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PHYSICS OF CANCER

New tools and fresh perspectives

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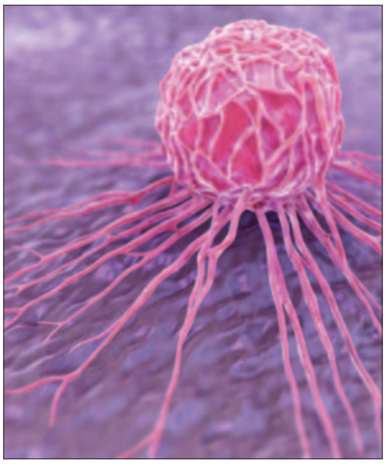

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The Next Generation
of High Voltage Intelligent Control

Introducing our NEW family of versatile Power Supplies

The new generation of FJ, FR,EJ & ET series high voltage dc power supplies from Glassman, feature an embedded microcontroller, with front panel LED displays and multi-function front panel rotary encoders, allowing selectable coarse and fine adjustment.

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Quanta

For the record

I am a triumph of modern medicine, physics and chemistry

US rock musician **Lou Reed** *on* Facebook
The 71-year-old former Velvet Underground frontman took to *Facebook* to reveal that he is "bigger and stronger than ever" following a successful liver transplant in May.

At heart I am a physicist, I look at everything in my life trying to find the single equation, the theory of everything

Actor **Will Smith** *quoted in* New York Magazine
Smith, who recently starred together with his son Jaden in the science-fiction film *After Earth*, reveals his affinity to physics, adding that he is a "student of patterns".

I never got into *Star Wars*, maybe because they made no attempt to portray real physics. At all

Neil deGrasse Tyson, *director of the Hayden Planetarium in New York, talking to* Business Insider
Tyson was commenting after being asked if he preferred *Star Trek* over *Star Wars*.

It's based on new research that's being done in particle physics by the young men and women at Columbia University

Actor **Dan Akroyd** *speaking on the* Larry King Now *show*
Akroyd was speaking to veteran talk-show host Larry King about plans for a *Ghostbusters 3* film, which will apparently be centred on work into extra dimensions.

Working at CERN is one step up from having any old PhD

Dominic Connor, *head of quantitative finance recruitment firm P&D Quant recruitment, quoted in* eFinancialCareers
Connor claims that there are many people who have doctorates in physics but CERN is the place to find top PhDs in physics and computing.

You will never think of your breakfast in the same way again

Postdoc **Andong He** *from Yale University quoted in a Yale press release*
He and colleagues claim to have discovered how different shapes of cereals join together to form different patterns when they float in milk.

Seen and heard

NASA

Print your own food

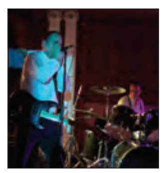
It may have first appeared on the Starship *Enterprise*, but a firm in the US is trying to bring something akin to the "food replicator" into the real world. Texas-based outfit Systems and Materials Research Corp has been given a $125 000 grant from NASA to develop a "3D food printer" that could create custom meals for astronauts in space. Currently astronauts take with them pre-packaged nosh but the company says the new printer would vastly reduce waste – a key factor for future long-distance space missions. The printer would create synthetic food in a low-gravity environment layer-by-layer by combining powdered protein, starches, fats and flavours with water or oil. "The 3D printing system will provide hot and quick food in addition to personalized nutrition, flavour and taste," the firm wrote in its proposal to NASA. So when exactly will astronauts be tucking into printed pizzas? Don't hold your breath. "These are very early-stage concepts that may or may not mature into actual systems," says NASA spokesperson Allard Beutel.

Space fiction

Still on space, next month sees the launch of what could be one of the biggest films of the summer. *Elysium*, starring Matt Damon and Jodie Foster, is a science-fiction blockbuster set in the year 2159. In the film there are two classes of people: the very wealthy who live on a space station called Elysium and the rest who live on a ruined Earth fighting poverty and disease. Although the film sounds like the crazed dream of Virgin Galactic boss Richard Branson, its promoters say it does feature some parallels with the real world. One example they quote is the blossoming industrial space sector depicted where private firms transport people from Earth to the space station and back. Elysium is also based on a "Stanford torus" – a donut-shaped space station that was proposed by researchers from Stanford University in 1975. Who'd have thought?

The physics of custody

Divorce is a complex matter, even more so when children are involved. Many custody arrangements instruct each parent to have the kids every other weekend, but what happens when divorced parents already have children with two or more ex-partners? Is it still possible to arrange one's affairs so that every couple has either all the kids together on one weekend or no kids at all? Well, that problem has now been tackled by Andrés Gomberoff from the Universidad Andrés Bello in Santiago, Chile, and colleagues who have modelled all the possible permutations using graph theory (arXiv:1305.0935). They conclude that no, such custody arrangements are not possible, saying that the problem turns out to be equivalent to finding the ground state of a spin-glass system. Gomberoff's team is now extending its calculations to include other real-life issues such as a parent who must work every other weekend. "We think that these problems are an important source of stress in modern life," the authors write.



A musical reunion

Some 20 years after hanging up their drumsticks and guitars, the band formally known as the Spontaneous Emissions returned in May to perform a set of classic rock and roll at the University of Sheffield's annual physics Hicks ball. The band was formed in 1991 at Sheffield by four then-PhD students: Nigel Clarke (drums), John Cockburn (bass guitar and vocals), Lee Elliot Major (rhythm guitar and harmonica) and Chris Hawkins (lead guitar and vocals). Clarke is now head of physics at Sheffield, Cockburn is a physics lecturer in the department, while Major is director of development and policy at the Sutton Trust and Hawkins works at the science consultancy firm Tessella. To the delight of students at the ball, the quartet played a 40-minute set after dinner with hits ranging from "Twist and shout" to "Brown eyed girl". There is even talk of more band performances to come, as well as a possible UK university tour. Yet one band members has some misgivings. "Since my most vivid memory of touring is attempting to call the breakdown services at 2 a.m. after our van ran out fuel following a gig in Hull, I'm in no great hurry to repeat the experience!" Clarke told *Physics World*.

Frontiers

In brief

Ultracold quantum-magnetism simulation

Quantum magnetism has been mimicked – or simulated – using ultracold fermionic atoms for the first time. Researchers in Switzerland and France placed potassium-40 atoms on a 2D square lattice created by criss-crossing laser beams. By controlling the interactions between atoms, the team put pairs of atoms into antiferromagnetic configurations, with spins pointing in opposite directions. Quantum magnetism plays an important role in a range of solid-state phenomena, but it can be difficult to calculate its effect on materials such as high-temperature superconductors. Such quantum simulations should therefore lead to better theoretical models of a range of solids and the team is already collaborating with theorists on this effort (*Science* 10.1126/science.1236362).

Rethinking the wake pattern for ships

Physicists in France have studied the V-shaped wakes created by boats as they move through water, and claim that Lord Kelvin might have been wrong to say that the wakes fan out at a constant angle of 19.47°, no matter the speed of the vessel. Wakes are produced by interference between water waves created by a boat, but it has long been unknown why fast-moving boats produced smaller-angle or narrower wakes. By analysing images from Google Earth, using measurements of boats' hull lengths and wake angles, and calculating their velocities, the researchers have built a new mathematical model. They found that at higher speeds, boats cannot produce waves longer than its hull; so the wake angle then depends only on the speed of the boat, narrowing as it moves faster (*Phys. Rev. Lett.* **110** 214503).

Pulsars map the way for space missions

A method for navigating spacecraft autonomously using pulsars has been developed by a group of researchers in Germany. Although the idea of using pulsars for stellar navigation was first proposed in the 1970s, the team has, for the first time, discussed the type of pulsars best suited for such navigation and has determined what sort of detector would be used. The new work determined that only "rotation-powered" pulsars are suitable for navigation and that choosing the detector would depend on mission specifications, such as size, orbit and power consumption. A large craft would be more suited to a radio array; while compact X-ray detectors would work better with current missions, where there are space and weight restrictions (arXiv:1305.4842).

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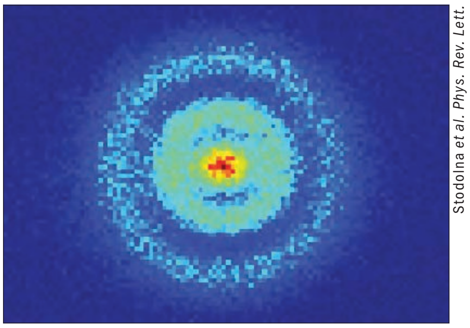
Quantum peek into hydrogen atom


Stodolna *et al. Phys. Rev. Lett.*

Eye of the atom Experimental observation of the nodal structure of a hydrogen atom.

The first direct observation of the orbital structure of an excited hydrogen atom has been made by an international team of researchers. The observation was made using a newly developed "quantum microscope", which uses photoionization microscopy to visualize the structure directly. The team's demonstration proves that this type of microscopy, which was first proposed more than 30 years ago, can be experimentally realized and can serve as a tool to explore the subtleties of quantum mechanics.

The wavefunction contains the maximum knowledge that is available about the state of a quantum system, with its square describing the probability of where exactly a particle might be located at a given time. Although it features prominently in quantum theory, directly measuring or visualizing the wavefunction is no easy task, as any direct observation destroys the wavefunction before it can be fully seen.

In the new work, Aneta Stodolna of the FOM Institute AMOLF in the Netherlands, along with Marc Vrakking at the Max Born Institute in Berlin, and other colleagues in Europe and the US directly obtained the "nodal structure" of the electronic orbital of a hydrogen atom by placing the atom in an electric field and exciting it with laser pulses to a Rydberg state. The ionized electron escapes from the atom and follows a particular trajectory to the detector. Given that there are many such trajectories that reach the same point on the detector, interference patterns are produced, which the researchers magnified by a factor of more than 20 000 using an electrostatic zoom lens. The pattern directly reflects the nodal structure of the wavefunction (a "node" being where there is a zero probability of finding an atom).

As the recorded patterns are on the millimetre scale, they can be observed with the naked eye on the 2D detector and recorded with a camera system. "What you see on the detector is what exists in the atom," says Vrakking. The group observed several hundreds of thousands of ionization events to obtain the results, with the same preparation of the wavefunction for each.

Having visualized the hydrogen atom, the team is now analysing the helium atom using the same method (*Phys. Rev. Lett.* **110** 213001).

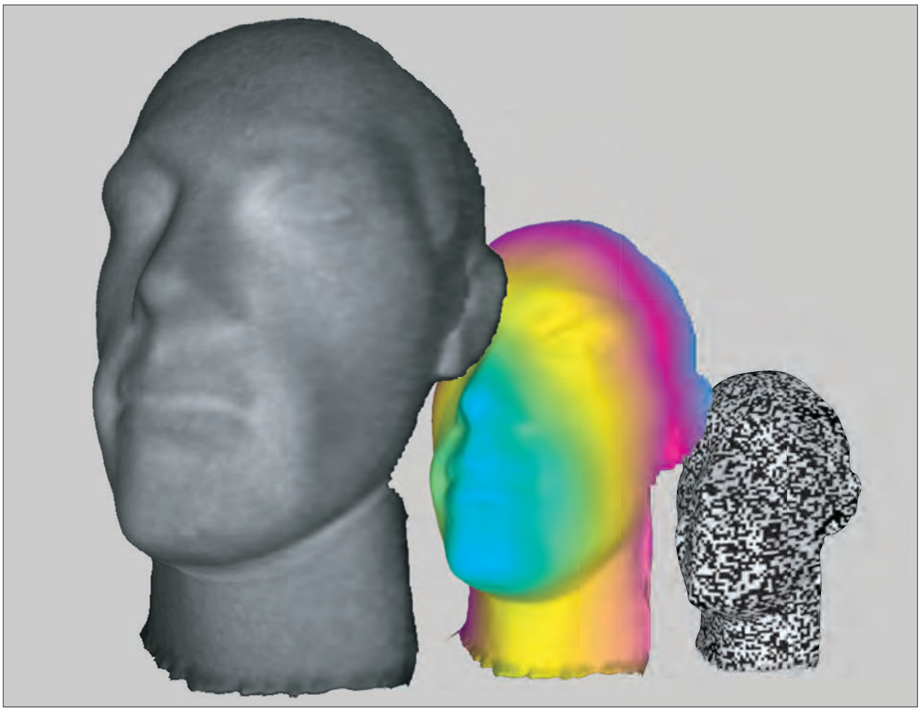
Dark matter doubles up

A new type of dark matter that could strongly interact with regular matter to form large discs that would overlap galaxies has been postulated by a group of researchers in the US. Dubbed "double-disc dark matter" (DDDM), it has been proposed by a team led by Lisa Randall at Harvard University. If the matter exists, it would suggest that leading candidates for dark matter – weakly interacting massive particles (WIMPs) and axions, which rarely collide with one another – do not tell the whole story.

By considering the characteristics of the dark matter surrounding our own Milky Way galaxy, the researchers calculate that as much as 5% of this invisible stuff might not be weakly interacting. They also say that DDDM would probably dissipate energy while retaining angular momentum from its motion about the galactic centre, causing it to form a thin disc just as ordinary galactic matter does. They work out that the dark and visible discs would have about the same mass, meaning that the densities of DDDM and normal matter in the universe would be roughly equal.

According to the team, DDDM discs would contain the dark-matter equivalent of protons and electrons interacting via an analogue of electromagnetism, so creating "dark atoms". Group member Matthew Reece explains that evidence for the dark disc's existence could come from the gravitational effect it has on the motion of the billion Milky Way stars, which the European Space Agency's upcoming Gaia mission will study. Annihilating DDDM particles would, given enough sensitivity, also produce "strikingly different" signals from those of the ordinary dark matter that existing space-based detectors PAMELA, Fermi and AMS-02 are looking out for. Direct detection, however, would be more difficult (*Phys. Rev. Lett.* **110** 211302).

Sun *et al.*, University of Glasgow/*Science*



'Ghostly' 3D images taken without a camera

Imaging systems could be heading in a more simplified direction, now that a 3D system that does not require a conventional camera has been developed by researchers in the UK. Baoqing Sun, Miles Padgett and others from the University of Glasgow, along with colleagues at the University of Cambridge, created a simple 3D imaging system using nothing more than a basic light projector, four single-pixel detectors and a computational imaging technique known as "ghost imaging" that creates images using "intelligent illumination". The team used the projector to illuminate a polystyrene model of a human head with computer-generated random binary speckle patterns. The light reflected from the head was collected by the detectors, which are placed at varying angles. Thanks to the random binary speckle patterns – which illuminate the object with a "chequered" pattern – and the varying angles of the detectors, the team was able to see a clear shading profile in the images. The image above shows different versions of the reconstructed head – the left head is a 3D view of the greyscale image from the detectors, the middle image is the final reconstructed 3D head, while the right head shows the binary speckle patterns used by the group (*Science* 10.1126/science.1234454).

Galaxy's black-hole hub

Astrophysicists in the US think that an immense cloud of gas currently swooping around the centre of our galaxy could reveal a multitude of small black holes nestled there. The G2 gas cloud will pass through the galactic centre over the next 12 months, where it will encounter the small black holes and produce bursts of detectable X-ray radiation (*Phys. Rev. Lett.* **110** 221102).

Since the 1970s astronomers have postulated that a hub of small black holes lurks incognito near Sagittarius A* – the supermassive black hole at the centre of the Milky Way. Based on star formation and death rates, simulations predict as many as 20 000 small black holes in the innermost region of the galaxy, each with a mass several times that of our Sun. With the G2 cloud set to make its closest approach to Sagittarius A* in early 2014, its impact on the small black holes could be seen by NASA's NuSTAR and Chandra telescopes.

Imre Bartos of Columbia University in New York, and colleagues, carried out simulations depicting the number and distribution of stellar black holes, together with the predicted trajectory of the gas cloud, and calculated that G2 should encounter around 16 such objects on its journey. The team looked at how much radiation these encounters should produce, and the chances of existing instrumentation being able to spot their faint signals from 25 000 light-years away.

Bartos stresses that uncertainties linked to limited information about the cloud's density and speed can cause the radiation value to change by a factor of 100. More promising, perhaps, is the prospect of finding evidence for so-called intermediate-mass black holes – their encounters with G2 would produce significantly more and brighter radiation than their smaller counterparts.

Innovation

Hello to acoustically invisible walls

A rigid wall can be transformed from a total reflector of sound to an almost perfect transmitter by perforating it with tiny, regularly spaced holes covered by a thin elastic membrane, say researchers in Japan and Korea. The discovery is an acoustic analogue to the phenomenon of extraordinary optical transmission (EOT), which allows electromagnetic waves to pass almost unhindered through a lattice of sub-wavelength holes in a barrier that would otherwise be opaque in some metamaterials.

It has been known for a while that if the holes contain a material with a refractive index close to zero, the wavelength of light in the holes becomes extremely long, and thus its velocity becomes extremely large. The faster a wave travels, the more energy it carries, allowing the energy of the entire wavefront to squeeze through the tiny holes. Such media are called epsilon-near-zero (ENZ) materials because refractive index depends on permittivity – a kind of electrical inertia that represents the resistance encountered when forming an electric field in a medium. An ENZ material offers almost no resistance to such displacement.

Now, Sam Lee of Yonsei University in Seoul, Oliver Wright of Hokkaido University and colleagues have produced an analogue of the ENZ metamaterial for sound waves. They achieved this by covering the holes with a thin membrane of ordinary cling film. With the tension tuned so that the membrane's resonant frequency is the same as the frequency of the incident waves, the membrane's resonance amplifies its oscillations. The resonance moves the air through the holes as though the air has no inertia, allowing it to move in response to even a small displacement, transporting all the energy of the waves through the barrier.

On the other side of the barrier, Huygens' principle dictates that each hole produces spherical wavefronts. The separation between the holes is much less than the wavelength of the sound, meaning the interference pattern reconstructs the plane wave in much less than one wavelength, so the barrier is effectively invisible to the propagating waves.

The researchers tested their metamaterial design by placing an acrylic barrier perforated with four small holes in a tube. They found that with the barrier perforated by bare holes, only 9% of the waves' energy was transmitted. With a membrane placed over the holes, this proportion jumped to 81% (*Phys. Rev. Lett.* **110** 244302).

News & Analysis

J-PARC hit by radiation leak

Japan's massive J-PARC physics facility has been shut down after 34 workers were exposed to increased levels of radiation. **Michael Banks** reports on the fallout from the incident


J-PARC

Out of action Lying on the north-east coast of Japan, the $1.5bn Japan Proton Accelerator Research Complex generates and studies a range of particles such as neutrons, neutrinos, kaons and muons.

Experiments at the $1.5bn Japan Proton Accelerator Research Complex (J-PARC) have been cancelled until further notice following a leak at the facility that exposed workers to small amounts of radiation. It is expected that J-PARC will not be fully online until early next year once a full investigation has been carried out. In an English statement on its website, Japan's Nuclear Regulation Authority (NRA) says that "radiation control was not appropriately managed" and that the incident showed a lack of a proper safety culture at the lab.

Writing to J-PARC users, the facility's director Yujiro Ikeda has apologised for the incident and the failure to prevent some users and workers from being exposed to higher-than-normal levels of radiation. He says that a full investigation into the cause of the accident is now taking place together with a complete review of safety practices and emergency procedures. "Our first priority is to restore public trust in the facility by developing and implementing measures to prevent the reoccurrence of an accident and to provide a safe experimental environment for users and workers," he writes. Naohito Saito, deputy director of J-PARC, told *Physics World* that rebuilding trust within the local community "would take some time".

Elevated levels

Lying on the north-east coast of Japan, 120 km from Tokyo, J-PARC is located in Tokai and is jointly operated by the Japan Atomic Energy Agency (JAEA) and the KEK particle-physics lab in Tsukuba. The facility boasts three massive machines – a 200 MeV linear accelerator, a 3 GeV proton synchrotron and a 50 GeV proton synchrotron. These are used to generate a range of particles such as neutrons, neutrinos, kaons and muons by accelerating protons and smashing them into various targets.

J-PARC also has three big scientific labs designed to exploit such particles. One is the Materials and Life Science Experimental Facility, which uses the 3 GeV proton beam to generate neutrons and muons for a range of experiments in materials science and biology. The Hadron Experimental Facility produces kaons and antiprotons, while the Tokai to Kamioka (T2K) neutrino experiment fires these almost massless ghostly particles some 300 km through the Earth to the Super-Kamiokande detector located 1 km underground in the Mozumi mine in the city of Hida.

The radiation leak occurred on 23 May at the Hadron Experimental Facility. According to an accident statement released on J-PARC's website, at 11.55 a.m. a malfunction occurred as the proton beam was being delivered from the 50 GeV synchrotron to a gold target that produces the subatomic particles. Under normal conditions around 3×10^{13} protons are slowly extracted to the target over a period of 2 s, but the malfunction instead delivered 2×10^{13} protons in under 5 ms – some 400 times the intensity of normal operation. This damaged the $6 \times 6 \times 66$ mm gold rod target, causing radioactive material to be discharged into the target area and beamline as well as to leak into the experimental hall, which contains four experimental stations that were at the time occupied by users.

Upon detecting an anomalous reading, the "machine protection system", which controls the delivery of the beam to the Hadron Experimental Facility, did stop the beam. However, after almost 10 minutes of checks and test shots to the target, engineers reset the beam, thinking nothing was wrong. Yet gamma-ray monitors located in the Hadron Experimental Hall measured an increase in radiation levels of around 4 μSv/hr – some 10 times higher than normal.

Engineers then began to test if the detectors were picking up radiation from inside or outside the hall and decided to turn on the ventilation fans mounted on the building's walls. As this was found to reduce the level of radiation picked up by the gamma-ray monitors, the beam was turned back on, the thinking being that the elevated levels of radiation originated from outside. However, when the dose rate increased again 45 minutes later, J-PARC engineers stopped the beam once more.

As the radiation rate was still much lower than the 25 μSv/hr maximum dose as stipulated by government regulations, it was assumed there would be no danger to the environ-

The bumpy road for a world-class facility

June 2002 Delegates attend the groundbreaking ceremony for the $1.5bn Japan Proton Accelerator Research Complex

June 2008 First neutrons are produced at J-PARC's Materials and Life Science Experimental Facility

July 2009 Official inauguration of J-PARC in Tokyo is attended by more than 1000 scientists from all over the world

March 2010 First neutrinos sent from J-PARC are detected at the SuperKamiokande detector located 1 km underground in the Mozumi mine in the city of Hida

March 2011 J-PARC is shut down for nine months following a 9.0 magnitude earthquake that struck Tohoku, Japan, with roads and buildings at the facility badly hit

23 May 2013 Leak hits the lab, exposing 34 workers to elevated levels of radiation, triggering a temporary closure ment and so engineers turned the ventilation fans back on to further reduce the radiation rate in the hall. It was not until 5.30 p.m. that all workers were evacuated. Although around 100 individuals were in the controlled area of the Hadron Experimental Facility during this incident, only 34 were exposed to the higher radiation dose. Their total exposure was under 1.7 mSv – equivalent to a computerized tomography scan of the head but still not exceeding that maximum dose as stipulated by law for nuclear industry workers.

The following day – 24 May – the JAEA's Nuclear Fuel Cycle Engineering Laboratories contacted J-PARC to say that three of their nearby monitoring posts had picked up a slight increase of radiation – occurring at the same time as J-PARC began to ventilate the experimental hall – although the levels were still within normal range. It was not until around 10 p.m. on 24 May that J-PARC bosses reported the accident to the NRA and the Atomic Energy Regulatory Committee – a legal requirement.

