

# Faster than fairies

### ULTRA-FAST CHANGES IN THE NATURE OF MATERIALS COULD SPEED UP ELECTRONICS, SAYS S ANANTHANARAYAN

Faster than fairies, faster than witches, Bridges and houses, hedges and ditches. — RL Stevenson.

agnetite, or ferric oxide, the magnetic ore of iron, is known to change suddenly from being a conductor of electricity to an insulator at the low temperature of about 153? Celsius below freezing. It is known that the change is one of crystal structure, but the steps by which the change takes place are still not clear. Understanding the nature of the transforma-tion could help develop new kinds of electronic devices

ic devices. S de Jong, R Kukreja, C Trabant, N Pontius, CF Chang, T Kachel, M Beye, F Sorgenfrei, CH Back, B Bräuer, WF Schlotter, JJ Turner, O Krupin, M Doehler, D Zhu, MA Hossain, AO Scherz, D Fausti, F Novelli, M Esposito, WS Lee, YD Chuang, DH Lu, RG Moore, M Yi, M Trigo, P Kirchmann, L Pathey, MS Golden, M Buchholz, P Metcalf, F Parmigiani, W Wurth, A Föhlisch, C Schüßler-Langeheine and HA Dürr, from California, Indiana, Germany, Italv the Netherlands and Switzerland report Italy, the Netherlands and Switzerland, report in the journal, *Nature*, their work



Evert Johannes Willem Verweii

ture of the iron oxide. As the temperature

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the change in mag-

the change in hag-netite occurs in two steps — one that is under a third of a million millionth of a sec-

ond long and the next that lasts less

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The transition in magnetite is ca-lled the Verweij tr-

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ond.

falls, the structure changes from an upright, *cubic* form to an inclined form with unequal sides, called the *monoclinic* form. The crystal structure is made up of a framework of the positive core of atoms, with outer electrons positive core of atoms, with other electrons participating in forming links with neigh-bouring atoms or groups of atoms. Rearr-angement of the framework leads to changes in the mobility of electrons, which can result in dramatic changes in conductivity, both electric and thermal. When magnetite cools to nearly the transi-

crystals of metal compounds, among others

things. The transition has been known to arise through a change in the crystal struc-

tion temperature (-153° Celsius), the direction of easy magnetisation of the crystals changes from along the cubic diagonal to the edge directions, and, at the transition form, the cu-bic form changes to the monoclinic form and one of the edges becomes the axis of magnetisation. As the change in the magnetisation property can be easily detected, this change is the experimental marker of the transition of crystal structure. And this property of iron oxide finds application too, from detecting traces of magnetite in ores or as a contami-nant to recognising bacteria that align along magnetic fields

But how this remarkable property comes about in ferric oxide is still not understood. The change in crystal structure is like a change from solid to liquid (melting) or from liquid to gas (evaporation). In such a change, the energy balance established among the molecules in the collection becomes unstable with increasing energy. The assembly then remains without increase of temperature till the additional energy needed in the next equi-librium state has been acquired and then ab-

ruptly transforms to that state, which is called another "phase". The authors of the paper in *Nature* explain

that when ferric oxide is cooled to cross the Verveij transition, the higher temperature state of electrons that are not always bound to atoms, which allows conduction, "freezes" into



an ordered structure where iron atoms, which are charged because they have lost either two or three electrons, hold together in an eight-sided, stable formation. This tying down, as it were, of electrons results in a jump in resistivity, along with the change from the cubic arrangement to the lower temperature, monoclinic phase. While the details of the change in structure have been elusive, there has been recent progress in understanding the group of atoms that makes up the network of basic un-its in magnetite. This unit consists of three iron atoms, two that have lost three electrons and one that has lost two electrons – a unit called a *trimeron*. These are the groups that present the extent of bound or unbound electrons that account for the electrical properties of magnetite

In many metal oxide materials, like magnetite, it is the behaviour of such units that is examined to explain the freeing or freezing of charge carriers, sometimes found to arise at the same time as changes in the crystal structure. But as there are usually a great number of factors present and the different phases are close together, in terms of energy, it has not been possible to prise apart the changes that go into phase transitions. The case of magnetite, among these, has features that make it simpler than others and magnetite offers the possibility of allowing the basic mechanism in the group of materials to be viewed.

The researchers used what amounts to high speed motion picture recording of the phase transition, as the energy of the crystal material was pumped, in doses that were a fraction of million millionths of a second apart. The pumping was with a laser that fired in pulses. at this rate, and the response of the crystal for-mation was monitored by watching the way Xrays were scattered by the plane faces of the crystals. Scattering of X-rays is a well worn way of finding out how atoms are placed in crystals. X-rays have wavelengths that are of

the order of the distance between scattering layers and X-rays scattered in any direction by different layers would be "in or out of step", depending on the distance between the layers and the angle of scattering. Examining the scattering pattern can then reveal the struc-ture of the crystal, particularly in the case of

magnetite, whether it is cubic or monoclinic, and also any conditi ons in between. The researchers used

a pumping laser with pulses that were 70,000 million million the of a

nised with X-rays in pulses 10,000 million millionths of a second apart, generated by the Free Electron Laser at the Linac Coheretn Light Source in Stanford. In this facility, coherent, laser-like light is emitted not from transitions laser-like light is emitted not from transitions in atoms but by the motion of the wriggling of a beam of electrons that is passed through an alternating magnetic field. Starting from a low temperature, well below the transition temperature, energy was pumped in while the

which takes a longer, 1.5 million millionths of

Electronic devices work by switching elec-tric currents on or off, depending on other electric signals, using silicon-based devices, like switching up to 100 billion times a second. But the switching from insulator to conductor and many times faster. "The understanding we have gained as to

how the transformation between the two states straddling the Verwey transition takes place could aid in the choice and design of oxide materials aiming at harnessing the enormous differences in electrical conductivity available in these systems," say the authors in their paper.

Significantly her coca — and alcohol — consumption rose temporarily six

months before her sacrifice, almost cer-tainly at some major Inca ceremony. It is conceivable that it was at or

shortly before this event (potentially the Inca winter solstice festival of Inti

Ravmi) that the second part of the sel-

ection procedure occurred in which she was chosen for eventual sacrifice. For at

mately buried with her in her moun-

tain-top sacrificial tomb. In Inca cul

ture, key transformations (for instance

the elevation to full human status at the

age of three) were marked by a ritual-ised haircut.

fice approached, she was plied with in-creased amounts of coca and large

quantities of alcohol — almost certain-ly in the form of maize beer (up to 20 per cent alcoholic content). The Uni-

versity of Bradford scientists, analy-sing her hair, identified evidence that

her alcohol intake rose fivefold in the four to six weeks prior to her sacrifice.

dulled any feelings of apprehension she might have felt about her impending

fate. This increase in alcohol supply

seems to have occurred as she was tak

Certainly the alcohol would have

As the time earmarked for her sacri-

THE WRITER CAN BE CONTACTED AT

## SYSTEMS FOR **STUDYING GENES**

did

TAPAN KUMAR MAITRA EXPLAINS WHY BACTERIOPHAGES ARE SO ATTRACTIVE TO GENETICISTS

rom its inception in the mid-19th century, genetics has drawn upon a wide variety of organisms for its experimental mat-erials. Initially, attention focused on plants and animals, such as Mendel's peas and the fruit flies popu-larised by later investigators. Around 1940, however, bacteria and viruses came into their own, providing biologists with experimental systems that literally revolutionised the science of genetics by

bringing it to the molecular level. Bacteriophages, or phages for short, have been especially important. These are viruses that infect bacterial cells. It is easy to obtain huge numbers of phage particles in a brief period of time, which greatly facilitates screening for mutants — phages with heritable variations — thereby making it possible for geneticists to identify particular genes. Some of the most thoroughly studied phages are the T2, T4, and T6 (the so-called T-even), which infect the bacterium E. coli. The three T-even phages have similar structures. The head of the phage is a protein capsule that is shaped like a hollow icosahedron (a 20-sided object) and filled with DNA. It is attached to a protein tail, which consists of a hollow core surrounded by a contractile sheath and terminates in a hexagonal baseplate, to which six tail fibers are attached In the replication cycle of the T4 phage the bacterium is proportion-ately larger, as the electron micrograph indicates. The process begins with the adsorption of a phage parti-cle to the wall of a bacterial cell. When the phage collides with the cell, it "squats" so that its baseplate attaches to a specific receptor protein in the wall. Next, the tail sheath (1) contracts, driving the hollow core through the cell wall. The core forms a needle through which the bacterio phage DNA is injected into the bacterium (2). Once this DNA has gained entry to the bacterial cell, the genetic information of the phage is transcribed and translated (3). gives rise to a few key proteins that subvert the metabolic machinery of the host cell for the phage's benefit, which is usually its own rapid multiplication. Since the phage consists simply of a DNA molecule surrounded by a protein coat (its capsid), most of the metabolic activity in the infected cell is channelled toward the replication of phage DNA and the synthesis of capsid proteins. The phage DNA and capsid proteins then self-

The structure of bacteriophage -65 nm-Head DNA 225 nm Tail core Tail sheat Tail Basenlate Tail fibe DNA Bacteria 1 Adsorption of phage particle to host cell

volume is mixed with bacterial cells growing in liquid medium to allow adsorption of the phages to the bacteria. The mixture is then spread on to solid (agar-containing) nutrient medium in a Petri dish. Upon incubation, the bacteria multiply to pro-duce a dense "lawn" of cells on the surface of the nutrient medium. But wherever a virus particle has infect-ed a bacterial cell, a clear spot appears in the lawn because the bacter-ial cells there have been killed by the

multiplying phage population. Such clear spots are called plaques. The number of plaques appearing in the bacterial lawn represents the number of phage particles in the original phage-bacterium mix-ture, provided only that the initial number of phages was small en-ough to ensure that each gives rise

to a separate plaque. The course of events is called lytic growth and is characteristic of a virulent phage. Lytic growth results in lysis of the host cell and the production of many progeny phage particles. In contrast, a tem perate phage can either produce lytic growth, as a virulent phage does, or integrate its DNA into the bacterial chromosome without causing any immediate harm to the host cell.

An especially well-studied example of a temperate phage is bacte-riophage 1 (lambda), which, like the T-even phages, infects E. coli cells. In the integrated or lysoge-nic state, the DNA of the temperate phage is called a prophage. The are phage is called a prophage. The prophage is replicated along with the bacterial DNA, often through many generations of host cells. Dur-ing this time, the phage genes, though potentially lethal to the host, are inactive, or repressed. Under cer-tain conditions, however, the prophage DNA is excised from the bacterial chromosome and again enters a lytic cycle, producing progeny

#### Secrets of the Incas ties of the mild Andean stimulant coca ANALYSIS BY A UK TEAM (from which cocaine is now extracted).

SHOWS TEENAGE GIRL WAS GIVEN COCA AND ALCOHOL BEFORE RIRUALISTIC DEATH, WRITES DAVID KEYS

A rchaeologists are piecing togeth-er the real-life tragedy of a 13-year-old girl chosen as a gift to the gods, who was killed more than five cen-turies ago on the summit of a sacred that ceremony the research shows that a small portion of her hair was rem-oved. Indeed the shorn hair was ultifour-mile-high mountain in South America. By pioneering a remarkable biochemical analytical process to extract data from her hair, British scientists have been able to trace the nature of her food and drink consumption over

the final 24 months of her life. Much of the key data was revealed in the US scientific journal, *Proceedings of the National Academy of Sciences*, aug-menting other data from the same research team, published six years ago. "We have been able to quite literally unlock history from her hair, giving voice to a very personal account of what happened to her," said Dr Andrew Wilson of the University of Bradford who has been leading the scientific res-

earch. The hair analysis and other evidence reveals, for the first time, the treatment of human sacrificial victims from the moment of selection to the point of death. It reveals how the teenager was given a natural stimulant and substantial quan-tities of alcohol. Her tragic story may well have begun not far from where she was ultimately sacrificed in what is today a mountainous area of north-west Argentina. It was an area that had been conquered by the Inca Empire in the second half of the 15th century. The Incas and indeed some earlier

South American civilisations believed that agricultural fertility — and pros-perity and success in general — relied, at least in part, on ensuring divine help by making human sacrifices to the gods It is thought that throughout Inca history tens of thousands of such sacrifices were carried out. Periodically, substantial numbers of children were selected for imperial service by local Inca officials and sent to the empire's capital. Cusco, in what is now Peru. There, further selection processes took place in which some, males as well as females, were allocated to the emperor as servants and retainers. Many of the girls were given as wives to members of the Inca elite or were al located to religious institutions as trainee priestesses. But others (boys as well as girls) — physically the most perfect individuals with no physical blemishes were selected for sacrifice. The scientific analysis of the teenager's hair suggests the possibility that the first part of the selection procedure, earmarking her for some form of impe rial service, took place exactly a year before her eventual sacrifice. For the analysis revealed that her diet changed abruptly from a peasant one to a meat and-maize one, normally associated with the Inca elite. The latest research reveals she also started consuming considerable quanti-



TheStatesman

KOLKATA, WEDNESDAY 31 JULY 2013

#### Smart-tooth sensor

The unstoppable proliferation of wearable tech into polite society continues to blur the lines between science fiction and reality with a new tooth-sensor that can tell you when you're eating too much. Developed by a team of Taiwanese scientists, the news was released in their paper under the snappy title of "Sensor-Embedded Teeth for Oral Activity Recognition". The scientists say the new sensor "recognises human oral activities, such as chewing, drinking, speaking and coughing". The most important part of the



sensor is an accelerometer (the same gadget that knows whether your smartphone is upright or on its side) that distinguishes between the "motion profiles" of all the different and entertaining things you do with your mouth.

The team says their research is a big improvement on previous sensors aiming to record "oral activities" simply because of where the sensor is placed. Having the tech take the place of a tooth "has the advantage of being in proximity to where oral activities actually occur" and allows the sensor to correctly identify what's going on in your mouth 94 per cent of the time.

Once the sensor has figured out whether you're chewing the cud or just chewing the fat, this data can then be turned into meaningful information on how you spend your day and recommendations for a healthier lifestyle.

