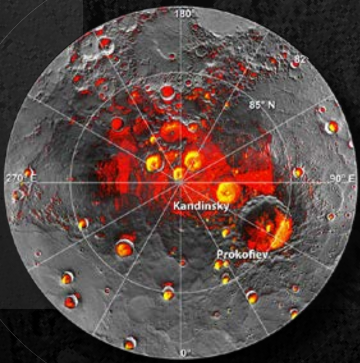
A relief map of the surface of Mercury's northern hemisphere; the lowest areas are purple, shading through to red for the highest areas.



This false-colour image is designed to show up the chemical and mineral compositions of different areas of the planet.



Messenger detected higher than average gravitational field strength in the areas coloured red; this suggests the planet's substructure is denser in some parts than others.



Mercury's north pole; because the planet is tilted at just 1°, the regions shown in red never see direct sunlight. Radar observations suggest that the areas shown in yellow contain frozen water and other volatile substances.

NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington