ANIMAL PHYSICS
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Quantum pioneers bag Nobel prize ● Hitachi develops quartz storage ● Space centre opens in Ghana ● Romania targets laser facility ● Laser-based uranium enrichment ● NIF misses key fusion target ● IBM Zurich 50 years on

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Animal physics
How the zebra got its stripes
In an intriguing explanation for this age-old mystery, Jon Cartwright reports how zebra hides deter pesky flies

Walking on water
Stephen Ornes explains how the patterns pond skaters create in dyed water have finally revealed how these insects move

Lapping it up
Cats and dogs have a lot in common in terms of how they drink, says Jon Cartwright

Fly away home
Mark Denny examines how birds use techniques based on optics, acoustics, geomagnetism and celestial mechanics to navigate vast distances

Riding raindrops
How do mosquitoes survive getting hit by raindrops more than 50 times their own bodyweight? Stephen Ornes reports

Vespan voltage
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Why lions roar like babies cry
Ingo Titze explains why big cats and babies have vocalizations that are hard to ignore

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For the record

I’m determined to be a part of starting a population on Mars
Virgin chief executive Richard Branson speaking on CBS news
Virgin Galactic is expected to launch the first commercial flights into low-Earth orbit next year but Branson seems to have even bolder plans for the company.

It’s almost a textbook example of scientific integrity
Nobel laureate Anthony Leggett from the University of Illinois quoted in Science
In 2004 physicist Moses Chan announced he had discovered a process where ultracold, highly pressurized solid helium can flow like a liquid without a viscosity, which he dubbed supersolidity. However, in a recent paper he admits quite openly that supersolids probably do not exist at all.

I am in love with Curiosity
Lawrence Krauss from Arizona State University writing in the New York Times
That’s NASA’s latest Mars rover, in case you were wondering.

Maybe you should consider it may be attitudes like yours that put girls off
A-level physics student Rachel Horner writing in The Times
Horner was commenting on an article in The Times that suggested making physics more relevant to girls by asking questions such as how a hairdryer works or the elastic limits of tights.

Without you, I would have nothing to say the next time I stand on a mountain
Brian Cox from the University of Manchester
Cox, who bagged this year’s President’s Medal from the Institute of Physics for his “achievements in promoting science to the general public and inspiring the next generation of physicists”, thanked the physics community at the awards ceremony in London.

It’s about humanity’s struggle against the inevitability of what the second law is
Muse drummer Dom Howard speaking to the BBC
Muse’s sixth album – The 2nd Law – is named after the second law of thermodynamics and features tracks such as “Sustainable” and “Isolated system”.

seen and heard

From Russia with Lovell
“The Soviets tried to remove from my brain all memories of my visit to Yevpatoria.” No, it’s not the latest plot in the James Bond franchise, but what the late astronomer Bernard Lovell wrote in his diaries, which have now been released by the University of Manchester following his death in August, aged 98. The attempted Soviet brainwashing happened in 1963 when Lovell – founder of the Jodrell Bank Observatory at Manchester – was on a visit to Yevpatoria in Crimea as part of a British delegation to visit astronomy facilities there. During the trip, Soviet officials apparently failed to persuade Lovell to defect to the Soviet Union. However, upon his return to the UK, Lovell became “mysteriously ill”, with doctors unable to say what was wrong with him. The late astronomer claimed this was because Soviet spies at the KGB had tried to wipe any of the details of the visit from his brain “by some means – probably radiation”. Lovell was so spooked by the freak illness that he even wanted to give up astronomy. “I was proposing to resign from Jodrell and go into the Church,” he wrote. Luckily, his family persuaded him to carry on in science.

Security nun too good
A nun, a painter and a gardener walk into a nuclear installation. It might sound like the start of a dodgy joke, but the US Department of Energy (DOE) is certainly not laughing. In the early hours of 28 July, Megan Rice, an 82-year-old nun, together with her accomplices Greg Boertje-Obed, a 57-year-old housepainter and Michael Walli, a 63-year-old gardener, broke into the Y-12 National Security Complex in Oak Ridge, Tennessee, which houses some 350 tonnes of bomb-grade uranium. The activists managed to use bolt cutters to get through not one, not two, but three separate fences surrounding the complex. Still evading security, the trio then hung banners around the facility and splashed fake blood on the building’s walls. They were only caught when they started banging on walls with hammers. The DOE’s National Nuclear Security Administration has now issued a “show cause notice” to security contractor Babcock & Wilson Technical Services giving them 30 days to explain why they shouldn’t be sacked.

No small beer
Still on nuclear issues, in the summer of 1955 the US Atomic Energy Commission exploded a series of nuclear bombs in Nevada in what is known as Operation Teapot. It has now been revealed that one of the many important lines of inquiry during these tests was what would nuclear survivors drink? To test such a scenario, officials placed bottles and cans of beer at different distances away from the blast site with the nearest being a mere 300 m away. Surprisingly, almost all the cans survived the blast, with some of the bottles being smashed only by flying debris. The authors of a 17-page report The Effect of Nuclear Explosions on Commercially Packaged Beverages note that the radioactivity of the beer was “well within the permissible limits for emergency use”. One official even had the arduous job of putting the beer through its paces, concluding that while some of the beer had “slight flavour changes” the taste was still of “commercial quality”. The beer that was placed closest to the blast site was, however, “definitely off”. So next time you survive a nuclear holocaust – remember to grab a beer.

Mind-bending cutlery
If you’re looking for something to liven up dinner table conversation, how about some new fractal-inspired cutlery? The Infinity Set has been designed by Pavel Boytchev from Sofia University for this year’s fractal art competition run by the website Fractal Forums. The set contains: a Cantor fork named after German mathematician Georg Cantor; a recursive spoon that will apparently “never let you spill a drop of soup, ever”; and a knife inspired by the Koch snowflake as described by the Swedish mathematician Helge von Koch. Although the cutlery is not yet for sale, Boytchev says that someone has approached him to make a cast and produce it in silver. Let’s hope the price doesn’t match the name.
## Frontiers

### In brief

**Bursting bubbles drive micromotors**

Researchers in the US have shown that certain kinds of Janus spheres—tiny spheres coated on one side with one material and on the other side with another—actually propel themselves in a particular direction when placed in a chemical solution because one of the faces (but not the other) blows bubbles. The team carried out its experiments in a 5% solution of hydrogen peroxide in water and captured the behaviour of the micromotors—with one face coated with titanium and the other with platinum—using a fast CCD camera. The researchers described the propulsion mechanism by combining equations describing the growth of bubbles, the viscous drag of the water and the pressure drop expected when a bubble bursts (Phys. Rev. Lett. 109 128305).

**Spin friction seen for a single atom**

An international team says that it has measured the spin-dependent component of friction of a single atom as it slides across a magnetic surface, for the first time. The researchers created a manganese-on-tungsten-substrate material that is anti-ferromagnetic on the small scale and then studied the friction of this system by using a spin-polarized scanning tunnelling microscope with a cobalt atom at the tip, which moves from one lattice site to the next. Comparing experimental results with simulations, the researchers were able to conclusively say that spin-dependent friction contributes substantially to the overall frictional force experienced by an atom in a magnetic system. They say that their results provide an essential step towards developing a fundamental theory of friction (Phys. Rev. Lett. 109 116102).

**Meteorite points to Vesta’s dynamo**

A team of scientists in the US says that the asteroid Vesta probably had a rotating liquid core in its early history. This created a dynamo that produced a magnetic field strong enough to magnetize the rocks on its surface. As it was previously thought that only larger planets had dynamos, the work suggests that protoplanets may be more planet-like than previously thought. Other data also show that the surface of Vesta is less space-weathered than expected. The team says that there is a good chance that it is the magnetic-field remnant that is responsible for this, as the strength of the field required to shield the Vestian surface from the solar wind matches the actual field strength deduced from the meteorites used to study magnetism on Vesta (Science 10.1126/science.1225648).

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### Unveiling the origins of galactic jets

Astronomers have observed the base of a relativistic jet emanating from a galaxy for the first time. The jet was seen coming from the M87 galaxy, which like most other galaxies has a supermassive black hole at its heart. In some of these "active galaxies", matter falling into the black hole forms an accretion disc that generates huge amounts of radiation across the electromagnetic spectrum. About 10% of active galaxies also have a relativistic jet of matter emerging from their cores, but the exact formation mechanism of these jets is still not understood completely.

M87 is a huge elliptical galaxy, located just over 50 million light-years from Earth, that sends a long, thin jet of plasma 5000 light-years into space. However, the radiation at its centre is so intense that the photons of light often scatter off each other, blocking our views of the base of the jet. Now, astronomers, led by Sheperd Doeleman of the Massachusetts Institute of Technology's Haystack Observatory have spatially resolved the base of the jet using the Event Horizon Telescope (EHT), which consists of telescopes across California, Arizona and Hawaii. Using very-long-baseline interferometry meant that the team could achieve unprecedented resolution.

The base of the jet was revealed to be only 5.5 Schwarzschild radii in extent—significantly smaller than the accretion disc. The Schwarzschild radius is the distance from the centre of the black hole to where the velocity required to escape its gravitational pull exceeds the speed of light. The diminutive size of the jet-base allowed the team to infer some properties of the black hole producing it.

"Models suggest the jet would appear 7.4 [Schwarzschild radii] across for a non-spinning black hole," says Doeleman. For a spinning black hole, such as the one at the centre of M87, the accretion disc orbits in the opposite direction to the spin and the researchers had expected the base of the jet to be more than 9. The fact that it is as small as 5.5 implies that although the black hole is spinning, the accretion disc follows the direction of spin.

"We have formally linked very small-scale regions, where general relativity is important, to large-scale jet structures," Doeleman adds (Science 10.1126/science.1224768).

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**Nano Planck violation**

A team of physicists in Austria has shown that a silica fibre just 500 nm across does not obey Planck’s law, which describes how the energy density of the radiation emitted by a black body varies with its temperature. Although Planck’s law does provide very accurate predictions for the radiation spectra of real objects, physicists have known for many decades that the law does not apply to objects with dimensions that are smaller than the wavelength of thermal radiation.

Max Planck assumed that all radiation striking a black body will be absorbed at the surface of that body, implying that the surface is also a perfect emitter. But if the object is not thick enough, the incoming radiation can be lost instead of being absorbed, which lowers its emission. In this latest work, Christian Wuttke and Arno Rauschenbeutel of the Vienna University of Technology made their nano fibre by heating and pulling a standard optical fibre. They then heated an ultra-thin section, just a few millimetres long, by shining a laser beam through it and used another laser to measure the rate of heating and subsequent cooling. Bounced between two mirrors integrated into the fibre a fixed distance apart, this second laser beam cycled into and out of resonance as the changing temperature varied the fibre’s refractive index and hence the wavelength of radiation passing through it (arXiv:1209.0536).

By measuring the time between resonances, the researchers found the fibre to be heating and cooling much more slowly than predicted by the Stefan–Boltzmann law. Instead, they found the observed rate to be a very close match to that predicted by a theory known as “fluctuational electrodynamics”, which takes into account a body’s size, shape and characteristic absorption length.

Jet setters Simulated image of a jet launched from a spinning black hole surrounded by an accretion disc.

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Here's a fun exercise – take a piece of paper and use a compass to draw two concentric circles that define a ring. Then replace the pencil in the compass with a hard tip to indent a concentric crease in the paper halfway between the inner and outer edge of the ring. Cut out the ring and then fold along the crease all the way along its circumference – if you are careful you will have created a 3D saddle such as the one in the photograph above. This is a simple example of “curved-crease origami”, the mechanics of which have been studied in detail for the first time. Marcelo Dias, Christian Santangelo and colleagues from the University of Massachusetts and Harvard University have developed a set of equations to describe the physics of these structures (Phys. Rev. Lett. 109 114301). Their description is based on several parameters, including the ratio of the width of the ring being folded to the radius of the ring, the angle of the crease and the “stiffness” of the crease and of the material itself. The team derived an equation for the total energy of a creased ring in terms of these parameters and then calculated the energy using several analytical and numerical techniques. The team hopes that the work will lead to practical 3D materials that are both strong and flexible.

Why 275 is magic for ice

How many water molecules does it take to make the smallest possible ice crystal? About 275 is the conclusion of researchers in Germany and the Czech Republic, who have developed the first ever technique for probing large clusters of water molecules. Until now, most studies of water molecules have focused on small clusters with 12 molecules or fewer, but the structure of these objects bears little resemblance to bulk ice. The difficulty mainly arises in determining exactly how many molecules a cluster contains, which is usually done by ionizing the clusters by hitting them with high-energy radiation. But researchers would rather study neutral water clusters than charged ones.

In the new work, Thomas Zeuch at the Institut für Physikalische Chemie in Göttingen, Germany, uses two clever tricks to analyse neutral water clusters containing hundreds of molecules. First, each water cluster is doped with a single sodium atom. Second, before being ionized, the doped clusters are excited with infrared radiation, increasing their temperature and altering their structure to further lower their ionization potential. The clusters can then be ionized with a $390\, \text{nm}$ ultraviolet laser, which has low-enough energy to avoid fragmentation. The sizes of these ionized water clusters are determined using time-of-flight mass spectrometry.

To probe their structure, the infrared spectra of the water clusters are then studied at wavenumbers between 2800 and 3800 cm$^{-1}$, corresponding to the vibrational frequencies of oxygen–hydrogen bonds. This vibrational spectroscopy provides an insight into the arrangement of water molecules inside the cluster. Zeuch and colleagues obtained infrared spectra for cluster sizes ranging from 85 to 475 molecules and found that the transition from vibrations at 3400 cm$^{-1}$ (indicating liquid water) to 3200 cm$^{-1}$ (ice) began at around 275 molecules. The first crystalline ice occurred in the centre of the cluster, forming a ring of six hydrogen-bonded water molecules in a tetrahedral configuration. By 475 molecules, the infrared spectrum was dominated by the ice structure: the formation of the ice crystal was all but complete (Science 337 1529).

Innovation

First flat lens focuses light without distortion

Physicists in the US have made the first ultrathin flat lens, eliminating the optical aberrations seen in conventional lenses that have spherical surfaces. As a result, the focusing power of the flat lens also approaches the ultimate physical limit set by the laws of diffraction.

“Most optical components found in devices today are quite bulky because the light-beam shaping is done by changing the optical path of incident light rays, which requires changes in lens thickness,” says team leader Federico Capasso of the Harvard School of Engineering and Applied Sciences. “In our lens, all the beam shaping is done on its flat surface, which is just 60 nm thick.”

In an ordinary lens, light rays travel more slowly in the thicker, central regions than in the thinner, peripheral regions as a result of the smaller phase velocity of light in glass, compared with air. The new lens is different in that it is a nanostructured “metasurface” made of optically thin beam-shaping elements called optical antennas, which are separated by distances shorter than the wavelength of the light they are designed to focus. These antennas are wavelength-scale metallic elements that introduce a slight phase delay in a light ray that scatters off them.

The metasurface can be tuned for specific wavelengths of light by simply changing the size, angle and spacing between the nanoantennas, which are different shapes and sizes and oriented in different directions on the lens surface. This causes the phase delays to be radially distributed around the lens so that light rays are increasingly refracted further away from the centre, which focuses the incident light to a precise point.

According to Capasso, the new lens does not suffer from the image-distorting features that are typical of lenses with spherical surfaces. Instead, a well-defined, diffraction-limited, accurate focal spot is created, and no complex corrective techniques are required. The Harvard team made its lens by first depositing a nanometre-thin layer of gold onto a substrate. It then stripped away parts of the gold to leave behind an array of V-shaped structures (the nanoantennas) that were evenly spaced in rows across the surface of a silicon wafer.

The most obvious applications for the lens include photography and microscopy techniques that require compact objective lenses with very large numerical apertures. “But we can also imagine optical fibres with patterned facets for new imaging and medical applications,” adds Capasso (Nano Lett. 10.1021/nl302516v).
Quantum pioneers scoop Nobel prize

Serge Haroche and David Wineland share this year’s award for controlling individual quantum systems, as Hamish Johnston reports

The 2012 Nobel Prize for Physics has been awarded to Serge Haroche from the Collège de France in Paris and David Wineland from the National Institute of Standards and Technology (NIST) in Boulder, Colorado, “for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems”. The pair will share the SEK 8m (£750 000) prize and receive their medals at a ceremony in Stockholm on 10 December.

In a statement, the Royal Swedish Academy of Sciences said that Haroche and Wineland had “independently invented and developed methods for measuring and manipulating individual particles while preserving their quantum-mechanical nature, in ways that were previously thought unattainable”. According to Lund University physicist and Nobel committee member Anne L’Huillier, the pair’s work represents “the first tiny steps towards building a quantum computer”.

In a telephone interview with Swedish journalists shortly after the announcement was made, Haroche said he knew he had won the prize when he was out for a walk with his wife and his mobile phone rang displaying a Swedish number. “I sat down on a bench before I answered,” added Haroche, who later celebrated over a glass of champagne. Haroche paid tribute to Wineland, saying he was happy to share the prize with him. “He is a fantastic physicist and to be in his company is certainly a great pleasure for me and a great recognition.” Wineland returned the compliment, telling Physics World that he and Haroche have been friends for a long time. “So it’s nice to share it with him.”

Single photon control

Haroche was born in 1944 in Casablanca, Morocco, and in 1971 received his PhD from Université Pierre et Marie Curie in Paris. He shares half of the prize for developing a new field called cavity quantum electrodynamics (CQED) whereby the properties of an atom are controlled by placing it in an optical or microwave cavity. Haroche focused on microwave experiments and turned the technique on its head – using COED to control the properties of individual photons.

In a series of groundbreaking experiments, Haroche used CQED to realize Schrödinger’s famous cat experiment in which a system is in a superposition of two very different quantum states until a measurement is made on the system. Such states are extremely fragile, and the techniques developed to create and measure CQED states are now being applied to the development of quantum computers.

In 2006 he used a single atom to count the number of photons in a cavity – and managed to show that the cavity contained one photon without actually destroying the photon, as would normally happen when a quantum state is measured. Haroche says that this “quantum non-demolition” measurement, along with the Schrödinger’s cat experiments, have been the highlights of his career.

Master of ion control

Wineland’s interest in atomic physics began while he was PhD student in the lab of Nobel laureate Norman Ramsey, where he built a deuterium...
maser. He got his first taste of trapping a single charged particle – albeit an electron – when working with Nobel laureate Hans Dehmelt at the University of Washington. Wineland then moved to NIST, where his first task was to help make NIST’s new caesium atomic clock operational.

Around 1980 Wineland became interested in trapping single ions because it seemed clear that they could be used to create very precise clocks. The challenge, however, was how to cool an ion, because its thermal motion has a detrimental effect on the precision of the clock. To achieve this cooling, Wineland developed a laser-based technique to remove quanta of vibrational energy from ions. This “sideband” technique of cooling can also be used to put an ion into a superposition of states – including a Schrödinger’s cat state.

In the early 1990s the NIST group was developing quantum-control techniques for use with single-ion clocks. Wineland told Physics World that his interest in quantum computing was sparked by a conference at the University of Colorado, where the idea of a quantum computer was introduced by quantum-information pioneer Artur Ekert of the University of Oxford. It became clear the nascent quantum-computing protocols subsequently proposed by theorists such as Peter Zoller and Juan Ignacio Cirac were similar to the quantum-control techniques the NIST group was developing for clocks.

“In a sense we were lucky because we were also working towards entanglement,” he says, “and in 1995, working with Chris Monroe, we made our first ion-based quantum gate.” Since then, the NIST group has worked out ways of connecting several quantum gates, making them smaller and integrating the components on a single chip. More recent achievements include integrating all the components needed to perform all the steps needed for large-scale quantum processing on one chip.

A major breakthrough

Rainer Blatt of the University of Innsbruck in Austria, who works in the field of quantum control, told Physics World that the Nobel committee chose well in awarding the prize to Haroche and Wineland, saying the pair developed techniques that have laid the groundwork for many of today’s nascent quantum-information systems. Blatt cites development of “quantum-logic spectroscopy” – which allows a single ion to be used as an optical clock – by Wineland’s group at NIST as an important application of the control techniques, along with the creation of a small-scale device that performs all the functions required in large-scale ion-based quantum processing.

Blatt adds that Haroche’s framework for controlling the interaction between a single atom and a single photon is currently being used to develop ways of exchanging quantum information between atoms and photons. This could allow physicists to create quantum computers in which data are stored in stationary quantum bits (qubits) based on atoms, which are relatively stable over long periods of time. Data could then be transmitted between atoms using photons, which can preserve their quantum information while traveling relatively large distances.

“Observing, manipulating and controlling individual quantum systems has been a major breakthrough of the last few decades,” quantum-optics pioneer Alain Aspect of Laboratoire Charles Fabry in Paris told Physics World. “Schrödinger doubted that it might ever be possible, but this year’s laureates have done it.”

Indeed, thanks to the work of Wineland, Haroche and others, fundamental quantum mechanics has enjoyed a renaissance over the past two decades, with both physicists believing that more recognition from the Nobel committee will be forthcoming. “We are working in a very strong community of researchers and there will be more Nobel prizes in the future,” says Haroche.

Australia opens SKA precursor

The A$160m Australian Square Kilometre Array Pathfinder (ASKAP) – the world’s most powerful survey radio telescope – was officially opened in a ceremony on 5 October. Located in an arid, radio-quiet region of Western Australia, ASKAP is a demonstrator for the ambitious SKA project, which is to be split between sites in Australia and southern Africa. Comprising 36 dishes 12 m in diameter, ASKAP spreads across 30 km² and will operate between frequencies of 700 MHz and 1.8 GHz. The telescope has 30 times the power – expressed as a combination of sensitivity and field-of-view – of the US-based Very Large Array. Key to its power are unique “phased arrays” at each dish’s focus point that can simultaneously capture 188 separate signals over a 30° field of view (150 Moon widths). More than 350 astronomers from 150 institutions around the world have already booked up all the observing time on ASKAP for the coming five years.

Peter Pockley
Publishing

Rejected manuscripts receive citation boost

A study of some 80 000 journal articles submitted to 932 journals over a two-year period has found that having your paper rejected may not necessarily be a bad thing. At least, that is the conclusion of a report led by Vincent Calcagno, an ecologist at the Sophia Agrobiotech Institute in Sophia-Antipolis in France, which found that rejected papers that are then accepted by another journal pick up more citations than papers that are submitted and published straight into that same journal.

Calcagno wrote a computer program that sent an e-mail to the corresponding authors of more than 200 000 articles in the biological sciences asking them if they had previously submitted the paper to a different journal and, if so, to give the name of the journal. After painstakingly analysing the 80 000 replies, the authors found some expected traits such as the fact that the highest-impact-factor journals receive the majority of first submissions and that, if an author is rejected, they then send their manuscript to a journal with a lower impact factor. Calcagno also found that around 75% of papers are accepted on their first submission, which indicates that scientists are efficient at picking the right journal for their paper.

However, there were a couple of surprising results from the study. Papers that had been rejected and then resubmitted to another journal garnered more citations than a paper that was published in that journal on the first attempt. Calcagno concludes that the process of rejection, where a researcher is forced to rewrite and possibly do follow-up work to gain better results, actually improves the quality of the paper. “The most likely explanation to me is that reviewers and editors really do do their job and significantly increase the quality of the final paper,” he says. “Another explanation is that the longer it takes to publish a paper, the longer it will be before it is cited.”

Calcagno also found that, if at first you don’t succeed, a study of journal submissions and rejections claims there are benefits of being rejected.

Industry

Hitachi closes in on quartz data storage

They say the only safe way to preserve information is to set it in stone – but the next best option may be to set it in quartz. That is, according to researchers at Japanese electronics giant Hitachi, who have developed a “semi-perpetual” quartz-based data storage that could survive for millions of years.

Hitachi has been working on permanent methods of data storage for the last five years, driven by the concern that paper, CDs, hard disks and other storage media will not stand long-term physical disturbances and may not be easily readable with future technology. In 2009 Hitachi scientists found that they could store data optically in 3D in quartz, and showed that the medium had the potential to be highly durable and straightforward to read.

Data are stored in the quartz with a femtosecond laser, which alters the structure of the quartz to make “dots” of a different refractive index. One dot represents the binary digit one, while the absence of a dot represents a zero. The dots can be read using a conventional optical microscope, which sees the dots as dark, blurred spots.

The company has now announced three developments that bring the technology a step closer to practical use. One of these is the use of a device in front of the laser known as a “spatial-light modulator”, which allows 100 bits to be recorded in the quartz simultaneously. Another is a system to read the data quickly, and avoid the mistakes that arise when dots on different layers appear as noise. This system increases the image contrast on the layer being read so that the dots appear with greater definition.

Most impressive, perhaps, are the latest results on tolerance. Hitachi scientists annealed the quartz for two hours at a temperature of 1000 °C, and found that they could read the data afterwards just as easily as before. Hitachi says this feat shows that “long-term data storage in the order of several hundred million years is possible”.

Keisaku Shibatani, a spokesperson for Hitachi Europe in the UK, told Physics World that while the capacity of the medium is still small, the company hopes it will improve. “We hope it will be practical by around 2015,” he says.

James Chon, a physicist who develops optical data storage at the Swinburne University of Technology in Hawthorn, Australia, agrees that quartz could be a good permanent storage medium, but could be let down by its brittleness. “Quartz can easily break into pieces when subjected to impacts,” Chon warns. “Further, during data recording, high peak-power pulsed lasers are used, which could also impart huge internal pressures and cause breakage.”

Jon Cartwright
Women in physics

Physicists show bias against female job applicants

A study has found that researchers assessing the employability of early-career scientists subconsciously favour male students over females. The bias, which was seen to exist in both male and female physicists and was also exhibited by chemists and biologists, is thought to be a contributing factor towards the under-representation of women in physics (Proc. Natl. Acad. Sci. USA 109 16474).

Undertaken by psychologist Corinne Moss-Racusin and colleagues from Yale University, the study involved 127 tenured scientists across six universities in the US being asked to provide feedback on an excerpt from a job application for a graduate-level lab technician post at another institution. The excerpt – developed by an academic panel – was designed to be as realistic as possible and was identical, except that 64 of the scientists were told the applicant’s name was Jennifer, while the other 63 were told the applicant’s name was John. The scientists were told that their feedback would help the applicant’s career development, unaware that both the candidate and the post were fictitious. The candidate was painted as promising but not exceptional.

The study found not only that the scientists rated the male applicant as significantly more competent and hireable than the (identical) female applicant, but also that they would have given the male student a higher starting salary. “Male and female science faculty members, including physicists, said they were more likely to hire the male student,” says Moss-Racusin. “They also offered to pay him about $4000 more per year on average and were more likely to offer him career mentoring, relative to the identical female student.”

The bias shown by the researchers was independent of gender, age and seniority, indicating that even women show a subconscious bias against other women. The innate nature of the bias is thought to be evidence of the influence of a society-wide stereotype that men make more competent scientists, influencing even “very well meaning, very well trained scientists who emphasise objectivity and egalitarianism in their daily lives”, according to Moss-Racusin.

Amy Graves, a physicist from Swarthmore College, near Philadelphia, who specializes in gender studies in science, says she is “saddened, but not amazed,” says Graves. “If [the candidate] were an absolute standout, prior studies suggest that [the authors of the study] might not have seen this evidence of a genuine, unconscious bias.”

According to Moss-Racusin, having structured and transparent mentoring is one solution to the problem. She recommends guidelines to help standardize support across all students and the use of secondary mentors. “One of the biggest predictors of success and retention within academia, especially for women and racial minority students, is identifying with a role model or a good mentor.”

Meanwhile, a pilot mentoring programme – Women in Technology Sharing Online – was launched last month by the Piazza online education platform and by Harvey Mudd College in Claremont, California. By introducing female students to mentoring, the sponsors hope to increase the retention of women in science.

Jude Dineley

Africa

Ghana opens space science and technology centre

Ghana has joined South Africa and Nigeria in becoming a leading centre in African astronomy with the foundation of the Ghana Space Science and Technology Centre (GSSTC). Officially opened last month, the GSSTC will focus on climate change, meteorology, natural resource management and national security. The space centre, which is located in the capital Accra, is also expected to be used to accelerate the development of mobile telecommunications and IT services in Ghana and west Africa.

The Ghanaian government began to establish a space and technology excellence centre in 2010 in association with Vodafone Ghana and the African-led bid for the Square Kilometre Array radio telescope (which will now be split between sites in Australia and southern Africa). Indeed, the GSSTC will work on converting a redundant 32m dish, donated by Vodafone, into a telescope for astronomy research (see Physics World October p7).

Kofi Awoonor, chairman of the council of state, says that research undertaken at the GSSTC will boost the country’s science and technology development as well as promote jobs for young people and get students interested in astronomy via its scholarship scheme. Ghana is seeking $5bn from institutions such as the World Bank and the International Finance Corporation to help nurture astronomy teaching in the country as well as find ways to develop commercial applications from space research.

The GSSTC currently consists of eight researchers and two students, but it is looking to increase the total number to 60 by 2014. Investment in infrastructure and personnel development will come through a partnership with the Space Generation Advisory Council in Ghana (SGAC-Ghana), which seeks to educate and involve students and young professionals in the creation of international space policy. “We have already embarked on outreach programmes in various schools, tours to interesting scientific sites, and have also created interesting competitions to spark the minds of young space enthusiasts,” says SGAC-Ghana’s Michael Afful, who is also a research student at the South African National Space Agency.

Toby Brown
US grants licence for uranium laser-enrichment plant

The US Nuclear Regulatory Commission (NRC) has issued a 40-year licence to build and operate the first commercial plant that will use lasers to enrich uranium for use in civilian nuclear reactors. GE Hitachi Nuclear Energy, which licensed the technology from Silex Systems in 2007, expects to decide “within the next several months” whether it will go ahead with construction.

Although details of how laser enrichment works remain scarce, the concept emerged more than three decades ago, but only in recent years has commercialization become feasible. According to reports, the process involves shining laser light – with a wavelength of around 16 µm – on uranium-hexafluoride (UF₆) molecules, which absorb the incoming photon, causing the UF₆ molecules to separate, leaving uranium-235 nuclei.

GE Hitachi Nuclear Energy anticipates enriching uranium-235 to 8% purity, whereas US light-water reactors currently use about 5%-enriched uranium. But given that laser-enrichment plants can be relatively small, do not use much power and are cheap to operate, critics fear that the technology could take enrichment to much higher levels and increase the risk of nuclear proliferation.

“If you have a technology that is easily hidden and easily capable of producing highly enriched uranium, than that’s a matter for concern,” says James Acton, a senior associate in the Carnegie Endowment for International Peace’s nuclear-policy programme. “There’s no fundamentally different technology to get above 8% enrichment.” The American Physical Society, which warned two years ago that laser enrichment could be used to manufacture nuclear weapons covertly, has now filed a petition to the NRC requesting that it reviews proliferation risks before issuing any future licences for laser enrichment.

However, Christopher White, a spokesperson for GE Hitachi Nuclear Energy, insists that “we cannot use 8%-enriched uranium for any purposes other than energy production for light-water reactors”. The NRC adds that a study carried out by the US State Department revealed no risk of proliferation. “It concluded essentially that it was in the US interest to bring the technology here where it could be properly safeguarded, rather than having other countries develop it,” NRC spokesperson David McIntyre told Physics World.

Peter Gwynne
Boston, MA
Fusion

NIF misses key ignition deadline

The future of fusion research at the $3.5bn National Ignition Facility (NIF) is hanging in the balance after scientists failed to meet a target of achieving ignition – a self-sustaining fusion reaction that produces more energy than it consumes. NIF – a huge laser-fusion lab at the Lawrence Livermore National Laboratory in California – was meant to spend its first two full years of operation on a co-ordinated series of experiments aimed at achieving ignition. But on 30 September those experiments, known as the National Ignition Campaign (NIC), officially ended with ignition still some way off.

NIF’s neodymium-doped glass laser is the world’s highest-energy laser and produces 192 beams with a combined energy per pulse of more than 1.8MJ. It uses this beam to crush a peppercorn-sized pellet of fusion fuel (usually a mix of the hydrogen isotopes deuterium and tritium) to achieve temperatures and pressures greater than in the core of the Sun. This technique, called inertial confinement fusion (ICF), causes the hydrogen nuclei to fuse, releasing large amounts of energy.

While ignition would show that fusion is a potential source of energy, NIF’s primary purpose is to validate computer simulations of nuclear explosions to help maintain the US nuclear-weapons stockpile. But ignition was considered so vital to both those goals that the NIC was given 80% of time on NIF during its two-year run.

A report from the National Nuclear Security Administration (NNSA), which funds NIF, concluded in July that the probability of ignition before the end of 2012 was “extremely low”. Reasons cited for the slow progress were that too much of the capsule material is mixing with the fuel, that the implosion velocity is too low and that the implosion is not symmetrical enough. But perhaps the biggest problem is that Livermore’s computer simulations, on which much of the work at NIF is based, are not accurately predicting what is happening during laser shots.

The schedule-driven NIC was also criticized for not having the flexibility to pause and investigate these unexplained phenomena and find out why prediction differed from experiment.

\[\text{[Without ignition] even the value of the facility for stockpile stewardship is compromised,\} says Christopher Paine of the Natural Resources Defense Council, an environmental group in Washington, DC. “They’ve wasted over $5bn.”\]

The NNSA plans to submit a report to Congress this month explaining what barriers to ignition remain, how they can be overcome and what implications there are for stockpile stewardship. “We’re figuring out how to manage the programme from here on out,” says Mary Hockaday, deputy associate director for weapons physics at Los Alamos National Laboratory in New Mexico, who led the first draft of the report.

Critics, however, argue that NIF will never achieve fusion because of the types of lasers and targets that Livermore chose. They say that it should be handed over to researchers for high-energy-density experiments and a new ICF programme launched using different lasers, different targets and a lower-risk staged approach to building facilities.

Some researchers say NIF would be more likely to succeed if it used a “direct drive” method. NIF currently uses indirect drive in which the lasers do not shine directly on the fuel capsule but instead onto a small metal can enclosing it. The lasers heat the can white-hot so that it emits a pulse of X-rays that then make the capsule implode.

Livermore researchers, however, insist that no such changes are needed. “I’m confident we will get to ignition, but we can’t work to a deadline,” says Livermore director Penrose Albright. Whatever happens, the quest for ignition is likely to slow as from next year weapons scientists are slated to get more than half of NIF’s operating time.

\[\text{Daniel Clery} \]
The industrial academy

IBM’s Zurich Research Centre opened its doors 50 years ago, quickly becoming a world-leading research lab. But does it still live up to its illustrious past? Philip Ball travels to Switzerland to find out

It is easy to imagine, as you stroll around IBM’s research laboratory in the Zurich suburb of Rüschlikon, that you are on a university campus. The place has that laid-back vibe, those poster-decorated corridors and that faintly dishevelled appearance. For many researchers visiting from the nearby Swiss Federal Institute of Technology (ETH), it is almost like an annex of their own institution. Indeed, countless distinguished scientists – from ETH and elsewhere – have spent time at IBM while seeming scarcely to notice any differences from academia.

That has been the intention since the research centre was constructed some 50 years ago. When Ambros Speiser, the lab’s first director, dedicated the centre in May 1963, he noted that the only way it could succeed was “to become part of this [European] scientific community”.

Not only did it survive, but it thrived. In the early 1980s scientists at the Rüschlikon lab made a series of breakthroughs. In 1981 Gerd Binnig and Heinrich Rohrer invented the scanning tunnelling microscope (STM) – the first microscope that could resolve the structures of surfaces at atomic resolution. Binnig subsequently collaborated with fellow IBM researcher Christoph Gerber and Stanford University physicist Calvin Quate to devise the atomic force microscope (AFM). These and related scanning probe microscopes have not only revolutionized surface science but also become the iconic tools of nanotechnology, enabling atomic-scale fabrication and manipulation. Binnig and Rohrer’s achievement was recognized when they were awarded the 1986 Nobel Prize for Physics.

That year was a high-water mark for IBM Zurich, for it was then that another pair of scientists at the centre, Alex Müller and Georg Bednorz, discovered superconductivity in a class of inorganic materials – lanthanum barium copper oxide – at the unprecedentedly high temperature of 30 K. Their finding triggered a frenzy of research around the world, and within barely a few months other copper-oxide materials had been synthesized that superconducted at temperatures as high as 90 K. The record finally reached 135 K in 1993. Müller and Bednorz won the 1987 Nobel Prize for Physics, making it two years in a row for the IBM lab.

“Without these Nobel prizes this lab would not be what it is today,” says Walter Riess, the laboratory’s department manager of science and technology. “In particular, what Binnig and Rohrer did 30 years ago is still impacting us.” Indeed, the Rüschlikon lab’s new $90m nanotechnology centre, which opened in May 2011 and was built in collaboration with the ETH, is named the Binnig and Rohrer Nanotechnology Center.

With a legacy like that, IBM Zurich might be forgiven for resting on its laurels. But that does not look likely. As well as investing in the new nanotechnology centre, which includes a suite of “noise-free labs” (see box), the laboratory is expanding into fields that could determine the future of the company’s core business of information technology, including topics such as spintronics and molecular electronics. It is also branching out into new areas as diverse as bioinformatics, solar cells, battery technology and biomolecular-structure determination.

Mr Watson comes to Europe

IBM’s predecessor – the Computing Tabulating Recording Company – was created in the pre-computer era in 1911, when the firm made machines for tabulating data using punched cards. Its founder, Thomas J Watson Sr, rechristened the parent company International Business Machines in 1924, and by the 1930s its tabulators became known as computing machines. As primitive electronic computers began to appear in the 1940s, Watson opened the company’s first research laboratory in New York in 1945.

Collaboration with academia was always IBM’s style. In the 1950s it cultivated ties with the Massachusetts Institute of Technology and by the time IBM opened its Almaden Research Laboratory in the nascent Silicon Valley at San Jose, California, in 1952, it was a leading force in US computer science and the emerging field of information science and technology. Despite the travails of the 1990s, when industrial research became increasingly short-termist and application-focused, IBM has managed to re-establish a strong research profile in basic physics.

In 1956 Thomas Watson Jr – the eldest son of Thomas J Watson Sr – decided it was time to tap into Europe’s scientific expertise. With most of Europe still piecing itself back together after the war, neutral Switzerland seemed a wise location. Speiser was put in charge of the operation, which was initially very modest and focused on the area of data processing. In 1962 he identified the plot of land in Rüschlikon as the best site for a permanent European lab. Looking out from the campus at Lake Zurich on one side and the alpine pastures on the other, it is not hard to see why.

The future of computing

IBM now has 12 research laboratories around the world, including centres in Australia, India and Japan. But the glory years of the 1980s have given the Zurich lab a glamour that is hard to match. It is keen to capitalize on that success, in particular to maintain a leading profile in nanotechnology. In cultivating basic research, however, the Zurich lab takes a relaxed view of any corporate commercial agenda and is not strongly application-driven. “Ideas come from the bottom up – you try to hire the best people, and they bring ideas that they want to pursue,” says the lab’s director Matthias Kaiserswerth.

That commitment to science is also a conscious attempt to maintain the respect of the academic community. “We’ve not followed the model that many companies have where they outsource the basic research to universities,” says Kaiserswerth. Echoing Speiser’s foundational
strategy, he believes that “to be an accepted partner with universities, we need to be able to have an eye-level conversation with them”.

Besides, IBM has long known that staying competitive in its core business of information technology requires substantial inputs of basic science. In particular, as the shrinking of microelectronic circuitry starts to approach the physical limits of what silicon can achieve, entirely new approaches, devices and materials will be needed to sustain the trends in computing power.

However, Kaiserswerth says that silicon’s life can be extended by working on how the devices are structured, arranged and deployed on chips. One of the problems with current transistor designs is that, as the distance between the source and drain terminals decreases, the gate electrode becomes less able to turn the device off. In other words, it leaks. One option being pursued at Zurich is to make transistors from silicon nanowires, in which the gate is wrapped all around the circumference of the wire, giving better gating control.

Another ruse is to switch from 2D side-by-side packing of devices on chips to 3D stacking. This could cut the distances signals have to travel between devices, which makes integrated circuits slow and power-hungry. With these approaches, silicon microelectronics could keep pace for maybe another 5–10 years.

But what comes after that? No one knows, and IBM is not trying to guess. What the Zurich lab does recognize is that it is no good developing a replacement from scratch when silicon comes to the end of the road—the exploration of alternatives has to start now. Riess says that there is no obvious leading candidate yet, so IBM is exploring several, among them carbon nanotechnologies (such as nanotubes and graphene), molecular electronics and spintronics, as well as devices such as quantum computers.

We mustn’t lose sight of who pays the bills—it is IBM’s customers. They’re not paying us to do basic research, but to solve their problems.

New horizons

The pervasive influence of information technology means that any major computer company now has to concern itself with much more than just handling bits. For example, IBM has begun to venture into energy technologies, in part because energy consumption and management is becoming key to the performance of supercomputers. While the power demand of microprocessors is dropping (the number of flops per watt is rising), the miniaturization and massive integration of computer circuits means that supercomputers consume a huge amount of energy, much of which must be dissipated as heat.

IBM researchers have already developed water-cooling technologies to help supercomputers avoid meltdown. But IBM’s interests in energy are broader. Researchers at the Zurich lab are, for example, developing solar concentrators for photovoltaic cells, and IBM has launched the Battery 500 project to develop a battery that can power a car for 500 miles without need for recharging. The company’s researchers are investing a lot of effort in the lithium-air battery, which captures the chemical energy of the reaction between lithium and oxygen.

“IBM is not in the business of making batteries for electric vehicles,” Riess explains, “but it has lots of experience in computational sciences and materials. IBM has partnered with two companies in Japan and hopes someday to bring this technology to the marketplace.”

Bioinformatics is becoming another focus at the Rüschlikon lab. But if the encroachment of information technology into all areas of science is a boon for IBM, there is also in the end only so much it can follow up. “We’re a small lab and can’t do everything,” says Kaiserswerth. “If you let 1000 flowers bloom like a university, they might all be very interesting but they’re not going to have any impact.

We mustn’t lose sight of who pays the bills—it is IBM’s customers. They’re not paying us to do basic research, but to solve their problems.”

The triumphs of the 1980s have created a hard act for IBM Zurich to follow. But it is not a matter of trying to produce more of the same. The industry has changed since then: there are new pressures and priorities, and new ways of working. “The time horizon from research to market has shrunk,” admits Kaiserswerth. The open-source movement has also profoundly affected how a company such as IBM thinks about intellectual property. The question has become “finding the right balance between what’s proprietary and what’s open”.

For basic science, the move towards openness seems to be paying off. Involving a partner such as ETH not only offers a way of spreading the costs of facilities such as the nanotechnology centre, but also invites new ideas, projects and collaborators. In the past few months, IBM Zurich researchers have made headlines with the direct mapping of a spin helix in spintronics, the commercialization of an affordable tool for nanoscale sculpting, and the measurement of charge distribution and bond orders in single molecules with the AFM. If there’s no telling where the next Nobel might come from, they are certainly keeping their options open.
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The magic of animals

There is much interesting physics to be discovered by studying how animals behave

“Never work with children or animals,” runs the old adage. But some physicists and engineers certainly do work with animals and their efforts are the inspiration behind this special issue of Physics World devoted to “animal physics”. While this topic is not quite a sub-discipline in its own right, there are certainly plenty of fascinating examples of fundamental physics principles providing clues to how animals function or behave.

Given the huge variety of species in the animal kingdom, however, this issue could not possibly contain information about every animal type – or even of a suitably representative cross-section of species. Instead, we examine a selection of animals chosen simply on the basis that they each have some interesting physics involved in their daily lives. So in this issue you can read about how mosquitoes survive collisions with raindrops (pp.44–45), why a certain species of hornet has an in-built solar cell (pp.48–50) and how some birds, such as the European robin, navigate by detecting the relative orientation of the Earth’s magnetic field (pp.38–42).

We also examine the age-old question of why zebras have stripes (pp.27–28) – one theory suggests it’s because light reflects off the animals in such a way that flies avoid biting them. Closer to home, we look at two of our favourite pets and ask whether cats and dogs drink in the same way (pp.34–35). There are also articles on how lions roar (pp.52–53) and the physics of how pond skaters literally walk on water (pp.31–32), along with seven fabulous full-page images.

If this issue has whetted your appetite for animal physics, you can delve into even more content in the following ways:

- Members of the Institute of Physics can watch a series of video and audio clips embedded in the digital version of this magazine – including some great footage of those raindrop-colliding mosquitoes – either online at www.iop.org/membership/login.jsp or via our apps for smartphones and tablet devices.
- David Hu from Georgia Institute of Technology’s “laboratory for biolocomotion” will present a special online lecture for Physics World at 3.00 p.m. GMT on Thursday 8 November, which you can view by registering at physicsworld.com.
- The Physics World photo challenge this month on Flickr invites you to share your images on the general theme of “animal physics”. For more information visit www.flickr.com/groups/physicsworldphotochallenge.

One thing to note is that we have deliberately chosen not to cover the field of biomimetics and bioinspiration, which involves researchers taking principles from natural systems and applying them to engineering and technology. While the diffraction-created colours of some butterflies, for example, have certainly taught physicists a thing or two about advanced photonics, in our view the creatures themselves are fascinating enough in their own right and deserve to be looked at just on their own. Moreover, there is something inherently appealing about finding that physics crops up – sometimes quite unexpectedly – at the heart of how some animals behave.

And, of course, there are all those pretty pictures too.
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The benefits of reaching out

Publicizing research is becoming an ever more important part of a physicist's job. Pablo Jensen argues that rather than just taking time away from research, outreach can actually foster it.

Leading researchers and the academic institutions they belong to often point out that it is important to establish strong ties between science and society. Astronomer Martin Rees, former president of the UK's Royal Society, once noted, for example, that “researchers need to engage more fully with the public”. Indeed, the Royal Society itself recognizes this, and is keen to ensure that such engagement is both “helpful and effective”.

But outreach is sometimes given a bad name. It is not uncommon to hear researchers complain that “it’s always the same people doing it” or “those who do outreach are no longer doing science” and even that “it can harm your career”. Indeed, a survey carried out in 2006 by the Royal Society entitled Factors Affecting Science Communication found that most scientists think that research is the “only game in town”, with public engagement done as a secondary activity when their “real” work is finished. The Royal Society report also found that as many as 20% of researchers surveyed feel that “scientists who communicate a lot are not well regarded by other scientists”.

So are these criticisms fair and are they true?

Positive effects

Outreach is actually a common activity, being done by more researchers than you may think. By looking at the records of some 7000 scientists working at the French National Research Council (CNRS), I found that around 60% of researchers have done at least one form of outreach over a five-year period. Not surprisingly, the data show that the most active area in physics is astronomy, with 26% of astronomers being involved in some form of outreach each year. (The figure for theoretical physicists, in contrast, is just 4%).

One interesting fact from our study is that the number of physicists doing outreach increased sharply between 2004 and 2005, which happened to be the World Year of Physics – celebrating the centenary of Einstein’s five great papers of 1905. The fraction of active scientists, however, did not drop back to 2004 values after this was over. This “ratchet effect” suggests that specific events taking place during a limited time can be effective in achieving long-term commitment for public engagement.

Certain sub-disciplines that have recently experienced an increase in their outreach activities have, in some cases, done so because of a “social demand”. One example is nanoscience, which is receiving huge sums of money from grants to do outreach to discuss the potential risks and avoid the negative kind of reaction that genetically modified crops received.

But are those doing outreach active scientists? As it turns out, when you compare the data on outreach to the academic records taken from Thomson Reuters' Web of Science database, it appears that scientists doing outreach are actually more academically active than average (Public Understanding of Science 20 26).

Such researchers publish, on average, more papers per year (2.38 versus 2.28) and their papers are cited more often. The main explanation for this extra productivity is that being involved in public outreach is strongly correlated with seniority; in other words, those in higher positions simply do more outreach work. This creates a virtuous circle with high-profile researchers appearing on radio or TV becoming more visible outside the scientific community, and therefore getting asked to do more and more outreach work.

This may partly be an effect of the work division between junior and senior scientists, which leads juniors to focus on experiments while senior scientists devote most of their time to “general” questions. Senior researchers also spend much time establishing and maintaining social net-works both inside and outside the scientific community. These occupations are clearly more in line with dissemination activities, which demand putting scientific problems into perspective.

Thanks to the size of our sample, it was also possible to study statistically the influence of dissemination activities on the promotion of junior researchers to more senior positions to see if doing outreach harms career progression. We found this not to be the case. The statistics show that even if outreach is officially recognized as a duty of CNRS researchers, it is certainly not detrimental or done by those who are not good as researchers. It may not actually help in getting a more senior job but it does no real harm either.

Embedding science in society

We do, however, need to tackle the way that some institutions view outreach. The message sent by many workplaces seems to be: interact with the public if you find it fun, but not within your working time, which must instead be used for publication of articles in international journals. This needs to change.

The general public already understands science from different perspectives – historical, practical, institutional and political. But scientists should consider that for many people science is a strange and technical subject owned only by those who work in the lab. So we need to think about how outreach should be most effectively carried out. Should it be aimed at informing the public of technical aspects of research – “look how incredible our technical feats are; don’t be afraid” – or should there also be room for open debates on the usefulness of the public money spent on these topics?

To me, science outreach should be only the first step towards embedding science into society and connecting scientific knowledge to everyday culture. To progress in that direction, as scientists need to, we should learn more history and philosophy. It would also be beneficial to spend a small fraction – say 1% – of our budget to allow social scientists into our labs, to study and discuss the social and cultural dimensions of our work. Reaching out is a wonderful way of learning about society and science. We need to do more of it.

Pablo Jensen is a physicist at Ecole Normale Supérieure de Lyon and is the author of Atoms in my Cappuccino: Can Physics Explain Everything? In 1997 he founded the Cafe Scientifique initiative, e-mail pablo.jensen@ens-lyon.fr
Having recently discussed in this column whether skateboarders and other athletes really “know” physics, here Robert P Crease wonders if primates do as well.

A dozen years ago Daniel Povinelli – an anthropologist at the University of Louisiana – published *Folk Physics for Apes: the Chimpanzee’s Theory of How the World Works*. The book perplexed many readers. Both the preposition “for” (in the title) and the noun “theory” (subtitle) seemed to imply the existence of a body of knowledge that is used by primates, or that at least could be taught to them. Povinelli, however, concluded that primates are unable to reason using imperceptible concepts from physics, such as force and gravity.

But reasoning with such concepts is an indispensable part of physics as we humans practise it. What, then, could the phrase “physics for apes” really mean?

**Applied physics**

One possible answer is illustrated by the research of my colleague Matthew O’Neill from the anatomy department at Stony Brook University, who studies the evolution of locomotor behaviour in humans and other primates. He brings animals into the lab, puts markers – in the form of paint or reflective spheres – on body parts corresponding to specific anatomical landmarks, and videos the creatures as they cross a runway. Sensors in the runway measure the force that limbs apply to the ground, while the x, y and z coordinates of each marker are digitized to track their paths in 3D space, allowing O’Neill to quantify motion and forces. Using an approach known as inverse dynamics, he combines this data with ball-and-stick limb models to calculate the torques on each joint, which tells him how much muscle force is generated at the hip, knee or ankle during, say, a stride.

This set-up lets O’Neill work out the overall forces that are generated when humans – as well as chimpanzees and lemurs – walk and run. O’Neill finds this information into detailed, 3D representations of the primate’s pelvis and hind limbs, which in turn lets him predict the energy creatures consume when moving. He checks these values against direct energy measurements based on how much oxygen humans and other animals inhale – and on how much carbon dioxide they produce – when moving on a treadmill.

**Living, kinetic physics**

Maxine Sheets-Johnstone – a philosopher whose research includes movement and evolutionary biology – takes another approach that relates primates and physics. She treats primates as living creatures navigating complex, highly social and sometimes threatening worlds. For such a primate, as for any living creature, the world is never the same from one day to the next. Even if that animal has a repertoire of movements, it has to choose which one to use and how to adapt it to each new situation, considering questions such as which other creatures are present, and if the ground is dry or slippery. These decisions often involve a kind of physics intelligence, but not one that applies theoretical concepts.

In one essay, Sheets-Johnstone discusses a picture of a young male baboon gesturing a picture of a young male baboon gesturing to, and then carrying, a one-year-old female across a tricky section of a cliff face. “The gestural invitation”, she explains, “testifies to at least three distinct awarenesses on the part of both male and female baboon.” The first is the awareness that the cliff is too big or jagged for the young female to cross; the second is that the male can cross it; and the third is that the male can cross it even with the female on its back.

These awarenesses, Sheets-Johnstone notes, involve what she calls “kinetic intelligence” or “living kinetic physics”. The primate thinks concretely in kinetic terms about the forces it is able to deploy to traverse that passage. Primates are even known to test branches before trusting their weight to them. The ability to use such kinetic intelligence is a key factor in evolution.

Primates are not the only creatures with kinetic intelligence. Beavers building a dam, she points out, make complex choices about which arrangements of what construction materials are sturdy enough to withstand strong counter-forces. “Walking on the beach near my house,” she told me, “I still marvel that gulls know they can pick up a mussel shell, fly over stones, drop the shell and break it open so that they can feast on the inside.”

There’s a non-theoretical physics involved in that practice.

**The critical point**

O’Neill’s locomotion studies approach human and non-human primates from the outside, as if they were machines working in an abstract space. Primate physics here means that body of theoretical knowledge and experimental equipment that experimentalists find necessary to understand primates’ motions in this way.

Sheets-Johnstone, on the other hand, examines a kind of knowledge learned and practised by the primates themselves. She calls it “a living kinetic physics” lived through truths about weight, ballistics, spatial orientation, effort or force. This kind of physics knowledge, grounded in and acquired through experience rather than concepts, is like the kind of knowledge that skateboarders have when executing moves. There are thus two possible meanings of “primate physics” – the kind that primates use to navigate the world, and the theoretical kind used by the humans who study them. Whether chimpanzees can theorize, though, depends on what you mean by “theory”.

Robert P Crease is a professor in the Department of Philosophy, Stony Brook University, and historian at the Brookhaven National Laboratory, US, e-mail rcrease@notes.cc.sunysb.edu
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Parity violations

Magdolna Hargittai’s article on Chien-Shiung Wu (September pp38–43) reminded me of an incident that might be of interest to your readers. In January 1958 I attended the meeting of the American Physical Society in New York where Wu presented the results of her experiment on parity violation in beta decay of cobalt-60. In a 20 minute talk she described the experiment and announced that the result was that beta-decay indeed violated parity conservation and the combination of amplitudes was $S + T$, the sum of the scalar and tensor currents.

After the applause, Richard Feynman, who was sitting a few rows behind me, spoke up slowly and dramatically in his broad Brooklyn accent with the words “That’s gotta be wrong!” He then explained briefly that he and Murray Gell-Mann had constructed a theory which predicted an amplitude of $V - A$, where $V$ and $A$ are the vector and axial vector currents, respectively. The idea of the theory was that the vector current is conserved, as in electromagnetism, and the axial current is partially conserved.

In the afternoon, there was a public announcement that there would be an extra nuclear physics session in the evening with an announcement from Wu. I attended, of course, and she calmly stated that she had been through her notebooks, attended, of course, and she calmly stated that she had been through her notebooks, and there was a sign error. Feynman was right: the results required $V - A$. Sometime later, the nuclear physicist Maurice Goldhaber told me that there had been active discussion behind the scenes before the meeting with Isidor Rabi and others on the correct sign, but he did not know if Wu was involved in the discussions. My impression was that the theorists got together with her in the afternoon and helped sort out the sign error.

David Bugg
Queen Mary, University of London, UK
david.bugg@stfc.ac.uk

Interesting article on Wu, and a clever cover illustration – but it’s a pity that the polarities of the current and of the magnetic field in the illustration do not correspond with one another. (This has got nothing to do with parity.) In fact, the battery terminals are also incorrectly drawn, because the long one is usually taken as positive. Both of the mirror-image illustrations have these faults.

The easiest “fix” would be to reverse the labelling of the (conventional) current and the positive battery terminal; the direction of the magnetic field would then be correct. This error would have cost our first-year engineering students two or three marks in a test.

Trevor Derry
University of the Witwatersrand, South Africa
trevor.derry@wits.ac.za

Cover artist Ele Willoughby replies: I should have noticed that the printed image does not obey Ampère’s circuital law and associated right-hand rule for solenoids, as my background is in physics, and I too would have deducted marks from any student who submitted it as a diagram. The error was introduced because the image is a relief print. To produce it, I first drew the image onto lino with, the correct orientation for the polarity of the currents with respect to the magnetic fields. I then carved away the “negative space” (an artistic term that sounds very odd in a physics context), inked the block and burnished the image onto paper. This method naturally produced a reversed – and thus incorrect – image. Ironically, the error is similar to the underlying physics of the experiment!

Like many printmakers, I occasionally forget to reverse lettering when printing text, and this may be because the instinct to draw letters in the correct orientation is so strong. Similarly, when drawing electromagnets as part of the design of this print, I found I instinctively made sure they obeyed the right-hand rule, rather than the appropriate reversed left-hand rule. This does not excuse the error, but I hope it helps to explain it.

Incidentally, the schematic representation of beta decay in magnetic fields and the violation of parity observed by Chien-Shiung Wu are correct as shown, and readers may appreciate that I depicted the particles in cobalt blue as an allusion to the cobalt-60 employed in Wu’s experiment.

Nuclear deterrents

In his article “Britain’s bomb” (October pp40–44), author Richard Corfield briefly reviews the moral need for countries such as Britain, the US and Russia to have nuclear weapons. As part of this review, he suggests that “Today, there is no conceivable set of circumstances under which the democratically elected government of the UK would unilaterally use the bomb – it would always be working as part of a team with its NATO allies. Put simply, Britain’s bomb is now part of a supra-national deterrent”.

This statement is hard to reconcile with the words of the UK government white paper The Future of the United Kingdom’s Nuclear Deterrent. This paper, published in 2006, appears to set out some circumstances in which unilateral use of the bomb by the UK might occur, and suggests that such potential uses are in addition to the bomb operating as part of a supra-national deterrent. More specifically, the white paper states that an independent centre of nuclear decision-making “makes clear to any adversary that the costs of an attack on UK vital interests will outweigh any benefits” and “also enhances the overall deterrent effect of allied nuclear forces”. It adds that an independent deterrent “provides the assurance that it can be used to deter attacks on our vital interests”. The UK’s nuclear forces, it insists, “must remain fully operationally independent if they are to be a credible deterrent”.

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According to a 2006 report by the Oxford Research Group on the future of Britain’s nuclear weapons, each of the (maximum 48) nuclear warheads of the UK’s Trident submarines is “generally assumed to have an explosive yield of…100 kt”, although this might be reduced to 1 kt (by removing the tritium bottle) or 10 kt (by “switching out” the thermonuclear stage).

As Corfield notes, the explosive power of the bombs dropped on Hiroshima and Nagasaki were equivalent to about 15 kt and 19 kt of TNT, respectively. The number of immediate deaths from these bombs has been estimated at 140 000 and 74 000. These figures are consistent with estimates made in 2002 by I Helfand et al. (Br. Med. J. 324 356) of the likely effect of a 12.5 kt explosion at ground level near the port area of New York City, which suggested that more than 50 000 people would be killed in the initial blast and from direct radiation, and an additional 200 000 would die from the effects of radioactive fallout afterwards.

Such documented effects of nuclear weapons in the 10–20 kt range are relevant to any discussion of the morality of the UK’s nuclear weapons.

Brian Drummond
Edinburgh, UK

Political decisions

I was puzzled by the subtitle of your October editorial (p17): “On science alone, voters may find it hard to decide between the presidential candidates”. As you correctly point out, President Obama considers climate change “one of the biggest issues of this generation” and wants to limit emissions, while Romney claims that “there is no scientific consensus on the issue” and opposes a carbon tax. Thus it seems clear that one candidate respects and accepts the verdict of science, while the other does not.

Robert Crease makes exactly this point in his article “How to vote” in the same issue (p21), and states that “a necessary qualification for candidates for public office is a respect for the scientific process and its infrastructure”. Yet he declines to apply the principle to the current case of Obama vs Romney. No doubt Physics World is anxious not to venture into the murky world of political opinion. However, when an entire political party – the US Republican Party – consistently seeks to undermine the findings of science on issues such as evolution and climate change, it is important that scientists speak out clearly and unequivocally.

Cormac O’Raifeartaigh
Waterford Institute of Technology, Ireland
coraifeartaigh@wit.ie

Small science, too

Physics World’s “Focus on Big Science” was very interesting. But would it not be appropriate to do a focus on “small science”, too? I say this because there are a lot of people doing physics individually or in small groups (in industry as well as universities), but there is a risk that the image given to the public is that physics is all about large groups studying rather abstruse topics. The quality of thinking required in physics and the appreciation of how the world works needs to be more widely available in UK industry.

John Chubb
Cheltenham, UK
jchubb@infostatic.co.uk

The editor replies: We have also published focus issues on nanotechnology, optics and vacuum technology this year, so we have certainly looked at “small science”, even though it may not have been billed as such. We could, of course, do more.
Animal physics

All animals use the laws of physics, but some animals do so with more style than others. This special issue of Physics World reveals the extraordinary physics behind animal activities from the everyday – such as how cats and dogs drink – to the otherworldly, such as this shrimp’s special sight. From stripy zebras and roaring lions to agile mosquitoes and solar-powered hornets, this issue looks at the physics of animal magic at its best.
Super shrimp

If the animal kingdom had superheroes, the mantis shrimp would be the leader of the pack. This crustacean — nicknamed by biologists as the “shrimp from Mars” — has not one but two superpowers. Known by some fishermen as “thumb splitters”, these shrimps have a pair of 5 mm wide appendages called dactyl clubs that can deliver an instantaneous force of more than 700 N. That is enough to spear their prey through the heart, pummel its shell to pieces or even to fracture aquarium glass. These creatures also have a pair of the most complex eyes ever discovered: they can differentiate between right- and left-handed circularly polarized light. To do so, their eyes use a biological version of a “quarter wave plate”, which converts circularly polarized light to linearly polarized light, which is then detected by photoreceptors. While its strength is clearly a virtue, the reason for this shrimp’s optical superpower is unknown.
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Rewarding Challenging Teaching
Biophysicists are offering new clues to this age-old mystery, as Jon Cartwright reports

Rudyard Kipling’s *Just So Stories* tell how various animals came to be. “How the rhinoceros got his skin”, “How the camel got his hump” and “How the whale got his throat” are some of the titles in the famous 1902 collection. The British writer never wrote a story entitled “How the zebra got his stripes” – although if you read his words closely, you’ll discover that, spooked by the leopard, the zebra fled into the forest and adopted stripes as a disguise.

That was just fiction, but a few decades earlier, in 1867, the British naturalist Alfred Russel Wallace had put forward a similar idea – that the zebra evolved stripes as camouflage against predators in the tall grass. Wallace’s fellow naturalist Charles Darwin disagreed, pointing out that zebras prefer to hang out in open savannahs, where tall grass is rare. And so the scientific debate began: how did the zebra get his stripes?

Biologists have not been short of proposals. There are at least 10, including that stripes afford zebras a means to recognize one another, or that they provide an indication of fitness for potential mates. But none of these hypotheses has seen much supporting evidence, according to biophysicist Gábor Horváth at Eötvös Loránd University in Budapest, Hungary, and colleagues.

Horváth’s group, which includes researchers from Szent István University, also in Budapest, and Lund University in Sweden, has been investigating one of the more persistent hypotheses: that the stripes somehow prevent zebras getting bitten by flies. Some flies, particularly the large biting tsetse, carry parasites that cause diseases such as trypanosomiasis, also known as sleeping sickness. This disease causes fever and lethargy, and can be fatal. If zebras ward off the parasite-ridden tsetse with their stripes, they would have had an evolutionary advantage over non-striped equids, such as horses and donkeys.

There ain’t no flies on us

As far back as the 1930s, scientists had noticed that tsetse flies are not attracted to striped targets, and instead tend to congregate on solid-coloured objects. But how much the zebra relies on this effect has been unknown.

Horváth’s group set up experiments near the river
Danube in Szokolya, Hungary, on a hot, sultry horse farm that was rife with tabanids (popularly known as horseflies) — another species of biting fly that habitually attacks livestock. In one experiment, the researchers propped up one white and several black-and-white striped plastic surfaces, covered with glue, to capture any flies that landed. They found that the white surface was much more attractive to tabanids than the striped surfaces. Moreover, they found that the striped surfaces became less attractive with decreasing stripe width. Stripes narrower than about 7.5 cm – a range zebra stripes fall into – were particularly adept at repelling tabanids.

To check that there was nothing unique about flat surfaces, Horváth’s group constructed several zebra-shaped models in brown, black, white and black-and-white striped finishes. Again, the striped model was most effective at warding off tabanids, followed by the white, the brown and finally the black models.

But what makes a striped pattern so successful? As you might expect from biology, it comes down to reproduction and eating. Tabanids like to congregate around water because they lay their eggs in it, and because water draws in the herbivores on which they feast. Since water reflects light in a linear polarization (parallel to the water surface), tabanids seek out linearly polarized waves.

Yet colour, as well as water, can influence reflected light’s polarization. According to the Fresnel equations, which describe the behaviour of light transmitted between different media, light reflected from an object’s surface becomes polarized parallel to that surface, whereas light reflected from an object’s subsurface becomes polarized perpendicularly. Since bright white objects reflect light from both their surface and subsurface, they produce light of both parallel and perpendicular polarization — which, combined, produce light that is unpolarized. Black objects, on the other hand, reflect light only from their surface; as a result, they produce light mostly of parallel polarization.

Horváth and colleagues thought that striped black-and-white surfaces might confuse tabanids by producing light that is both linearly polarized and unpolarized. To test this idea, the researchers propped up grey surfaces that had stripes of certain polarization. As they expected, it was the surfaces with stripes of alternating polarization that were most effective at repelling tabanids (J. Exp. Biol. 215 736). Zebras, it seems, confound tabanids by fragmenting the polarization of light bouncing off their stripy hides.

Tim Caro, a biologist at the University of California, Davis, in the US, holds the work in high regard. “I think the study is sexy, clever, elegant and very provocative,” he says. But, he adds, “the issue is whether it means anything for our evolutionary understanding of colouration in zebras”.

Here is where it gets tricky. For starters, tabanids are not tsetse, the chief carrier of sleeping sickness. Unlike tabanids, tsetse do not lay their eggs in water, so on that basis there is no reason for them to have polarization-sensitive vision; whether they seek specific polarizations for other purposes is unknown. This means that tsetse may not respond to zebra stripes in the same way as tabanids, says Caro.

But even if tsetse are confounded by stripes, the flies may not have been the evolutionary cause of them. Various species of tsetse are found from the tropics to the Arctic, yet only zebras, which live in Africa, have stripes; Asian horses, for example, do not. And if the defence mechanism were particularly effective, one might expect stripeless equids to be bothered more by roaming flies. But Caro believes this is not the case. “I spent a June in a Berlin zoo comparing swishing rates of tails in all seven species of equids,” he says. “There’s really no difference between them.”

Horváth and his colleagues themselves admit that the fly-repelling nature of zebra stripes could be cancelled out by the fact that zebras stink. “Real zebras have a very strong odour and breathe out CO₂,” they say. “It is conceivably possible that the odour and CO₂ are attractive to tabanids and may overwhelm the small visual [repulsion] of the striped coat pattern.”

So how did the zebra get his stripes? Certainly, biophysics is offering new clues. But, given the complex factors surrounding animal evolution, we may have to accept that the ultimate answer will never be black and white.
Spin cycle

It is a matter of survival. A soaking-wet dog, in cold weather, would need to use a massive 20% of its daily calorific intake to dry itself using body heat and evaporation alone. Instead, dogs and many other mammals have developed a more efficient method that uses only a 10th of the calories: the wet-dog shake. In a study of 16 animal species, including creatures great and small, researchers took a closer look at this spin-dry mechanism using high-speed cameras. Shaking in all cases began at the head and then propagated towards the tail. The looser the animal's skin, the more it could rotate and the faster it could whip around — and so less effort was needed to overcome the surface tension to eject drops. Small animals had to shake more quickly than large animals, with mice, for example, shaking 30 times per second and grizzly bears doing so only four times per second.
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Walking on water

Why can pond skaters skip so effortlessly across water? Stephen Ornes explains how these creatures’ secrets were revealed using dyed water and a high-speed video camera

Gods in Ancient Egypt could do it; so allegedly could Buddha and Jesus. But for the rest of us lowly human beings – at least, those of us without divine parentage or supernatural abilities – the closest we can get to walking on water is to strap on a pair of pontoon shoes and hope for the best (an idea first envisaged in sketches by Leonardo da Vinci). But in the animal kingdom, the ability is nothing new. The basilisk lizard uses its specially shaped feet to slap the surface hard enough to keep from sinking as it runs across water. Dolphins use the same technique with their tails, as do some birds.

Most insects take a different approach. The vast majority of the million or so identified species of insects live either in the air or on land, but a tiny fraction – about 0.1% – live on water, at least part of the time. One of those water dwellers, the pond skater (also known as the water strider), is particularly adept at staying afloat. It can sit still atop the water, or scurry across at speeds of 150 cm/s – about three miles per hour.

The reason why pond skaters can stay afloat is that the surface tension of water acts like a skin. Water molecules have cohesive forces between them, and the pond skater’s weight is too small to overcome those forces. That is fine for standing still, but if the insect wants to move, Newton’s third law of motion dictates that it has to push on something – and the only thing available is the water.

Our latest knowledge of these little animals is largely thanks to the efforts of David Hu, who as a mathematics graduate student at the Massachusetts Institute of Technology (MIT) spent four years studying them, analysing their sizes and shapes and trying to understand the physics that keeps these bugs afloat. He worked on the project with his PhD supervisor, John Bush, who focuses on tackling real-world fluid-dynamics problems.
Animal physics: Pond skaters

“They have to row without breaking the surface of the water,” says Hu, now running his own biology-meets-mechanical-engineering lab at the Georgia Institute of Technology in Atlanta. “If they move too quickly, they will break the surface. That’s a non-intuitive idea for people to grasp, but you can see it if you push on the surface of water gently with a paperclip. You see these ripples of waves shoot out, and the pond skaters basically have to row on them very gently.”

Hidden vortices
Before Hu’s work, experiments and observations had suggested that pond skaters propel themselves forwards by making tiny ripples in the water with their legs. This idea was intuitively appealing because these “capillary waves” are readily visible in the wake of a pond skater skipping across a wet surface. But it led to a problem called “Denny’s paradox”, first articulated by biologist Mark Denny in 1993. He pointed out that infant pond skaters cannot move their legs faster than the phase speed of the capillary waves – a feat necessary to create them.

Hu and Bush decided to investigate using pond skaters gathered from local ponds. These creatures reproduced in the laboratory and so gave the researchers plenty of infants with which to investigate Denny’s paradox. And to see what was really happening in the water, Hu and Bush filmed the insects using a high-speed camera.

They found that pond skaters use the middle of their three pairs of legs like a rower uses oars in a rowboat. When an oar slices the water, it creates swirling vortices just beneath the surface that twist away from the boat, imparting forward momentum past the air-water barrier. Similarly, the pond skater’s legs leave behind the same vortices under the water’s surface. In Bush’s lab at MIT, the vortices became visible when the scientists sent the pond skaters scampering across water filled with colourful floating particles.

Bush and Hu noted that the action also created capillary waves – those tiny ripples observed by Denny and other biologists – but calculated that those waves’ contributions to the bug’s forward motion were much smaller than they had anticipated, and not strong enough to move the bug.

Coveted coating
What is also interesting about pond skaters is that specialized hairs coated in a wax-like substance cover their legs, and bubbles on these hairs keep the water out. There are, according to Hu, thousands of hairs per square millimetre and the waxy substance on the hairs is coveted by human designers and materials scientists because synthetic materials usually rely on waterproofing chemicals that wash away. “No-one knows how to make a permanent water-repellent material,” he says.

It is these hairs that make the pond skater’s rowing action possible. Only the very tips of the hairs penetrate the surface of the water, creating those vortices and, in turn, transferring momentum past the air-water barrier. The particular arrangement of those hairs resembles those on a butterfly’s wings that shuttle water droplets towards the wingtips. On pond skaters, those hairs point in a particular direction, giving the insect a preferred direction and ensuring that the pond skater does not veer off course – whether alive or dead.

“If you have a dead water strider and blow on it, it will still go forward,” Hu says.

Hu has gone on to look at how other insects, including land dwellers, survive around water. In 2011 he and a team from his lab described how colonies of Brazilian fire ants, normally abysmal swimmers, weave themselves together to build a waterproof raft. On its own, a single ant is not very water repellent, but when they link together arm in arm they can create “waterproof surfaces similar to how we create Gore-Tex”, Hu says. The principal idea is the same: create a fabric that is highly textured and uses tiny pockets of air to keep water out. But the ants, like the pond skaters – and the gods – are much better at it than human inventors.

“We understand all these great things in nature,” Hu says, “but we still can’t build an equivalent in our everyday lives.”
Shake that tail

The most memorable trait of peacocks is their beautifully coloured fanned-out train feathers. A close second is the racket they make. But there is one aspect you may have missed: peacocks sometimes give their fans a little shimmy. While all we hear is a rustling sound, we are oblivious to an additional deep rumbling pitched below our hearing range. The shimmies come in two modes: ripples that move from the centre to the sides of the feather array, and a shudder that radiates from the base to the ends of the feathers. Peacocks use these low-frequency, infrasonic rumbles when approaching peahens are far away, reserving their high-frequency shrieks for nearby females, possibly because infrasound can carry for long distances and penetrate shrubbery. Peacocks also respond to recordings of other peacocks’ rumbles, suggesting that the signals may be territorial as well.
Lapping it up

Cats are slow and elegant, dogs are quick and messy – but is the physics of their drinking all that different? Jon Cartwright reports

Cat and dog lovers, psychologists tell us, are a species apart. Those who like cats are sensitive yet open, while those who like dogs are bolder and more self-disciplined. But if there is one trait common to each, it is an endless fascination with their pets.

Roman Stocker is a case in point. “I love cats,” he says. “I just happened to be watching my cat over breakfast one morning, and then I started wondering: has anyone looked into how a cat laps?” To the average cat owner the question would have ended with idle musing, but to Stocker, an engineer at the Massachusetts Institute of Technology (MIT), it was to spark a minor flurry of interest into our favourite animals’ drinking habits.

The science of water consumption in the animal kingdom is a little more complex than you might think. Some animals, such as frogs, absorb water through their skin, while others, such as the desert-dwelling kangaroo rat, can extract enough moisture from their food. Unsurprisingly, drinking as a means of water consumption is the most popular, but even this has its variants. Vertebrates with big cheeks – pigs, sheep, horses, humans and so on – can suck in water, whereas mammals with no cheeks, including most carnivores, cannot. Instead, carnivores must use their tongues; they must lap.

Cat cam
To satisfy his curiosity about cat lapping, Stocker returned home from his lab in 2008 armed with a high-speed video camera. As any feline fan knows, it is not easy to make a cat behave according to one’s own wishes. After several attempts, however, the MIT engineer had a few seconds’ slow-motion footage of his cat lapping from a bowlful of milk. To his surprise, he discovered that its tongue did not penetrate the liquid to scoop it up. Rather, the tongue curled downwards towards the cat’s belly until the top of the tongue – the dorsal side – just rested on the liquid’s surface. As the cat lifted its tongue, it drew up a column of liquid that got thinner and thinner until the cat’s jaws closed, completing the process.

Lapping without scooping might sound tricky, but you can perform a similar feat yourself with a teaspoon and a glass of water. Having rested the underside of the teaspoon on the water’s surface, it is possible to slowly draw up a short column of water thanks to surface tension. Try to draw it up more than a few millimetres, however, and gravity will take over: the column will pinch off and collapse.

Cats need to raise water higher than a few millimetres, so they must try a bit harder. Fortunately, cats’ tongues are moist and hydrophilic – that is, they attract water – and by pulling up sharply from a water surface, they can accelerate the column. The column’s inertia carries it higher – a couple of centimetres or more – until it is finally beaten by gravity. It is this competition between inertia and gravity, Stocker hypothesized, that sets the height of pinch-off – which, ideally, is inside the cat’s mouth.

Feline frequency
Working with engineering colleagues at MIT, Princeton University in New Jersey and Virginia Polytechnic Institute and State University, Stocker created a mathematical model of cat lapping, assuming a flat, perfectly hydrophilic disc moving away from a water surface. The researchers tested their model’s predictions using a mechanically driven glass disc for which they could adjust the radius, maximum speed and height. The model was found to work well, correctly predicting the height of pinch-off.

A corollary of the researchers’ findings was that there should be an optimum frequency of lapping. Too slow, and the cat’s mouth would miss most of the water before it drops; too fast, and very little water would rise in the first place. It turned out that this optimum frequency should scale inversely with the size of the tongue – specifically, with the square root.
of the tongue’s radius. And because the radius of a cat’s tongue is roughly proportional to the cube root of the cat’s mass (the body of even the biggest cat, the tiger, is essentially a scaled-up domestic), the optimum frequency should scale inversely with mass to the power one-sixth.

Inspired, Stocker’s group pored over YouTube videos of six other species of felines, including leopards, lions and tigers, estimating their masses and measuring their lapping frequencies. “The data seemed to confirm the prediction,” says Stocker, whose paper drawing together these feline findings was published in November 2010 (Science 330 1231).

Not everyone was impressed, however. A month after the publication, physicist Michael Nauenberg at the University of California, Santa Cruz, criticized Stocker and colleagues for assuming that the water in their model is in hydrostatic equilibrium, when actually, he said, it is in continuous motion. Nauenberg proposed that the optimum lapping frequency could in fact be determined simply from the time it takes for water in the column to fall back to the surface (Science 334 311). “This time interval was first given by Galileo,” he says, “and I have shown that it accounts well for the observed lapping frequency of cats and other felines.”

Nonetheless, as Stocker points out, Nauenberg ultimately predicts the same scaling of frequency with mass – the power-minus-one-sixth relationship. “The bottom line is still that cats lap by taking maximum advantage of the balance between inertia and gravity,” Stocker says. “If it’s his explanation or ours, that fact does not change.”

Enter the dog lovers

But Nauenberg’s was not the only criticism Stocker would have to shoulder. In their original paper, Stocker and colleagues claimed that, in contrast to the “elegance and complexity” of cat lapping, dog lapping merely involves a messy, ladle-like motion. “Although the dog’s tongue also curls [backwards] it penetrates the liquid surface and scoops up the water,” they wrote. Not so, said biologists Alfred Crompton and Catherine Musinsky at Harvard University in Massachusetts. Like cats, the Harvard researchers pointed out, dogs have no cheeks to contain water while they shift their tongues to swallow. So where would the scooped water go?

As it happens, Crompton and Musinsky had already performed their own study on dog lapping, but had not considered it worthy of formal publication until Stocker and colleagues’ paper came out. Unlike the engineers, the Harvard biologists did not create a mathematical model or perform mechanical experiments. However, they did have access to a high-speed X-ray machine. Directing this device at Crompton’s dog as it lapped some barium-laced milk, they could follow step-by-step the trajectory of the milk and the dog’s tongue.

True, the dog’s tongue does initially scoop up liquid, they found. But this liquid spills over the sides as the tongue rises, with some of it collecting in a newly formed column beneath. This column adheres to the dorsal side of the tongue, and is carried into the dog’s mouth until the jaw closes. The results were published last year (Biol. Lett. 7 882).

“The fact that the dog’s tongue tip penetrates more deeply into the liquid than a cat’s does, and consequently sprays more liquid around as the tongue rapidly withdraws, may give the impression that dogs drink by spooning liquids into their mouths,” Crompton and Musinsky write. They insist that cats and dogs “share the same basic mechanism for lifting liquid from a bowl into the oral cavity”.

Stocker admits that he was fooled by the messiness of dogs’ lapping, and he likes the Harvard biologists’ study. But he reckons it might not be so simple as scooping water versus lifting it by adhesion. “Dogs probably use a combination of the two,” he says. “Their tongue does pierce the water but, contrary to what we thought, that does not impede them from also having a significant column of liquid that also sticks to the dorsal side of the tongue. The tongue scoops up the water, but that plays just a small part.”

Perhaps, then, dogs and cats are not so dissimilar as their owners. A minor discovery, but one that has nonetheless caught the interest of those inside the scientific community and out. “One can write several papers you consider pretty good and no-one takes any notice,” observes Crompton, who has spent years studying functional anatomy. “Then you talk about dogs and cats people say, ‘Oh, this is good stuff!’”
Next month in Physics World

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Explore the life of Edward Hutchinson Synge, who made remarkable contributions to physics before, in his late forties, being declared clinically insane.

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Desert dew

The Namib Desert on the south-west coast of Africa is one of the hottest and driest environments on the planet. That does not stop its resident Namib Desert beetle finding drinking water, which it collects from the early morning fogs that drift in off the Atlantic. In the beetle’s morning routine it first crawls out of the sand and sticks its bum in the air so its body is at about 45° to the ground. Then it plays the waiting game. As the sparse sea fog blows across the beetle, tiny water droplets start clinging to a set of hydrophilic bumps on its back, which are 100–500 µm in diameter. The bumps are about 500–1500 µm apart and surrounding them is a waxy, hydrophobic surface. As more droplets stick they start to aggregate until, at diameters of 4–5 mm they become heavy enough to roll off the bumps and into the waxy channels, where they roll downwards under gravity and arrive at the beetle’s mouth.
Fly away home

Far from being “bird brained”, members of the avian family have an amazing array of techniques to help them navigate their way across vast oceans and continents. **Mark Denny** examines the physics of bird navigation

We all know, if only vaguely, that birds are great navigators. A good example is the swallow, which might spend the northern summer nesting under English eaves before migrating to South Africa for the winter – only to return the next summer to the very same nest site. It does not take much reflection to realize that these birds must have sophisticated navigational capabilities. But a deeper look into bird migration shows that many other species are capable of equally astonishing acts of navigation. To perform them, they rely on a wide scope of techniques, incorporating optics, acoustics, magnetism and celestial mechanics.

Birds exhibit varying degrees of navigational capabilities, from simply following coastlines and using the Sun’s position in the sky as a direction indicator (common throughout the animal world) to “dead reckoning” and finally true navigation, which requires both a compass and a map. At the more complex end of this scale, a fully fledged navigator such as a pigeon can figure out its current location and plot a course to a known location (its home, say) using external cues alone.

This amazing ability was revealed in a “displacement” experiment carried out in the 1950s, when a number of migratory Manx shearwaters were removed from their nest burrows on the Welsh coast, transported to New England and then released. The eastern seaboard of the US was unknown territory to these birds, yet they found their way home within a few days – indeed, the first was back in its burrow before the letter announcing their release reached Wales!

The displaced birds must have known where they were released. Otherwise, they could not have plotted a homeward course. But how?

A sense of direction

Before we look into examples of true navigation in the avian world, let us first consider a simpler method: coastal piloting. This technique uses landmarks and coastlines as references, and it was a favoured method among early human explorers such as the Phoenicians, who may have circumnavigated Africa 2400 years ago. In the avian world, the Arctic tern is a coastal piloting champion, generally sticking to coastlines on its migratory journey from its northern circumpolar breeding grounds to Antarctic latitudes (and back again the following spring). Arctic terns get plenty of navigation practice: they spend most of their lives migrating, and a typical bird may travel two million kilometres during its lifetime.

In principle, the Arctic tern could make its return journey north simply by reversing course. In practice, seasonal wind patterns oblige it to take a different route when travelling south–north than when travelling north–south. Perhaps for this reason, the Arctic tern, like many birds, has an internal compass as a back-up. In fact, birds have developed at least two distinct types of compass – magnetic and celestial – and many long-distance navigators, such as the pied flycatcher, possess both.

The most common form of celestial compass in the animal world is a Sun compass. The Sun’s location provides information about direction, but this information is only useful if the time of day is also known, since it is necessary to compensate for the 15° per hour movement of the Sun across the sky; for exam-
At 2 p.m., the Sun is 30° west of south. Like most animals, including humans, birds possess “circadian clocks”, or biomechanical processes with periods of about 24 hours, which are adjusted/reset by external cues such as daylight. Such internal clocks are accurate enough for use in a Sun compass.

Some birds, such as the savannah sparrow and the yellow-rumped warbler, have a particularly sophisticated Sun compass that works even when the Sun is obscured by clouds or after it has set. These birds can tell the difference between polarized and unpolarized light, which is very useful for orientation because sunlight becomes polarized when scattered in the atmosphere. The degree of polarization is a function of this scattering angle, and it hits a maximum when the scattering angle is 90°. Being able to perceive polarized light thus allows navigating birds to see the sky as patterns of varying brightness that depend upon the Sun’s direction, even if the Sun is obscured by clouds or has just set, since scattered light may reach their eyes even though direct sunlight cannot.

Many night-migrating birds set off on their journeys just after sunset, so polarized light gives them a nod in the right direction. Later, stars replace the Sun as a reference point. Nocturnal-migrant birds learn the night sky as nestlings: they stare up at the stars and note that Polaris, the North Star, always remains stationary. We know this from studies of nestlings brought up in planetariums, where the artificial night sky can be controlled. For example, in the mid-1970s the American neurobiologist Stephen Emlen found that nestlings reared in a planetarium...
Animal physics: Birds

where Betelgeuse is the pole star learn (wrongly) that Betelgeuse is due north. When released into the wild, they navigate via Betelgeuse and head off in the wrong direction.

Some birds use dead reckoning, which requires both a compass and an application of vectors. By measuring their speed, their direction of travel and the time they have travelled in that direction, migrating birds (or human sailors or desert ants – dead reckoning is widespread) build up a history of velocity vectors. By summing these vectorially, they can determine their location relative to where they started. Because this process uses only internally generated information, significant errors can accumulate, so birds and other animals quite often use celestial observations to calibrate their positions.

Some of the evidence for avian dead reckoning comes from observations of caged migratory birds. During times of the year when they should be migrating, caged birds seem restless and spend a disproportionate fraction of their time at a compass point of their cage corresponding to their migration direction. If, during migration, they would normally change direction after three days, then the caged
birds exhibit a preference for the new compass point after three days. This behaviour is known as Zugunruhe, or “migratory restlessness”.

**Animal magnetism**

Many birds can sense the strength and direction of the Earth’s local magnetic field, and use this to determine where they are. This “map sense” is believed to stem from tiny particles of magnetite in their brains; the geomagnetic field exerts a torque on these particles in proportion to the field strength, and it is thought that some birds can sense this torque. They accrue detailed knowledge about their location by sensing magnetic anomalies that arise from the geology of the Earth’s crust – in other words, they form a magnetic map. A large deposit of iron ore, for example, will give rise to a complex pattern of geomagnetic field strength that changes with position. Note, however, that the complex nature of geomagnetic navigation in birds remains an active area of research, with recent studies suggesting that the quantum-mechanical phenomenon of electron spin may play a role.

A map tells a bird where it is in the world, but to know how to get where it wants to go, a navigator needs a compass as well. A bird’s magnetic compass is not perfect. In particular, it is subject to the effects of magnetic declination, or the difference between true north and magnetic north. The current average magnetic declination is something like 11°, but because magnetic field lines are not even close to being straight, declination varies widely along a given field line (figure 1a).

As with celestial compasses, there are different types of magnetic compass. A few birds, including the Swainson’s thrush, possess a polarity compass, which senses magnetic field direction just like a manufactured hand-held compass does. Birds with a polarity compass can simply follow a course indicated by their compass, though declination effects mean that this will not necessarily be the shortest route over long distances. Most birds, however – including the European robin, the pied flycatcher, the dunnock and many warbler species – have developed an inclination compass, which detects the angle of inclination of geomagnetic field lines relative to the local horizontal (figure 1b). Birds with this sort of compass can sense the direction of the equator (where the inclination angle is zero) and of the poles (where it reaches a maximum).

An inclination compass does not distinguish between poles, however, and its use also becomes complicated when crossing the equator. For example, when a migratory bird with an inclination compass flies south from the northern hemisphere, it must first fly towards the equator, where its compass becomes useless because there is no vertical component to the field lines. Then, having passed through to the southern hemisphere, it must fly away from the equator; if its algorithm only told it to fly towards the equator, it would have to turn around and head back the way it had come.

Given the relative simplicity of polarity compasses, why do birds bother with the inclination variety? Perhaps the complicating effects of varying magnetic declination are less severe for inclination compasses. For example, artificial magnetic fields have been shown to interfere with a bird’s magnetic map, but not with its inclination compass. It seems plausible that in some cases, it may be enough for a bird to know its latitude, without the distraction of possibly erroneous direction information.

As for how inclination compasses work within bird brains, a group of researchers led by Katrin Stapput at Germany’s Goethe University Frankfurt recently showed that the inclination compass sense of a European robin is linked to the visual field of its right eye, and is therefore processed in the left hemisphere of its brain. Other birds, including homing pigeons and the domestic chicken, have the same sort of right-eye compass, and it is likely that many other birds exhibit such lateralization (differences of function between the left and right sides of the brain) as well. It may be that, like the “heads up” displays used by fighter pilots, which project information onto a transparent screen in front of their windshield, these birds see magnetic direction information superimposed upon what they perceive optically. This might, for example, appear as a fuzzy shadow that varies in intensity with compass direction (figure 2).

**The sounds of home**

Migratory birds of many species can follow coastlines and mountain ranges even at night or while above clouds, and it is thought that they use acous-
Animal physics: Birds

3 Long-haul flight

Map (left) of the southward migration route of Australasian bar-tailed godwits (right) on their flight from Alaska to New Zealand, as recorded by radio tags attached to nine individual birds. As such transmitters get lighter, it will become possible to attach them to smaller migrating birds without hurting their flying abilities, making it likely that more of these impressive journeys will come to light.

tic cues to do this. Evidence suggests that birds construct acoustic maps of the world by tapping into the low-frequency, low-amplitude seismic waves that are generated by water waves, and form the dominant background to seismic recordings at any point on the Earth’s surface. These “microseisms” propagate inland from their ocean or lake of origin, and are shaped by prominent land features such as cliffs and mountain ranges, which act as directional antennas when reflecting such waves. Thus, the spectrum of low-frequency sound (below 0.25 Hz) provides a background hum that varies with location as a result of the Earth’s varying surface (above and below sea level).

Tests on homing pigeons (a non-migratory species, but one with exquisite navigational capabilities) show that their hearing at frequencies below 10 Hz is at least 50 dB more sensitive than that of humans, and that they can detect frequencies as low as 0.05 Hz. At 1 Hz, for example, their hearing threshold is about 20 dB below the microseismic background, even though pigeons do not vocalize at such low frequencies, so it seems likely that they are listening to the Earth. Birds (and other animals) usually fix the direction of sound from the phase difference of a given source between their ears, but for such microseisms, which have wavelengths of several kilometres, the phase difference is too small for this method to work. Instead, it seems likely that pigeons use Doppler information to locate the direction of a microseism source while flying.

Sensor fusion

Improvements in satellite telemetry and ever-shrinking transmitters have enabled researchers to track smaller and smaller birds, with remarkable results. For example, the longest non-stop migratory flight that we know about is that of the Australasian subspecies of bar-tailed godwit, which flies from New Zealand across the open Pacific to the Yellow Sea. This journey of 10,500 km takes eight or nine days – impressive for a bird with a wingspan of only about 80 cm. They then make a second long flight to their breeding grounds in Alaska. The return journey to New Zealand takes them 11,500 km across the central Pacific (figure 3). The journey of Pacific golden plovers that breed in western Alaska and overwinter in Hawaii is not as long, but navigationally it is just as impressive. The Hawaiian Islands are among the most isolated in the world, and appear on a map as small dots in the middle of a featureless ocean. The lives of the plovers thus depend upon accurate navigation, and their journeys clearly require true map-and-compass navigation as well as astonishing feats of endurance. Many migratory birds use several different navigation techniques, depending on the circumstances. In human navigation, we refer to this multiplicity as “sensor fusion”. For example, a nocturnal migrant might start at sunset, navigating via polarized light, then switch to celestial navigation as the night wears on. If the stars become obscured by clouds, it might fall back on its magnetic sense. This ability of birds to use, in adaptable combinations, a celestial or geomagnetic compass, plus an acoustic or geomagnetic map, is truly remarkable. Technological improvements (such as smaller radio transmitters) guarantee that we will continue to be astonished by new revelations in this fascinating field. In the meantime, we may just gain a bit more respect for the humble pigeon and garden robin – there is much more to these birds than meets the eye.
Sterile skin

Shark skin is famous for its low friction in water—a trait that swimsuit manufacturers have attempted to recreate with questionable success. But what may prove even more useful to humans is the fact that nothing grows on shark skin. Up close, the skin is a repeating array of “dermal denticles”, each about 100 µm across and with three sharp and pointy ridges. In 2008 a company called Sharklet, based in Florida, revealed a plastic film that it says can keep hospitals clean. Based on shark skin, the surface is covered with diamond-shaped bumps that prevent the build-up of bacteria, including *E. coli* and *Staph. aureus*. Unlike chemicals that are designed to kill these bacteria—but which inevitably leave a few behind to multiply—Sharklet’s film works by preventing the micro-organisms that settle on it from growing to colony sizes large enough to infect humans.
To humans, falling rain usually amounts to little more than a minor inconvenience. After all, we are big and raindrops are small – they splatter on our heads and sleeves, and we end up a little wetter. But a mosquito’s mass is only 2–3 µg and the largest raindrops may weigh up to 100 µg. To those tiny bugs buzzing about in the rain, a gentle spring shower comes on like a downpour of London taxis, cascading from the sky at terminal velocity. No matter how quick a bug may be, it is going to get hit.

And yet, they live. Furthermore, they even prefer environments where mid-air rain collisions are part of everyday life.

“Mosquitoes live in damp, tropical environments, regularly collide with raindrops up to 50 times their own body mass and yet, remarkably, they live on to bite another victim. **Stephen Ornes** explains how scientists have figured out how these insects survive such a violent impact.
around waterfalls and places where it’s going to rain,” says David Hu, an engineer at the Georgia Institute of Technology in Atlanta. “They are up to 50 times lighter than a raindrop, and we knew that they had to have some interesting way to survive daily occurrences of rain in their environment.”

To explore these suspicions, scientists in Hu’s lab have been bombarding the flying, biting insects – obtained from the Center for Disease Control and Prevention, across town – with simulated showers. They recorded the collisions with high-speed cameras, and after months of analysis attributed the lowly mosquito’s survival to the same property that makes a raindrop so threatening: its mass. Reporting in a study led by graduate student Andrew Dickerson in the journal *PNAS* in June, the engineers explicated the pest’s manoeuvrings and explained the underlying physics (109 9822).

What saves the mosquito is conservation of momentum. A raindrop has a large mass and falls at about 6–9 m/s. The flying mosquito has little mass or velocity. As a result, say the Georgia Tech engineers, when the two collide, the raindrop barely slows, which means its impact force is minor – something on the order of 2–6 mN. The sturdy exoskeletons of mosquitoes can easily endure such a heavy load, so the collision does not crush them.

It does, however, take them for a wild ride.

### Tai chi masters

If a mosquito is sitting on solid ground when it is struck, the story ends differently. When a raindrop hits the ground or lands on a person, it breaks. On the ground, with nowhere to go, a mosquito would suffer an (unsurvivable) impact of about 10 000 times the ground, with nowhere to go, a mosquito would hit the ground or lands on a person, it breaks. On struck, the story ends differently. When a raindrop

For a mosquito sitting on solid ground when it is hit. Dickerson, who led the mosquito experiments, says he did not initially expect the mosquitoes to be able to escape. But they do; after the fall but before they splat on the ground, the mosquito and the raindrop part ways.

“I was surprised that they were able to separate from the raindrop so quickly,” he says. “I thought that as soon as they were hit, they would be pushed to the ground.”

Instead, he says, the mosquito slides out from under the drop and recovers. (But not for long; the researchers found that during a rainstorm, a mosquito gets hit by a sizable drop on average once every 26 seconds.) That escape manoeuvre is an amazing phenomenon to witness – not because it is particularly virtuosic, but because it seems sloppy and accidental. Dickerson and Hu, after a few trials, caught it on video (http://dickerson.gatech.edu/file/Mosquitoes.html).

### Pesky test subjects

When viewed in slow motion, the video shows what the human eye hides: mosquitoes can take a beating and, after a quick fall, slide out from under the drop without breaking it.

From the perspective of a mosquito, Dickerson points out, the whole process seems passive: you are flying along, you get pummelled by rain, you fall and you separate, all without exerting any real action.

“Mosquitoes have a high drag form, with their legs and wings spread,” he says. “When the raindrop pushes the mosquito along, you get some instability between the two, and wherever that instability shows up, it is going to pull the mosquito out from under the raindrop.”

To capture the process on video, the researchers had to come up with a novel experimental set-up. They found that dripping water on mosquitoes was easy enough, but approximating the speed of raindrops was difficult. When they dropped water on the mosquitoes from three storeys above, the water travelled fast enough, but they “still got a lot of aerodynamic variation and couldn’t get the drops to hit one spot”. The researchers succeeded when they set up a jet that fired water at the bugs at raindrop speed – about 9 m/s – and turned on the high-speed camera. The footage demonstrated the forces at play: the mosquito buckles on impact, surface tension keeps the drop intact and the bug slides away unharmed.

Dickerson, who is still working on mosquitoes, says an understanding of how the bugs survive may give us new ideas for how to kill them. That may not be good news for these little insects, but it could help those working on the diseases spread by these nasty blood-suckers.
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Sharp shooter

The archer fish is an expert marksman with a unique ability. With deadly accuracy it can knock prey from a nearby branch using a powerful jet of water squirted from its mouth. Despite this fish’s name, it is more of a shooter than an archer. Using its body effectively as a water pistol, it presses its tongue against a long, narrow groove in the roof of its mouth to form a tube, then compresses its gills to send a liquid missile into the air. The stream of water can travel as far as 5 m, during which time it can form a significant arc under the influence of gravity. Not only does the fish have to take this into account when aiming but it must also compensate for the optical illusion caused by the refraction of light at the water–air boundary. A master of its art, the fish compensates for these two physical phenomena and can accurately hit butterflies, spiders and grasshoppers within 2 m and at elevation angles of 45–110°.
Vespan voltage

Tushna Commissariat explains why Oriental hornets are masters of solar power

The life of a worker hornet is one of monotonous servitude. After the queen picks her nest site in the spring and produces her first set of subjects, they are immediately set to work. Chores include foraging for food, guarding the nest, taking care of the brood and building comb cells to make room for more eggs.

Hornets live in hot climates and – like humans – are vulnerable in the midday Sun to overheating and becoming damaged by the increased ultraviolet (UV) radiation during these hours. Given their sensitivity, they sensibly concentrate their activity to the early morning. But there is one species that breaks the rules: the Oriental hornet. Along with mad dogs and Englishmen, it goes out in the midday Sun.

Oriental hornets live in underground nests and so to make room for more comb cells the worker hornets remove soil, which they pick up using their mandibles and drop off 5–10 m from the nest. It was this innocent daily activity that caught the attention of a group of scientists back in 1967, who wondered whether something peculiar was going on. Led by the late Jacob S Ishay of Tel Aviv University in Israel, the team realized that while most species of hornet are most active in the early hours, moving out of their nests twice as often than at any other time, Oriental hornets seem to be at their most active at midday.

Although it might seem that these hornets are just late risers, their rather intricate behavioural patterns led to the realization that they appear to correlate their digging activity with the amount of incident solar radiation, being most active at noon and least active at dusk. Indeed, a 2004 study by the same group shed further light on this correlation, finding strong links between hornet digging activity and UV-B radiation in particular.

But arguably, the most interesting discovery of this group is the reason why hornets are such sun lovers: their bodies are living solar cells. Not only that, but they combine an organic semiconductor solar cell – the traditional p–n junction route to harvesting solar energy – and another type of photovoltaic device called the dye-sensitized solar cell.

Sun trap

In 2009 all of these clues led a former student of Ishay called Marian Plotkin, who was then at Tel Aviv, and her colleagues to look at the Oriental hornet’s exoskeleton in closer detail. Plotkin, supervised by David J Bergman, was hoping to find evidence for the morphology the insect would require to harvest the Sun’s energy – they were looking for the hornet’s in-built solar cell (Naturwissenschaften 97 1067).

The exoskeleton of the Oriental hornet consists mainly of brown cuticle, along with two stripes of yellow cuticle encircling its abdomen and a number of grooves about 500 nm wide and 160 nm high, while the yellow cuticle surface turned out to be a bumpy series of interlocking oval plates about 500 nm wide and 100 nm high, each with a tiny depression at its centre. It was already known that below both surfaces lies a stack of about 30 thin sheet-like structures known as lamellae, which decrease in thickness from top to bottom (figure 1).

Wondering how these nanostructured surfaces interact with sunlight, Plotkin sent the images to Stuart Boden and Darren Bagnall – both experts in nanoscale systems – at the University of Southampton in the UK, hoping that a computational model would shed some light on the way in which these hornets utilize light. The nanoscientists did not disappoint. Using computer models, they found that the nanostructured surfaces act as an anti-reflective coating. “The structure, on the whole, increases the absorption power of the hornet by 5% more than if it were just flat,” says Boden.

Furthermore, they found that the ridged brown cuticle surface acts as a diffraction grating: rather than all the emitted light passing through to the underlying lamellae in a straight line, some light is diffracted at the surface and travels diagonally through the lamellae, meaning it has a longer path length. When this diagonal light reaches the bottom-most layer of the cuticle, Plotkin and colleagues suggest it may then undergo total internal reflection and make subsequent passes of the lamellae.

Solar powered

Over the years Ishay and his team performed many experiments on Oriental hornets, finding early on that when part of the hornet is illuminated – be it dead, alive or under anaesthetic – a voltage of about 10–100 mV can be measured between the illumi- nated and dark parts of the cuticle, indicating that the cuticle has photovoltaic properties. They also found that the appearance of voltage was not instantaneous: there was a delay before the peak voltage was reached and also attenuation once the light was switched off – indicating that the cuticle is, in electrical terms, a capacitor.

Ishay’s group also found that when the hornet is illuminated, the cuticle’s resistance to current rises and saturates, but then drops when the light is removed – suggesting that the cuticle acts as an organic semiconductor that traps electrons that have been kicked by the light from the valence band to
the conduction band. Electrons are thought to get trapped by excited oxygen molecules \( \text{O}_2^+ \) in the cuticle. Light energy not stored in this way might create polarized electric domains, which would cause dipoles to align with the domains – another form of stored energy.

Light is thought to be absorbed in the lamellae throughout both colours of cuticle. Light is also absorbed in the brown and yellow pigment molecules that give the two cuticle types their colour. The brown pigment melanin is found throughout the layers of the brown cuticle, while the yellow pigment xanthopterin is found below the transparent lamellae in the yellow cuticle in tightly packed barrel-shaped granules – a structure that increases the effective surface area available for light absorption. Xanthopterin is a yellow, crystalline solid found mainly in the wings of butterflies and in the urine of mammals.

But while light is absorbed throughout both cuticle types, there is something extra special about the yellow cuticle. In an experiment in the 1990s, Ishay and colleagues had found that anaesthetized hornets come round faster if they are illuminated with UV light. However, if various body parts of the anaesthetized hornet are coated in the correction fluid Tippex, the insects take different times to wake up. While control hornets were found to require 31 minutes to wake up, hornets with painted abdomens took 73 minutes. This indicated to the team that there was something peculiar happening in the yellow cuticle – why was it so good at harvesting light?

As part of their recent study, Plotkin and colleagues Arie Zaban and Idan Hod – both experts in the field of dye-sensitized solar cells – at Bar-Ilan University in Israel, set about demonstrating the light-harvesting powers of xanthopterin by using it in a dye-sensitized solar cell. While the conversion efficiency of the cell was low at only 0.335%, it demonstrated that the pigment is capable of generating electricity from sunlight. The researchers point out that they did not
re-create the actual structure of the hornet in the solar cell and that doing so might increase the efficiency considerably. Previous experiments by others had already shown that melanin can be used in a dye-sensitized solar cell with 0.023% efficiency.

The release
While it looks like the Oriental hornet has some amazing capabilities, it is difficult to predict why its structure evolved as it did. “The surface structure might be an accidental morphological aspect for all that we know,” muses Boden. As for what the stored electricity is used for, that question is still largely a mystery. From Ishay’s studies it is thought that a lot of the energy gets spent once the hornet is back in its nest, where the polarized domains gradually depolarize and the electrical energy gets released as a current.

Another possibility is that after the hornets have been out of the nest in strong UV-B light, which forms harmful ozone and free radicals in their bodies, these radicals get broken down by the electric current back in the dark nest. In fact, Ishay conjectured that the length of time for which the hornets are out of the nest is an optimal balance between excavating enough soil and not being hit by too much dangerous UV-B light. Another use is for motor activities such as flight, and for keeping cool: insects do not have sweat glands, so to avoid overheating the hornet might cool itself and the nest brood by blowing air through its respiratory tubes. Also, in the dark nest, hornets glow: as excited electronic states relax, the hornets fluoresce, which could be useful for the hornets to identify each other and to get their bearings.

Given that humans have been chasing the dream of sustainable energy for decades, we can only hope that further research could let us unlock the secrets of harvesting solar energy as effortlessly as the humble hornet.
The snapper shrimp, also known as the pistol shrimp, is only 3–5 cm long but produces a clicking noise even louder than that of a sperm whale. How does this tiny animal make such a din? The clue is the shrimp’s disproportionately large claw, which originally led researchers to suggest that the sound comes from mechanical contact when the shrimp snaps its claw shut. However, studies using high-speed cameras have shown that something more interesting is going on. As the claw closes, a jet of water spurts out at around 25 m/s—so fast that the pressure in the jet drops to below the vapour pressure of water. Tiny air bubbles, which are found throughout sea water, expand rapidly to create larger bubbles. The water pressure quickly returns to normal and these air bubbles implode violently, at extreme pressures, and temperatures of more than 5000 K. The resulting supersonic shock wave stuns or even kills small prey nearby.
Animal physics: Lions

One thing common to mammals, birds and some amphibians is that they all make sounds using their vocal folds (or what are also known as vocal cords). Indeed, their ability to “vocalize” is a regular and necessary activity, whether to communicate where they are, to convey their need for food or protection, or to demonstrate their strength, size or social belonging. Moreover, any given species develops an inventory of sounds in order of importance of these needs.

One way to differentiate vocal sounds acoustically is by their tonality – in other words, whether a specific pitch dominates our perception of the sound, or whether the pitch is overshadowed by rhythmic bursting and roughness. Birds, for example, can sing or shriek – just compare the songs of finches and cardinals with the cries of crows and blue jays. House cats can hiss, growl or miaow, the latter being the more tonal variety. Aggressive behaviour in sexual and combative activity, meanwhile, is often associated with rough sounds.

But the most fearful vocalization, at least to humans, is the roar of a lion or tiger, which is characterized by being low in frequency, rough (aperiodic) and very intense. Big cats can in fact produce sounds of up to 114 dB at a distance of about a metre (if you wish to get that close) with lung pressures no greater than a human would use. This intensity is some 20 times louder than a lawn mower at the same distance. About 50 roars can be produced in a 90 second bout of highly active vocalization. Indeed, our ears are accustomed to the fact that low-frequency sounds are usually emitted from large objects and high-frequency sounds are emitted from small objects. A roar with low frequencies is therefore expected to come from a large animal that could well overpower us.

When an angry lion roars, the sounds it emits can terrify anyone within earshot. But, as Ingo Titze explains, the properties of a lion’s roar have some surprising similarities with those of a crying baby.

Ingo Titze is executive director of the National Center for Voice and Speech at the University of Utah and a professor at the University of Iowa, e-mail ingo.titze@utah.edu

One thing common to mammals, birds and some amphibians is that they all make sounds using their vocal folds (or what are also known as vocal cords). Indeed, their ability to “vocalize” is a regular and necessary activity, whether to communicate where they are, to convey their need for food or protection, or to demonstrate their strength, size or social belonging. Moreover, any given species develops an inventory of sounds in order of importance of these needs.

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Sounds intense

We know that when animals are extremely angry or scared – or have some intense need – the sounds they emit become distorted or irregular because so much muscular effort is applied that the tissues get stretched as far as they can go. Known as “bearing down” or overblowing, this effect is sometimes exploited by rock singers and brass-instrument players. Loudness in vocalization is almost always associated with the desire to get attention – to be heard.
above other animals and environmental sounds.

The vocal folds of lions and tigers may have developed a structure that helps them to emit the loud, rough and low-frequency sounds that are characteristic of roaring. The vocal folds of the great cats, for example, are some 2.5–3.5 cm long – nearly three times those of humans – and we know that long vocal folds produce low-pitch sounds, like long piano strings. But pitch cannot easily be determined in a rough sound because it has many component frequencies that are not harmonically related.

In lion and tiger vocal folds, there is not much of a vocal ligament – the thin band of collagen fibres used by many other species (such as humans, pigs and elk) to produce high-pitched squeals. Without this ligament, lions and tigers typically roar with dominant frequencies below 100 Hz, although they can crank it up to 200 Hz. Human males, in contrast, can go from 100 Hz to 600 Hz, while human females can go even higher because their vocal folds are shorter than those of males.

From a biophysical point of view, the important implication of lions’ and tigers’ long vocal folds that vibrate without the constraints of a vocal ligament (or muscle fibres close to the edge) is that they produce a rough sound. In most animals collagen and muscle fibres under tension vibrate with a dominant fundamental frequency, just as a vibrating violin string produces tonal sounds when it is taut. In lion or tiger vocal folds, in contrast, the layer of fat that is part of what would be ligament in the adult human is easily deformed, which means that the vocal fold vibrates with a large amplitude but the vibration does not have a regular pattern. This is rather like a floppy string, which produces many different modes of vibration that do not have harmonically related (tonal) frequencies.

The other interesting point about lions’ vocal folds is that the surfaces facing each other are very flat, forming two nearly parallel plates when brought together for phonation (figure 1). Indeed, both theoretical calculations and lab experiments carried out on excised lion and tiger larynges reveal that this parallel-plate configuration has a much lower threshold phonation pressure when compared with rounded or non-parallel surfaces. Low threshold pressure allows large amplitudes of vibration without excessive lung effort to produce loud sounds.

Like a baby

Two vocalizations that are rarely compared side-by-side, however, are the roar of a lion or tiger and the cry of a human infant. One is the sound of strength and dominance, the other the sound of pure helplessness, so it might not seem as if they have much in common. In fact, they do share several traits, both being loud and having a harsh, grating quality that cannot easily be ignored. Both are also designed to attract as much attention as possible – although the messages being conveyed are very different. The baby broadcasts “come to me now, I need your help”, while the lion is saying “stay away from here, this is my territory”.

It is interesting to compare the size of the vocal folds of human infants to those of the great cats. From experiments carried out on larynges taken from cadavers, we know that the vibrating vocal fold length in infants is about 2–3 mm, whereas those in big cats are about 10 times longer. On the basis of a vibrating string model, this 10:1 ratio predicts the difference in the frequencies produced, with a vocalization of 50 Hz for the great cats and one of 500 Hz for human infants, with considerable variation in both. Although the frequency is inversely proportional to vocal-fold length, the morphology of the internal vocal-fold tissues does not follow any scaling rule.

To our limited knowledge, the vocal folds in infants have a simpler structure than those in adults, with an epithelium (or skin) encapsulating a soft, gel-like material. In this sense, human infants have vocal folds that are more like those found in adult lions and tigers, with their vocal ligaments not having sufficiently developed to let them control their pitch by applying tension along the length of the vocal fold. The “thyroarytenoid muscle”, which is part of the vocal folds, in babies is also not developed near the surface where the vocal folds come together, like in the great cats, further restricting control of tonality.

In conclusion, the biophysics of roaring can be explained at two levels. First, the big cats have long, floppy vocal cords that vibrate somewhat chaotically, with many modes of vibration present at the same time. They have large amplitudes, however, because thick, flat and parallel vocal folds are easy to set into vibration with air flowing between them.

But understanding how the vocal folds of many species are structured – and how this affects the sounds produced – is not just of academic interest. This research is also helping scientists and physicians to decide how best to reconstruct vocal fold tissue in patients whose tissue has been damaged due to illness or injury. It is even of use to singing teachers, voice coaches, speech-language pathologists and other “behavioural vocologists” who seek to help others to strengthen their voices for various needs. Once again, we humans have a lot to learn from the animal world.
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Not many life stories in physics involve Nazis, illicit sex, a strange cat and the genetic code. Thus, a new biography of the great Austrian physicist Erwin Schrödinger is always of interest, and with *Erwin Schrödinger and the Quantum Revolution*, veteran science writer John Gribbin does not disappoint.

Many *Physics World* readers will be aware of Walter Moore’s 1992 biography *Schrödinger: Life and Thought*, which remains the definitive text on this colourful quantum pioneer. In fact, Moore also published an edited (and sadly neglected) version of his book for a popular audience, and Gribbin’s book is pitched more at this level. The new biography offers little new historical material, but Gribbin’s lucid style makes for an excellent introduction to this intriguing scientist and, indeed, to the world of quantum physics.

Gribbin sets the stage with a brief introduction to classical physics, followed by a description of the first quantum revolution. The work of Planck, Einstein and Bohr is described accurately yet succinctly in the author’s characteristic clear prose. The story continues with a description of the second quantum revolution, from Louis de Broglie’s hypothesis of wave–particle duality to Schrödinger’s brilliant wave mechanics (with Heisenberg’s matrix mechanics along the way). This is a familiar story for physicists, but one we never tire of reading.

The debate concerning the philosophical implications of the new theory is explained carefully, with a clear description of what became known as the “Copenhagen” interpretation. Einstein’s distrust of this interpretation is well known, but it is often forgotten that Schrödinger shared his views. As Gribbin points out, it is interesting that the father of wave mechanics had no faith in the idea of a wavefunction that collapses on observation, as posited by the Copenhagen camp. This objection is best exemplified by Schrödinger’s famous thought experiment of a cat that is neither dead nor alive before observation. Gribbin has written on Schrödinger’s interpretation of the quantum wavefunction many times before, notably in *In Search of Schrödinger’s Cat* (Bantam 1984) and *Schrödinger’s Kittens and the Search for Reality* (Phoenix 1996). Still, the wavefunction pioneer’s objection to the Copenhagen interpretation is worth restating.

The fascinating story of Schrödinger’s life and career is skilfully interspersed with the science. This is no easy task, given that he spent chunks of his career in Vienna, Jena, Zurich, Berlin, Oxford, Graz and Dublin, but Gribbin manages to maintain the reader’s interest throughout these sojourns without sacrificing accuracy. A good example is Gribbin’s description of the infamous Graz episode, when — having unwisely returned to Austria from Oxford in 1936 — Schrödinger penned a cringeworthy letter of apology to the Nazis, who had come to power in Austria following the *Anschluss* with Germany. As Gribbin explains, the publication of this letter damaged Schrödinger’s reputation abroad, while doing little to allay the Nazis’ suspicions of him.

Into this crisis came a life-saving offer from neutral Ireland. Impressed by the Institute of Advanced Studies in Princeton, the Irish premier Éamon de Valera had decided to set up a similar institute in Dublin, with Schrödinger at the helm. The peripatetic professor accepted with alacrity and with the help of De Valera, he arrived safely in Dublin in October 1939.

He and his ménage, that is, Schrödinger set up house in Dublin with his wife Anna, his mistress Hilde and Ruth, his daughter by Hilde. As Gribbin points out, this arrangement was quite unusual in holy Catholic Ireland, yet it is a curious fact that the Schrödingers felt much more at home in Ireland than they had in Oxford. Gribbin offers the explanation that in Ireland “there was a marked contrast between what was officially approved and what people actually did”, which I think is about right. In any event, Schrödinger indulged in numerous romantic affairs in Dublin without sanction, producing two further children out of wedlock.

The description of Schrödinger’s years in Dublin is the most enjoy-
able part of Gribbin’s story and there are many moments of humour. For example, Gribbin describes how, in its early years, the Dublin Institute for Advanced Studies attracted the attention of the Irish Times satirist Myles na Gopaleen, who caused a stir when he observed that “Professor Schrödinger has been proving lately that you cannot establish a first cause. The first fruit of the institute, therefore, has been to show that there is no God.” The institute’s authorities were furious; Schrödinger himself was unperturbed. At the same time, Gribbin is careful not to underestimate the work Schrödinger did in Dublin, from his research in general relativity to his attempts at a unified field theory, from his work on the interpretation of quantum theory to his speculations in molecular biology.

The fact that the Dublin institute became a leading centre for the study of relativity forms an important part of Schrödinger’s legacy, but it is his work on molecular biology that is surely the most extraordinary aspect of his career. In 1943 Schrödinger gave a series of public lectures in Dublin in which he asked how hereditary information might be encoded in living cells. While much of the work he spoke about was not original, a book based on the lectures – called What is Life? – went on to be a major influence in the field of genetics.

In the last chapter of the book, Gribbin considers Schrödinger’s interpretation of quantum theory from a modern perspective. He reviews several important developments of the past half-century, from the theoretical work of David Bohm and John Bell to the experiments of Alain Aspect and Anton Zeilinger. He then introduces the “many-worlds” interpretation and draws an intriguing connection between it and Schrödinger’s philosophy. There is an interesting point here, but the discussion is coloured by Gribbin’s own dislike of the Copenhagen interpretation.

This is a lucid biography of a brilliant scientist whose life and philosophy continues to intrigue. Although it contains little new historical material (apart from some lovely photographs and a nice surprise in the epilogue), Erwin Schrödinger and the Quantum Revolution is a cracking good read that will be enjoyed by physicists and non-physicists alike.

Cormac O’Raifeartaigh lectures at Waterford Institute of Technology, Ireland, and writes the science blog Antimatter, e-mail coraifeartaigh@wit.ie

Web life: Ask Nature

URL: www.asknature.org

So what is the site about?
Ask Nature is a site devoted to biomimicry, an interdisciplinary field in which practitioners study how animals and plants solve problems, and then use those solutions to develop better human technologies. The site lists many instances of technology imitating life, including a surgical bandage inspired by gecko feet, a fog-harvesting mesh inspired by a desert beetle and a ceiling fan inspired by the seed pod of a sycamore tree. In total, there are nearly 200 examples of actual bio-motivated inventions described on the site, but they are just the tip of an iceberg of possibilities. Ask Nature also contains an astoundingly large catalogue of animal and plant strategies that might inspire solutions to human technological problems. Known as the “Biomimicry Taxonomy”, this catalogue contains around 1500 entries.

Can you give me some examples?
The Morpho butterfly keeps itself dry and clean in its rainforest environment thanks to nanostructures on its wings that make them both extremely hydrophobic and self-cleaning. Such structures have inspired new types of paint, textiles and glass that require less labour and fewer chemicals to keep clean. Another rainforest denizen – a medium-sized bird called a toucan – has an outsized beak that can be up to a third of its length, while making up only 5% of its weight thanks to the beak’s foam-like interior structure and thin outer layer. This light-but-strong construction might prove useful in ultralight aircraft components, or perhaps the panels in cars that protect people from injury during crashes. Not all of the taxonomy’s entries are rainforest species, but the richness and sheer biodiversity of these areas does seem to promote the development of novel adaptations. Yet another reason, if one were needed, to be concerned about their disappearance.

How is the taxonomy organized?
Each entry in the Biomimicry Taxonomy is assigned to one of eight “function groups”, which are in turn divided into 30 sub-groups and 162 separate functions. For example, the high-level function group “move or stay put” is split into two sub-groups, called “attach” and “move”. Attachment is further divided between permanent and temporary stickiness, while movement is grouped by travel that takes place in (or on) gases, liquids and solids. This seems sensible enough, but taxonomy is not always an exact science, and the system used in Ask Nature occasionally throws up a few anomalies. For instance, it seems odd that the hairy footpads of the fennec fox (which help it move over desert sand without slipping) are classed under “movement”, while the cloven hooves of the mountain goat (which help it move over rocky terrain without slipping) are categorized as “attachment”.

How should I use the site?
If your interest in animal science has been piqued by this special issue of Physics World, the Ask Nature site is a great place to learn more about the amazing adaptations that animals (and plants) rely on to survive. For casual browsers, the two dozen or so “featured strategies” on the site are a good place to start. These entries are more complete than most others, with detailed explanations, references and photos as well as basic explanations of strategies and their possible applications to human technologies. If you are looking for inspiration on a particular design challenge, though, you would be better off using the site’s extensive search function. To get the best results, you may need to do some lateral thinking. As the site puts it, you might want to ask “How would nature reduce drag?” or “How does nature move through air?” rather than something more direct, such as “How would nature design an efficient wind turbine blade?” In the process, you might even find that merely looking at the problem in a different way helps lead to a solution.
This summer I took a break from lecturing at a graduate training school in Boulder, Colorado, to attend a talk by the soft-condensed-matter physicist David Weitz. His lecture was about colloids, and in the middle of it, he began to reminisce about the field’s early days. Weitz is now at Harvard University, but in the mid-1980s he was working in Exxon’s research and development centre in Annandale, New Jersey – a key international node in the development of soft-matter physics. The Annandale centre hosted some of the first conferences that catalysed the field’s formation, but as Weitz explained, the conference organizers had a problem: nobody knew what to call this new kind of research. After some debate, they fell back on the only internationally comprehensible name they could think of: “De Gennes physics”.

That the name of Pierre-Gilles de Gennes should become attached to an entire area of physics indicates his stature as an extraordinary visionary, one who spent his life transforming existing fields, such as superconductivity, and creating brand new ones, such as soft matter. He won the Nobel Prize for Physics in 1992 for his application of methods from condensed-matter physics to liquid crystals and polymers, but he also made his mark by exploring new ways of using theory and interacting with experiment, challenging entrenched institutions and becoming a passionate advocate of education. And of course, he topped it all off with a colourful personal life, in which he fathered two families of children and became a serious amateur artist. Small wonder, then, that an English translation of Laurence Plévert’s biography Pierre-Gilles de Gennes: a Life in Science has been eagerly awaited.

Plevert, a journalist, began interviewing De Gennes in 2005 – two years before the latter’s death. Author and subject worked from notebooks of jottings made by the latter over a 40-year period, and a long list of colleagues, family, collaborators and friends also contributed. The result is a thoroughly researched book. Even one of De Gennes’ closest friends, Phil Pincus of the University of California at Santa Barbara, found that Plévert unearthed episodes they had never spoken about. In Pincus’ case, it was De Gennes’ part in France’s North African nuclear-weapons tests that emerged from obscurity. For me, there was much in the book to fascinate and provide depth to this inspiring character, whom I had known since first meeting him during my PhD in the mid-1980s.

For example, in the first chapter Plévert gives the De Gennes family’s unusual history of French Protestantism an in-depth treatment, suggesting a thought-provoking connection to De Gennes’ later trajectory as someone whose thinking was strongly differentiated from traditional French theoretical physics. Similarly, anecdotes from his post-doctoral period with Charles Kittel in stylish and sunny 1960s Berkeley somehow resonate with his later ease at combining the serious with the flamboyant. I was also unaware of just how closely De Gennes was involved with early neutron-scattering experiments on vortex lattices in type II superconductors. Such close collaboration between theorists and experimentalists gave the French researchers an edge, and characterizes much of the methodology of soft-matter physics today.

After describing De Gennes’ childhood and early career, the book’s narrative tangibly picks up pace when it turns to his time as an assistant professor in Orsay, where his leadership potential first became apparent. De Gennes founded a superconductivity research group there in 1961, only to divert the entire group to the new field of liquid crystals after seven years. Later, at the Collège de France, he did the same with the wider field of soft matter. Plévert keeps this career-related thread ticking along in an accessible manner, weaving between general-audience explanations of techniques such as the renormalization group (one of the methods that De Gennes took from mathematical physics and planted in a new area) and diatribes against his subject’s bêtes noires. These were many and varied, and included conservative traditions in science, the pursuance of long-dead scientific questions, over-formal methods in science education and the editorial prevarications of Nature (after an invited article was rejected, he refused further invitations to write for the journal).

The other thread in the book’s tapestry is De Gennes’ personal relationships, both public and pri-
But Truman was wrong. In 1949, the Soviets surprised human civilization several times over. Weapons on the planet to destroy all life. And soon there would be enough nuclear weapons, the other side would retaliate, and access to resources could be suicide, then no one, in theory, would be crazy enough to use one.

The U.S. government detonated its first bomb at Alamogordo, New Mexico, on July 16, 1945. The story behind the Trinity test becomes a common occurrence in the Nevada desert. Test detonations like Trinity became a means of showing the power of the bomb's arsenals. Since these stockpiles couldn't be used, countries found a different way to demonstrate the power of their arsenals.

Jonathan Fetter-Vorm, a New York-based author and artist, has produced a graphic novel, Trinity: A Graphic History of the First Atomic Bomb, which depicts the Manhattan Project early in 1945. He dedicates the book to all those who dedicated their lives to creating the bomb, including hundreds of other émigré scientists from Poland to Jewish parents in 1908, and during the Second World War, he joined hundreds of other émigré scientists in contributing to the Anglo-American bomb projects. Unusually, however, Rotblat recognized the peculiar horror of nuclear warfare even before the first bombs were dropped, and after leaving the US-led Manhattan Project early in 1945, he dedicated the remaining six decades of his life to advocating the elimination of nuclear weapons. Andrew Brown's new biography of Rotblat, Keeper of the Nuclear Conscience, covers the entire span of his subject's life, with a special focus on Rotblat's work with the anti-nuclear Pugwash Conferences on Science and World Affairs - an organization he founded, and with which he shared the 1995 Nobel Peace Prize. The book's early chapters are full of perceptive details about Rotblat's character and the forces that shaped it. One particularly good example is Brown's observation that Rotblat, in his later life, refused to eat potatoes; apparently, they reminded him of the bitter-tasting tubers that he and his family consumed in Poland during the First World War, under near-starvation conditions. It is also interesting to see familiar stories of physics in the 1930s refracted through a Polish lens. As Brown makes clear, during the lean inter-war years, the level of physics talent in this newly reborn country far outstripped the available research funds. As a result, Rotblat and his Warsaw-based colleagues did their nuclear research on a shoestring: while the likes of Enrico Fermi could afford radioactive samples weighing whole grams, Rotblat had to make do with a few tens of milligrams. The chapters on Rotblat's participation in (and eventual departure from) the Manhattan Project are similarly insightful, and much enhanced by an account of the early bomb work done by Britain's Maud Committee and Tube Alloys programme. Somewhere in the middle, though, the book loses focus. The back-and-forth politico-scientific discussions on nuclear test bans that took place during the 1950s and 1960s make slow reading, and long passages contain little, if any, mention of Rotblat himself. Things do, however, liven up a little towards the end, as Brown describes how Rotblat became "an old man in a hurry", anxious to keep the spirit of Pugwash alive into the new millennium and as unconcerned as ever about irritating government officials.

Tom McLeish is a soft-condensed-matter physicist and pro-vice-chancellor for research at Durham University, e-mail t.c.b.mcleish@durham.ac.uk
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Some people decide to do a PhD because they think it will help them get a job. I thought so too, and in a way, I was right. My PhD did indeed lead me to my current job but, more importantly, it gave me the opportunity to become an entrepreneur and create jobs for other people.

I am originally from Iran and I earned my undergraduate degree in applied physics at Tehran’s Sharif University of Technology, followed by a Master’s degree from Shahid Beheshti University in the same city. Then I decided to come to the US to get my PhD, and I chose the University of Louisville (UofL) in Kentucky thanks to Robert W Cohn, who offered me a research assistantship and became my thesis adviser in the electrical engineering department.

At the start of my PhD, I often asked myself whether I wanted to become a professor or a researcher in a large established company such as IBM or Intel. I was particularly unsure whether switching between physics and electrical engineering would help or hurt my chances of finding a job in academia. I still do not know how my career would have worked out if I had not decided to found my own firm, NaugaNeedles.

An accidental discovery

My research project at UofL involved working on direct patterning of liquid metals, such as gallium, using atomic force microscopy (AFM). One day in 2004 I found by accident that gallium interacts with metal films, such as gold and silver, at room temperature in a way that produces interesting self-assembled nanostructures. For example, when a molten gallium droplet was placed on a silver film, I observed very long needle-like structures form immediately inside the gallium droplet in ambient conditions.

After talking to my adviser, we decided it might be possible to grow these “nano-needles” selectively at the end of AFM probes. Our idea was to coat AFM probes with silver film, move them deep into a small gallium droplet, and then pull away from the droplet to grow freestanding nanoneedles. I prepared 15 probes coated with silver film and tried to grow needles on them. After investigating the finished samples using a scanning-electron microscope, I found that only one of them had worked. Still, the fact that I had reproduced the effect was promising, so when I showed the result to Cohn, he gave me two thumbs up. At the same time, I began thinking about the commercial potential of the technology, especially for fabrication of specialized AFM probes. Currently, most AFM probes have a conical silicon tip, but although these probes are cheap (just $10–20 each), they do not last very long – after a few scans they become dull and useless. Another problem with commercial silicon probes is that they do not conduct unless coated by the user. In addition, their conical tips cannot image deep micro- and nano-structures. A conical AFM probe with a conductive nanoneedle grown at its tip would, in contrast, be electrically conductive, capable of imaging deep trenches and longer-lasting than conventional probes. Finally, the simple geometry of these probes would make them useful for quantitative force microscopy measurements.

Considering all these advantages, I thought that my devices could make a successful business. But a few hours later, reality began to set in. How could I manufacture such a product? I was living in a foreign country on a student visa. I had $500 in my bank account. I knew that starting a business costs a lot of money, and I did not have much knowledge or experience of the business world. All of these things kept me from taking immediate action on my idea. Nonetheless, between 2004 and 2006, I continued working on the technology and its applications, and they ended up forming the main part of my PhD dissertation.

When I graduated in July 2006, my wife was still a PhD student at UofL, so I started working as a postdoc there in order to stay in the area until she finished her degree. I looked for opportunities outside academia, too, but I soon realized that my chances of finding a job in the Louisville region as a PhD graduate in nanotechnology were close to zero. On the positive side, the lack of job opportunities at someone else’s company encouraged me to start my own. I told myself, “I got a PhD not to get a job, but to create jobs,” and I signed up for a day-long “business boot camp” at UofL to help me get started.
Learning the ropes
At the boot camp, I learned about several funding opportunities, including one programme called Small Business Innovation Research (SBIR) that gives US government grants to small firms, and another “matching fund” initiative sponsored by the state of Kentucky. I also realized that there are “angel investors” who invest money in start-ups and various sources of venture-capital funding. All of this made me realize that having $500 in savings was not going to be a problem, as long as I had a promising technology. That is when I took my first step towards establishing a company: I paid a $45 fee to register NaugaNeedles LLC with Kentucky’s secretary of state. So far, so good, I thought; I had a company now, and it only cost me 45 bucks! My next step was to ask my PhD adviser if he would be interested in joining NaugaNeedles as the first member of its board of advisers. He accepted, and so did a few others, including the president of Zyvex Labs, an established nanotechnology firm based in Texas.

Now I had a company and a board of advisers. What next? The immediate answer, I realized, was “nothing” – I couldn’t do anything if I had no cash. So my next step was to apply for a $25 000 grant from the state of Kentucky via a “concept pool fund” aimed at early-stage start-ups. I obtained this funding in November 2007, and it allowed me to make a website for NaugaNeedles, prepare evaluation samples for potential customers using facilities at UofL, and develop a business plan. This small fund was instrumental to NaugaNeedles’ success, because it helped me find a few customers who were ready to pay for my company’s product.

During this early phase, I began collaborating with a physicist, Ron Reifenberger, and a mechanical engineer, Arvind Raman, at Purdue University in the neighbouring state of Indiana. As a result of this collaboration, in 2009 NaugaNeedles received funding via the US National Institutes of Health. This NIH grant allowed us to demonstrate that nanoneedles could be used as “nanocantilevers” for mass sensing, as well as measuring interaction forces at the piconewton (10−12 N) level.