Minimizing delay

It is unknown when the facility will come back online, but all experiments at J-PARC have been cancelled until the end of July. According to Saito, J-PARC bosses are not in a position to restart the experiments and their first priority is to investigate the causes of the accident to develop more robust systems to prevent other "major failures". Indeed, Saito says that J-PARC is planning to have a long shutdown later this year to upgrade the linac, which would have run until January. He hopes that this could minimize the delays to the facility.

Hopefully the shutdown won't be for too long and the impact not too severe

Also affected by the shutdown is T2K, which will not receive a beam of neutrinos from J-PARC as long as the accelerator is offline. Dave Wark, a high-energy physicist at Imperial College London and former international co-spokesperson of the T2K experiment, says that the impact may not be so bad, given that the facility was supposed to be shut down for an upgrade from the end of July until early February 2014. "We already have data for the summer conferences, so we will have interesting physics results for this year. Hopefully the shutdown won't be for too long and the impact not too severe."

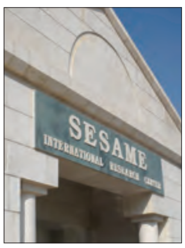
Middle East

Europe backs SESAME with magnets and cash

A synchrotron radiation facility being built in Jordan to stimulate regional co-operation in the Middle East is to receive fresh European funding. The $100m-plus Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) is to get €5m from the European Commission to build magnets at the CERN laboratory in Geneva, with CERN providing much of the necessary manpower and expertise. The Italian government, meanwhile, has said it will also provide €1m for the project, subject to approval of its 2013 budget by a parliamentary commission.

SESAME will be a third-generation synchrotron source producing intense X-ray beams for use by scientists in fields from condensed-matter physics and chemistry to biology and archeology. It is being built near the Jordanian capital of Amman by a nine-member collaboration – comprising Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey – and will be the first synchrotron source in the region (see February 2012 pp12–13).

Some $50m – supplied by host Jordan and others – has already been invested in the project. This includes the land and building that will house the facility, which was completed in 2008, as well as a source and booster accelerator recycled from the now decommissioned BESSY-1 synchrotron in Berlin. However, another $35m is needed to construct the facility's 40 m-diameter main storage ring, which will use the CERN magnets to hold electrons at 2.5 GeV, and to attach four beamlines. With Iran, Israel, Jordan and Turkey each having pledged $5m last year, the latest European funding still leaves a hole of around $8m. SESAME member states will also have to find $10m to cover running costs that they have already agreed to pay.



Michael Banks

Plugging the gap The European Commission is to provide €5m towards the construction of the SESAME synchrotron in Jordan.

The president of SESAME's council, Christopher Llewellyn Smith from the University of Oxford, told *Physics World* he is "optimistic" that the remaining funds can be found or, if necessary, partly deferred – meaning that the machine could start up by the end of 2015, with experiments kicking off the following year. He hopes that the US can help to plug the gap and perhaps also contribute some of the extra $25m needed to increase the beam's intensity and add a further three beamlines once the machine is online. "There is a lot of support and goodwill towards SESAME in the US," he says, although he cautions that "budgets are being cut and a US contribution is by no means assured".

Although Llewellyn Smith says SESAME "will not be the world's best synchrotron", since it will neither produce the highest energies nor the greatest intensities, he believes it will "certainly be competitive", adding that "if you have the right idea you could use it to win a Nobel prize". He also thinks that the machine's scientific credentials will determine its political impact. "If it is a first class scientific instrument then scientists will want to go there," he says.

SESAME's scientific director Hafeez Hoorani admits that the quality of the facility's experiments could prove a stumbling block, pointing out that one of the experimental stations to be used was first built for another synchrotron nearly 30 years ago. He also believes it will prove tough attracting scientists from the region's "major players" – Israel, Turkey and Egypt – given their access to established synchrotron sources in Europe and elsewhere. But he notes that the project has had positive effects even before switching on. "Scientists from Iran are speaking with scientists from Israel," he says. "This is already an achievement."

Edwin Cartlidge

Russia

New Russian academy chief targets reforms

Physicist Vladimir Fortov has been named as the new president of the Russian Academy of Sciences (RAS) – one of the world's largest research organizations. Fortov won 58% of the votes of RAS academicians, beating off two RAS vice-presidents: economist Alexandr Nekipelov and the 2000 Nobel-prize-winning physicist Zhores Alferov. Fortov plans to reform the 289-year-old body, which runs more than 400 institutes and employs nearly 100 000 scientists.

Fortov is director of the RAS Joint Institute for High Temperatures in Moscow working in areas such as shock waves and detonation, plasma physics, and physical mechanics. In 1993, during the turbulent period following the dissolution of the Soviet Union, Fortov was put in charge of the Russian Foundation for Basic Research, a new government-backed funding organization outside the RAS. The foundation grew rapidly under Fortov's leadership, adopting western methods of peer review and competitive funding, despite strong opposition from the RAS.

In 1996 Fortov was made science minister and deputy prime minister at a time when government relations with the RAS were at a low ebb, but he managed to keep the peace during his two years in the job. "The conflict between the ministry and the academy was a real vendetta, a battle of annihilation," Fortov said during the recent election campaign, adding that he wanted to normalize relations if elected president.


MIPT

Changes ahead Physicist Vladimir Fortov is looking to make reforms to how the 289-year-old Russian Academy of Sciences operates.

Fortov takes over as RAS boss from mathematician Yuri Osipov, who has been in charge since 1991 and is widely credited with protecting the former Soviet Academy during the collapse of communism so that it emerged, largely unscathed, as the Russian Academy. But with government funding a fraction of what it was in the Soviet era, researchers have been left with meagre salaries and little money to carry out experiments. Few young people are becoming researchers and the average age of RAS scientists is increasing rapidly.

These problems have diminished the RAS's stature in recent years. Relations between the ministry and academy have also soured since Dmitry Livanov was appointed Russian science minister last year. He said he wants to transfer research activity from RAS institutes to universities and to create a "scientific council" to oversee all basic research.

Aleksei Zheltikov, a physicist at the RAS Photochemistry Centre in Moscow thinks that having a fair funding system in place to support research in RAS institutes is important. However, for him one of the most urgent issues to be addressed is the "lack of an adequate system of regular salaries for scientists". Yet hopes are high that Fortov can turn things around. "He has an indisputable academic record in plasma physics and is a very good organizer of science," says polymer physicist Alexei Khokhlov, vice-rector of Moscow State University.

Daniel Clery

Japan

Monju reactor back on hold over safety concerns

The restart of Japan's Monju experimental fast-breeder reactor has been postponed due to safety concerns. On 30 May Japan's Nuclear Regulation Authority (NRA) slapped the plant's operator – the Japan Atomic Energy Agency (JAEA) – with an order barring any work towards restarting Monju until safety procedures are overhauled. As *Physics World* went to press it was unclear when the plant would reopen.

Located in Tsuruga, Fukui Prefecture, Monju is intended to be a key piece of Japan's nuclear-fuel-cycle strategy. The reactor, which went critical in April 1994, is designed to burn a mixed uranium–plutonium-oxide fuel and produce more fissile material than it consumes. But Monju has been offline for most of its life. A year after starting up, plant operators tried to conceal the extent of a massive leak of sodium coolant and the fire that followed. Public and political outrage over the cover-up – together with technical glitches – delayed a restart until May 2010. Three months later a 3.3 tonne piece of the fuel-handling system fell into the reactor vessel during refuelling and remained stuck there until June 2011.

Uncertain future Japan's Nuclear Regulation Authority has blocked plans to restart the troubled Monju fast-breeder nuclear reactor in March 2014.

In the wake of the March 2011 disaster at the Fukushima Daiichi nuclear power plant, the Japanese government put the Monju project on hold, pending a review of the nation's energy policy. That decision was reversed when the current administration came to power last December and the JAEA was aiming to restart Monju by March 2014.

However, the NRA has now uncovered that there have been inadequate inspections of more than 10 000 key components at Monju, including safety-critical equipment. The NRA has therefore blocked any work towards a restart, with NRA chairperson Shunichi Tanaka telling the Japanese press that the JAEA lacks a suitable "safety culture". A JAEA spokesperson says that the agency is now reviewing the NRA order and that a target date for restarting Monju cannot be set until the investigation is complete. Shojiro Matsuura, who took over the JAEA presidency on 3 June, visited Monju three days later and according to the local newspaper *Fukui Shimbun* urged staff "to reconsider the meaning of a culture of safety and work to enhance it".

Dennis Normile
Tokyo

US research

Livermore slashes 10% of workforce

The Lawrence Livermore National Laboratory (LLNL) in the US has begun laying off around 10% of its 6500-strong workforce in preparation for "challenges" in the lab's 2014 budget, which will start on 1 October. The lab's redundancy offer gives workers one week of base salary for each year of continuous service, up to a maximum of 26 weeks. As *Physics World* went to press, 399 individuals had accepted the lay-off's terms.

The Obama administration's budget request for 2014 includes about $1.48bn for the LLNL – a sum that lab director Parney Albright told a Senate subcommittee last month "will significantly limit our ability to utilize the National Ignition Facility and undermine [our nuclear] stewardship programme". However, even this figure is uncertain, given the political disputes between the Democratic administration and the Republicans who have a majority in the House of Representatives and a blocking minority in the Senate.

Albright adds that there are still a number of "unknowns" in the 2014 budget request. "It is clear the budget proposal will face an uphill battle in Congress this summer," he says. "It is our hope that implementing the [redundancy programme] now, rather than waiting for additional details on the 2014 budget, will put the laboratory in a better position to address whatever budget realities we'll face." According to lab spokesperson Lynda Seaver, "the voluntary redundancy is available to all employees, though some could be denied due to critical skills".

LLNL/Jacqueline McBride

Cutting costs The Lawrence Livermore National Laboratory is offering voluntary redundancies to prepare for budget cuts in 2014.

The lay-offs at LLNL follow more than 550 permanent employees having accepted severance packages last year from the Los Alamos National Laboratory when it faced a reduced budget and little prospect of increases. LLNL itself offered voluntary redundancies in 2008 but, according to Seaver, did not get "the numbers we had hoped for". The lab then resorted to compulsory redundancies, which some employees challenged in the courts. Indeed, in late May five lab staff were awarded more than $2.7m when a local jury found that the LLNL had violated a contractual promise that it would lay the workers off only for a "reasonable cause". The LLNL will reconsider its response to the impending financial situation – which could still include forced redundancies – as soon as it knows its final budget for 2014.

Meanwhile, further budget woes are threatening the Massachusetts Institute of Technology's Alcator C-Mod fusion project, which faces closure within a year as the US government moves fusion funds from home-grown projects to international collaborations such as ITER. The administration's proposed 2014 budget includes no funding for C-Mod and its shutdown would lead to 70 staff losing their jobs and leave only two fusion experiments in the US. The Massachusetts Congressional delegation has called for restoration of funds for the programme, which produces more PhDs in fusion and plasma physics than any other US institution.

Peter Gwynne
Boston, MA

Industry

D-Wave sells second quantum computer – this time to NASA

Canadian firm D-Wave Systems has announced it will install one of its quantum computers at the Quantum Artificial Intelligence Lab, which opened in May at NASA's Ames Research Center in California. The new 512-qubit system, called "D-Wave Two", will be used by NASA, Google and the Universities Space Research Association (USRA), which jointly run the lab. This is only the second system that the company has supplied to a customer, with its first – a 128-qubit system – having been bought in May 2011 by the US-based defence and security contractor Lockheed Martin in a deal believed to be worth more than $10m.

According to Vancouver-based D-Wave, the computer will be available for use in October and will be accessible to researchers via the USRA. The firm says that the system will be used "to develop applications for a broad range of complex problems such as machine learning, Web search, speech recognition, planning and scheduling, search for exoplanets, and support operations in mission control centres".

Hartmut Neven, director of engineering at Google, says that the firm is involved in the project "to study how quantum computing might advance machine learning". NASA, meanwhile, says that it is interested in using quantum computers to "solve difficult optimization problems in aeronautics, earth and space sciences, and space exploration".

D-Wave Two uses a process called "quantum annealing", which is a technique for finding the global minimum of a function. When solving such problems, conventional computers often get stuck in a local minimum that has a greater value than the global minimum. Quantum annealing uses quantum tunnelling to cross barriers between local minima to find the absolute minimum in a much more efficient way than conventional methods.

D-Wave Systems

Cashing in NASA, Google and the Universities Space Research Association will use one of D-Wave's quantum computers to solve a broad range of "complex problems".

This approach also differs from conventional quantum computers – which are kept in a fragile quantum state throughout the calculation – in that it involves making a transition from a quantum to classical system. As a result, D-Wave's approach may be more robust to environmental noise than conventional approaches.

D-Wave says that Google, NASA and the USRA subjected its 512-qubit system to a series of benchmark and acceptance tests before installation. "In all cases, the D-Wave Two system met or exceeded the required performance specifications, in some cases by a large margin," claims the company.

Hamish Johnston

Energy

Europe's carbon-capture plans branded a 'farce'

Ambitious plans by Europe to develop carbon capture and storage (CCS) have lost momentum and degenerated into a "farce", according to a new report from the CCS advocacy group ENGO Network. With the development of CCS in Europe now lagging behind other global regions, the report – *Moving CCS Forward in Europe* – says CCS is not getting the same level of political, industrial and non-governmental support as renewable energy, such as wind and solar power.

CCS involves capturing the carbon dioxide (CO_2) emitted from the burning of fossil fuels and then transporting it to secure geological storage sites underground. Currently there are no commercial-scale CCS projects under construction, even though in 2007 the European Council agreed to have up to 12 CCS commercial-scale "demonstration projects" in operation by 2015. "What should have been an international success story for Europe has turned into a farce," the report adds.

Chris Littlecott, senior author of the report and a policy adviser at the independent not-for-profit organization E3G, told *Physics World* that EU efforts to advance CCS "are too slow, lack strategic vision and are failing to attract investment". Littlecott adds that if Europe is truly serious about fighting climate change, then CCS policies urgently need to be refreshed. "But that requires a broader vision and creative thinking to accelerate action. More of the same foot dragging won't be enough," he says.

Statoil

Scaling back Although the European Council planned to have as many as 12 commercial-scale carbon capture and storage "demonstration projects" in operation by 2015, none has yet been built.

The report suggests two main "policy options" to accelerate the development of CCS technology in Europe. One is a legally binding EU requirement for member states to capture an agreed percentage of their total CO_2 emissions by 2030 and the other is a "complementary blend of CCS market incentive schemes" to encourage investment in CCS projects, such as feed-in tariffs, grant schemes, loan guarantees and capacity auctions.

Antony Benham, a senior geologist and business development manager at the Nottingham Centre for Carbon Capture and Storage, agrees with the arguments outlined in the report, particularly "the need for concerted action from the EU and other governments to assist in the deployment of CCS at a commercial scale". Noting that CCS can cut CO_2 emissions by up to 90%, he says it is a "vital and necessary bridging technology" until sufficient electricity can be produced from non-fossil-fuel sources. "At present, the costs of CCS, principally those associated with extracting and concentrating the CO_2 from its source, are relatively high," he says. "However, as more CCS plants come online, the cheaper the technology will become in the future."

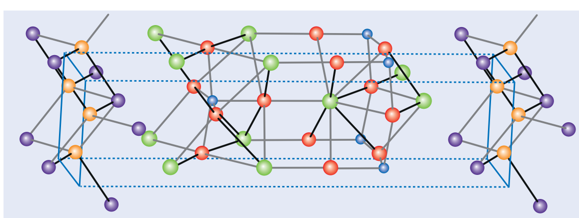
Ned Stafford
Hamburg

Publishing

Iron-selenide superconductivity is top topic

Research into a new breed of superconductors that were only discovered in 2009 is the leading field in physics, according to analysis from the information provider Thomson Reuters. Work on iron-selenide superconductors comes out top in the *Research Fronts 2013* survey, garnering a total of 49 "core" publications – papers that are frequently cited together – with the field as a whole having around 2000 citations in total. Work on spin-orbit coupled Bose–Einstein condensates is second with 48 core papers and 1752 citations, while direct detection of dark matter is third with 48 core papers and 3285 citations – edged out as its core papers have an older average age.

The report, co-authored by David Pendlebury and Christopher King, examines citation patterns – including the size and average age of the core literature as well as the number of citing papers and citations – to search for areas of research that are achieving "particular mass and momentum". Pendlebury admits that citation analysis is by definition a retrospective view, but says that "by focusing on the research fronts with the youngest core literatures, we were trying to bring things as near to real time as possible".



EPL

Big attraction An analysis of citation data has revealed that work on iron-selenide superconductors is a leading field in physics.

In astronomy and astrophysics the top research front is work on the expansion of the universe – Galilean cosmology – with 34 core papers and 1584 citations, followed in second place by papers on the redshift of galaxies in the Hubble Ultra Deep Field, with 31 core papers and 2415 citations. Work on sterile neutrinos at the electronvolt scale comes third with 41 core papers and 2472 citations, again losing out on the top spot as a result of the older average age of the core papers.

Another report published last month by Thomson Reuters – *The Hottest Scientific Researchers and Research* – picks out the top papers in 2012 by the number of citations received over a short time, with research into the Higgs boson occupying the top two spots. Top of the list was a paper by the ATLAS collaboration, which bagged 202 citations by the end of 2012 (*Phys. Lett. B* 710 49). In second place was a paper on the combined search for the Higgs that had garnered 195 citations by then (*Phys. Lett. B* 710 26). In total, 11 papers, accounting for more than a fifth of the 51 featured papers in the report, related to work on the Higgs.

Andrew Williams

Europe

Croatian scientists look to EU boost

After 10 years of negotiation and debate, Croatia this month becomes the 28th member of the EU. Only the second former-Yugoslav state to join the bloc after Slovenia, many hope that Croatia's entry to the EU – and the estimated €11.5bn of funding available to the country between now and 2020 – will help to boost Croatian science and let its researchers collaborate better with the rest of their EU colleagues.

Croatia currently has around 6000 full-time scientists and many have already won cash from the EU's Seventh Framework Programme (FP7), which Croatia joined as an "associated country" in 2006. There have so far been 232 successful applications for FP7 funding, which corresponds to a success rate of 17.2% – slightly below the EU average of 21.7%. However, the science ministry points out the €59m that Croatia's scientists received through the seven-year programme is almost 40% more than Croatia has contributed to it. There is also a new plan in place to raise Croatia's capacity to win more funding from Horizon 2020, the successor to FP7, which will have almost twice as much cash up for grabs.

But not everything is rosy for Croatia's scientists, with the country spending only 0.75% of its GDP on science compared with the EU average of 2%. Another problem is that the success rate for domestic grant applications in Croatia is 85% – a figure many say is far too high to be meritocratic or promote excellence.

One issue at stake is that many research groups are too small. According to Croatia's science ministry, some 2000 government-funded research projects are worth a total of just €6500 a year and each involves, on average, only two scientists and one PhD or postdoc researcher.

"The problem is that only a relatively small percentage of our scientific groups are competitive on a world stage," says Stipan Jonjić, a medical researcher from the University of Rijeka, the first scientist from Croatia to be awarded a European Research Council grant. "This puts us into an inferior place when applying for EU and other scientific funds."

Vlatko Silobrčić, a member of the Croatian Academy of Sciences and Arts, says one problem is that government agencies lack expertise to support scientists' applications to EU funds. "There are more and more announcements about workshops that are supposed to prepare participants [for applying to EU funds]," he says. "I am not sure that all of those workshops are run by people with real qualifications."

Joining the club Croatian scientists will be hoping to tap into more funding after the country joins the EU on 1 July. Shutterstock/bunyos30

Srete Nikolovski, an electrical engineer from the University of Osijek, agrees that there is a problem of government support for researchers. His team was the first in Croatia to be awarded a EUREKA Information Technology for European Advancement (ITEA) grant, and he claims that bad or inconsistent administration "destroyed" his projects, with the government cutting or cancelling its co-funding commitment. This meant he had to abandon some projects that had already been approved by the ITEA board.

"Our administration and bureaucracy are not capable of backing up scientists in applications," he says. Government agencies for EU projects are filled with economists who know little about specific science issues, says Nikolovski, for whom the experience of working with the agencies responsible for co-financing EU funds was "negative and frustrating".

Despite scientists in Nikolovski's field of information technology and renewable energy "showing they are capable of getting and conducting EU projects", he plans to avoid applying for any EU funds administered by Croatian agencies.

Another issue is that a 2008 ministry decision to co-fund successful FP7 projects and reward scientific excellence for those projects that receive over €100 000 was shelved in the wake of the 2009 economic crisis, though the ministry now says it will co-fund future projects to 15% of their value.

Mićo Tatalović

Sidebands

Brazil builds new synchrotron

Construction has begun on a new synchrotron in Brazil that will be the first high-intensity X-ray source in Latin America. Called Sirius, the $330m synchrotron is a third-generation light source that will generate intense beams of X-rays for experiments in fields such as condensed-matter physics and biology. Sirius, which will have a circumference of 518 m, will contain 13 beamlines and is expected to be open for users in 2017. The 3 GeV synchrotron will be located at the Brazilian Synchrotron Light Laboratory (LNLS) in São Paulo, which has been operating a smaller 93 m-circumference X-ray source since 1997, providing 16 beamlines for around 1500 users each year.

Cambridge plans Maxwell Centre

A new £63m centre that will bring basic research in physics together with industry is to be built at the University of Cambridge. Called the Maxwell Centre, it is designed to house around 230 people and will contain lab space, seminar rooms and "interactive spaces" when open in 2015. Funding for the project will come from the Higher Education Funding Council for England as well as from the Winton Programme for the Physics of Sustainability and firms such as Hitachi, Toshiba and Tata Steel. Scientists from academia and industry will work at the centre in areas such as scientific computing, advanced materials and the physics of biology and medicine. The centre will also run a graduate programme to help students prepare for working in industry.

Gamma-ray telescope kicks off

The DESY laboratory in Germany has commissioned the first telescope prototype for the €150m Cherenkov Telescope Array (CTA). Designed at DESY, the prototype will be built in the next couple of months before researchers perform tests on the 12 m telescope. Due to begin construction in 2015, the CTA will study gamma rays with energies in the 0.1–100 TeV range, allowing astronomers to study supernova explosions, binary star systems and active galactic nuclei. CTA telescopes will be split between the northern and southern hemispheres, the sites of which have yet to be decided. The northern hemisphere site will contain around 20–30 telescopes distributed over a square kilometre while the southern area will include 70–100 telescopes extended over 10 square kilometres.

Particle physics

Europe prioritizes LHC upgrade and beyond

A series of planned upgrades to the Large Hadron Collider (LHC) that will enhance the machine's potential over the next couple of decades should be a top priority for particle physics, according to an update to the European Strategy for Particle Physics released by the CERN Council at the end of May. The strategy also stresses the importance of global collaboration to the future of European particle physics, particularly in designing a future linear collider as the next big experiment in particle physics after the LHC.

Two main options for it are currently on the table including the International Linear Collider (ILC), the technical design of which was completed last month. If built, it would feature a 31 km-long track of superconducting cavities that can accelerate electrons to energies of up to 500 GeV. The other option is the Compact Linear Collider – still in the research and development phase – which would operate at higher energies than the ILC and rely on a "two-beam" concept.

Europe's original particle-physics strategy, which was adopted by the CERN Council in 2006, focused on developing the LHC, laying the groundwork for a linear collider and investigating the case for future neutrino experiments. The revision builds on this, taking into account subsequent progress – notably the LHC's discovery of the Higgs boson. The strategy calls Japan's offer to host the ILC "most welcome", adding that it "looks forward" to discussing possible participation with Japan in its bid. "A strong interest expressed in the European Strategy for Particle Physics will definitely bring in a positive influence on how our effort is to be received in Japan," Yasuhiro Okada, a trustee at KEK, Japan's high-energy physics laboratory, told *Physics World*.

CERN

One for the future An update to the European Strategy for Particle Physics stresses the importance of global collaboration in building the next big experiment in particle physics.

The report also stresses the continued importance of investing in outreach, scientific education and technology transfer to enable the public to engage better with, and benefit from, particle-physics research. "The strategy recognizes Europe's strength [and] depth in particle physics," says Agnieszka Zalewska, president of the CERN's council and member of the group that developed the strategy update.

"The new European strategy is a tribute to the great strength that international collaboration brings to science," says Paris Sphicas, a physicist at CERN and the University of Athens, who is chair of the European Physical Society's high-energy and particle-physics division. "The update to the strategy, which is firmly based on the continuation of the current successful model, paves the way to a road full of promise for a rich and exciting physics programme in the coming decades."

Ian Randall

People

Heinrich Rohrer: 1933–2013

The Swiss condensed-matter physicist Heinrich Rohrer, who shared the 1986 Nobel Prize for Physics, died in May at the age of 79. Rohrer won the Nobel prize for inventing the scanning tunnelling microscope (STM) at IBM's Zurich Research Laboratory. Rohrer shared one half of the prize with his IBM colleague Gerd Binnig, while the other half went to Ernst Ruska for his invention of the electron microscope.

Rohrer was born on 6 June 1933 in the small town of Buchs in the Swiss canton of St Gallen. The family moved to Zurich in 1949 and Rohrer studied physics at ETH Zürich where he was taught as an undergraduate by Wolfgang Pauli and Paul Scherrer. He stayed on to do a PhD on the mechanical properties of superconductors and he continued working on superconductors at Rutgers University in the US.

In 1963 Rohrer joined IBM Zurich, where he worked initially on magnetic materials. He encouraged Binnig to join the lab in 1978 and the pair studied tiny defects on the surface of silicon – which at the time were hindering the miniaturization of electronic devices. To gain a better understanding of these defects, Rohrer and Binnig built the first STM in 1981.

Jesse Karjalainen

Atomic pioneer Heinrich Rohrer allowed us to see atoms on surfaces for the first time.

An STM works by scanning an atomically sharp tip over the surface of a sample to create a topographical map that reveals individual atoms. The tip is held less than one nanometre from the surface and a voltage is applied so that electrons can quantum-mechanically tunnel between tip and surface. This tunnelling current depends strongly on the tip–surface separation and this is used in a feedback loop to keep the tip the same distance from the surface.

The STM has become an important instrument for surface physics and materials science. A number of related microscopy techniques have since been developed in labs worldwide, including atomic force microscopy. Rohrer became an IBM Fellow in 1986 and he headed the physics department at IBM Zurich from 1986 to 1988. The Binnig and Rohrer Nanotechnology Center was opened at IBM Zurich in 2011 in honour of the two laureates (see November 2012 pp12–13).

Hamish Johnston

Creating physics stars

Korea has begun an ambitious $5bn plan to create 50 new institutes dedicated to fundamental research. Michael Banks meets physicist **Se-Jung Oh**, president of the Institute for Basic Science, to find out more

What is the Institute for Basic Science?
The Institute for Basic Science (IBS) is essentially modelled on the Max Planck institutes in Germany. We will create some 50 research centres by 2017 with each having around 50 researchers. Each will have one director and then three or four group leaders with their own PhD students and postdocs. Each IBS institute will carry out research in a specific area of basic science such as femtosecond lasers or the interface of oxide materials. We want to recruit the best scientists and give them full autonomy to carry out their own research.


IBS

Institute builder Se-Jung Oh.

Where did the idea come from?
Everybody in the Republic of Korea agrees that we should invest more in basic research. The question is how to do it? Korea has developed rapidly over the last 40 years or so thanks to our focus on applied commercial technologies. However, basic science is still lacking. I believe we now need to focus on long-term team-based research in basic science.

When did the plan start?
The idea for the IBS was conceived by the former president of Korea, Myung-bak Lee. He pledged to increase the proportion of money spent on basic science from 25% of the $15bn government R&D budget in 2012 to 35% over five years, as well as create an international science business belt, where science and industry can come together. The IBS initiative took three years to go through parliament and in November 2011 it was finally established.

What is the IBS's current status?
We have about 150 applications for director positions, a third of which come from scientists based overseas. So far we have selected 19 directors, with 13 centres already in operation and we are still in negotiations with the other six. Hopefully by the end of the year we will have 25 directors.

Where will the institutes be based?
Some 15 of the 50 centres will be in Daejeon, forming our headquarters, with the rest dotted around the country at existing institute and university campuses. Initially they will be based in university departments, but by 2017 we hope that each institute will have its own separate building. They will cover all the natural sciences – mathematics, chemistry, life science, physics and earth sciences, for example.

How much funding will each institute receive?
We will support each centre with up to $10m per year and we guarantee such support for 10 years. There will be no need for scientists to apply for other funding, but they can apply for foreign funds if they wish. We hope this level of support will attract top people to work here. Indeed, globalization is an increasing factor now and we have to be able to import the best brains from abroad to compete.

Can anyone apply?
Yes, and we encourage people to do so. A successful applicant's main post will be at the IBS and they will also have a post at a neighbouring university, where they will be able to teach one course per year.

Globalization is increasing and we have to be able to import the best brains from abroad to compete

How will you attract more foreign researchers?
We aim to have 30% of IBS researchers from foreign countries. Both Korean and English are official languages at the IBS, so all documentation will be in English. We will also give personal support such as helping with moving expenses, providing housing and subsidizing tuition for their children.

Is there a danger the IBS will lure top people away from Korean universities?
Some people complain that too much money is being spent on the IBS, but we have to create an environment where we can compete with places such as the Max Planck institutes. We don't think the existing Korean system can create superstars, such as Nobel laureates.

Will funding for basic research at universities now fall?
I insisted that research grants for the National Research Foundation, the main grant body in Korea, should not be reduced because of the IBS as we don't want to drain out existing money for universities. Indeed, some scientists prefer the university environment and way of working as well as the social status and pension.

One major IBS initiative is building a rare-isotope accelerator in Daejeon; what is the status of the project?
We are currently in the design phase of the facility, which will provide a wide variety of rare isotopes to carry out research in nuclear and atomic physics as well as materials science. The $1bn funding for the accelerator is secure in the long-term spending plan, but every year we will still have to apply to get the money. So it could be delayed one or two years beyond the 2017 target, but I am confident it will be built.

How does Korea's new president view the IBS project?
President Geun-hye Park pledged in her campaign that she will increase the basic science budget from 35% to 40% of the government R&D budget over five years. Her government also cites the IBS as one of the core projects it will support.

It must be an exciting time for you?
It is a lot of pressure, but it is exciting to build a new institution. I guess it will be difficult to make them world class in a short time, which may take a number of years.

Is the IBS really about giving Korea its first Nobel winner in science?
We believe it will help foster potential Nobel prize winners. We do not say this is the purpose of the IBS but rather aim to create an environment where this can happen.
● www.ibs.re.kr

Comment

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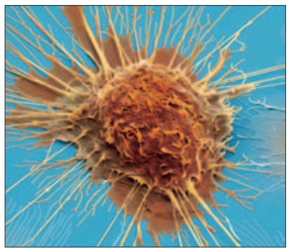
Tackling cancer

Physicists are opening up an invaluable new path in the fight against cancer

Why, you might be wondering, is *Physics World* devoting a special issue to the "physics of cancer". Well, we should first say that this issue is not about the treatment, diagnosis or imaging of cancer using X-rays, magnetic fields, protons or other subatomic particles. These are areas where medical physicists have made – and continue to make – many valuable contributions. In fact, the digital version of this special issue includes some recent videos we created examining these endeavours (see below).


Science Photo Library

What this special issue instead focuses on is a fledgling area of research in which physicists – and other physical scientists – are trying to bring a new perspective to our fundamental understanding of cancer. Biologists have spent decades and billions of dollars chasing an elusive "cure" for cancer, largely on the assumption that it is at heart a disease of the genes. Get to grips with those genetic mutations, the thinking goes, and powerful new therapies will follow. But despite the massive sums spent, the death rate from cancer in the US, for example, has dropped by just 11% since the 1950s. Tackling tumours with drugs, radiation or the surgeon's scalpel can, it seems, only get you so far.

Rather than seeing cancer purely in terms of genetic mutations, some physicists are instead examining the physical parameters that control how cancer cells grow, evolve and spread around the body. Atomic-force microscopists, for example, are exploring the curious finding that cancer cells are softer than healthy cells whereas tumours are hard lumps (pp33–35). Other researchers are seeing if tumorous cells can be prevented from proliferating by manipulating their electrical polarization (pp25–26). Meanwhile, experiments with confocal microscopy suggest that the physical rotation of breast-cancer cells could hold clues as to why they can become malignant (pp28–29).

But physics' contribution to cancer involves more than just using new techniques. It is also about doing what physicists do best: namely looking at a problem (cancer) with fresh, unbiased eyes and seeking its underlying principles. One physicist at the heart of this new effort – Paul Davies – is even proposing a new theory of cancer (pp37–40). He suggests it is caused by malfunctions in the mechanisms that instruct cells when to multiply and when to die, which makes them revert to an ancient genetic "sub-routine" that dates back to our roots as multicellular creatures. When this sub-routine is triggered, the cells start acting selfishly and out of control.

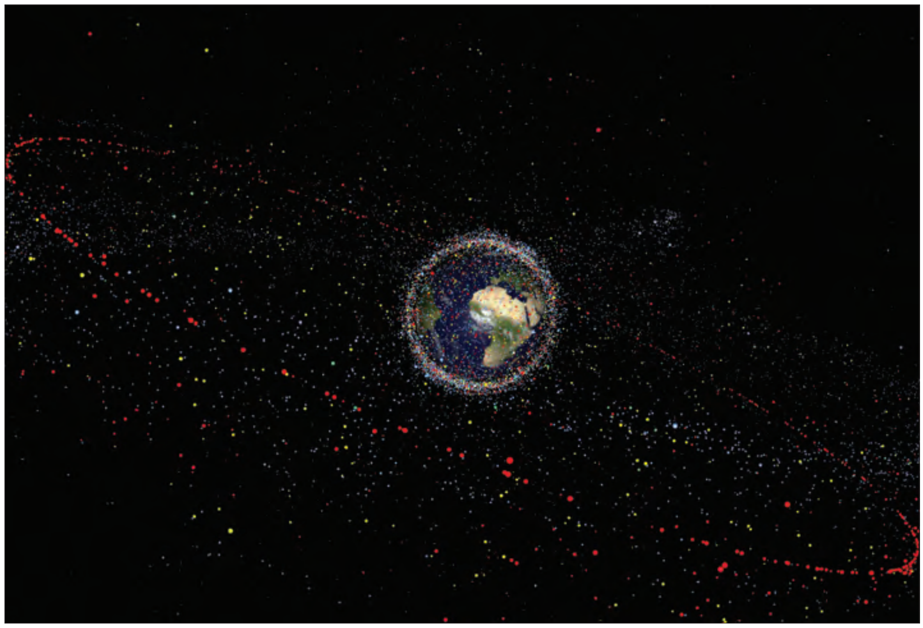
Davies might be wrong of course, but surely it is right for physicists like him to bring fresh insights and ask disruptive questions. Their work might not lead to a cure, but it could improve existing treatments, for example by letting drugs be carried directly to tumours in nanoparticles or by helping physicians to make an early diagnosis of metastasis. Physicists are sometimes accused of arrogance when they tread on others' turf, but that seems a small price to pay for the rewards that could be reaped.

physicsworld 25 years

Don't miss our series of films we made at the Massachusetts General Hospital in Boston – one of the leading medical centres in the US – about the pioneering ways in which its researchers are improving the treatment of cancer patients using the powerful technique of proton therapy. The films are embedded in the digital issue and can be viewed at *physicsworld.com*.

Tackling space debris head on

The rapid growth of "space junk" in low Earth orbit threatens to destroy existing and future satellites, **Brian Weeden** calls for more international co-operation to deal with the danger


ESA

Junk alert This image released in April maps all known man-made space objects

"Space junk" is increasingly becoming a household term. Indeed, it features in a recent US Air Force TV advertisement and is even the main protagonist in the new film *Gravity* starring George Clooney and Sandra Bullock. The two stars play astronauts who must fight to return to Earth after a wayward piece of space debris destroys their space shuttle, with passion and dramatic twists no doubt soon to follow.

While the Hollywood depictions of space junk may be long on the drama and short on the physics, space debris and collisions in space are a real problem that is getting an increasing amount of attention. There are more than 22 000 pieces of human-generated space debris bigger than 10 cm currently being tracked in orbit, and an estimated 500 000 pieces as small as 1 cm that are currently too small to track regularly. With the relative velocities between objects in orbit routinely approaching 10 km/s, even these small objects pose a significant hazard to active satellites (see June 2012 pp28–32).

Recent events such as the 2009 collision between an active US commercial communications satellite and a defunct Russian military communications satellite have created thousands of new pieces of debris in some of the most highly used and congested regions of Earth orbit. Satellite operators have already seen an increase in the frequency of close approaches between space junk and the 1000 or so active satellites. Indeed, in 2012 operators performed more than 70 manoeuvres to reduce the probability of a collision between their satellites and another object in orbit.

Clean-up operations

Scientists at some of the world's biggest space agencies have been examining the growth in the space debris population for nearly 30 years now. At a recent conference on space debris in Darmstadt, Germany, the results from six different space agencies were presented that confirmed the bad news. Even without any new satellite launches, the existing debris population in low Earth orbit (LEO) will continue to grow over the next few decades through debris–debris collisions. Such collisions are mostly the result of small pieces of space debris hitting larger pieces, such as dead satellites and spent rocket bodies, which creates many more pieces of small debris. This process raises the collision threat in certain regions of Earth orbit, and ultimately the cost and risk of space activities.

Delegates in Darmstadt also agreed on the need to begin removing space debris from orbit to help mitigate this collisional cascade process. Computer models show that reducing the amount of debris created from current operations as well as post-mission disposal of satellites is not enough. But combining these activities with removing 5–10 large objects per year from the most congested regions of LEO could greatly reduce the growth in the debris population over the next two centuries. Key questions include which objects should be removed, when do they need to be removed, what the best methods of removal are and who will pay for the removal.

A space object is owned by the state which placed it in orbit. One country cannot just grab any piece of space debris it wants

A central element in all of these questions is the international nature of the problem. More than 60 countries currently operate at least one satellite, and 12 countries have demonstrated the ability to place objects in orbit. Breaking the debris population down by mass, Russia is responsible for roughly 40% of space junk, followed by the US (30%), China (20%) and the rest of the world (10%). Under the current international legal framework, a space object is owned by the launching state, or states, which placed it in orbit. This means that one country cannot just grab any piece of space debris and do what it wants with it.

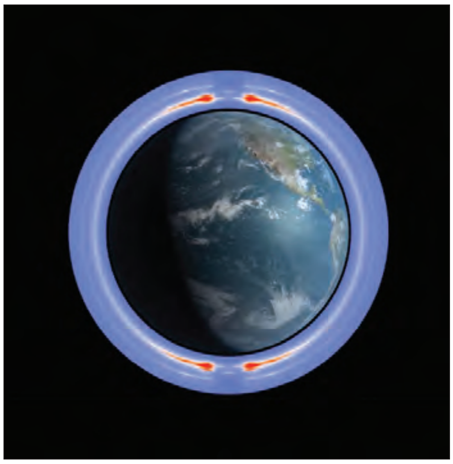
Tackling the space debris problem is thus going to require international cooperation at some level. At the very least, it will involve discussions between scientists from many countries to decide which objects are the most pressing priority to remove. It will also involve further development of concepts for removing large objects, most of which have yet to be demonstrated in space. Finally, there is the question of money. Although there may be situations where countries decide to remove one or more of their own objects with their own funding, it is likely that the financial burden will not be evenly distributed. Countries will have to negotiate who will be responsible for what, and how to provide incentives for countries to either remove their own space objects or give permission for others to do so.

Building space awareness

A technical demonstration mission to remove a large piece of space debris that involves multiples countries would be a significant step forward. It would enable further progress on the technical and operational side, as well as providing a specific example with actual legal and policy issues to sort out. Currently, much of the legal and policy debate revolves around notional scenarios that get bogged down in hypotheticals. An actual mission would present a concrete set of problems to solve and enable a more functional discussion.

The foundation for all these activities is "space situational awareness" (SSA), commonly defined as information about the space environment and activities in space. SSA helps keep scientists informed about the evolution of the space debris population and develop better models of its long-term growth. SSA also helps satellite operators predict close approaches between their satellites and other space objects that could result in collisions, and plan manoeuvres to reduce that probability.

SSA has historically been a mission performed for national security reasons and


ESA

Danger zone This forecast of space debris density in 2055 shows that the highest debris collision risk is at the poles, now and in the future.

currently the US military operates the largest network of radars and optical telescopes for tracking space objects. However, more international cooperation is needed here to both expand the geographic coverage of these tracking efforts and combine the tracking with the positional data that satellite owners have on their own satellites.

The development of a single, international entity to provide SSA for all satellite operators is probably not the optimal technical or political solution. Rather, we should have multiple analysis hubs that share data, which is likely to be a more pragmatic and workable solution. Shifting the responsibility for aspects of SSA essential to safety of spaceflight away from the military and towards civil agencies will also help reduce the barriers to cooperation and data sharing that currently exist.

Taken together, improving SSA, developing and testing the technologies for removing large debris objects, adopting best practices for minimizing the creation of debris during space operations, and committing to properly disposing of satellites and rocket bodies at the end of their usable life present the best way to deal with the threat of space debris. This is not something that one country can implement alone. Rather, it will take an international effort and actions by multiple countries to ensure that humanity can continue to use space for all the many benefits it provides in the future.

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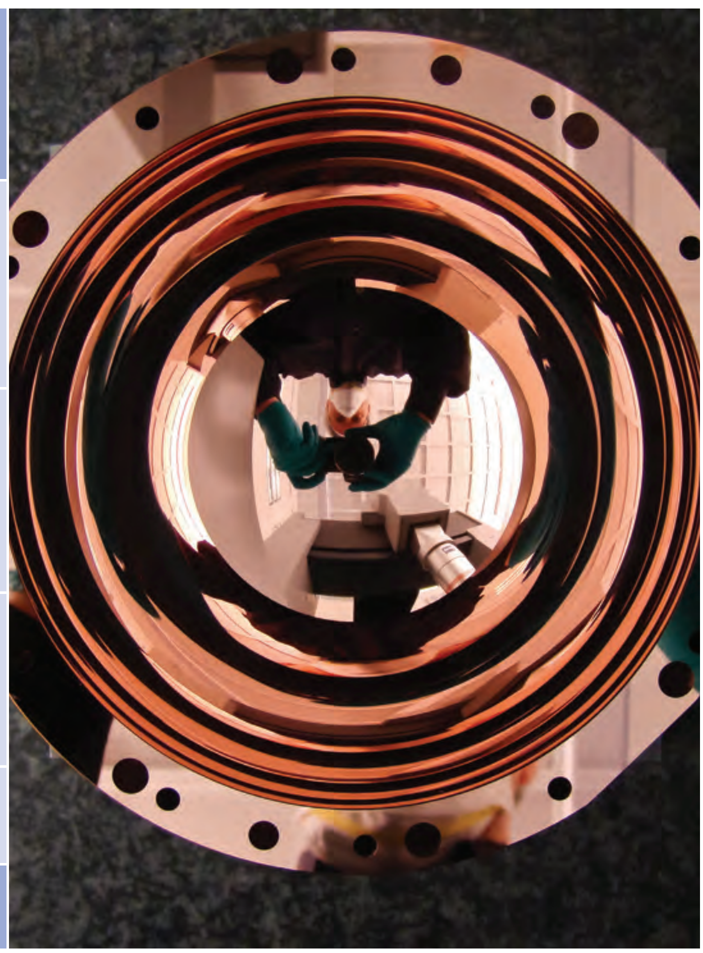

Michael de Podesta/NPL

Critical Point The Treiman effect

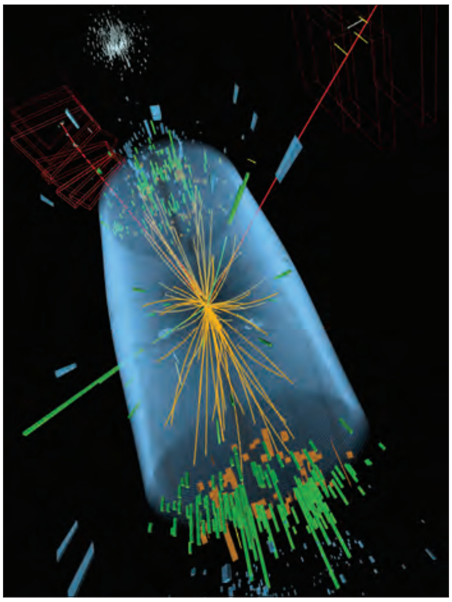
Robert P Crease discusses an often-overlooked feature of the discovery process

The art of discovery comes in two versions. One is the formal textbook version often promoted by my philosophical colleagues. The other is messy reality. The latter, however, has few phenomenological traits that might help us construct a theory about discovery in general. A rare instance is something I call the Treiman effect, named after the late Princeton University theorist Sam Treiman.

I met Treiman just once – and that was only briefly at a conference – yet the encounter was enough to make me admire the way he was not content with the usual formal and tidied-up pictures of scientific discovery. I've also spoken with many of his former students, who remember his deep and intuitive grasp of scientific practice. One of them, my colleague Alfred Goldhaber, recalls that whenever Treiman finished discussing some extraordinary new discovery, he would often say, almost as a catchphrase, "So…we are invited to jump to two conclusions at the same time." One conclusion would be about the discovery itself. The other would be that the route to the discovery has more than one consequence, and finding those consequences reinforces one's confidence in them all.

As an example, Goldhaber cites Niels Bohr's famous trilogy of papers of 1913–1914, in which he proposed the then seemingly far-fetched idea that electrons in an atom can exist only in specific, discrete orbits. Bohr's idea resolved at a stroke the mechanical problems that plagued Ernest Rutherford's "planetary" atomic model and, moreover, accounted for the spectral lines of hydrogen that had been quantified by the Swiss physicist Johann Jakob Balmer (see June pp34–38). But Bohr went further, arguing that lines in the spectra of the Sun that had been seen by the Harvard astronomer Edward Pickering with four times the frequencies of the Balmer lines must be from helium. (Twice the nuclear charge gives four times the frequency.)

Other scientists, however, argued that Pickering's lines came from hydrogen, but with denominators in Balmer's formula that were four times smaller, and hence frequencies that were four times bigger. Bohr faced a different challenge from the British astronomer and spectroscopist Alfred Fowler. Fowler studied the Pickering lines in his laboratory and verified that



CMS Collaboration, CERN

Multiplicity The route to a discovery, such as the Higgs boson, has more than one consequence.

they came from (singly ionized) helium, but noted that – contrary to Bohr's proposal – the frequencies were not 4 but 4.0016 times their values for hydrogen. When Bohr realized that he had not accounted for the increase in effective or "reduced" mass of the electron when it revolves around the helium instead of the hydrogen nucleus, he recalculated the frequency ratio and found it should indeed be 4.0016. This agreed with experiment to five significant figures.

"Game, set, match!" Goldhaber says. Bohr had not only discovered that the Pickering series was indeed produced by ionized helium, but had also greatly reinforced scientific confidence in his then-radical assumptions about atomic structure. This episode overwhelmed the scepticism of many scientists regarding Bohr's audacious proposal. "It showed that you weren't dealing with a single discovery," says Goldhaber, "but with a complex of things that snapped together as neatly as a car door slamming into place."

A physicist's physicist

Treiman, who died in 1999 at the age of 74, specialized in quantum field theory, in which he mentored many of the finest US theoretical physicists, including the Nobel laureate Steven Weinberg. Often called a "physicists' physicist", Treiman was famous for his beautifully organized and fluently delivered lectures. He would give these as if prepared for manual labour, with shirt sleeves rolled up to his elbows. (He did have a jacket, but would wear it only on the first day of each semester, hanging it in his office in case of sartorial emergency.)

Yet Treiman was not warm and fuzzy. He was cool and clearheaded – reserved without being remote, dedicated without being distant. Treiman knew that a researcher usually gropes about with a complex of assumptions, intuitions and speculations that form a kind of mental map. Any discovery you then make is also significant in that it brings new trust in this map, even when you find elements must be changed. Research is like filling in a crossword puzzle: finding that a certain word fits solidly and securely confirms not only that word but also the validity (or invalidity) of the other pencilled-in words that had inspired you to come up with it in the first place.

Treiman took an unconventional route into physics. He had originally studied chemical engineering for two years at Northwestern University, attracted there in 1942 by the subject's "nice mixture of science and practical usefulness appropriate to a time of war". After a spell in the US Navy, where he learned to repair radio equipment, Treiman moved to the University of Chicago, acquiring bachelor, Master's and PhD degrees in physics. He then landed a job at Princeton, where he was to spend virtually his entire academic career – first in an experimental cosmic-ray physics group, then in particle-physics theory. Treiman's background in engineering and experimental physics surely played a role in his clear-eyed assessments of the research process.

The critical point

It is easy to oversimplify the discovery process – to portray it as moving progressively from a solid base of what we know, guesses about what we don't, tests of those guesses and new knowledge added to the original base. The Treiman effect, however, directs our attention to a deeper process at work in which each new result affects our assessment of the path we have been taking all along. This is as true of the Higgs boson discovery as of the Bohr atom; the Higgs discovery does not simply give us another particle, but reinforces our trust that we were on the right track in the first place. The Treiman effect shows us that, in often strange ways, our research programmes continually feed back on all of what we thought we already knew.

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Feedback

Letters to the editor can be sent to *Physics World*, Temple Circus, Temple Way, Bristol BS1 6HG, UK, or to **pwld@iop.org**. Please include your address and a telephone number. Letters should be no more than 500 words and may be edited. Comments on articles from *physicsworld.com* can be posted on the website; an edited selection appears here

Where's the carbon?

In his article "Mopping up carbon" (June pp23–27) David Appell states that CO_2 taken up by vegetation is returned to the atmosphere when the vegetation dies. Some of the carbon content of dead vegetation actually becomes methane, and this is both good news and bad. It is bad news in that methane is a more powerful greenhouse gas than carbon dioxide. It is good news in that methane from such a source in sufficient concentration forms a carbon-neutral fuel. Such a fuel is of course referred to as landfill gas (LFG) and finds considerable application in some countries. To blend "conventional" methane from natural gas with LFG is to generate carbon credits. LFG is the only carbon-neutral form of methane that we have.

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As a pedantic chemistry teacher I would like to point out that the ball-and-stick models on the front cover of the June issue are quite clearly of water and not carbon dioxide. CO_2 molecules have a linear geometry, double bonds between the central carbon and the two oxygens, and colour-wise, it is standard to depict carbon as black and oxygen as red.

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Impressive cover picture on the June issue – I didn't know nanotechnology had advanced to the level of reconfiguring interatomic bonds. I guess if normally linear CO_2 molecules could be disguised as water, it would make them easier to extract from the air by "mopping up", as David Appell's article puts it?

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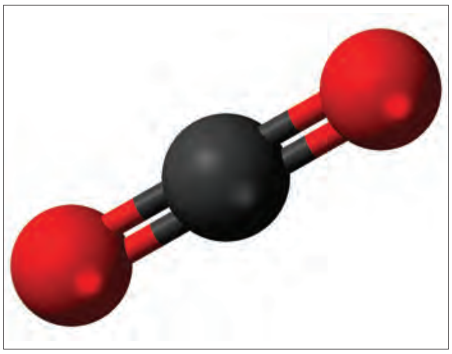
Oh dear! The molecules all over the cover of *Physics World*'s June issue on "Capturing CO_2" appear to be water – they are certainly not CO_2. The carbon-dioxide molecule is straight, not bent through ~120°. This has major effects on its infrared spectroscopy, and hence on its effect on global warming. The number of vibrational modes, selection rules and rotational energy levels are all radically influenced by the fact that the molecule is linear, not "bent".



The right one A molecule of carbon dioxide: linear, double-bonded and depicted in black and red.

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The editor replies:
I would like to pretend that we used an illustration of water instead of carbon dioxide to test readers' knowledge of triatomic molecules, but unfortunately it was just a mistake. Apologies.

Publication changes not all for the better

Physicists of a certain age will likely remember going to libraries to drag heavy copies of bound journals back to their departments for copying. The first part of this task involved muscular contortions as one broke the spine of the hard-bound volume in a fight to get the pages of interest flat on the copy-glass. Then came filling out a card index, and finally storage in a filing cabinet – a sarcophagus for information made of sharp-edged metal. Personally, I remember spending many days as a PhD student and postdoc running between library and photocopier while an experiment ran or a sample annealed in my vain attempt to get on top of the literature. And how did I know which papers to look at? From references mentioned in copies of papers I already had, or by using the monster printed compendium that was *Chemical Abstracts*. Kids, you don't know what you missed!

Search tools and PDF files have changed all that. But is all that is promised for the future of scientific publishing for the best? In the seemingly all-pervasive, headlong rush towards an openly accessible, download monitored, automatically ranked and pre-digested brave new world of scientific publishing, can I be the only one who – while taking advantage of click here and a download there – is heading just as quickly in the other direction?

In a recent item in *Nature* (**495** 437), Jason Priem painted a picture of a world "Beyond the paper" in which a personalized recommendation engine will deliver "the five most important things for you to read that day". In the maelstrom that is way too many titles to scan, let alone articles to read, this new filtering scheme is very appealing. In some ways, we are already there, albeit in an embryonic way. But the online experience fails to deliver in the same way that the photocopier failed to deliver. I don't want to increase the volume of information I process. What I want is to engage more deeply with the ideas, data etc. that interest me, to think it over, to reflect.

Making a photocopy didn't get the paper into my head any more than storing a PDF file does, so in some sense it is not a question of technology but of approach. I find that reading that paper version of a paper/journal is much more effective, but that's just me – a product of my time. Whatever medium you use, fight the siren call to just graze information.

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A subtle point about Bohr

Jon Cartwright's interesting and informative article on quantum philosophy ("The life of psi", May pp26–31) mischaracterizes Niels Bohr's stance as anti-realist by suggesting (in the illustration on p29) that Bohr believed that "quantum theory [does not] describe an objective reality, independent of the observer". The mischaracterization amounts to the difference between an adjective and an adverb. The adjective "independent" must refer to "reality"; whereas "independently" would refer to the verb "describe". Bohr was well known for not always being crystal clear regarding his position, but in general, he felt that an objective reality was being studied by human experiments – albeit using human concepts that did not capture the essence of that reality.

Numerous quotations can be found in Bohr's writings to support this claim. In fact the very quote attributed to Bohr in that illustration speaks against Cartwright's characterization: "It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature."

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A shorter journey

I really like the Lateral Thoughts article "A golden galactic journey" (May p60), in which the author describes how far he and his wife have travelled during their 50 years of marriage. The numbers are very impressive, and as I was preparing a lecture, I thought that it might be of interest to my first year class – always good to show students really big numbers!

But perhaps based on the caution of age, I thought I would verify some of the numbers in the article first. Unfortunately, the figure given for the distance the Earth travels around the Sun over 50 years is approximately an order of magnitude too large; I suspect an additional digit has crept into this number.

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Early medical scans used animals, too

Ian Pykett's letter on "Pioneering veggie MRIs" (May p23) reminded me of something I heard about Sir Godfrey Hounsfield, who shared the 1979 Nobel Prize for Physiology or Medicine for developing the X-ray computed tomography (CT) scanner. After experimenting with scans of solid objects, he turned his attention to biological samples such as an animal stomach and a fresh cow's head. Due to bleeding in the cow's head as a result of stunning before slaughter, this scan did not show the ventricles of the brain. It was suggested that he obtain a cow's head from an abattoir practising Jewish ritual slaughter, where stunning is not used and the animal has its throat cut by a very sharp knife used by a highly experienced practitioner. I understand that he did so, and that this was the first time the ventricles of the brain were seen by X-rays.

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Correction
The cover of our Focus Issue on Nanotechnology showed a heterostructure of graphene and barium nitride, not barium nitrate as stated (p1).

Comments from *physicsworld.com*

Stephen Hawking gets a lot of conference invitations. By all accounts, he turns most of them down – so when the 71-year-old cosmologist agreed to speak at last month's Israeli Presidential Conference, it must have come as a pleasant surprise for the event's organizers. Their next surprise, however, was anything but pleasant. In May Hawking announced that he would not be attending after all, as he was joining an academic boycott against Israeli institutions ("Stephen Hawking boycotts high-profile Israeli conference", 8 May; "Hawking's academic boycott divides opinion", 9 May; see also June p8). Are such academic boycotts worthwhile? And did Hawking make the right decision on this one?

I think Hawking was manipulated by people whose motives he did not understand.
Michael Lerman

A perfect example of the universal concept that great intelligence rarely results in great wisdom.
B Cook

Good for Hawking. He should be commended. Israel is a thug and is punishing the Palestinian people for their leaders' actions. On that basis, perhaps Hawking should boycott America as well.
Carl

Another sad case of victory of propaganda over reason. I would understand if he refused to travel for health reasons. I would understand if he refused to travel for fear of getting killed by a Palestinian rocket. But if the two above are not the concern then I don't understand why, if he has anything to criticize about Israel, he refuses to travel to the best place to do so. And maybe learn a bit about what really happens there.
kasuha

So he needs to travel to Israel to find out what is going on? Seriously? I wonder how Hawking calculated the entropy of a black hole without travelling to one? You must be a lobbyist for the airline industry.
Carl

Hawking's absence from a conference dealing with "the human aspects that are shaping the world, including issues such as geopolitics, education and new media" will leave the gathering to be satisfied with dilettantes such as Tony Blair, Bill Clinton and Mikhail Gorbachev, without the profound wisdom on these questions that Hawking, from his vast experience, could have contributed. I say, cancel the conference!
b s chandrasekhar

Academic boycotts tend to be counterproductive. If the objective of the boycott is to protest the policies of the Israeli government, it attacks the wrong target. Like many other right-wing governments, Netanyahu's tends to be suspicious of and hostile to academia, in which many of its strongest critics teach. In fact, in the last years there have been (so far unsuccessful) government-inspired attempts to stifle academic criticism. Hawking and others would have been much more influential had they attended their conferences and used the opportunities to express *ex cathedra* their criticism of Israeli policies.
Zvi Solow

In 1992 Serbia (with Montenegro) was put under international sanctions for Milosevic's interference with Bosnian internal fighting. Scientific organizations such as the Serbian Association of Physicists were banished from international groups such as the European Physical Society (EPS). Supplies of scientific journals were stopped, including those of individual subscribers like myself. At a council of the EPS the question was raised about whether Serbian individuals should be expelled from international groups, too, but when one member from France reminded the council that not all Serbs support Milosevic (citing a letter I wrote to *Physics World* in June 1993), the discussion stopped. By the way, it is me who has been boycotted by Serbian institutions, including my own, ever since, for this sort of activity.
Petar Grujic

I think Hawking is exercising his right of association, or more importantly, his right not to be associated.
TDM

A boycott of anything is what's called "non-violent resistance" and is simply saying "No thanks!" I applaud Hawking and hope that others take note.
Kaylee Rob

Joining a boycott suggests that there is a clear transgressor and a clear victim. Claims of draconian Israeli oppression would be more believable if Israel hadn't (twice) proposed the creation of a Palestinian state and the end of the conflict.
m lv

I think Hawking himself expressed the self-defeating nature of the boycott when he stated, "Had I attended, I would have stated my opinion that the policy of the present Israeli government is likely to lead to disaster." In other words, it's better to keep communication channels open and be able to do something in a proactive way, rather than just stay away.
Julio Herrera

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An electrical misunderstanding

Cancer cells aren't bad, they're just not being treated right – or at least, that is what one US group's research seems to suggest. **Jon Cartwright** reports on their findings

Jon Cartwright is a freelance journalist based in Bristol, UK, http://jcartwright.co.uk

Few diseases instil more fear than cancer. More than any other illness, the rhetoric surrounding the diagnosis and treatment of cancer conjures images of an innate "badness" invading the body. The feeling is not just a popular impression but one that is reinforced through cancer therapy, which – be it radiotherapy, chemotherapy or surgery – is generally aimed at eradicating "malignant" cells.

But what if cancer isn't some case of "cells gone bad", some genetic defect? To put it another way, what if tumour cells can be made to act normally, given the right motivation? That is the question being asked by a group of researchers in the US, who have found that simply regulating the voltage of tumorous cells could be enough to stop them spreading out of control. Their work is in its very early stages, but already it is being viewed as a possible new way of detecting and treating cancer.

"There's been a little bit of disbelief, because it's a whole different ball game," says Mustafa Djamgoz, a

Michael Levin and Brook Chernet

Electric dream Tumorous cells (highlighted in red) have consistently lower voltages than healthy cells. So could regulating cell voltage be a way to cure cancer?

cancer biologist at Imperial College London who is not involved with the research. "But it's opened up a whole new set of opportunities."

A curious link

The link between voltage and cancer goes back to the late 1930s, when the US anatomist Harold Saxton Burr used a new-fangled device called a voltmeter to show that tumour tissue has different electrical properties from normal tissue. In the early 1970s Clarence Cone, a biophysicist at NASA's Langley Research Center in Virginia, traced this difference to a disparity in cell polarization, or how much more negatively charged the inside of a cell is compared with its outside. Tumour cells, Cone found, are less polarized than normal cells, and he suggested that electric polarization might somehow be a regulator of cancer and other cell proliferation.

Some 40 years later, biologist Michael Levin at Tufts University in Medford, Massachusetts, and doctoral student Brook Chernet have found persuasive evidence that Cone was right. In their experiment, they injected messenger RNA that encodes human oncogenes – genes that can transform normal cells into tumour cells – into tadpoles. Next, they soaked the frog larvae in fluorescent dye. This dye was voltage-sensitive, fluorescing more brightly when the cell polarization was greater.

Levin and Chernet did not know which tadpoles would develop tumours. However, as soon as a tadpole exhibited a dark patch of low fluorescence, indicating lowered cell polarization, the researchers segregated it from the others to monitor it. They found that, over several days, such patches of lowered polarization nearly always developed into tumours, confirming the link between cell polarization and cancer.

According to the Tufts pair, the two phenomena – lowered polarization and tumour development – are connected by a straightforward chain of events. Cells become polarized when there is an imbalance of the positive and negative ions that flow in and out of cells through channels in cell membranes. But polarization itself regulates the operation of so-called transporter proteins, which pump signalling molecules through the channels. Through their experiments, Levin and Chernet have found that a lowered polarization inhibits the function of a transporter protein that draws in the signalling molecule butyrate, which, through various enzymes, controls the expression of growth genes. With less butyrate in the cell, these genes are free to instigate abnormally high, cancerous growth.

From discovery to treatment

The obvious way to stop such growth is to increase the polarization of the tumorous cells, so that more butyrate can be drawn in to curb growth-gene expression. To test this hypothesis, Levin and Chernet split their oncogene-injected tadpoles into two groups. One group received injections of messenger RNA that encodes proteins for new ion channels. The new ion channels drew more negative ions into the tadpole cells, thereby increasing the cells' polarization. The result was that the injected group of tadpoles did not develop nearly so many tumours as the untreated group, demonstrating that polarization is indeed a way to reign in tumours – at least in tadpoles (*Dis. Model Mech.* **6** 595). To pave the way for clinical trials, Levin and Chernet will now have to show that the same results can be found in mammals.

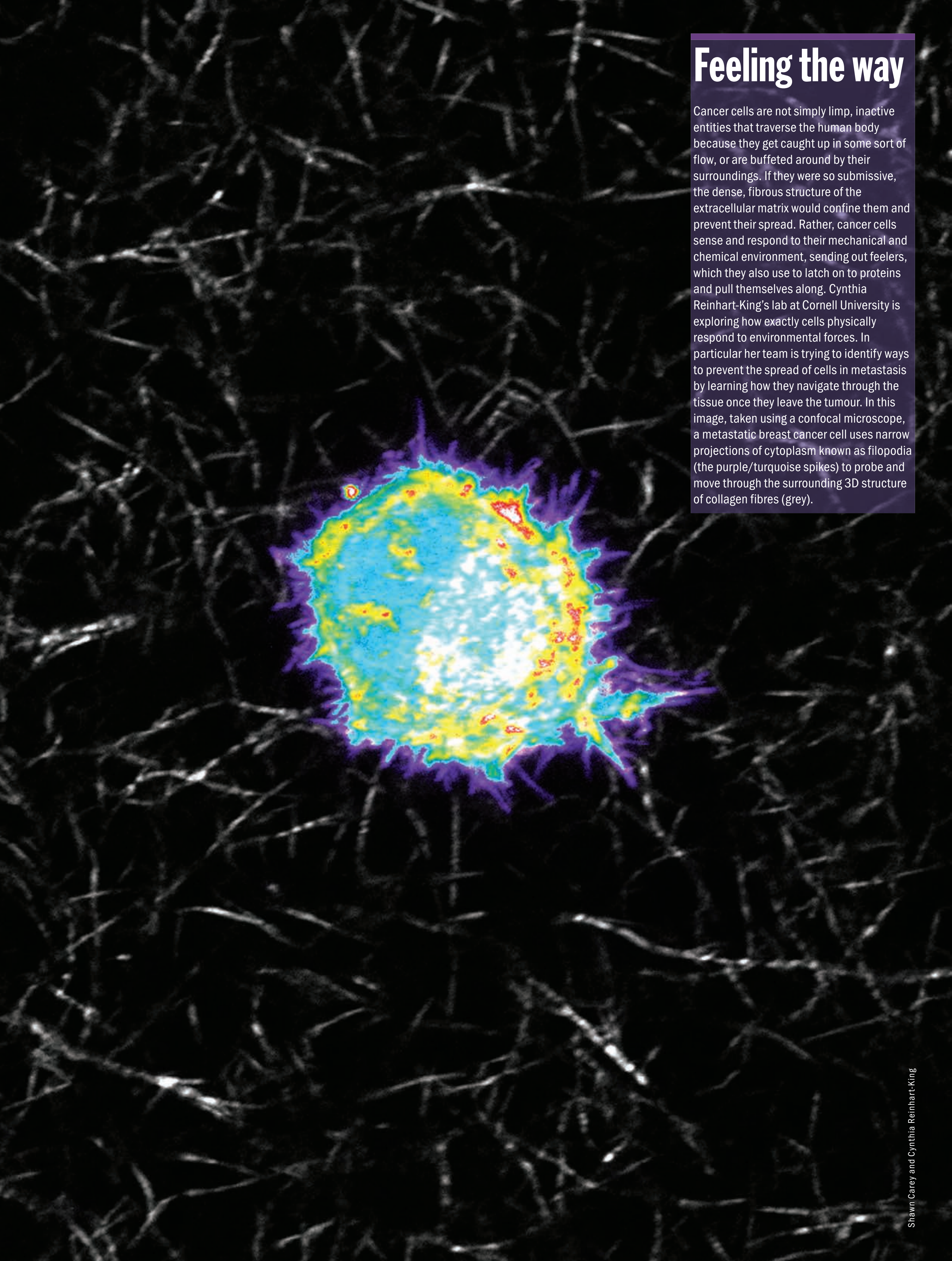
One question raised by the Tufts pair's work is whether it sheds any light on why tumours arise in the first place. Levin is quick to point out that cell voltages are not directly affected by external sources of electromagnetic radiation, which means that his findings neither support nor detract from the notion that electronic devices such as mobile phones can cause cancer, as is sometimes claimed. However, he does say that the growth of tumours would likely be provoked by anything that perturbs the normal electrical communication between cells. One possible perturbation could lie with holes in cell membranes, called "gap junctions", that allow cells to "dock" with one another and share ions. Tumour cells are known to have lowered gap-junction communication compared with normal cells, which could be why their polarizations go awry.

Biophysicist Geoffrey Abbott at the University of California at Irvine thinks the Tufts research has promise. But he points out that any therapy involving the manipulation of ion channels has risks, since the channels also play crucial roles in healthy tissue, such as in the regulation of cardiac rhythm. If there were a way to alter membrane potential by focusing on ion channels only in tumorous tissue, and not healthy tissue, he says, then "this direction could hold real therapeutic potential".

In any case, Levin thinks his research is important because it is encouraging scientists to consider the possibility that tumour cells are not irrevocably damaged. Various observations already support this idea: implant aggressive carcinoma cells into a mouse embryo, for instance, and only healthy tissue will develop, not tumours. "We have to get away from the idea that it's always physical matter that's at the root of the problem – that there's a damaged gene, or a chemical toxin," says Levin. "It's not always that." ■

Feeling the way

Cancer cells are not simply limp, inactive entities that traverse the human body because they get caught up in some sort of flow, or are buffeted around by their surroundings. If they were so submissive, the dense, fibrous structure of the extracellular matrix would confine them and prevent their spread. Rather, cancer cells sense and respond to their mechanical and chemical environment, sending out feelers, which they also use to latch on to proteins and pull themselves along. Cynthia Reinhart-King's lab at Cornell University is exploring how exactly cells physically respond to environmental forces. In particular her team is trying to identify ways to prevent the spread of cells in metastasis by learning how they navigate through the tissue once they leave the tumour. In this image, taken using a confocal microscope, a metastatic breast cancer cell uses narrow projections of cytoplasm known as filopodia (the purple/turquoise spikes) to probe and move through the surrounding 3D structure of collagen fibres (grey).

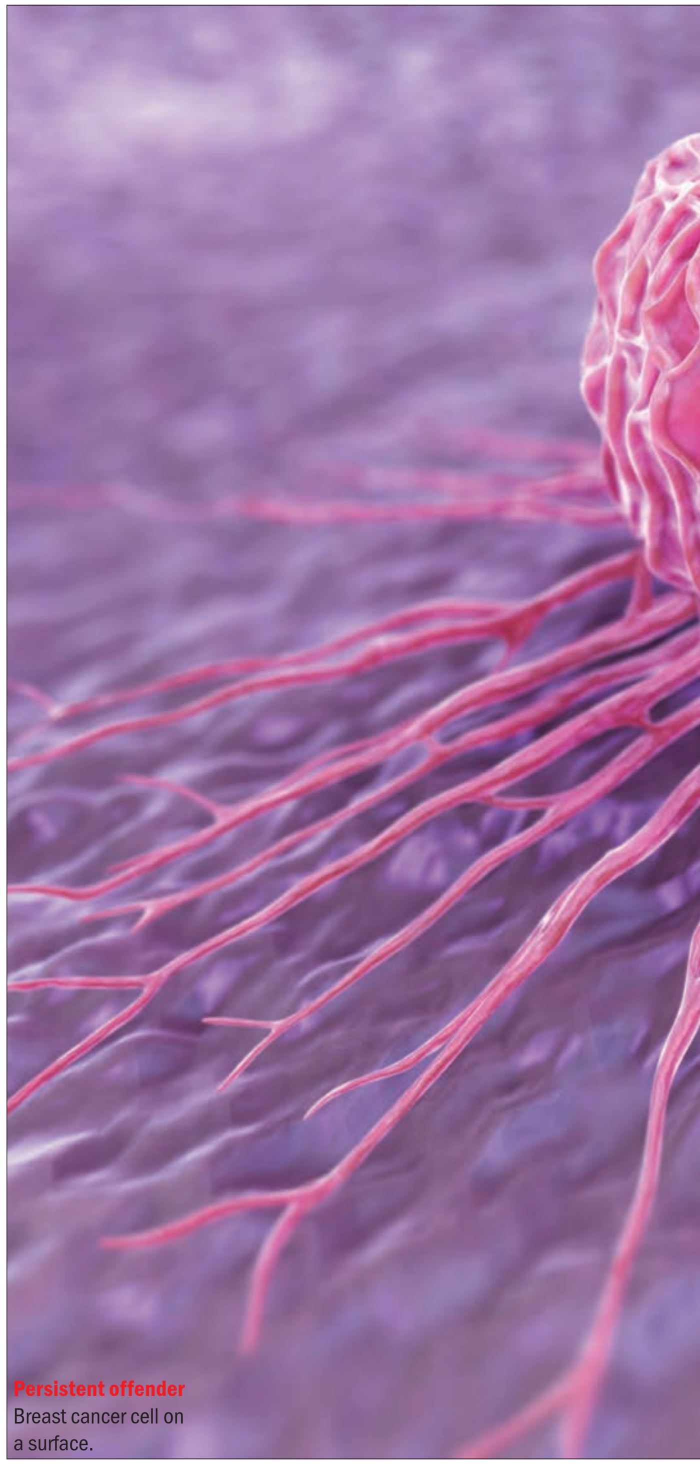


Shawn Carey and Cynthia Reinhart-King

Breast cells in a spin

Physics is providing some clues about what causes breast cells to turn malignant, although, as **Edwin Cartlidge** discusses, a full understanding is probably some way off

Edwin Cartlidge is a science journalist based in Rome, e-mail edwin.cartlidge@yahoo.com



Persistent offender
Breast cancer cell on a surface.

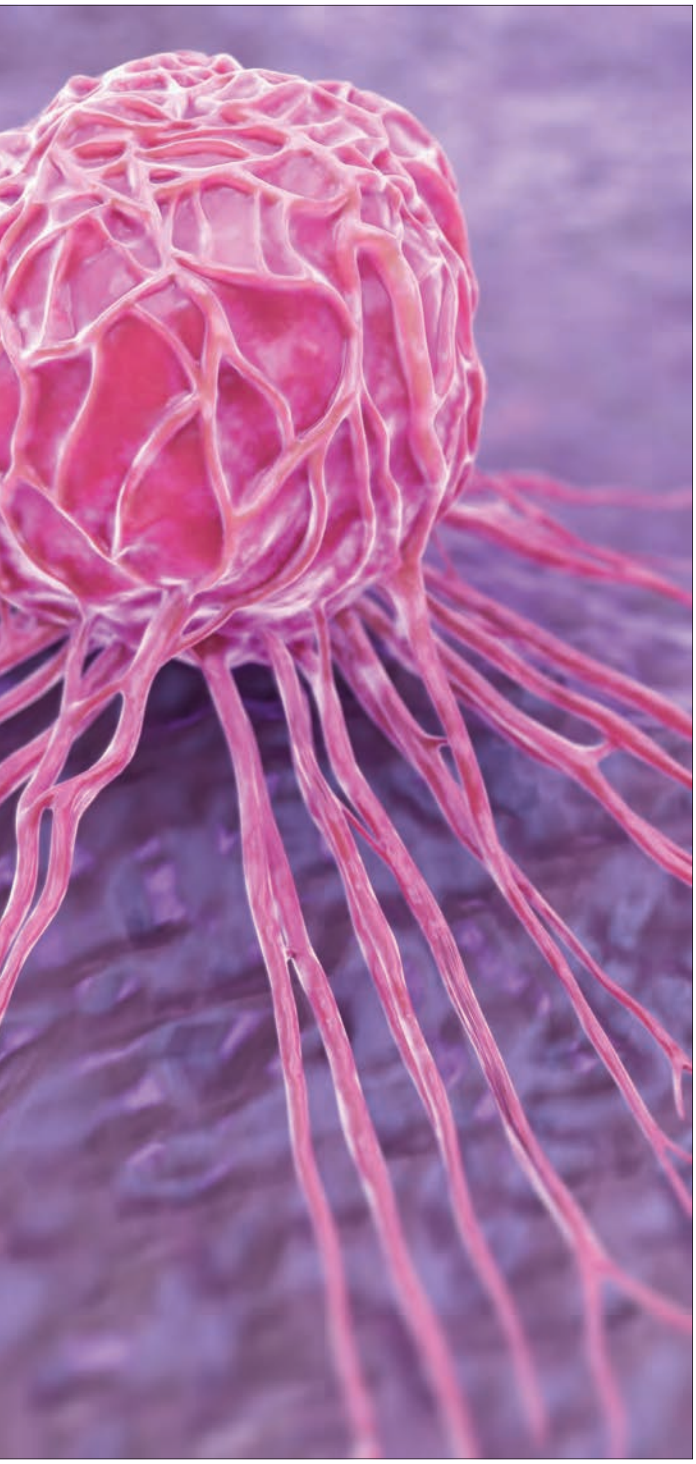
For years conventional wisdom has held that cancer is essentially a genetic phenomenon. Mutations of DNA inside cells' nuclei get blamed for causing cells to reproduce uncontrollably and form potentially malignant tumours. However, one researcher who has been challenging this gene-centred view is the Iranian-American biologist Mina Bissell, who has argued since the early 1980s that cancer also depends on how cells interact with their environment. Her ideas were at first ignored by experts, but 30 years of persistent research have won many critics round. In particular, she showed that changes to the protein scaffold surrounding breast cells known as the extracellular matrix (ECM) can determine whether or not those cells behave malignantly.

"We are learning more and more that although mutations might be the trigger, much of the subsequent dynamics of cancer is determined by cells' environment," says Paul Davies, a physicist at Arizona State University who studies the evolutionary origins of cancer. "It is nature versus nurture again, and it looks like the latter is at least as important as the former." (Davies expands on this point elsewhere in this special issue in his article "Exposing cancer's deep evolutionary roots", pp37–40.)

Malignant breast cells usually clump together in amorphous lumps, but Bissell and colleagues at the Lawrence Berkeley National Laboratory in California have shown that such cells can be coaxed into forming spherical shapes, just as healthy cells do. They have done this by placing the cells in a gel that serves as a laboratory surrogate for the ECM and then manipulating the cells using chemicals known as inhibitors. These inhibitors disrupt the signalling in integrins – proteins that stick out either side of the cell wall and allow a cell to communicate with the ECM. However, their finding raised the question of how exactly this manipulation caused the spherical structures, known as acini, to form.

Enter physicist Kandice Tanner, who joined Bissell's group in 2008. Having specialized in imaging biological tissue during her doctoral and postdoctoral research, Tanner approached the problem using a technique known as confocal microscopy. This involves building up 3D images of objects, in this case cells, by scanning multiple thin sections of the objects using a small depth of field. Such 3D imaging allows cells to be suspended in a gel, avoiding the physical distortion that takes place when cells are mounted on slides during 2D imaging.

Using the fourth dimension – time – Tanner was able to track both healthy and (coaxed) malignant cells as they formed the acini. These spherical structures measure around a tenth of a millimetre across and inside the breast consist of two shells each containing a different kind of so-called epithelial cell – one to turn nutrients from the blood into milk, and the other



Science Picture Co/Science Faction/SuperStock

to contract the sphere in order to inject that milk into a network of ducts that connect with the nipple.

Playing back the images as a video, Tanner found something no-one had predicted. She saw that while forming acini the cells rotated. The process starts off with just one cell rotating, either clockwise or anticlockwise, at a rate of around one revolution an hour. That rotation is then maintained while the cell divides and its progeny in turn divide, leading to a coherent motion in which the 12–15 cells that eventually make up each of the (single-layered) acini rotate in step as a sphere.

To investigate the effect further, the group disrupted the rotation of cells by disabling a protein that regulates cell movement. This resulted in cells that no longer rotated but instead moved in a random motion and formed loose aggregates rather than spherical acini.

A cause of disagreement

The results appear clear cut. However, the interpretation does not. A press release accompanying the researchers' paper, published in 2012 (Tanner *et al. PNAS* **109** 1973), confidently stated that the researchers had "discovered a rotational motion that plays a critical role in the ability of breast cells to form the spherical structures". It is not clear, however, whether the links between the rotation and the formation of acini, and between acini formation and non-malignancy, are causal or are simply correlations, and, if they are causal, in which direction the causality acts.

"This work may eventually provide some insight into how cells create complex structures," says Robert Weinberg, director of the Ludwig Center for Molecular Oncology at the Massachusetts Institute of Technology. "The processes described in this paper appear to be disrupted in cancer cells. However, it's a real stretch to conclude that this represents a cause of cancer rather than one of the multiple consequences of normal cells undergoing transformation into tumour cells."

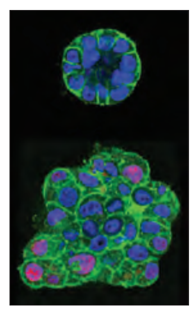
A big help in interpreting the results would be a well-founded model. Tanner says that the cellular rotation is "like a spider spinning its web, with the cell remodelling the matrix and setting up a roadmap to guide successive divisions". But as of yet she is not sure why exactly such a process would produce spherical structures.

Davies believes that the explanation is unlikely to be purely physical, such as the direct action of an apparent centrifugal force, but thinks it is instead probably mediated by biology – pointing out that mechanical forces can switch genes on and off. On the other hand, biophysicist Stuart Lindsay, also at Arizona State University, thinks the answer could actually lie in simple geometry. But he admits he is making only a well-informed guess.

Biology's limits

Lindsay in fact regards anyone attempting to create biological theories as "extremely optimistic", adding that he prefers to "go and measure" as well as he can.

Davies too says "there is no such thing as theoretical biology", arguing that within biology "there are no obvious underlying principles" (with the exception of Darwinian evolution), but, he says, "just a load of special cases". He explains that drawing out patterns is made difficult by the individual nature of cells, but he remains optimistic that physicists can help to improve things. "Biologists trawl through facts looking for correlations," he says. "But the great thing about physicists is that they can connect the dots. They are trained to spot significant facts amid a welter of detail." While it is not possible to say that the non-rotation of breast cells causes cancer, Tanner's work nevertheless sheds some light on the behaviour of cancerous and non-cancerous cells. ■

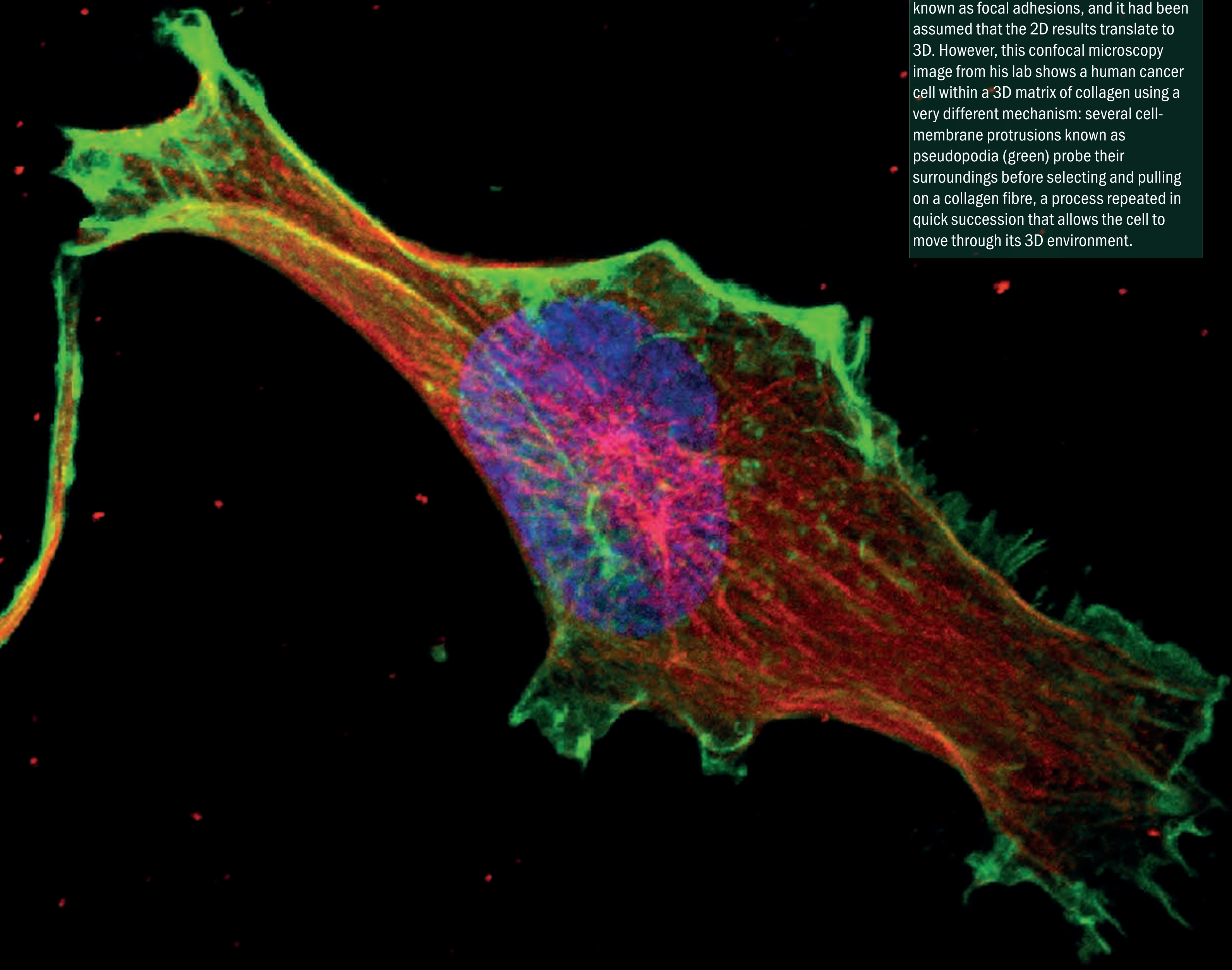


Fletcher Lab, University of California, Berkeley

Good and bad
A healthy-looking acinus compared with an amorphous structure.

Life in 3D

Cancer researchers used to look at cells under the microscope by mounting them on glass slides – a 2D environment. But as we now know that the physical environment significantly affects the behaviour of cancer cells, scientists are looking again at their properties by suspending the cells in 3D gel-like environments that more closely resemble conditions inside the human body. One researcher exploring 3D behaviour is Denis Wirtz at Johns Hopkins University. Previous studies have shown that cells move in 2D using protein clusters known as focal adhesions, and it had been assumed that the 2D results translate to 3D. However, this confocal microscopy image from his lab shows a human cancer cell within a 3D matrix of collagen using a very different mechanism: several cell-membrane protrusions known as pseudopodia (green) probe their surroundings before selecting and pulling on a collagen fibre, a process repeated in quick succession that allows the cell to move through its 3D environment.



Denis Wirtz

Killing me softly

Anne Weston, LRI, CRUK, Wellcome Images

A nanomechanical signature of cancer cells at different stages of progression, measured using atomic force microscopy, could have diagnostic and prognostic potential as **Philip Ball** reports

Cancer is as much a problem of biophysics as of biochemistry. Disruptions in the cell cycle – the series of biochemical changes that lead to cell division and growth – are only the start of the problem, leading to unchecked proliferation of rogue cancer cells. This generally only becomes life-threatening if tumours "metastasize", meaning that the cells spread to other parts of the body. This journey puts them through some extreme contortions as they detach, migrate and find new homes. With metastases being the cause of 90% of human cancer deaths, it is crucial to understand the mechanical properties of cancer cells, and how these change as cancer progresses.

At the University of Basel in Switzerland, nanobiologists Marija Plodinec, Roderick Lim and their colleagues are attempting to get to grips with this issue by prodding and pulling on cancer cells using the nanoscale needle-like tip of an atomic force microscope (AFM). In doing so, they have found that the different stages in the development of cancer are marked by distinct shifts in the stiffness of the cells (M Plodinec *et al.* 2012 *Nature Nanotech.* **7** 757). Not only could this insight offer a new tool for diagnosis, but it could also ultimately supply a means of making a medical prognosis – that is, forecasting how a tumour might evolve.

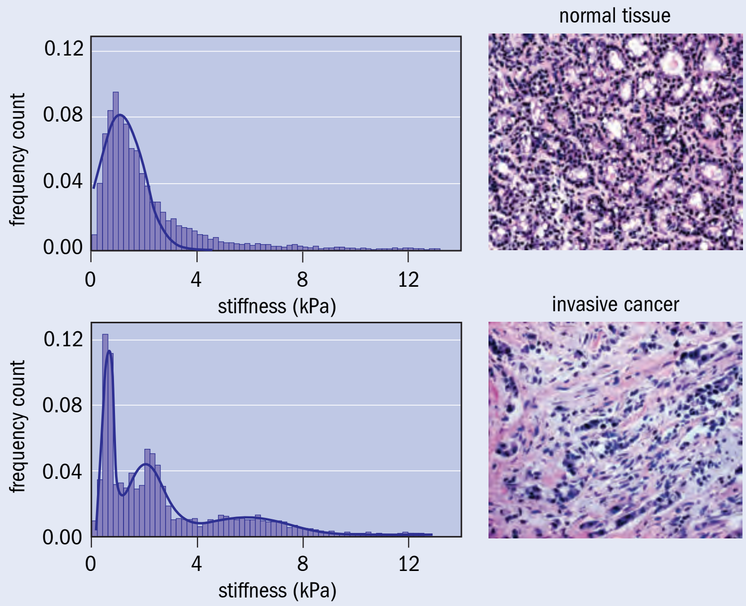
Spreading strategy

Metastasis shows cancer cells at their most insidious. Once a tumour has grown and developed its own system of blood vessels, the production of proteins called cadherins that stick cells together may decline, allowing some cells to become detached from the mass. These breakaway cells can then move through the extracellular matrix – the fibrous web of collagen and other ingredients that binds tissues together – until they reach a blood vessel.

Here a cancer cell will squeeze its way between the cells of the vessel wall and enter the bloodstream, which may carry it far from the original tumour.

Philip Ball is a science writer and journalist based in London, UK, e-mail p.ball@btinternet.com

1 Nanomechanical signatures of human breast tissue



Adapted with permission from Plodinec *et al.* 2012 *Nature Nano.* 10.1038/nnano.2012.167

A type of atomic force microscopy, which pushes a needle-like probe into samples to measure their stiffness, was used to characterize healthy (top) and malignant (bottom) human breast biopsies. Multiple measurements were made across the entire biopsies; the resulting histograms show the frequency of occurrence of each stiffness value measured. Healthy tissue shows a single stiffness peak representative of normal cells. Malignant tissue shows at least three stiffness peaks, the origins of which were identified using dye-staining techniques. The largest peak corresponds to cancer cells that are softer than normal cells, while the smaller peaks are the result of types of connective tissue. Images on the right show the healthy, and tumour-cell-dominated, appearance of the samples.

Eventually the cell will stick to the vessel wall again and squeeze its way out to seed a new tumour. The problem of unchecked tumour growth then changes from a local to a global problem in the body.

Tumours are notoriously stiff, forming a hard lump. But, seemingly paradoxically, it has become clear over the past decade that cancer cells themselves are more soft and compliant than normal tissue cells. According to biophysicist Denis Wirtz of Johns Hopkins University in Baltimore, Maryland, this decrease in cell stiffness is a ubiquitous feature of cancers, despite the huge differences in molecular pathways that might be involved. As such, it could be an indicator of some very general mechanism that makes tumours lethal.

Soft signature

Last year, Lim and colleagues measured the mechanical behaviour of human breast cancer cells acquired from biopsies. In their experiments, they pressed down on tissue samples with the AFM, probing many different areas, each about 20 by 20 μm across (containing three or four cells along with the extracellular matrix in which they are embedded) and measuring the depth of the indentation. For a given applied force, the deeper the tip sinks into the tissue (typically 150–3000 nm), the softer the tissue is.

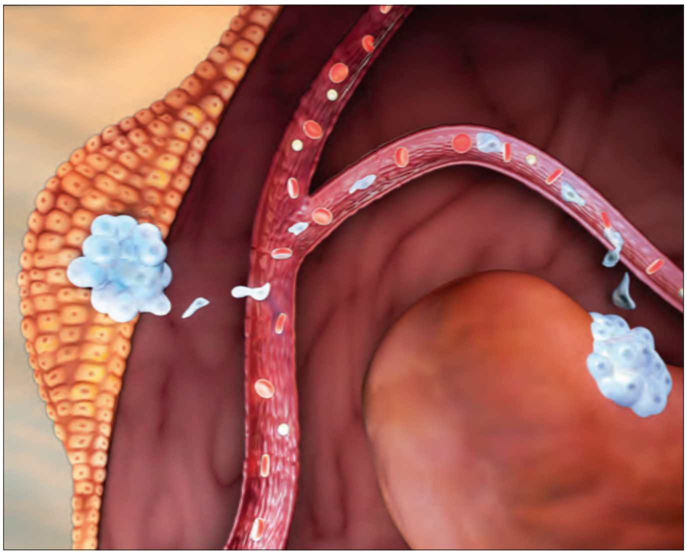
The researchers found that different types of cell had quite different mechanical signatures. After repeated measurements, the team plotted graphs of the frequency of occurrence of the stiffness values they measured (figure 1). A healthy sample produced a single stiffness peak with a roughly bell-shaped distribution of values, owing to slight, natural variations in the properties of healthy cells. But measurements from a malignant, invasive tumour showed more complex behaviour, with at least three peaks in a broad distribution. The biggest peak corresponded to a stiffness less than that of healthy cells, and by using standard histological techniques that stain particular cell types with a dye, the researchers established that this soft peak represented cancer cells. (The other peaks corresponded to connective tissue.)

So how do these properties change as a tumour metastasizes? In humans there are wide variations in how a cancer progresses, depending for example on genetic differences. So to obtain more uniform responses, Lim and colleagues switched instead to a strain of mice widely used as an animal model of human breast cancer, which are genetically identical and engineered to be prone to mammary tumours. They found the same kind of bell-shaped stiffness distribution for healthy mouse mammary-gland tissue, but as a tumour reached the "premalignant" stage at which cells have begun to change but not yet become malignant, the peak began to split in two. By the time the tumour became cancerous the distribution had two distinct peaks, with a large proportion of abnormally soft cells. At the same time, such tumours get stiffer overall. Lim and colleagues found that this stiffness was confined to the outer parts of the tumour, where there was a build-up of collagen in the extracellular matrix.

What do these mechanical changes tell us about the progression of biochemical events inside tumour cells? James Glazier, director of the Biocomplexity Institute at Indiana University, points out that, when cells are proliferating rapidly and unchecked, natural selection kicks in to favour particular cell types. Evolutionary pressures that lead to softer cells might thus be the agency by which cancer cells become lithe enough to slip through blood vessel walls and spread through the body.

As for what causes that selection, Lim's studies have revealed a clue: the soft cancer cells have relatively little oxygen (they are hypoxic). "It is these soft hypoxic cancer cells that successfully metastasize from the primary tumour in late stages of malignancy," says Plodinec, who is a postdoc in Lim's lab. The response to oxygen deficiency in the tumour might help to select flexible, mobile cells. "Any cell that can move far enough to escape a dead zone before it dies is favoured," says Glazier. "Unfortunately for us, these mechanisms also allow cells to metastasize. From this viewpoint, metastasis is an epiphenomenon, an accident of the selection pressures within the tumour."

But Wirtz is not convinced that softness is necessarily the most crucial aspect that leads to metastasis. He says that one of the robust features of metastasizing tumours is their diversity of cell properties. That fits with Lim's observations of a broader, multi-featured distribution of stiffnesses, but Wirtz thinks that metastasis might be more a question of tumours shedding many different cell types. "Millions of cells



Gunilla Elam/Science Photo Library

Splinter cells Artwork showing cancer cells (blue) migrating from a tumour (left) into the bloodstream and to another organ where they form a secondary tumour.

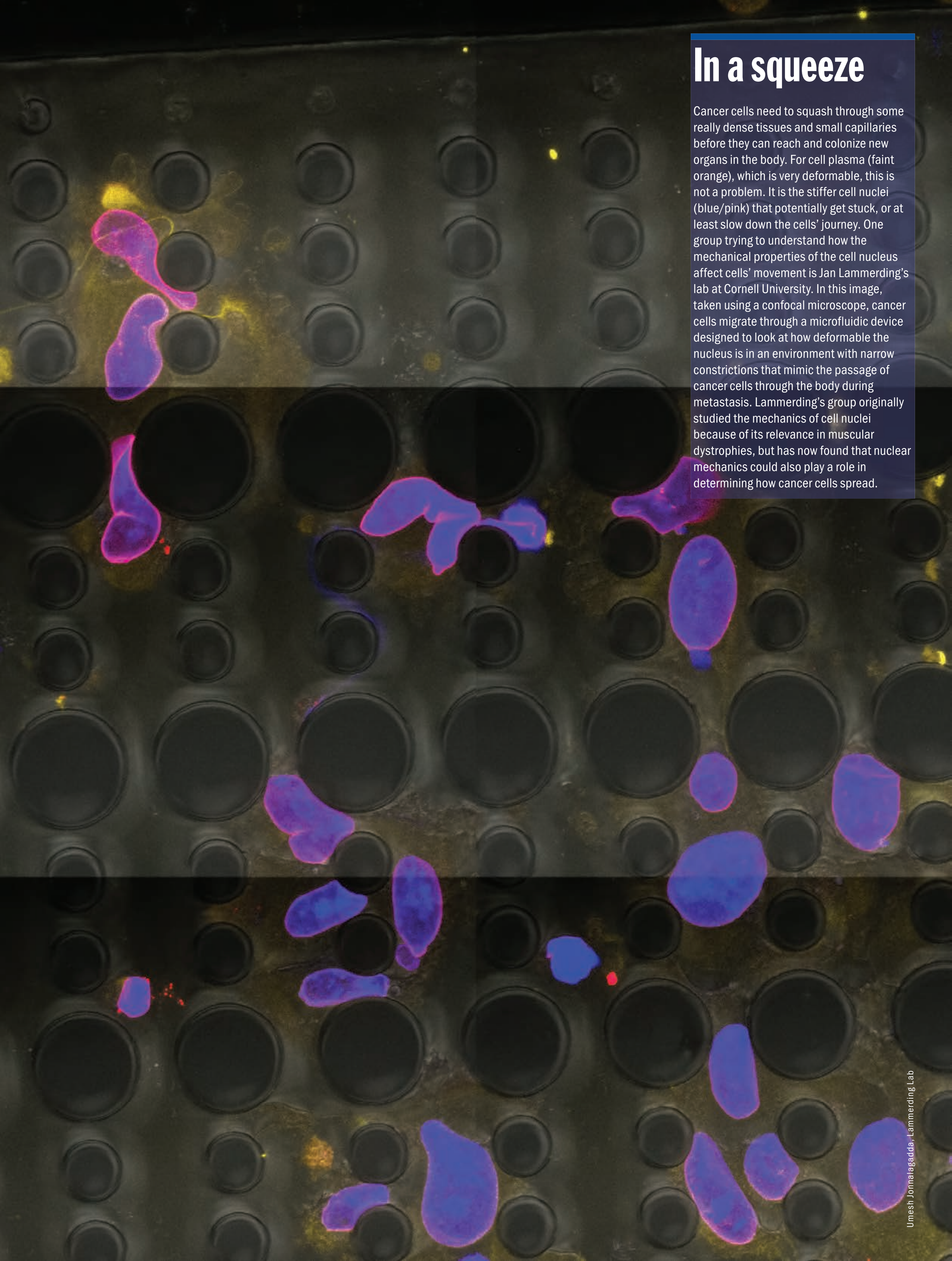
are shed each day from a tumour site, and most don't make it to a secondary site," he says. "I suspect it won't be the case that the most compliant are actually the most invasive." He hopes Lim's group might be able to test that prediction by isolating cells with different mechanical properties.

Prognostic potential

According to Robert Ros of Arizona State University, who has also used AFM to study cancer cells, such nanomechanical experiments "have a huge potential to build up knowledge about changes in cell mechanics during cancer progression". However, he is sceptical about whether AFM can be used as a diagnostic tool. "Cells typically show a large heterogeneity in the mechanical properties, which would require time-consuming measurements on a large number of them," he says.

But the Basel team is more optimistic. In partnership with the Swiss AFM company Nanosurf, Lim, Plodinec and their colleague Marko Loparic have developed the method into a standardized tool called ARTIDIS ("automated and reliable tissue diagnostics"). The nanomechanical method works with a broad range of tissue types, and might be applied to study other diseases too: the first ARTIDIS system has been installed at University Hospital Basel's eye clinic to collect data on retinal diseases.

As well as helping to understand how cancer develops, what everyone wants to know is if these observations offer new directions for forecasting its development and perhaps even arresting it. Prognosis is the key to effective treatment regimes, and Lim's team thinks that the onset of cell softening could add to the battery of biochemical techniques currently used. "Classical methods have no means of providing an early diagnosis for metastasis," says Plodinec. But using their approach, she says, "metastatic potential might be deduced at the primary tumour level, allowing physicians to intervene with therapies that prevent metastasis from occurring. Simply, more lives might be saved". ■

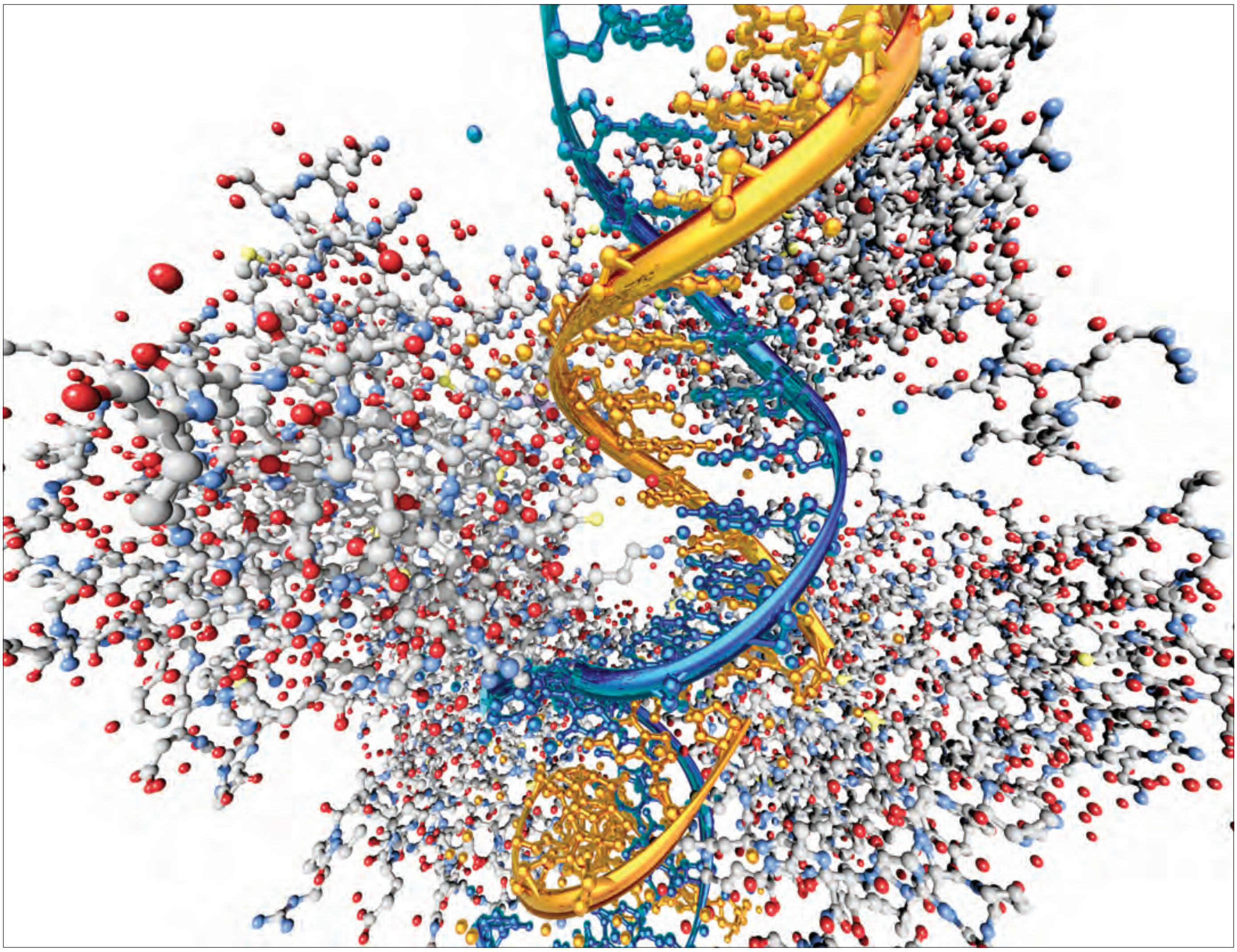


In a squeeze

Cancer cells need to squash through some really dense tissues and small capillaries before they can reach and colonize new organs in the body. For cell plasma (faint orange), which is very deformable, this is not a problem. It is the stiffer cell nuclei (blue/pink) that potentially get stuck, or at least slow down the cells' journey. One group trying to understand how the mechanical properties of the cell nucleus affect cells' movement is Jan Lammerding's lab at Cornell University. In this image, taken using a confocal microscope, cancer cells migrate through a microfluidic device designed to look at how deformable the nucleus is in an environment with narrow constrictions that mimic the passage of cancer cells through the body during metastasis. Lammerding's group originally studied the mechanics of cell nuclei because of its relevance in muscular dystrophies, but has now found that nuclear mechanics could also play a role in determining how cancer cells spread.

Umesh Jonnalagadda, Lammerding Lab

Exposing cancer's deep evolutionary roots


iStockphoto/Martin McCarthy

Paul Davies argues that cancer is an ancient genetic program present within us all, with roots in the dawn of multicellularity over a billion years ago

"The miracle of life." To a physicist, life does seem almost like magic. Faced with the sheer complexity of the living cell, many physicists feel bewildered. Yet some biological processes are remarkably deterministic. The development of the embryo is one. Cancer is another. Although there are inevitable patient-by-patient variations in the progression of cancer, generally speaking, once it is initiated the disease follows a depressingly predictable trajectory.

When a physical process follows a pattern, physicists can bring valuable insights from their discipline. Recognizing this, in 2009 the US National Cancer Institute created 12 centres for physical science and oncology in an effort to identify radically new approaches to cancer research and treatment.

When I was asked to lead such a centre, I knew almost nothing about cancer. My background in fundamental theoretical physics and cosmology prompted me to start with the basics. First of all I simply wanted to know what cancer is – how it is

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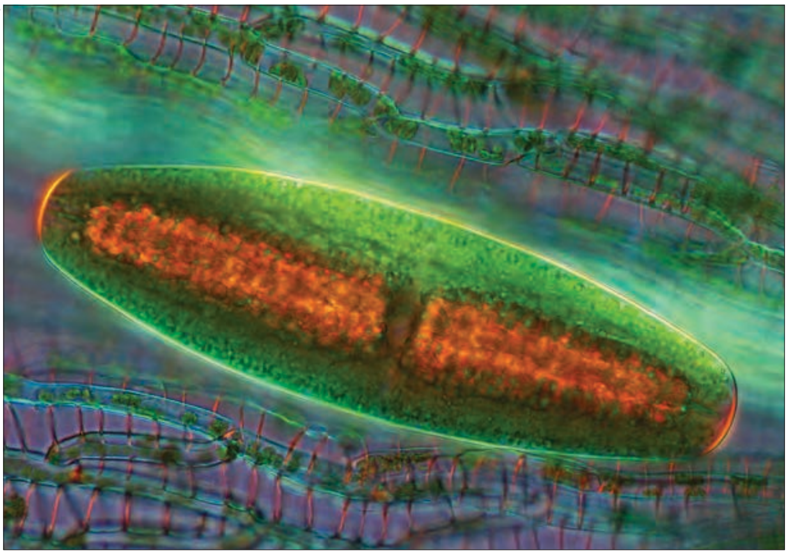
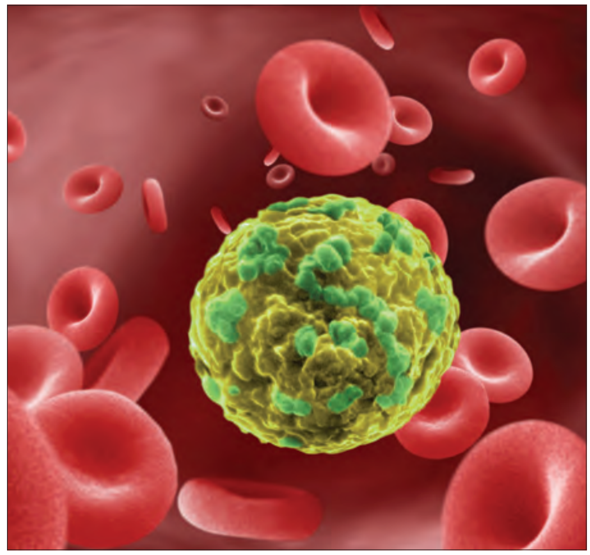


Marek Mis/Science Photo Library

Selfish cells Single-celled organisms act to preserve themselves, while cells in multicellular organisms act for the greater good.



Annie Cavanagh, Wellcome Images

Hitching a ride Cancer cells can become mobile and travel in the bloodstream to invade other organs.

defined. I then pondered what causes its distinctive hallmarks and predictable progression, and what physical parameters control its properties and behaviour. Meanwhile, I began thinking about why cancer exists at all and what its place is in the grand story of life on Earth.

Such questions are rarely asked by oncologists or cancer biologists, who mostly focus on the human disease aspect and are caught up in the frantic and expensive search for an elusive "cure".

A disease of the genes?

I soon learned that cancer is widespread among mammals, birds, fish and reptiles, suggesting it has deep evolutionary roots stretching back at least hundreds of millions of years. In fact, its prevalence in multicellular organisms implies it is deeply embedded in the logic of life. The genomes of nearly all healthy human cells, containing the entirety of an individual's inherited information, evidently come pre-loaded with a "cancer sub-routine" that is normally idle but can be triggered into action by a wide variety of insults, such as chemicals, radiation and inflammation.

Once initiated, most cancers follow a pattern. Cells first proliferate uncontrollably in a particular organ (cancers are specific to organ types) forming a tumour or "neoplasm" (new cells). After a time, some neoplastic cells become mobile, leave the tumour and spread around the body, invading and colonizing other organs. This process is called metastasis and accounts for 90% of cancer deaths.

To accomplish their journey, cancer cells mostly hitch a ride in the bloodstream or lymphatic system. In doing so they face formidable challenges – they tunnel through tissues, squeeze through membrane barriers and experience highly varying sheer stresses once inside the vessels. To cope with such trials, cancer cells systematically deploy many specialized properties and functions.

Evidence is mounting that the micro-environment at the cells' destination plays a key role in the success of metastasis. Primary tumours send out chemical cues into the body to "prepare the ground" for the invasion, and metastatic tumours create cancer-friendly niches by recruiting and adapting healthy cells. The disseminated neoplasm can display long-range organized behaviour that suggests a command-and-control, system-wide communication network mediated by various physical and chemical signalling mechanisms. The overall impression is of a carefully orchestrated and pre-programmed strategy – its aim to multiply cancer cells and colonize new sites – which is unleashed when neoplastic cells somehow evade the normal regulatory mechanisms of the organism and embark on their own agenda.

Whenever one encounters highly organized and efficient behaviour in biology, a ready explanation lies at hand: Darwinian evolution. Orthodox explanations suppose that cancer results from an accumulation of random genetic mutations, with the cancer starting from scratch each time it manifests, and over a period of several years evolving survival traits within the host under the pressure of selection by the body's defences. Viewed this way, cancer is a disease of the genes that produces an aberration of normal cellular function – rogue cells running amok and developing their own agenda, which conflicts with that of the host organism. And it is true that many cancer cells are genetic monsters, with deranged and sometimes duplicated chunks of DNA, grotesquely malformed and swollen nuclei and wholesale rearrangements of their chromatin (genetic material).

The standard explanation leaves many puzzling questions, however. If the genetic mutations are random then the cells ought to be highly defective and vulnerable, yet paradoxically they are often fitter than healthy cells. There is no obvious reason why random mutational accidents should just happen to confer a whole series of mutually supportive survival traits in the same neoplasm, conveniently manifesting themselves in a period of just years or months. Cancer dormancy is also perplexing; in most cases, cancer (of the same organ variety) eventually returns, sometimes years or even decades after removal of a primary tumour, having somehow lain harmlessly quiescent somewhere in the body. Just what awakens it is a mystery. Another question is why cancer cells deliberately transplanted into certain tissues, or cancer nuclei into healthy cells, often results in normal behaviour. Conversely, normal nuclei implanted into cancer cells often become cancerous.

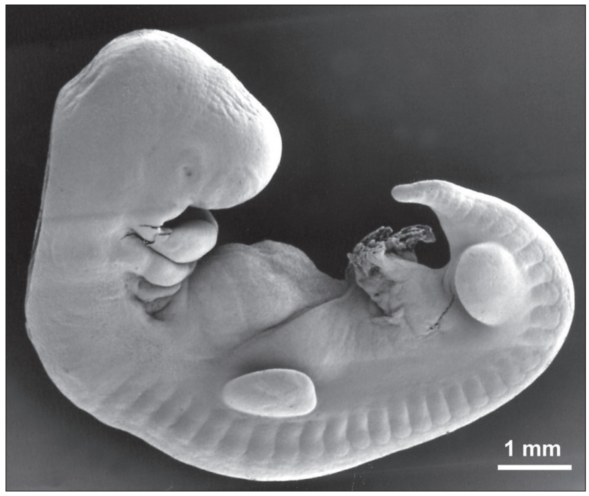
From a physics perspective, there are clues pointing to cancer as a phenomenon influenced by forces and fields – not one that is purely ruled by genetic instructions. It is fascinating, for example, that the Young's modulus of cells changes as cancer progresses, sometimes dramatically (they are generally softer), while the stiffness of the tissue that cells touch can affect their gene expression – a process known as mechano-transduction. Even more tantalizing is that electric potentials, across cell and mitochondrial membranes as well as through tissue, serve as an organizing field that affects both healthy and malignant behaviour.

All this adds up to a serious problem for the standard genetic model of cancer. While nobody would deny that genomic changes play some sort of role in driving the cancer phenotype (i.e. the physical tissue that results from expressing the information in the genes), at least as much weight must be given to environmental factors. This subject is collectively known as epigenetics and encompasses the effects of physical properties such as tissue architecture, elasticity and electric potential.

An ancient subroutine

To address these puzzles, Charles Lineweaver of the Australian National University and I have proposed a very different theory of cancer. Biologists agree that cancer is a breakdown of the contract between individual cells and the organism. This contract dates back to the dawn of multicellularity, over a billion years ago. Single-celled organisms replicate by division and are in a sense immortal. In multicellular organisms, immortality is relinquished and the genetic legacy of the organism is outsourced to specialized sex cells – eggs and sperm – known as the germ line. Although all cells in multicellular organisms have the same DNA, most of them differentiate into specific types – kidney, brain, muscle, etc. These are known as somatic cells, and they eventually die, for the greater good of the organism and its germ line. Somatic cells demonstrate this altruism every day in the phenomenon of apoptosis, or programmed cell death, which occurs after damage to a cell or as a result of ageing. But policing this contract is hard work, and requires complex regulatory mechanisms. If cells start to cheat, abandoning the ancient covenant by refusing to apoptose, then runaway proliferation results and a neoplasm forms.

Lineweaver and I build on this uncontroversial concept, but go much further by bringing insights from evolutionary biology, microbiology and astrobiology. (In this endeavour, we are collaborating with the NASA Astrobiology Institute.) In a nutshell, we agree that cancer is a type of throwback, or atavism, to an ancestral phenotype. Cells are usually regulated by mechanisms that instruct them when to multiply and when to die. What we believe is that when these mechanisms malfunction, the cells revert to the default option, a genetic subroutine programmed into their ancestors long ago, of behaving in a selfish way. To use a computer analogy, cancer is like Windows defaulting to "safe mode" after suffering an insult of some sort.



University of New South Wales

Building on the past This typical four-week-old human embryo looks similar to fish embryos, with proto-gills and a tail.

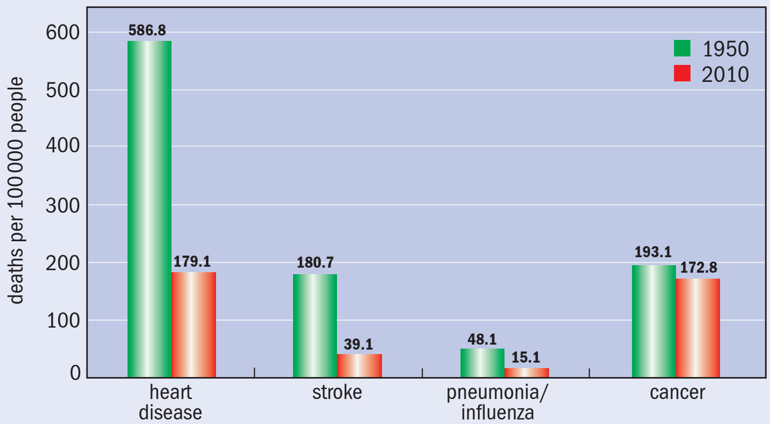
Our atavism theory appeals to the fact that the genomes of the organisms we see today retain traces of their evolutionary past. This is sometimes made strikingly apparent when humans are born with a tail or extra nipples, or dolphins with four fins instead of two, expressing ancestral phenotypes.

Ancestral genetic pathways will be preserved only if they continue to serve a useful purpose. One such purpose involves embryogenesis. When a fertilized egg develops, much of the basic body plan is laid down in the early stages. Because all animals share an evolutionary past, early-stage embryos bear clear resemblances to each other: even human and fish embryos show obvious similarities such as proto-gills and a tail. This is no surprise. Evolution builds on what has gone before (our remote ancestors were fish), and ancient features that have stood the test of time will likely be recapitulated. Altering or abandoning the ancient foundations of the developmental programme would fatally compromise the embryo's development. Very roughly, the earlier the embryonic stage, the more basic and ancient will be the genes guiding development, and the more carefully conserved and widely distributed they will be among species.

Another feature of embryonic cells relevant to our theory is that they start out "pluripotent" – they

To use a computer analogy, cancer is like Windows defaulting to "safe mode" after suffering an insult of some sort

A stubborn killer



The proportion of people dying from heart disease, stroke and pneumonia or influenza fell sharply between 1950 and 2010. However, the death rate from cancer has remained largely unchanged over the same period. The figures shown here relate to the US, although the story is similar in most other nations where reliable data exist. The data have been adjusted to reflect changes in the US age profile. Source: National Center for Health Statistics

remain capable of forming cells of any organ. As the embryo develops, so most cells differentiate step by step into their terminal forms (brain, lung, kidney, skin, etc). Although all cells in an organism possess the same genes, as differentiation proceeds, different genes get switched off and silenced, leading to different cell types being manifested. However, so-called stem cells retain a measure of pluripotency, and are present even in the adult form in order to replenish fully differentiated cells that are lost by ablation, damage or simply by ageing and undergoing apoptosis.

Lineweaver and I suggest that genes that are active in early-stage embryogenesis and silenced thereafter – which, by our hypothesis, are generally the ancient and highly conserved genes – may be inappropriately reactivated in the adult form as a result of some sort of insult or damage. This trigger serves to kick-start the cascade of maladaptation events we identify as cancer. So the "cancer subroutine" is really just a re-run of an embryonic developmental program. We envisage a collection of ancient conserved genes driving the cancer phenotype, in which the metastatic mobility of cancer cells and the invasion and colonization of other organs merely reflects the dynamically changing nature of embryonic cells and their ability to transform into different types of tissues.

The big picture is that we attribute cancer's survival traits to deep evolution on a billion-year scale, rather than orthodox explanations that point to evolution from scratch with each case of the disease. In our theory, the latter remains true, but is a small perturbation.

Mounting evidence

Evidence for deep links between embryogenesis and tumorigenesis have come from several experimental studies. Isaac Kohane, a paediatrician who specializes in bioinformatics, and his colleagues at Harvard University have identified a pattern of genes that are switched on in most cancers and shown that this same signature is active in early embryo development. John Condeelis, a biophysicist at Albert Einstein College of Medicine in New York, has demonstrated that invasive cancer cells have a gene expression profile resembling that of embryo tissue development.

Further evidence that supports our theory comes from experiments in which the nuclei of egg cells are replaced with cancer-cell nuclei. Astonishingly, embryos start to develop normally. But abnormalities eventually appear, at earlier stages when the cancer is more malignant (advanced). This inverse correlation of cancer stage with embryo stage is consistent with our theory. Cancer is rarely an all-or-nothing affair. Once it is initiated, it tends to follow a well-defined progression of accelerating growth, mobility, spread and colonization. Lineweaver and I envisage cancer progression within a host organism as like running the arrow of biological evolution backward in time at high speed. As the complex regulatory mechanisms of the body break down, the cancer defaults to earlier and earlier phenotypes, with the most malignant cells representing the most ancestral forms.

If we are right, the various distinctive hallmarks of cancer ought to map inversely onto the evolutionary tree of life. For example, cells display surface adhesion molecules called cadherins to help them stick together. As cancer progresses, the cadherin gene expression changes to a more ancient type. There are, in fact, many types of cadherin among multicellular organisms, and we predict that this backwards-in-time function of cancer stage will be seen in some of these too.

There is a quite different additional link between cancer and early forms of life. Cancer cells tend to adopt an ancient mode of metabolism known as fermentation, or glycolysis, which takes place in the cytoplasm of the cell. In contrast, healthy cells mostly use a process known as oxidation-phosphorylation, or ox-phos, which is performed within tiny organelles called mitochondria. The characteristics of fermentation are its ability to flourish in low-oxygen conditions (hypoxia), its high demand for sugar (glucose) and a low-pH environment – all conditions characteristic of tumours. Could it be, we wonder, that cancer's predilection for a hypoxic environment reflects the prevailing conditions on Earth at the time when multicellularity first evolved, before the second great oxygenation event?

Cancer touches every family on the planet and is a growing health and economic calamity. Attempts to tackle it with toxins, radiation and surgery are often little more than a delaying tactic. Life expectancy for someone with metastatic cancer has hardly changed in five decades, despite all the hype about imminent "cures". It is clear that some radically new thinking is needed. Like ageing, cancer seems to be a deeply embedded part of the life process. Also like ageing, cancer generally cannot be cured, but its effects can certainly be mitigated – for example, by delaying onset and extending dormancy. But we will learn to do this effectively only when we better understand cancer, including its place in the great sweep of evolutionary history. ■

Reviews

Liz Kalaugher

More ice, less politics

National Science Foundation

Some nice ice Palmer Station in Antarctica, where much of the US Antarctic Program's research is undertaken.

The White Planet: the Evolution and Future of Our Frozen World
Jean Jouzel, Claude Lorius and Dominique Raynaud
2012 Princeton University Press
£19.95/$29.95hb

For a book with such a Tintin-style title, *The White Planet* is disappointingly short on daring tales of scientific adventure in the world of snow and ice. Billed as bringing "cutting-edge climate research to general readers through a vivid narrative", it actually seems more suited to early-stage graduate students looking to learn about the wealth of information that can be extracted from ice cores and the history of this research field. And the book does have value for this audience: its three co-authors, Jean Jouzel, Claude Lorius and Dominique Raynaud, were all involved in the early days of some of the analytical techniques and ice-drilling expeditions they describe, and they are clearly passionate about their work.

But sometimes, this very expertise can be a hindrance. In places, *The White Planet* reads like a watered-down academic paper, with sentences that do little more than string together lists of dates, locations and drill depths achieved. The fact that the book is translated from French probably does not help; at one point the reader is told that meetings on a particular project move "alternatively" between Russia, France and the US, instead of "alternately". *The White Planet* also lacks a clear narrative thread and feels, in parts, like three or four textbooks sandwiched together.

After a fairly dry overview of the Earth's ice regions (which reads almost as if the authors were asked to bolt on an introduction for the layperson), the book quickly moves on to discuss its authors' real passion: glacial ice archives and what can be learnt from them. By drilling out ice cores roughly 10 cm across to depths of thousands of metres, scientists can build up a picture of past climate – the age of the ice increases the deeper they drill. Analysing the ice, trapped air and impurities such as volcanic ash or dust using parameters including isotope ratios, electrical conductivity and chemical composition provides information on a huge range of factors such as past temperatures, sea level, atmospheric composition, volcanic activity and solar variability. These reconstructions can go back hundreds of thousands of years.

The section on these ice cores reads more fluently than the introduction, but it lacks the sort of personal anecdotes from the authors that could have brought colour to their narrative. They must have been on many a polar trip, but only once do they come close to offering a personal insight into conditions. The big moment comes when they describe the "scientific trench" set up under the snow to investigate freshly removed ice cores for the Greenland Ice Core Project, which began drilling in 1990. Vital in the summer, when sunshine could lead to above-zero temperatures at the surface, the scientific trench remained at –15 °C and was, apparently, "a hive of activity in which about 40 people happily worked together". It is also disappointing that a book on such a potentially image-rich subject contains only two photographs: the cover image of New Zealand's Fox Glacier and a shot of air bubbles trapped in ice. Otherwise, expedition life is illustrated with black-and-white sketches, which cannot offer much realism. Employing simple analogies and providing basic explanations of technical terms would also help the non-specialist reader enormously; the use of the term "geothermal flux", for instance, without further introduction, is likely to scare many off.

Had *The White Planet* been promoted as an introductory graduate text, this would have been fine, but the authors seem keen to get their message about ice and what it tells us about the Earth's past and future climate to a wider audience. "Climate warming is one of the great challenges facing our civilization today, and the polar ice is a witness to and an essential actor in it," they write in their final chapter, adding that they hope that, as a result of their book, readers have become convinced that the destiny of polar regions is crucial for the planet.

Perhaps with this public outreach effort in mind, the later part of the book covers the history of the discovery of the greenhouse-gas effect, the Intergovernmental Panel on Climate Change and climate negotiations. It

They hope that readers will be convinced that the destiny of polar regions is crucial for the planet

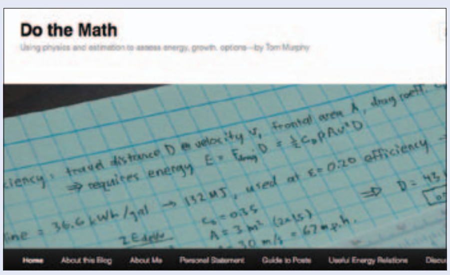
also examines the background to the 2007–2009 International Polar Year, takes a brief, if unexpected, foray into the history of pollution, and highlights promising areas of future cryospheric research. These include glacial ice coring that goes back at least 140 000 years in Greenland and 1.2 million years in Antarctica; reconstructing the climate of the last 40 000 years more precisely; almost year-by-year analysis of the climate of the last 2000 years; studying the biology of the subglacial Lake Vostok; and sampling at the Concordia base in Antarctica.

Along the way, the book provides an insight into the international politics behind the climate negotiations that took place in Bali in 2007 and Copenhagen in 2009. It also describes the politics of setting up large research projects. An ice-drilling programme at the Soviets' Vostok base in Antarctica, for instance, twice saw winter shutdowns because the station had not been restocked with fuel due to lack of funds after the fall of communism in the USSR. But arguably, there is too much detail about these political manoeuvrings and not enough context for general readers, who are likely to be less interested in the intricacies of running an international research collaboration than in the daily life of a scientist doing fieldwork in extreme conditions.

Despite its mis-labelling as popular science, the book does provide a valuable look at the science, history (at times it feels as if no researcher has been left un-name-checked) and politics of ice-core drilling and glacial-archive analysis. It will be of immense interest to those already involved in cryospheric science even if it is less successful in its stated mission of bringing a message to the general public. Read it if you are keen, but give it a miss if you're only mildly curious; a non-specialist reader who made it to the end would be likely to plead for more ice and less politics.

Liz Kalaugher is editor of *environmentalresearchweb*, a website produced by IOP Publishing to complement its journal *Environmental Research Letters*, e-mail liz.kalaugher@iop.org

Web life: *Do the Math*



URL: http://physics.ucsd.edu/do-the-math

So what is the site about?

Do the Math is a blog that "takes an astrophysicist's-eye view of societal issues relating to energy production, climate change, and economic growth," according to author Tom Murphy. A physicist at the University of California, San Diego whose main research project involves bouncing laser beams off the surface of the Moon, Murphy became interested in energy and the environment after teaching a course on the subject for non-science students. He has been blogging on energy-related themes since mid-2011, producing a total of 60-odd posts on topics that range from untapped sources of hydroelectric power ("How much dam energy can we get?") to strategies for keeping your tootsies warm in cold weather ("Heat those feet!").

What does it actually mean to take an "astrophysicist's-eye view" of this stuff?

Major ingredients in Murphy's writing include a focus on hard numbers, a healthy dose of estimation and what might be described as a "long view" on the relative importance of human civilization in the history of the universe. For example, the post on keeping your feet warm begins by modelling cold feet as a litre of water at 25 °C, which is approximately 12 degrees below normal body temperature. Next, Murphy works out how much energy it would take to rectify that 50 kJ deficit (based on the mass and specific heat of water – do keep up!) if you used hot water, a hair dryer, a heating pad or exercise as the means of heat transfer. We won't spoil the fun by revealing which of these methods uses the least energy, but the difference between the worst and best turns out to be more than an order of magnitude. Even by astrophysics standards, that's fairly significant.

What are some highlights?

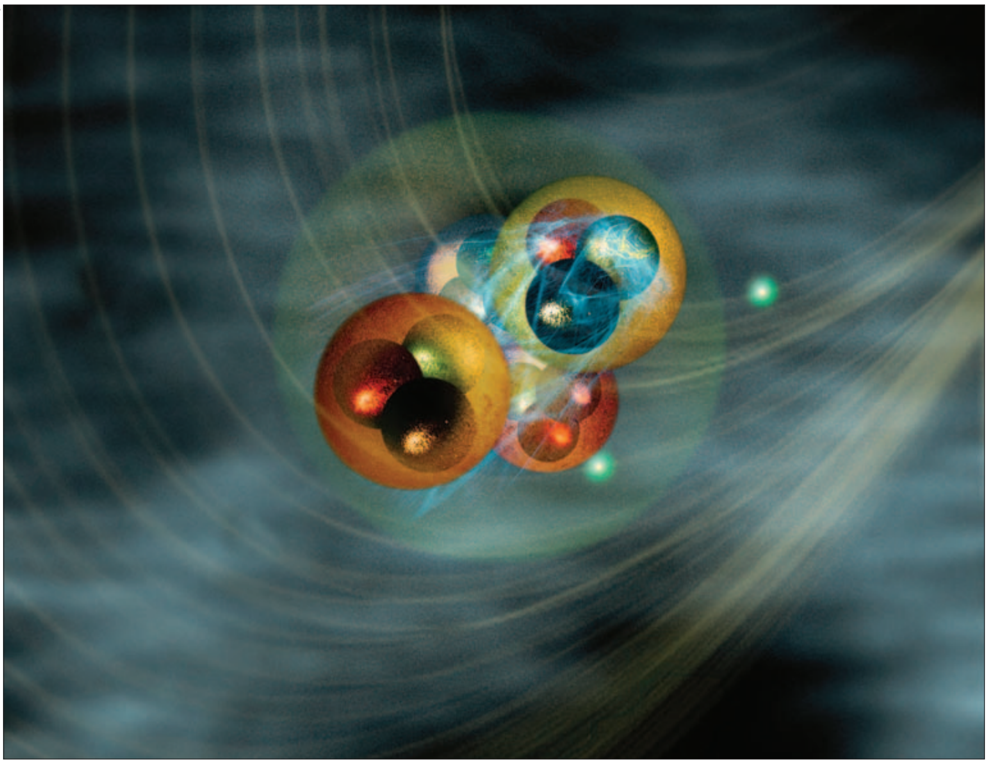
One of the most thought-provoking posts to appear on *Do the Math* so far (and also one of the most controversial) is "Exponential economist meets finite physicist". In it, Murphy describes a lengthy conversation he had with an unnamed economist at a dinner party. The conversation was a debate about whether physical principles place some kind of intrinsic (as opposed to practical) limit on economic growth, with Murphy arguing that they did and the economist disagreeing with him. Early in the discussion, Murphy wheeled out one of his favourite party tricks, which is to show that if human energy usage grows by just 2.3% per year – less than the average annual rate of growth in the US during its history, he notes – then in just 400 years, we will have pushed the Earth's average temperature above the boiling point of water. In other words, we'll cook ourselves. In Murphy's telling, at least, it was all downhill from there for the hapless economist – although as one commenter noted, it would have been nice to get the latter's perspective on the conversation, too.

Can you give me a sample quote?

This comes from the "personal statement" section of the blog, in which Murphy explains why he is so pessimistic about our energy future. "[We] have built a life of growth and prosperity based on a finite and soon-to-max-out resource with no equal replacement in sight. This is uncharted territory, and the fact that generations have experienced the fossil-fuelled upswing holds no predictive power over our future. Just because growth has been thematic does not mean it will always be so. The failure of most people to treat this possibility seriously is disheartening, because it prevents meaningful planning for a different future. We can all hope for new technologies to help us. But this problem is too big to rely on hope alone, and in any case, no practical technology can keep growth going indefinitely. I want to be clear that just because I am pointing out potential failure modes of our human endeavours does not mean that I am predicting a dismal future. It is clear to me that this can be avoided...The point of this blog is that we have to apply scientific scepticism to our lofty narratives so we aren't misled down a false garden path."

Richard Corfield

Exploring the initial conditions



Richard Kail/Science Photo Library

Star stuff
Yes, we are all made of it – but not helium, and Shubin's book explains why.

The Universe Within: a Scientific Adventure
Neil Shubin
2013 Allen Lane/Pantheon £20.00/$25.95hb 240pp

Despite being the second most abundant element in the universe, helium plays no role in the processes of life. The reason lies in its chemical structure: with no spare orbits in its outer shell of electrons, it cannot form the molecules of life. Oxygen and carbon, in contrast, have plenty of spare orbits in their electron shells, so life is based on these elements even though both are 20 times rarer than helium. The physical underpinnings of life are therefore hostage to the laws of physics.

This concept – and its central implication, that every organism alive today holds hints, within its organs, tissues and cells, of the long history of life on Earth and perhaps beyond – is one of the main drivers of Neil Shubin's book *The Universe Within*. There is nothing new in the idea itself, of course; Bill Bryson said as much, eloquently and amusingly, in *A Short History of Nearly Everything*. But Bryson is not a scientist, and for me, the best science writing is always done by those who are scientists first and journalists second. Shubin certainly fits this description. A palaeontologist at the University of Chicago as well as an accomplished popular-science author, he is responsible for one of the most important scientific finds of the last decade: the discovery of the fossil fish *Tiktaalik roseae*. This species of lobe-finned sarcopterygians from the late Devonian period (about 360 million years ago) has anatomical features of both true fish and four-limbed land animals, or tetrapods. Hence, Shubin is the discoverer of one of the most important of all missing links in the fossil record – the link that allowed the continents to be colonized.

The benefits of this experience are clearly on display in Shubin's enthusiastic and competent approach to the material in *The Universe Within*. Every sentence shows an intimate knowledge of the background to his field, leaving the reader with that most important sense of any reading enjoyment: authorial authority.

With its focus on ways in which the universe's long history has shaped the development of life, *The Universe Within* is in some respects a clever, updated and hyper-extended take on a theory that is almost as old as the theory of evolution itself: the theory of recapitulation. First propounded by the Prussian scientist Ernst Haeckel in the 1860s, this theory is based on the anatomically undeniable truth that, as organisms develop, they pass through stages that mimic the history of life through geological time. For example, both ape and human foetuses go through a stage in the womb in which they have gills. The mantra of the theory is "ontogeny recapitulates phylogeny" – that is, the gestation of a single organism parallels the evolutionary development of its entire species.

The interplay between ontogeny and phylogeny was a central interest of the late, great palaeontologist Stephen Jay Gould of Harvard University's Museum of Comparative Zoology. Since Shubin has a PhD from Harvard, perhaps it is no surprise that he reflects the interests of this greatest of all Harvard palaeontologists. However, Shubin takes the recapitulation idea much, much further, mixing in plenty of modern-day chemical and physical theory – including the comments about helium that opened this review – in an effort to extend it back to the evolution of the universe itself, as well as the development of the life forms in it.

As Shubin acknowledges, there is a limit to this kind of thinking, and the laws of physics only set out the ground rules for the grand drama that is evolution by means of natural selection. Here, once again, Shubin carries Gould's mantle, namely in his support for the importance of contingency (or chance, as I prefer to think of it) in mapping the course of evolution. Gould famously and controversially explained this theory with respect to the weird and wonderful fauna of the Burgess Shale, a rock formation that dates from the Lower Cambrian period, or about 560 million years ago. At that time, animals appeared on the sea floor that have no known descendants, either in the fossil record or in species that survive today. Evolution, Gould explained, was going through an experimental phase, throwing up new ideas and putting them out there to sink or (literally) swim.

Shubin takes this ball and runs with it, pointing out that our ability to perceive the colour red, for example, is probably a result of a random mutation that proved adaptively advantageous because it improved food acquisition. This, by the way, is an example of exaptation – another of Gould's pet theories.

At times, *The Universe Within* does read like a collection of essays (which was also Gould's staple form of popular-science communication) that has been rather uneasily super-glued into a single narrative. But for all that, Shubin's book is an entertaining read, and I quite liked the biographical vignettes that he throws in to leaven the science bread.

If you wish to sample the new palaeontology, in which fossils meet molecular biology and genomics against the backdrop of the deepest time of all – the 13-billion-year history of the universe – then *The Universe Within* is worth adding to your collection.

Richard Corfield is a freelance science writer based in West Oxfordshire, UK. His most recent book, *The Silent Landscape: in the Wake of HMS Challenger*, is now available as an ebook

Between the lines

Menagerie Theatre Company

Science for art's sake
David Meyer as an elderly Sir Isaac in the play *Let Newton Be!*, which has now been published along with essays about Newton.

Let Newton be!

Isaac Newton was not a fan of the theatrical arts. On the one occasion when he is known to have attended an opera, he ran away during the third act. So it seems fair to surmise that the father of gravitational theory would have absolutely hated Craig Baxter's play about his life, *Let Newton Be!* That, however, is no reason for the rest of us to avoid this excellent work. First performed in 2009 at Newton's own Trinity College, Cambridge, the play toured a handful of institutions in the UK and US in 2011; however, as a *physicsworld.com* reviewer argued at the time ("Newton's three body problem", 30 March 2011), it deserved a much wider audience. Fortunately, someone in the publishing world agreed, and the play is now available in book form as *The Isaac Newton Guidebook*. In addition to the text of *Let Newton Be!*, the guidebook also contains a series of scholarly essays on various aspects of Newton's life, introductions by both Baxter and Stephen Hawking and – best of all – a DVD of a performance by the splendid Menagerie Theatre Company. Probably the most useful of the essays is the one on Newton's feud with Leibniz. The nature of this dispute was so complex, wide-ranging and important that Newton novices should probably read the essay about it before watching the play. Other than that, though, this is not a work that requires much introduction. Just sit back and enjoy the spectacle as the three different actors who play Newton take you through his life, his works, and his famously difficult personality.

● 2012 Faraday Publishing £25.00/$40.00hb 176pp

Getting spammed

"Mail is easily deleted and so 'junk' mail is not really a serious problem." As an example of faulty prognostication, this statement – made in 1978 on a mailing list of ARPANET, the progenitor of today's Internet – surely ranks right up there with Lord Kelvin's supposed declaration that, by 1900, nothing new remained to be discovered in physics. The story of how junk e-mail, or "spam", evolved from a minor nuisance into a serious problem is thoughtfully and engrossingly told in *Spam: a Shadow History of the Internet*. Written by Finn Brunton, a historian of technology at the University of Michigan, US, the book is initially rather hardgoing, with clunky phrases such as "foundational ambiguities", "root paradigm" and "co-constitutive feedback loop" marring the introduction. However, once this little display of academic impenetrability is finished, Brunton the storyteller takes over. The rest of the book is pacey and packed full of interesting titbits, from the tale of the first commercial spam message (an advert for DEC computers that appeared on ARPANET on 1 May 1978), to an inside look at the professional spammers who plagued the loosely organized Usenet in the mid-1990s, and finally a sobering assessment of new forms of spam that seek to game search-engine algorithms. Like all good historians, Brunton is an interpreter as well as a narrator, skilled at placing facts in context. That ARPANET post about junk mail, for example, made sense at the time because its audience was a community of computer scientists, engineers, physicists and other defence experts who were used to collaborating and often knew each other personally. As Brunton puts it, the proto-Internet "was not the electronic frontier but a fairly small town, populated almost exclusively with very smart townspeople". Once that population expanded, old strategies for keeping noxious behaviour under control – including *ad hoc* flame wars and revoking offenders' access privileges – ceased to function. New ones had to be developed to replace them, and as Brunton explains, this is still very much a work in progress.

● 2013 MIT Press £19.95/$27.95hb 304pp

Alea iacta est

What does it mean for an event to be truly random? For science writer Brian Clegg, the answer depends on whether you are talking about classical randomness or chaotic randomness. As he explains near the beginning of his book *Dice World: Science and Life in a Random Universe*, classical randomness applies to things like roulette wheels and gambling dice: the outcome of a dice throw is uncertain, but it can be predicted using the standard tools of probability theory. Chaotic randomness, on the other hand, is the stuff of earthquake clusters, flapping butterfly wings and – in Clegg's view, at least – the mysterious alchemy that transforms a handful of books into bestsellers. These things, he explains, are not actually random at all in the classical sense, because they cannot be controlled and are not easily predicted. Once this distinction is established, the rest of the book takes the reader on a tour of various forms of randomness and the methods scientists and mathematicians have developed to describe them. In addition to relatively well-known pioneers such as Blaise Pascal and various members of the talented Bernoulli family, Clegg also highlights the work of some lesser-known contributors to the field, including the Italian scholar and gambler Girolamo Cardano (see May 2009 pp36–40) and John Graunt, a button-seller with a sideline in statistics who became a member of the Royal Society. A light, quick read overall, the book does get into some weighty material later on, when quantum randomness and Bayesian statistics enter the picture.

● 2013 Icon Books £12.99pb 288pp

Careers

Mixing physics and engineering

As an engineer in the naval-nuclear division of Rolls-Royce, **Steven Lawler** sees himself as an ambassador for physicists working in an engineering environment

Rolls-Royce

Flexible opportunity Steven Lawler uses both physics and engineering skills in Rolls-Royce's nuclear sector.

Rolls-Royce has been designing and manufacturing the nuclear heart of the UK's submarine fleet since the late 1950s. Over this period, the nuclear power plant inside the submarines has evolved many times, and the company's Raynesway facility in Derbyshire remains an exciting place to work. Here, engineers and physicists work together in a number of disciplines, from reactor physics to heavy-vessel manufacture, all with the aim of supporting current and future generations of the submarine fleet.

As a chartered engineer as well as a chartered physicist, I am fortunate enough to wear both "hats", and I am keen to promote the flexibility that the physicist offers to an engineering business. In an engineering environment, having a physicist's skills can provide an additional edge in creativity, problem solving and lateral thinking.

Planes, trains and automobiles

Like many other youngsters growing up in the 1970s, I found Carl Sagan's *Cosmos* TV programme inspiring, and my interest in understanding our universe started then. As a teenager I didn't really know what I wanted to do as far as a career, and in my case the default option was to follow my father, a self-employed engineer who committed himself to developing and growing his own business. He is now enjoying his retirement, and I look up to him just as much now as I did then; with such a role model, it seems inevitable that I would work in an engineering discipline. So after leaving school, I started my early career as a "technician apprentice" at a Birmingham firm, Metropolitan Cammell Weymann, which manufactured double-decker buses. The economic climate of the late 1980s forced the company to close down two years after I joined, but fortunately I was able to transfer my apprenticeship to the parent company, Metro-Cammell, which made railway rolling stock (including the then-new Channel Tunnel train). During this apprenticeship, I was also studying for a BTEC in mechanical engineering to get an academic foundation in engineering principles and skills that would tally with the practical experience I was gaining during the apprenticeship.

At the end of my apprenticeship, I was offered company sponsorship to get a degree in mechanical engineering, but although I was interested in engineering as a discipline, it was (and still is) some of the bigger questions about our universe that really inspired me – how it works, where we come from, where we are going, and so on. So instead, I studied for a BSc in natural sciences with physics.

After I graduated, I returned to the engineering world as a design engineer at a firm that made pumps for the automotive industry. At that time, computer-aided design (CAD) software was really beginning to take off, and I was trained on a number of CAD packages during the next few years. My role was very flexible and meant that I was immersed in a number of disciplines, including design, project management, prototyping and testing.

A few years later, I found a niche at Lucas Aerospace, a firm that designs and manufactures fuel control systems for both military and civilian aircraft and is now owned by Rolls-Royce as Aero Engine Controls. During my eight years there I progressed from design engineer to principal engineer and then lead engineer, when I developed my first management skills. My next move, in 2005, was to manage an engineering department at the aerospace transparencies business unit of GKN Aerospace – a career-changing event that gave me a significant amount of management experience. Then, in 2007, I saw an opportunity to use my physics skills at Rolls-Royce, and I took it with both hands.

New techniques, new people

Today, I lead a multidisciplinary team that develops advanced manufacturing and fabrication techniques for use within Rolls-Royce's nuclear sector. I am one of around 2500 employees in the submarines business unit of Rolls-Royce, and there is also a civil nuclear business unit.

The manufacturing systems we are developing as part of Rolls-Royce's "advanced concepts" team aim to improve manufacturing efficiency, deliver safe and high-quality products to our customers, and push the boundaries of current manufacturing and fabrication techniques. Due to commercial and security restrictions, it is not possible for me to describe our work in too much detail, but one technique is aimed specifically at the construction of nuclear components such as reactor pressure vessels. These large items have to be made of very thick steel due to their operating environment and the obvious safety considerations of the nuclear sector, and are produced from forged components that are fusion-welded together. At the moment, the complete construction of such a large vessel, including welding and inspection processes, can take several months, and one of the techniques we are developing is aimed at fabricating the entire vessel in just a handful of weeks. Clearly, this has the potential to make a huge difference to the lead time and costs required to build nuclear submarines.

Not many people in the business have the opportunity to push the boundaries in this way, and I am very fortunate to be in such an exciting role, and working for an energetic and dynamic business. It's a great job, and one that allows me to work with people across the whole business, as well as engaging with external industry partners and groups.

I recently completed an MSc in nuclear engineering with the University of Manchester and the Nuclear Technology Education Consortium (NTEC), with Rolls-Royce sponsorship – I didn't turn down the offer of a sponsorship opportunity this time! The degree has provided me with the nuclear engineering and science grounding to support my role, and also helped me touch base with my passion for physics.

There is a shortage of both engineers and physicists in engineering, and it concerns me that maybe this field isn't the "sexy" choice

Another big part of my job involves mentoring other employees, such as Rolls-Royce graduates and those coming through the nucleargraduates scheme (see January 2009 pp38–39). There is a shortage of both engineers and physicists in the engineering sector, and it concerns me that maybe this field isn't the "sexy" choice for school-leavers and graduates today. But without new blood coming through, then our manufacturing industry is doomed, so I see it as part of my responsibility to get physicists and engineers interested, motivated and excited about what we do. To do this, I volunteer some of my time as a member of the Institute of Physics panels for chartered engineer and chartered physicist. This also helps me keep in touch with what engineers and physicists are doing in other sectors, and I try to pass my knowledge on to people in the company who are working towards chartered status in their respective fields.

The nuclear sector in the UK is extremely dynamic at the moment, with a number of businesses gearing up in readiness for the "big push" to build new nuclear power plants. On the naval side, investment from the UK government and Rolls-Royce is being made for future submarine applications. All in all, it's a fantastic environment to be working in right now, regardless of your discipline – physicist, engineer, chemist, metallurgist or safety analyst.

Steven Lawler is an advanced concepts engineer at Rolls-Royce, e-mail steven.lawler2@rolls-royce.com

Once a physicist: Steven Mackey

Steven Mackey is composer and musician at Princeton University

What sparked your interest in physics?
I went to the University of California, Davis, and at first I was a pre-med major, studying to be a doctor. But that was a lazy decision on my part, because the only careers I knew about were doctor, lawyer and rock star (and I was already an aspiring rock star). Then I took a physics class and really liked it a lot; I liked the problem-solving aspects, I liked the fact that it seemed to be dealing with how the universe really works, and for me it was just an ideal blend of philosophy, cosmology and mathematics.

How did you get into music?
I'm a terrible singer, so when I was playing in rock bands as I was growing up, I became a sort of virtuoso with the electric guitar in order to make myself indispensable. Then, when I was deep in my physics study, I took a course on music appreciation. At the time, I knew nothing about classical music, but I was incredibly turned on by it. The band that I was playing with at the time was getting a lot of rejections from presenters – we'd get letters saying "Your band is really tight, but your original songs are kinda weird and hard to dance to." Then I heard classical music and I thought, wait, this stuff – you know, Stravinsky ballets and late Beethoven quartets – is also really weird and really hard to dance to! It seemed like the most psychedelic rock music I'd ever heard. And at the same time, I was pretty naive about what a physics career could be. It seemed like, well, gee, I guess I could join the military-industrial complex and design weapons or something. The zeitgeist of northern California in its post-hippy heyday definitely figured in my decision. In a different time and place, who knows what would have happened?

You went on to get your PhD in composition. What was that like?
It was wonderful in that I've never had more time in my life to just work on composing, but it was also difficult because I felt I was behind everyone else. The other people in my cohort had been composing music since they were eight and playing the piano since they were four, so I felt I needed to completely repress my rock background, put my electric guitar in my parents' basement and try to be someone I wasn't, which was a classical music nerd. But at the same time, I don't regret any of those years because I really developed my technique and knowledge of the repertoire. It was only afterwards that I started to realize that my background as a rock musician had some positive aspects.

How would you describe your composing style?
I write for traditional classical ensembles, such as string quartets and orchestras, but with the added spin that some of my works include the electric guitar, for example concertos for electric guitar and orchestra. I don't think of myself as being on any kind of mission to mix rock and classical music, though. It's more that I am personally mixed up at the DNA level; fundamentally, those things just inform how I think music should go.

What are you working on right now?
I'm writing a 35-minute work in several movements that was commissioned by the Los Angeles Philharmonic, the National Symphony in Washington, DC and Australia's Sydney Symphony. The commissioning contract calls it a symphony, but I haven't written a symphony before and I feel like I'm too old to start with Symphony No 1, so I probably won't call it that. Maybe I will start with Symphony No 5, since I like a lot of fifth symphonies (Beethoven, Sibelius).

How has your background in physics influenced your work?
When I was first starting to compose, it felt a lot like doing physics. There is something about the focus and immersion and the way you think about it for hours that is similar. Also, there's a certain discipline in the problem-solving aspect of physics, where the first step is to ask yourself what you can do to get closer to the answer. That's the approach I take to composition sometimes: if I imagine some music that's just a little bit out of my grasp – I can't quite bring it into focus to write it down – then I ask myself what activity I can do that will get me closer to this music. And some of my music involves setting up patterns with different periods and then waiting for the moment when those periods align and a big event happens. The calculations for making those things work are either the result of my studying physics or else they're from the same brain that enjoyed physics.

Have you kept up with any physics?
A little. Brian Greene, the string theorist, is someone I consider a friend, and listening to him talk has definitely rekindled my interest. But to really understand it, I'd have to get back into the mathematics, and that's something I laugh about – it came so easily to me, but 35 years later I couldn't do calculus to save my life. Conceptually it still fascinates me, though.

Careers and people

Spotlight on: Diego Martinez Santos

Monday 6 May 2013 was both a good day and a bad one for particle physicist Diego Martinez Santos. Born in Foz, Spain, in 1982, Martinez Santos played a leading role in commissioning LHCb, one of the four main detector experiments at CERN's Large Hadron Collider. On 6 May he received word that his contributions to LHCb had been recognized by the high-energy physics division of the European Physical Society, which awarded him one of its top prizes for early-career researchers: the Young Experimental Physicist Prize.

But on that same day, Martinez Santos also got a letter from Spain's Ministry of Science and Innovation. In it, an official at the ministry explained that Martinez Santos' application to the Ramón y Cajal (RyC) programme – a government-funded initiative designed to attract and keep high-calibre researchers in Spain – had been denied. The reasons given for the rejection included claims that Martinez Santos "had not yet demonstrated a clear capacity for scientific leadership" and "had achieved a level of international relevance that is less than researchers of a similar age".

The contradiction between the two letters struck him as absurd, and in interviews widely reported in the Spanish press, he spoke out against the wording of the RyC rejection. "It's not about getting the place or not, or that all of my colleagues thought I would be given it, but that I do not agree with a report that says this about me," he told *La Opinión A Coruña*. "It damages my reputation and whoever reads it will deny me a job." Martinez Santos, who is currently employed as a postdoc by Nikhef, the Netherlands' flagship institution for subatomic physics, told the newspaper that while he was happy working at CERN, and had received job offers from institutions in France and the UK, at some point he would ideally like to return to the University of Santiago, where he earned his PhD. However, he added, this seems unlikely in the current funding environment (see December 2010 p6). "All I can say is that the amount that Spain dedicates to research is less than in other countries. That is a fact."

Movers and shakers

Physicists **Gert Aarts** of Swansea University, **Marin Alexe** of the University of Warwick, **Jonathan Oppenheim** of University College London, **David Richardson** of the University of Southampton and **Ian Smail** of Durham University have been named as recipients of the Royal Society's Wolfson Research Merit Awards for 2013. Each will receive salary enhancements of up to £30 000 per year for five years as part of a programme funded by the Wolfson Foundation and the UK Department for Business, Innovation and Skills, aimed at supporting scientists at UK universities.

Steven Balbus of the University of Oxford and **John Hawley** of the University of Virginia, US have won the Shaw Prize in Astronomy. The pair, who were honoured for their study of magnetorotational instability in astrophysical accretion discs, will split the $1m award.

Lapo Bogani of the University of Stuttgart, Germany, has won the Nicholas Kurti European Science Prize for his work on magnetic nanomaterials.

The Perimeter Institute for Theoretical Physics has added eight new members to its group of Distinguished Visiting Research Chairs. **Matthew Fisher** of the Kavli Institute for Theoretical Physics, **Duncan Haldane** of Princeton University, **Ted Jacobson** and **Raman Sundrum** of the University of Maryland, **Peter Shor** of the Massachusetts Institute of Technology, **Dam Thanh Son** of the University of Chicago, **Andrew Strominger** of Harvard University and **Zhenghan Wang** of Microsoft will join 33 other scholars from all areas of theoretical physics who visit the Ontario, Canada-based institute for extended periods each year.

Atomic physicists **Leo Hollberg** of Stanford University and **John Kitching** and **Svenja Knappe** of NIST have been named as recipients of the 2014 Rank Prizes for their work on chip-scale atomic clocks. The UK-based Rank Foundation awards the prizes, which are typically worth £15 000 each, every two years to scientists working in the fields of optoelectronics and human or animal nutrition.

The high-energy physics division of the European Physical Society has given its award for achievements by early-career theorists, the Gribov Medal, to **Zohar Komargodski** of Israel's Weitzmann Institute of Science.

Laurence Littenberg has been named chair of the physics department at the US's Brookhaven National Laboratory.

Laser physicist **Thomas Pfeifer**, astrophysicist **Holger Johannes Pletsch** and materials scientist **Volker Presser** are among nine researchers to receive the German Physical Society's 2013 Heinz Maier-Leibnitz Prize. The €20 000 awards honour outstanding early-career physicists working at German institutions.

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Friday, 27 September - references.

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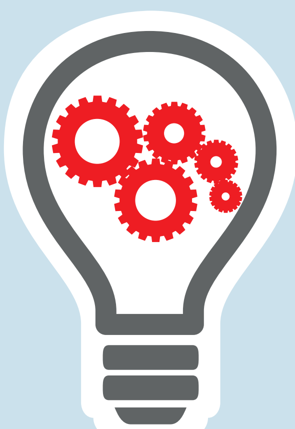

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The deadline for the submission of the application is August 31, 2013.

For detailed information on the application procedure we refer to the web-page of the graduate school of CUI:
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The Clatterbridge Cancer Centre NHS
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UNIVERSITY OF LIVERPOOL

PhD Studentship

Radiobiological Modelling in External-Beam Radiotherapy

Physics Department, Clatterbridge Centre for Oncology, UK and Department of Physics, University of Liverpool, UK

Location:
Clatterbridge Cancer Centre (CCC), Bebington, Wirral CH63 4JY UK

A PhD studentship funded by the Clatterbridge Cancer Centre Charity (CCCC) is available for 3-4 years starting in October 2013. University tuition fees and a tax-free stipend of ≈ £14,000 per annum will be provided. The project will be carried out in the Physics Department, Clatterbridge Cancer Centre, Bebington CH63 4JY, UK.

The project supervisors are Professor Alan Nahum, Dr Colin Baker and Dr. Julien Uzan.

Project description:
Maximisation of the effectiveness of radiotherapy treatment depends critically on being able to relate radiation dose distributions (and fractionation) in the tumour and critical organs to treatment outcome. Models have been developed for predicting the probability of 'controlling' the tumour (TCP), and the probability of inducing treatment-related side-effects in normal tissues (NTCP). This project will build on the work of the radiobiological modelling group at Clatterbridge (e.g. http://www.hindawi.com/journals/cmmm/2012/329214/) which focuses on applying TCP and NTCP models to the analysis and optimization of radiotherapy treatments, both at an individual and a population level.

Requirements:
Applicants should have a background in physical sciences and possess a minimum of a First Class or Upper Second Class Honours degree (or equivalent from a non-UK university). Experience in Radiotherapy Physics and/or Radiobiological modelling would be an advantage.

Interested candidates should send their CV and the contact details of two references to Professor Nahum; informal enquires are also welcome:
alan.nahum@clatterbridgecc.nhs.uk

+44 (0)151 334 1155 ext. 4169 (Secretary Sue Nixon: +44 (0) 151 482 7860)

Shortlisted candidates will be invited for interview at CCC (N.B. Travel and accommodation within the UK will be reimbursed).

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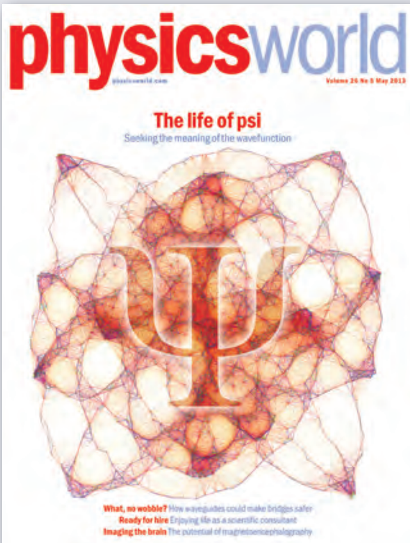

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Alice2007

Kate Gardner/Margaret Harris

Sumita found him in the corner, away from the bar, laptop screen reflected in his glasses, papers paved across the table around a drained wine glass and a long-forgotten coffee. "I'm surprised you got here before me, but less surprised to see you working," she said, smiling.

Removing his glasses, Robert looked up. "I didn't want to get lost in something and leave you waiting, so I left early." He glanced at the screen and back. "Or rather, I left at a sensible time and brought work with me."

She peered at the screen. "Coding? Debugging? Looks like an ungodly mash-up between Perl and some kind of markup. For all I know it's the latest thing. Being department chair keeps me away from the code face."

"Debugging... yes, I guess you could call it that. Looking for a fix, certainly. As for programming language, it's what you get when you form a team from computer scientists, molecular biologists, physicists and the like. The result is a bit postmodern – Perl meets XML meets JavaScript meets C++ meets...you name it."

"Fortran?" she asked, a challenge in her smile.

"Not on my watch." They laughed. "Some physicists still use it, but not me. My research group, my rules. Anyway, this mash-up of ours does the job."

"Which is?"

"A programmatic version of life, or as close as we've come to it. This is code for a leukaemia cell."

"Really? Wow. Genuinely, wow. I thought you were just taking a cross-disciplinary look at cells. I had no idea it was this hands-on."

Robert nodded. "But I'm being rude. Can I get you a drink?"

"Talking about life is always easier with a glass of wine. Dry white, please."

She sat, turning the laptop to face her, while Robert headed to the bar. Scrolling, scanning and drinking in the code, her eyes widened when she saw the filename – a name and a number.

She had dropped by his office the previous evening, a logical next step after months of corridor chats and post-steering-committee coffees. Across his desk, a skyline of books, journals and printouts surrounded his monitors, diagrams papered the walls and sketches, code fragments and URLs covered the whiteboard against the palimpsest of wiped swirls and forgotten ink. Robert had stood before the wall opposite, the glasses in his left hand against one diagram, the fingers of his right against another, head turning between them as if channelling the data physically, personally. Expression and gesture had revealed intensity his tidy appearance hid.

"You said to drop by some time," she had said. He had turned, breaking his connection with the wall. "The security guard said I'd probably still find you here, burning the midnight oil." In the corner she had spotted a pillow holding a cupboard door ajar, a makeshift wardrobe revealed through the gap. More work of art than place of work, a toothbrush rose from the pen-crowded mug on the desk.

"Oh, hi. Midnight oil? Candle, perhaps; they have two ends. I seem to be in the habit of burning both."

Sumita had smiled, commiserating. "What's cooking tonight?"

"Transcriptional regulatory networks and the influence of epigenetics."

Sumita had noticed something scribbled on the whiteboard, away from the photo, no more than a name and a number – a year?

"I'm a computer scientist – be gentle!"

With his glasses, he had pointed to a montage of hierarchical diagrams in the corner. "That one is basically the call structure of the Linux kernel, next to it Minix. You can do a similar thing for cells, treat them like operating systems, model their software architecture. That one there is the *E. coli* genome, that one a healthy human cell, that one a cancer cell."

She had leant in towards the diagrams. "Definitely the coolest thing I've seen all day – possibly all month. Life's structure is so different, almost inverted. More redundant, more resilient, I presume."

"And messier. Some of the mechanics around protein-folding gets a little hairy, which is why I have those guys down the corridor – they speak in dead alphabets and unmatched brackets. Makes code look like an advert for plain English."

Sumita had sighed. "I could spend all evening talking about this, but I'm meant to be somewhere else tonight. Which fits nicely with why I dropped by. Would you like to switch your caffeine drip for wine one evening?"

His eyes lit up. "Tomorrow?"

A smile, a nod, an echoed "Tomorrow." Turning to leave, she had caught sight of a photo clipped to the corner of the whiteboard. A wintry day, a gleaming bicycle, a girl smiling and proud. Sumita had noticed something scribbled on the whiteboard, away from the photo, no more than a name and a number – a year? The girl must be five or six, then. "Leaving passwords on a whiteboard? I'm surprised at you, Robert!"

Robert's perplexed gaze had followed her out.

When he returned with the wine, Sumita turned his laptop back to face him. "I don't mean to pry, but your research is…personal, isn't it?"

Robert looked down. When he looked back at her, the usual brilliance and focus in his eyes had dimmed and blurred. "Our group's brief is fairly loose, but the agenda – my agenda – is cancer. Leukaemia."

"On your whiteboard, that's not a password, is it? Your daughter, how is..."

"It's not a year of birth. It's...a sample year. The last."

Kevlin Henney is a software development consultant and writer with a physics degree in his past, e-mail kevlin.henney@gmail.com