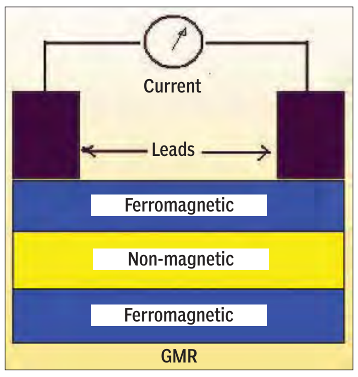
Boosting possible applications

NEW MATERIALS MAY HELP ELECTRON SPIN ENTER THE WORLD OF COMMUNICATIONS AND COMPUTING, SAYS **S ANANTHANARAYAN**

The electron has been at the centre of science since the 1890s, when it was discovered. We know it is as the particle whose motion is the meaning of the electric current, and electricity has transformed the world in the last century. With more of its many properties being discovered, the electron also ushered in the world of electronics — with the telephone, radio, television, the computer and all else.

But these are applications of the electron as a charged particle in motion. As a particle that exists in all atoms, and in a relatively free way in metals, the electron can be free of the atom and move, to carry current, run motors and boil water. As a charged particle, its movement can be blocked or promoted by other electric charges, or controlled by magnetic fields and this is the field of electronics. But apart from its mass and its charge, another remarkable property of the electron is that it seems to have a spin, which makes it behave as a tiny, moving magnet, too. This additional property has given rise to a separate field of applications, over and above the field of electronics.

A group of scientists in London and Vancouver report in the journal *Nature* that they have developed a low cost, versatile organic semiconductor material that is able to conserve a state of electron spin for a longer period of time, which would increase its field of possible applications.



Electron spin

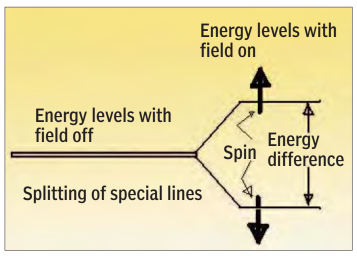
Electron spin was discovered while investigating why the emission spectra alkali metals, which have one electron in their outermost shell, split into two closely separated frequencies when a magnetic field was switched on.

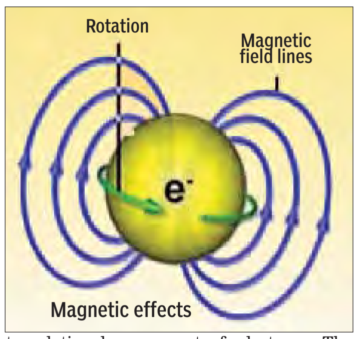
Wolfgang Pauli first suggested that this was because the energy levels of an electron in an atom existed not as single state but as a pair of closely separated states. Ralph Cronig suggested that the two states could be understood by associating a spin with the electron. Pauli did examine the idea but found that, given the size of the electron, it would need to spin so fast that its surface would move faster than light! Cronig seemed to have let the idea drop, but it was soon found that there was a way round the objection and Pauli came back to formalise a theory of electron spin, combining the principles of motion of a spinning top with quantum effects, which would be relevant at the scale of the electron. That electrons have spin had also been dramatically shown by an experiment by Otto Stern and Walther Gerlach where a beam of electrons was split into two when it passed through a powerful magnetic field.

The spin of the electron is also the reason for the property of magnetism. As the electron is a spinning charge, it has magnetic effect and behaves like an elemental bar magnet. In atoms that have an even number of electrons, the spins are opposite and matched and the atom has no net magnetic effect.

But where there is an "unpaired" electron, the atom itself is an elemental magnet. In many metals, called *ferromagnetics*, the crystal structure is such that atoms tend to orient themselves, either spontaneously or by the effect of a magnetic field, so that the electron spins are aligned and there is a powerful net magnetic effect.

Electrons, thus, create transient or permanent magnetic effects, which then impel or control the movement of other electrons in the form of electric currents and, hence, the great number of applications of electricity in modern times. But these applications, including electronics, are based on the linear, or translational, movement of electrons. The hugely significant fact that the electron has spin is not exploited. This kind of application, whose development perhaps needed the support of conventional electronics, appeared in the 1980s with the discoveries of how spin of electrons could also affect the passage of electric current.





The effect used was that passing a current through a ferromagnetic material resulted in the current getting *spin polarised*, or that the spin axes of the electrons were turned so that they all pointed the same way. This effect makes possible the effect of *giant magnetoresistance* (GMR), which comes about with a conductor that consists of at least two layers of ferromagnetic material separated by a spacer layer. When the directions of magnetisation of both layers are the same, the electrical resistance is lower, which is to say that a larger current flows, than when the directions are not aligned. As the direction of magnetisation can be readily controlled by en external field, the resistance of the layer becomes a sensitive sensor of magnetic fields.

The effect has been used to great advantage in the *read heads* of modern computer hard drives. The head consists of a GMR device that is exposed to the fast moving hard drive surface. The magnetisation of the drive sectors, which represents the data recorded, affects the electrical resistance of the device and transfers the data from the disc to the current that flows though the device. GMR very sensitive to slightest changes in magnetisation and the device is, hence, fast and reliable for reading disc data.

Information processing

But apart from such applications of retrieval or information from magnetic storage, for processing in the ordinary way future applications of interest are for processing of information itself. This idea involves the spin of an electron, viz, "up" or "down",being considered a unit of information, to be processed, for example by being admitted or blocked in a "spin gate", like conventional currents are managed by diodes or transistors. This would involve both the generation as well as the filtering of spin polarised currents.

The existing ferromagnetic- or metal-based devices do function as filters but they cannot amplify, or strengthen a signal and also cannot easily integrate with existing semiconductor-based electronics of diodes and transistors. This would not be true of semiconductor-based devices that could be multifunctional. Transfer of spin information across transitions may also bring in new technologies, including the use of optical interfaces, which may overcome the size limitations that electronics is now grappling with. But in these possible applications, an important consideration is the persistence of the spin information for a reasonable length of time. This property is important both for conventional computing, where the spin state would represent a value, and also for the ambitious *quantum computing*, where a object like an electron could represent both its possible states at once and could participate in massive, parallel computation tasks so long as its condition of being in *both states* is not destroyed by interactions with the environment, which would amount to a *measurement* of its state.

The authors of the paper in *Nature* note that solid state inorganic materials were first considered and then more exotic, large, complex molecules that acted as single molecule magnets entered the field. The complexity of the molecules gives rise to disturbances and they necessitate very low temperatures and isolation, in dilute solution, to sustain electron spin. In contrast, the material that the group has worked with is a common, low cost and simpler organic blue pigment molecule – copper phthalocyanine (CuPc), which is easily processed in thin film form, which is useful for inclusion in devices. CuPc has been found to maintain electron spin states for a whole 59 milliseconds and stay undisturbed for quantum computing for 2.6 microseconds, which are time spells that compare well with other materials, but at a practical temperature of five degrees Celsius above absolute zero.

Even at 80 degree Celsius above absolute zero, which can be maintained by use of liquid nitrogen, the time spells are 10 and one microseconds.

As this material is robust and easy to produce and handle, the authors believe its use would lead to effective applications where the property of spin is exploited by semiconductor technology.

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PLUS POINTS

Faster and safer

Li-Fi, an alternative to Wi-Fi that transmits data using the spectrum of visible light, has achieved a new breakthrough, with UK scientists reporting transmission speeds of 10Gbit/s — more than 250 times faster than "superfast" broadband.

The fastest speed previously reported was 3Gbit/s, achieved earlier this year by the Fraunhofer Heinrich Hertz Institute in Germany. Chinese researchers also claimed this month to have produced a 150Mbp/s connection, but some experts were doubtful without seeing further proof.


Professor Harald Haas coined the term Li-Fi and is at the forefront of research into the new technology.

The term Li-Fi was coined by Edinburgh University's Professor Harald Haas in 2011 though the technology is also known as Visible Light Communications. Many experts claim that Li-Fi represents the future of mobile Internet, thanks to its reduced costs and greater efficiency compared to traditional Wi-Fi. Both Wi-Fi and Li-Fi transmit data over the electromagnetic spectrum, but whereas Wi-Fi utilises radio waves, Li-Fi uses visible light. This is a distinct advantage in that the visible light is far more plentiful than the radio spectrum (10,000 times more, in fact) and can achieve far greater data density.

Li-Fi signals work by switching bulbs on and off incredibly quickly — too quickly to be noticed by the human eye. This most recent breakthrough builds upon this by using tiny micro-Light-Emitting Diode bulbs to stream several lines of data in parallel. The research was carried out by the Ultra Parallel Visible Light Communications project, a joint venture between the Universities of Oxford, Cambridge, Edinburgh, St Andrews and Strathclyde, and funded by the Engineering and Physical Sciences Research Council. Existing Led bulbs could be converted to transmit Li-Fi signals with a single microchip, and the technology would also be of use in situations where radio frequencies cannot be used for fear of interfering with electronic circuitry.

The makers of Li-Fi note that this quality might actually be an advantage in some scenarios, making Li-Fi more secure than Wi-Fi, with hackers unable to access unsecured Internet connections from out of sight of the transmitter.

JAMES VINCENT/THE INDEPENDENT

Snakes on the brain

Was the evolution of high-quality vision in our ancestors driven by the threat of snakes? Work by neuroscientists in Japan and Brazil is supporting the theory originally put forward by Lynne Isbell, professor of anthropology at the University of California, Davis.
In a paper published on 28 October in the journal *Proceedings of the National Academy of Sciences*, Isbell, Hisao Nishijo and Quan Van Le at Toyama University, Japan; and Rafael Maior and Carlos Tomaz at the University of Brasilia, Brazil, and colleagues show that there are specific nerve cells in the brains of rhesus macaque monkeys that respond to images of snakes.

The snake-sensitive neurons were more numerous and responded more strongly and rapidly than other nerve cells that fired in response to images of macaque faces or hands, or to geometric shapes. Isbell said she was surprised that more neurons responded to snakes than to faces, given that primates are highly social animals. "We're finding results consistent with the idea that snakes have exerted strong selective pressure on primates," she said.

Isbell originally published her hypothesis in 2006, following up with a book, *The Fruit, the Tree and the Serpent*, in which she argued that our primate ancestors evolved good, close-range vision primarily to spot and avoid dangerous snakes. Modern mammals and snakes big enough to eat them evolved at about the same time, 100 million years ago. Venomous snakes are thought to have appeared about 60 million years ago — "ambush predators" that have shared the trees and grasslands with primates.

Nishijo's laboratory studies the neural mechanisms responsible for emotion and fear in rhesus macaque monkeys, especially instinctive responses that occur without learning or memory. Previous researchers have used snakes to provoke fear in monkeys, he noted. When he heard of Isbell's theory, he thought it might explain why monkeys are so afraid of snakes.

"The results show that the brain has special neural circuits to detect snakes, and this suggests that the neural circuits to detect these reptiles have been genetically encoded," he said.

EVOLUTIONARY ADVANTAGE

TAPAN KUMAR MAITRA EXPLAINS THE INTERVENING SEQUENCES IN EUKARYOTIC GENES

Segments of eukaryotic DNA can be grown in E coli plasmids using genetic engineering technology. Plasmids containing a given eukaryotic gene can be identified by using radioactive hybridisation probes prepared from purified mRNA. When a variety of such cloned eukaryotic genes became available during 1977, molecular biologists were in for quite a surprise.

Unexpectedly, it was found that in eukaryotes the information for covalently contiguous mRNA was frequently located in noncontiguous DNA segments. In other words, genes are interrupted by insertions of noncoding DNA. These inserted DNA sequences, which are absent in the mature mRNA, are called intervening sequences or introns, which have been found in globin, ovalbumin, immunoglobulin, tRNA, and many other genes. Not all eukaryotic genes are interrupted; those coding for histones and some tRNAs, for example, are continuous.

The β-globin gene is interrupted by a DNA fragment 600 base pairs long inserted within the protein-coding sequence. A second, much shorter intervening sequence is found closer to the starting end of the coding sequence. The electron micrograph shows a cloned segment of mouse DNA that was hybridised to globin mRNA. When the RNA hybridises to the DNA, a "bubble" can be seen in which one strand is an RNA-DNA hybrid and the other is single-stranded DNA. Globin mRNA hybridises to two discontinuous regions of the genomic DNA, while the intervening sequence, which is not present in the 9S mRNA, remains as a loop of double-stranded DNA.

Intervening sequences are transcribed into precursor RNAs that are larger than the mature mRNAs. To obtain a functional mRNA these internal sequences must be excised precisely and the molecule relegated. This mechanism shown schematically has been called RNA splicing.

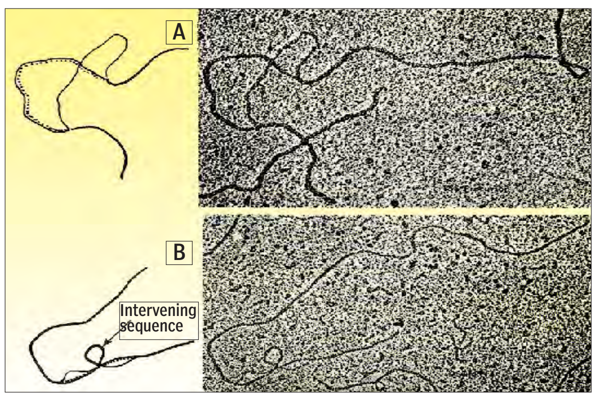
The β-globin gene is not transcribed initially as a 9S molecule, but rather as a precursor that sediments at 15S in sucrose gradients. This sedimentation value represents a molecule two to three times longer than globin mRNA, and this extra length is due to the presence of the intervening sequence. Mature 9S mRNA results from the removal of the intervening sequences, a process that takes place rapidly, since the 15S precursor has a half-life of less than two minutes.

While it is clear that several genes are interrupted at the DNA sequence level (the ovalbumin gene has eight introns), we do not know why this would be beneficial to eukaryotic cells. It has been suggested that some evolutionary advantage could be gained by the deletion or addition of whole functional units of amino acids (for example, from a neighbouring gene). In this way novel proteins could evolve more rapidly than by single nucleotide changes. The results for many protein-coding genes suggest that protein functional domains are separated by intervening sequences in the DNA and are consistent with the view that in evolution new proteins might be constructed from parts of old ones brought together by the splicing mechanism, which, incidentally, has not yet been detected in prokaryotes.

When eukaryotic cells are treated with a radioactive RNA precursor for short periods, most of the labelled molecules are incorporated into a population of large nuclear RNAs of variable length, the so-called heterogeneous nuclear RNAs (hnRNAs). These rapidly labelled nuclear RNAs are not related to rRNA or to tRNA; they contain three-inch poly A tails and five-inch caps; and they are larger than mature mRNAs. The average length of eukaryotic mRNA is 1,800 nucleotides, and that of hnRNA is 4,000, but some molecules can be 20,000 nucleotides long. Most of the hnRNA is never released into the cytoplasm and is degraded within the nucleus.

Nucleic acid hybridisation studies have shown that hnRNA contains more sequences than mRNA. It is estimated that six to 20 per cent of the information available in the genome is represented in hnRNA, while only one per cent is represented in cytoplasmic mRNA. Most of the hnRNA consists of mRNA precursor molecules from which the intervening sequences have not yet been removed, as in the case of the globin 15S precursor.

Once the intervening sequences are removed, the mature mRNAs can exit into the cytoplasm.



Visualisation of the intervening sequence of the globin gene in the electron microscope. A cloned segment of DNA containing the mouse b-globin gene was hybridised with 15S globin mRNA precursor (A) and mature 9S globin mRNA (B). The hybridised RNA is represented by a dotted line in the diagram. The 15S precursor hybridises in a continuous way, showing that the intervening sequence is transcribed into RNA. Note in B that the mature globin mRNA hybridises to two discontinuous regions of the DNA, and the intervening sequence remains as a loop of double-stranded DNA. It was from electron micrographs such as these that intervening sequences were first discovered.

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The blood detectives

JONATHAN BROWN REPORTS ON A BREAKTHROUGH IN READING STAINS THAT MAY HELP SOLVE CRIMES

A camera that can detect and date blood traces is set to revolutionise the science of crime scene investigation. Long considered the "holy grail" by forensic experts, a new hyperspectral imaging device that can scan for the visible spectrum of haemoglobin could dramatically speed up police inquires, lead to more convictions and reduce the number of miscarriages of justice, its creators have claimed.

A prototype built by researchers at Teesside University has demonstrated extraordinary levels of laboratory accuracy. Month-old blood samples can be dated to within a day, while fresh traces have been pinpointed to within an hour of their being taken, potentially helping police to establish a time of death immediately — a process which at present can take several days — and allowing detectives to build a more rapid chronology of events.

Blood samples and splatter patterns are one of the most commonly used forms of prosecution evidence in cases of violent crime. It is believed the technology could also be applied to other fluids, including perspiration, saliva and semen, which could also improve conviction rates for rapes and other sexual assaults.

Dr Meez Islam, a physical chemist and reader in the university's School of Science and Engineering, who led the team working on the project, said that identifying bloodstains often posed serious problems. Forensic teams were still working with techniques devised a century ago, and there was currently no effective way of dating blood. "Often you go to crime scenes and what appears to be blood isn't blood. Blood on dark backgrounds can be hard to see and there are traces of blood that are not visible to the naked eye. What this does is provide fast, at-the-scene identification of blood and speed up the investigative process, as items do not need to go back to a laboratory to be examined. To use hyperspectral imaging in a way that scans the crime scene for blood also means that the chances of missing a bloodstain are vastly reduced,' he said.

The new technology, which will be unveiled at a forensic science conference in Manchester next month, uses a liquid-crystal tunable filter and is able to offer immediate results. The filter works by isolating different wavelength bands of colour, so that it can detect blood against other similar-looking substances or in hard-to-spot locations such as on red clothing, carpets or furniture.


A new hyperspectral imaging device that can scan for the visible spectrum of haemoglobin is considered to be the "holy grail" for forensic experts.

Because blood changes colour over time, from bright red to muddy brown, at a known rate, the device is able to put an accurate age to a sample. At present, forensic scientists must paint on chemicals to areas where they believe blood may be present, hoping to produce a luminous or other reaction with iron found in haemoglobin. It is a procedure routinely demonstrated in television dramas such as *CSI: Crime Scene Investigation*.

But failure to locate samples has plagued a number of high profile cases. In the investigation into the murder in 1993 of teenager Stephen Lawrence, detectives were hamstrung by their inability to find any physical evidence linking the suspects to the killing. It was only during exhaustive laboratory retesting during a cold case review that a spot of Stephen's blood was found on the seam of the collar of a jacket belonging to his killer, Gary Dobson. In the case of south London schoolboy Damilola Taylor, murdered in 2000, experts missed a bloodstain on a trainer belonging to one of his killers.

At Teesside, which is marking 21 years since it became the first university to train graduates in forensic and crime scene courses, researchers believe the breakthrough could help to prevent a repeat of the blunders. Dr Islam said there had been interest in the innovation by police forces and he needed £100,000 to create a working model. "This is a fairly small investment for a relatively large societal impact. This could help reduce crime, stop the wrong people being convicted and make sure the right people go to jail," he said.

THE INDEPENDENT