Things really started to take off after my business plan won a prestigious $120 000 cash award from the Louisville-based Vogt Invention and Innovation Fund. I used this funding to get an additional loan of $120 000, and the combination of the two allowed me to rent manufacturing space, and build or buy the equipment that I needed to establish NaugaNeedles’ current facility. By June 2009 the facility was ready and in-house production began.

At about the same time, I applied for an entrepreneurship fellowship with a philanthropic organization, the Kauffman Foundation. I was selected along with 12 other top scientific researchers for a year-long programme that aimed to teach us how to take promising research forward to commercialization. Each of us had a business mentor and attended intensive workshops where we had the opportunity to network and learn from each other and from entrepreneurship experts. This fellowship allowed me to leave my job at UofL and become the first full-time employee of NaugaNeedles in October 2009.

Reaching maturity
One key question that start-up founders have to address is when to bring in new people and employees. For NaugaNeedles, this point came in mid-2008 – almost a year after the company was officially established, but also a year before we got our own manufacturing facility. By this time, I had realized that a lot of investors, both private and governmental, view the team as one of the most important aspects of a company; if you are a “one-man show”, no-one is going to take you seriously. After talking with several colleagues from UofL and old friends from other institutions, I expanded the company to include two additional employees: my partners and co-founders, Amir Birjandi and David Mudd, who are NaugaNeedles’ chief financial officer and director of operations, respectively.

Today, in addition to the three co-founders and the members of the advisory board, NaugaNeedles has six full-time and four part-time employees. We have launched several categories of products including high-aspect-ratio NeedleProbes (used for both conductive AFM scanning and imaging deep trenches) and exposed-end NeedleProbes, which are specialized for conductive AFM scanning under liquid media. Since its founding, the company has raised more than $2.5m in funds from various sources, and our production facility is capable of making more than 100 NeedleProbes per day – the equivalent of about $3m worth of products per year.

The lesson I take from this is that entrepreneurship is not as scary as it sounds. My main advice is that if you believe there is a business opportunity in your research, go after it! It is not as hard as you might think to start a business, even if all you have is $500 and one great idea.

Mehdi Yazdanpanah is the co-founder and chief executive officer of NaugaNeedles, e-mail mehdi@nauganeedles.com
What sparked your interest in physics?
I recall reading a paperback edition of Martin Gardner’s *Relativity for the Million*, probably when I was about eight or nine. From then on I was hooked. I had already been interested in the usual run of scientific topics for a kid — dinosaurs, chemistry, astronomy — but that book clinched my interest in physics.

You studied physics at the Massachusetts Institute of Technology (MIT) — did you enjoy it?
Yes, especially the lab work and computers. This was the 1970s, so like everyone else, I took a course in FORTRAN, believing that it would be the lingua franca of the digital millennium!

Why did you decide to become a writer?
I always wanted to be a writer because I enjoy books. It did not really occur to me that an aspiring author might seek an English degree.

What skills have helped you to succeed?
After MIT I had a brief career as an editor at a medical journal publisher, and that was useful. I learned about usage and editorial style, things that were not taught in my English classes (or in physics classes, for that matter).

How do you think your physics background has influenced your writing?
I think my physics background has been incredibly valuable in writing about social sciences and other non-physics topics. In physics the evidence is (relatively) clear-cut, and there is intense competition among ways of accounting for it. In the social sciences the evidence is a lot more slippery and you’ve got theories or schools or “trends” that, like evaporating salamanders, can survive for long periods without the need to slake their thirst on evidence. The physics background has been useful in discerning what’s “real” in the social sciences. Max Planck said that new scientific truths triumph only when their opponents die off, and I think that is true to an even greater degree in the social sciences.

What are you working on now?
I am writing a book on the predictability of human actions. Its historic point of departure is the “outguessing machine” that Claude Shannon built at Bell Labs in the early 1950s. It was a simple machine that played the game of “matching pennies” against a human. All the human had to do was to generate a random sequence. But Shannon knew this was incredibly hard to do: our minds aren’t built that way. Dozens of famous scientists and mathematicians visiting Bell Labs were challenged to match wits with the machine, and they all lost. Today the outguessing machine is a milestone of early artificial intelligence, not least because it managed to beat the world’s greatest geniuses with just 16 bits (2 bytes) of memory. In the book I show how the outguessing machine’s basic precept — that humans beings cannot act in a truly random fashion — has been influential in all sorts of fields, from tennis strategy to Internet marketing to high-frequency trading.

Do you have any advice for today’s physics students?
My advice would be to take a variety of courses in physics, mathematics and other fields. Success is often a matter of seeing a connection or an analogy that no-one else has. Your chances of doing that are greatest when you have stocked your mind with a rich assortment of “tangential” ideas.

Careers and people

Spotlight on: James Yeck
Veteran science project manager James Yeck has been appointed the new chief executive officer of the European Spallation Source. Yeck, who is currently the director of the IceCube neutrino telescope project, will take over Europe’s flagship neutron source at a crucial time, with construction on the €1.48bn facility due to begin next year in Lund, Sweden.

Yeck’s career in project management dates back to the early 1980s when, as a member of the US Peace Corps, he and another volunteer oversaw the construction of toilet/septic tank systems for 35 homes in the village of Nong Daen, Thailand. That project cost a modest $380.13, but after earning a Master’s degree in engineering at Northwestern University in Illinois and doing doctoral work on risk assessment at the University of Pennsylvania, Yeck soon moved on to bigger-budget operations. Between 1991 and 1997 he managed the construction of the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory in New York, which was completed in 1999 at an estimated cost of $617m. Afterwards, he moved to Fermilab, where he led the US component of the Large Hadron Collider construction project, with a budget of $531m. In 2003 he joined IceCube as its director, dividing his time between the $271m neutrino telescope’s University of Wisconsin project offices and its construction site near the South Pole. Between 2006 and 2009 he also served as deputy director of the National Synchrotron Light Source II project at Brookhaven.

Movers and shakers
Nuclear physicist Caterina Biscari of the National Institute for Nuclear Physics in Rome, Italy, has been appointed director of the recently opened ALBA Synchrotron Light Facility in Barcelona, Spain.

US dark-matter researchers Blas Cabrera of Stanford University and Bernard Sadoulet of the University of California at Berkeley have won the American Physical Society’s 2013 Panofsky Prize for their work on the Cryogenic Dark Matter Search experiment.

Roberto Car of Princeton University, US, and Michele Parrinello of the Swiss Federal Institute of Technology in Zurich have won the Italian Physical Society’s Enrico Fermi prize for discovering the eponymous Car–Parrinello method for numerically simulating molecular dynamics.

Optical physicist Ken Gratton has been appointed as the inaugural dean of the graduate school at City University London, UK.

Adaptive-optics specialist Olivier Guyon of the University of Arizona has received one of 23 so-called “genius grants” awarded by the US-based MacArthur Foundation in 2012.

Climate scientist Kurt Lambeck of the Australian National University in Canberra has won the 2012 Balzan Prize for earth sciences. The prize, worth about £500,000, is one of four given annually by the Switzerland-based Balzan Foundation to honour research in non-traditional or interdisciplinary fields.

Biophysicist Matthias Mann, who leads the Max Planck Institute for Biochemistry in Martinsried, Germany, has won the €750 000 Körber European Science Prize for developing new techniques for analysing proteins in a cell.

The Biophysical Society has presented its Margaret Oakley Dayhoff Award for early-career research to Jenny Ross of the University of Massachusetts Amherst, US, for her work on how tiny structures called microtubules organize and influence biological processes on a cellular level.

Agnieszka Zalewska of the Henryk Niewodniczański Institute of High Energy Physics in Krakow, Poland, has been elected president of the CERN Council.
THEORETICAL CONDENSED MATTER AND STATISTICAL PHYSICS (CM&SP) POST-DOCTORAL POSITIONS
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Appointments will be made for two years, with the possibility of renewal for one more year.

Applicants should be no more than 35 years of age at the time of application and should have obtained their Ph.D. after 2008. The application form can be accessed at the website: https://onlineapps.ictp.it/ENTER/APPLICANT/CP12.mhtml

Additional detailed curriculum vitae, list of publications and at least three recommendation letters (sent separately after submission of application) must all be appended on-line.

Deadline for receipt of applications: 13th January 2013.
Faculty Position in
Geometry and Topology in Physics
The University of Chicago

Position Title: Associate Professor

The Physics Department, the James Franck Institute (JFI), and the Enrico Fermi Institute (EFI) at the University of Chicago invite applications for faculty positions at the tenured rank of Associate Professor in an area broadly defined as Geometry and Topology in Physics and encompassing areas of condensed matter physics emphasizing topological aspects of quantum physics in new materials and quantum computation as well as aspects of general relativity and string theory, particularly gauge/gravity dualities and their applications. It is our hope that vibrant activity in this area will serve as a focal point of activities in both JFI and EFI, forming an intellectual bridge between the Institutes. To achieve this level of activity we aim to hire one or two faculty members in the next two years in addition to appointments that have already been made. We expect the first appointments will start in the Fall of 2013. We encourage applications from candidates with an outstanding record of research in the above areas.

Candidates must have a doctoral degree in physics or related fields and be several years beyond the Ph.D. Candidates are expected to have established an outstanding independent research program and will be expected to contribute to the Department's undergraduate and graduate teaching programs.

Applicants must apply online at The University of Chicago academic jobs website at http://tinyurl.com/cn25q98 and upload a cover letter, a curriculum vitae, a list of publications, and a brief research statement. The cover letter should be addressed to: Geometry and Topology in Physics Search Committee, Physics Department, The University of Chicago. In addition, three reference letters will be required. Reference letter submission information will be provided during the application process. Questions regarding the application process should be sent to Shadla Cycholl at scychol@uchicago.edu.

Review of completed applications will start in the Fall of 2012, and will continue until the positions are filled. To ensure full consideration, applications and recommendation letters should be received no later than December 15, 2012.

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Extra opportunities on offer: student conferences, innovation and commercialisation training, joint events with other CDT’s, outreach events. These contribute to building a group of outstanding scientists that will help to lead world research in nanoscience in the future.

Applications are invited for up to 20 PhD places on the NoWNANO programme. We welcome applications from graduates with a good degree (first or high upper second) in science, engineering or medical disciplines.

THE PROGRAMME

- 6-month training in fundamentals of nanoscience and core research techniques including 2 mini-projects in a choice of labs
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Candidates will require as a minimum a good degree in Physics (or related mathematics or engineering discipline). The successful applicant must have experience of developing software in a high level programming language (e.g. C/C++, Fortran, C#, VB.NET or Java). Experience in Windows programming would be an advantage.

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Successful applicants will take a leading role in supporting the development of new products and will be involved on a number of projects including both computational and experimental activities. Ideally candidates will have experience of medical accelerator systems and the ability to contribute in several of the areas that the Physics group is responsible for. Projects will often offer interaction with Research Hospitals and other Institutions, therefore exceptional written and spoken communication skills will be required. Our preference is for candidates to be educated to MSc or PhD level or equivalent. The ability to work to tight deadlines and within a successful team is also essential for these roles.

Current vacancies include:

- **R&D Physicist (Radio-Frequency):** This position is aimed to provide the business with technical support of Elekta RF systems in electron linear accelerators and associated developments, with particular focus on beam generation, transport, control and monitoring. This role will require an understanding of periodic accelerating structures, particle in-cell modelling, electron sources, high-power RF sources and electron beam dynamics. Candidates should have at least a degree (ideally a PhD) in Physics, Accelerator Science or closely related discipline. Candidates will have ideally a minimum of 5 years experience in RF physics/engineering and related areas, involved with modelling aspects of accelerating structures as well as RF waveguide experiments, either in a research or industrial environment. However applicants with less experience yet exceptional skills will also be considered.

- **R&D Physicist (Radiotherapy Equipment):** The position will involve designing, planning, implementing and managing test programmes in order to produce performance data for Elekta Radiotherapy Linac systems, according to international compliance standards and other business requirements. In this role, the candidate will be expected to provide technical advice to the business regarding physics QA and product performance issues, particularly with regard to the introduction of new technologies. Candidates should have at least a degree in Physics, Medical Physics, Radiation Physics or closely related discipline. It is desirable that they are educated to MSc or PhD level and have at least 5 years experience as a professional physicist, either in an industrial or clinical environment. Experience with radiotherapy physics QA programmes and tools is required.

- **R&D Physicist (Imaging):** The aim of this position is to provide physics support for the research and development of Elekta systems for Image Guided Radiotherapy. The Imaging Physicist will take a leading role in the design and experimental evaluation of new developments of kV and MV imaging systems; he/she will define technical specifications and address issues related to acceptance, quality assurance and regulatory requirements. To be successful in this role a thorough understanding of the physics of X-ray imaging, X-ray sources and detectors is required. Candidates should have an MSc or preferably a PhD in Physics, Medical Physics, Radiation Physics, Medical Imaging or closely related discipline. Candidates will be expected to have at least 3 years experience as an X-ray Imaging Physicist, either in an industrial, research or clinical environment, having developed significant knowledge in several of the following areas: design and evaluation of planar or tomographic X-ray imaging systems, imaging sensors and electronics, image quality test methods, image reconstruction algorithms, scatter correction methods, modelling of imaging systems, dosimetry of kV and MV photon beams.

- **R&D Physicist (Radiation Physics):** In this role, the candidate will be expected to provide technical advice to the business on radiation physics related issues and product performance, with regard to new developments of radiotherapy systems. Candidates should have at least a degree in Physics, Medical Physics, Radiation Physics or closely related discipline. It is desirable that they are educated to MSc or PhD level and have at least 3 years experience as a professional physicist working in the field of applied radiation physics, either in an industrial, research or clinical environment. Strong experimental skills and good computing skills for data analysis are required. Experience with medical linear accelerators will be an advantage.

To apply for these vacancies please visit our website www.elekta.com and apply via the careers section.
Consider a spherical cow

The spherical cow is normally treated as a comedic abstraction, one that gets brought up like a cud in jokes about ivory-tower physicists. However, I believe that this much-mocked beast has other lessons to teach us about physics, and especially about the animal physics covered in this special issue of Physics World. For the purposes of this essay, therefore, I would like you to take the phrase “consider a spherical cow” at face value, and actually consider such an animal as she gently rolls around her pasture, occasionally emitting milk and fertilizer from her fuzzy, curvaceous surface.

Now that this image is firmly in place, we can begin to put some meat (so to speak) on the spherical cow’s bones. The mass of ordinary cattle is highly breed-dependent, ranging from 350 kg for a petite Jersey heifer up to 1600 kg for a specialist draught bull. But since the spherical cow – let’s call her “Orbie” – is, herself, a nice round figure, it seems appropriate to pin her mass at the nice round figure of 500 kg. As for volume, cows, like humans, are mostly water, which has a density of 1 g/cm³. We can therefore estimate that our 500 kg bovine will occupy about 0.5 m³ of space. From this, it is trivial to calculate that Orbie’s radius is approximately 0.5 m.

Armed with these estimates, we can move on to consider how Orbie eats and drinks. Luckily, the mechanics of normal bovine grazing are such that eating requires relatively little adaptation. As the US National Forage and Grasslands Curriculum puts it, “When cows eat grass, their tongue sweeps out in an arc, wraps around the plant parts, then pulls them between the teeth on the lower jaw and a pad on the upper jaw.” Drinking will be harder for Orbie, though, because cows (unlike dogs) sip water rather than lapping it up with their tongues. This means that in order to obtain water, Orbie will first have to roll into a puddle, lake or river – and run the risk of drowning if she cannot get out.

But how does she roll around in the first place? My first thoughts on spherical-cow locomotion involved what I will politely term “wind” propulsion, but a quick calculation showed that this method would be impractical for a beast of Orbie’s mass, no matter how flatulent. I therefore turned my attention to the earlier stages of the bovine digestive system. A cow’s stomach contains four distinct compartments, and its digestive process involves shifting food around between them. Might this internal mass transfer produce enough angular momentum to set Orbie rolling? I suspect she would need both a full belly and an intuitive understanding of driven harmonic oscillators to get started. However, once in motion, she ought to be capable of self-directed rolling over a pasture-sized area.

What about longer journeys? Transporting Orbie will be easy if her destination is downhill, but other travel will require an animal-welfare-compliant lorry. Current British regulations specify that any vehicle used for transporting animals of Orbie’s mass must have a floor area of at least 1.3 m² per animal, be capable of maintaining an ambient temperature between 5 and 30°C, and have an airflow of at least 60 m³ per hour per kilonewton of payload. These allocations sound generous compared with, say, the London Underground, but a spherical-cow transporter would need better temperature controls and airflow, since Orbie’s minimal surface-area-to-volume ratio makes her prone to overheating. The lorry would need more floor space per animal, too, because – as the mathematician-physicist team of Fedor Nazarov and Yoav Kallus recently proved – 3D spheres waste more space than any other regular shape when packed into a 3D box.

As well as being inefficient packers, spheres are also bad at maintaining their shape when subjected to non-uniform pressures. This is bad news for Orbie, because the tiny area of her body in contact with the ground must somehow support half a metric tonne of unhappy pot roast, weighed down by the Earth’s gravity. Worse, the fact that she is spherically symmetric means that any part of her body – including sensitive bits such as her eyes and udder – could end up bearing this load.

For this reason, I have reluctantly concluded that a truly spherical cow is not possible. Instead, we must make a second-order approximation. I suggest calling this new creature “Bucky”, because instead of being perfectly round like Orbie, his surface is composed of 20 hexagons and 12 pentagons, arranged in the regular and interlocking pattern of a carbon-60 molecule. This “buckybull” structure retains much of the spherical cow’s essential rotundity, while avoiding her worst design flaws. In particular, Bucky’s facets could be slightly concave, such that his weight rests on the edges of his component polygons, rather than on the tenderer portions of his anatomy.

Some readers may regard this discussion as a load of bull. But even though the spherical cow exists only in the minds of physicists, I still believe there is merit in considering it. After all, who knows what sorts of creatures might develop on other planets, with different environments and gravitational pulls? If SETI’s first signal turns out to be a plaintive, Doppler-shifted “moo”, I will be delighted.

Margaret Harris is reviews and careers editor at Physics World, e-mail margaret.harris@iop.org
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- NRecon: cone-beam tomographical reconstruction from angular projections with multithreading and GPU-acceleration; virtual slices up to 15Kx15K pixels.
- DataViewer: visualization as a slice-by-slice movie or as a three orthogonal cross sections, centered at any point; dataset rotating and resampling.
- CTvox: realistic visualization by volume rendering, manipulation of object and camera, clipping tool, stereo mode, fast creation of animations.
- CTar: 2D/3D image processing and analysis for large format datasets, volume of interest selection, customization, batch processing, user plug-ins.
- CTvol: Realistic visualization by surface rendering (triangulated models), virtual 3D viewing environment, easy creation of 3D movies including stereo mode.

free QR-reader app is available in the AppStore

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