The technology is currently only in a prototype stage but the researchers propose that in future the sensor propose that in future the sensor could come equipped with Bluetooth to wirelessly "transmit sensor data to a nearby smartphone". The scientists also hope to shrink the device so it might fit into a tooth cavity. "Because the mouth is or exercise

"Because the mouth is an opening into human health," say the scientists, "this oral sensory system has the potential to enhance exiting oral-related healthcare monitoring applications such as dietary tracking.

JAMES VINCENT/THE INDEPENDENT

#### Tiger's tale

The white tiger is the most charismatic species of all. However, this rare variant of the orange Bengal time (Durthern the interior bare bengal tiger (Panthera tigris tigris) can be seen only in zoos because it is said they are the result of a genetic defect that does not allow them to survive in

the wild. Researchers from China and South Korea recently studied this speculation and have acquired insight into how white tigers got their colour. They mapped genomes of a family of 16 tigers living in Chimelong Safari Park in Panyu in Guangzhou province. The animals included both white and orange individuals and the researchers sequenced the genomes of the three parents in the family and zeroed in on the gene that codes for synthesis of pigments. The gene has long been associated with the light colour seen in some human populations and in other animals, including horses. They identified a mutation in the white tiger version of the gene, which appeared to inhibit the synthesis of red and yellow

pigments. This change has no effect on the



second apart, synchro

crystal structure and electronic response was probed by X-ray scattering. It was found that the transition from the low temperature insulator to the high temper-ature conductor took place in two steps – first, the very fast, 300,000 million millionths of a second, breaking down the existing network of trimerons, and then a rearrangement a second.

transistors. The speed of the arrangement de-pends on and is limited by how fast the switching can happen. While silicon-based devices are at their limit of speed. development of graphene transistors has pushed the speed of back in the case of ultracold ferric oxide is



assemble into hundreds of new phage particles (4). Within about half an hour, the infected cell lyses (breaks open), releasing the new phage particles into the medium (5). Each new phage can now infect another bacterial cell, making it possible to obtain enormous populations of phages — as many as 10<sup>11</sup> phage particles per millilitre in infected bacterial cul-

To determine the number of phage particles in a sample, a measured

phage particles and lysing the host cell

One reason bacteriophages are so attractive to geneticists is that the small size of their genomes (which may be either DNA or RNA) makes it relatively easy to identify and study their genes. The genome of bacterio phage l, for example, is a single DNA molecule containing fewer than 60 genes, compared with several thou-sand genes in a bacterium such as E. coli. Other phages are still smaller; in some instances they contain less than a dozen genes. Because of their simple genomes their rapidity of multiplication and the enormous num bers of progeny that can be produced in a small volume of culture medi-um, bacteriophages are among the best understood of all "organisms" In addition, they may have some practical benefits as well.

Given that phages are capable of destroying bacteria, some biotechnology companies are exploring the development of modified phages that might be useful in treating human bacterial infections, especially in cases where the bacteria have become resistant to antibiotics.

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en - probably in a litter - back to what may well have been her native land and to the mountain she would die on. Finally (conceivably at Capac Raymi, the summer solstice), exactly a year after the selection process had begun, she reached the foot of the sacred mountain Vulcan Llullaillaco. Probably still in her litter, she made the ascent, accom panied by priests and other officials along a special ritual road, built by Inca engineers.

The trek up the mountain would have taken at least one and a half days - and the party would have probably over-nighted at a way-station. At last, the moment arrived. Almost certainly wea kened by altitude sickness, alcohol and fatigue, the 13-year-old, wearing a brown dress and a magnificent headdress, was taken to the summit and killed (either by smothering, strangulation or expo sure to the elements)

Her body was interred in a specially prepared grave. It would be five long-centuries before her corpse — mummified by the intensely cold conditions of the mountain-top — would be found in 1999 by US, Peruvian and Argentine archaeologists investigating the sacrificial legacy of the Incas. The subsequent scientific investigation is only now vielding up the secrets of her tragic fate.

THE INDEPENDENT

synthesis of black pigment, explaining why the tiger still has the characteristic dark stripes on white fur. The study was published in Current Biology on 3 June 2013. Usually white tigers found in zoos have health issues, such as premature death. low fertility, stillbirths and deformities such as shortened legs, arching of the backbone and eye weakness. However, Shu-Jin Luo, one of the authors from the Peking-Tsinghua Centre for Life Sciences of Peking University, Beijing, says the problems are a result of inbreeding and not mutation.

K Ullas Karanth, director of the Centre for Wildlife Studies in Bengaluru, says the study is of theoretical interest. "White tigers have no conservation significance. They are like humans with some inherited genetic deficiency. The study does nothing to help the recovery of declining tiger populations in the wild."

ANJALI THAKUR/CSE-DOWN TO EARTH FEATURE SERVICE







