

CavMag

AUGUST 2014 Issue 12

News from the Cavendish Laboratory

ena

Inside

The Top Quark and Going Beyond the Standard Model
Phase Transiting to a New Quantum Universe
Tony Hewish at 90
Nano-spintronics
Physics and Industry: Past, Present and Future
Richard Hills FRS
Rutherford Schools Physics Project - An update
Maxwell, the Ether and the Michelson- Morley Experiment
Upcoming changes to the Physics curriculum
Keeping the show on the road
How you can contribute
News

5

Cavendish awarded Athena Swan Gold Award

e are delighted that the **Cavendish Laboratory** has been granted Athena **SWAN Gold Award status** in the 2014 Equality Challenge Unit's Athena SWAN Scheme. To set this success in context, 125 UK departments and universities applied for an Athena SWAN award in this round, and 89 were successful in attaining Gold, Silver or Bronze status. Only three Gold awards were announced in the April 2014 list, one of which went to the Cavendish Laboratory. We are the first Department in the University to attain this status and the first Physics Department in the UK with a gold award.

Head of Department Andy Parker wrote:

"Our Equality and Diversity team, led by Val Gibson and David Peet, have been engaged in a long-term effort to ensure that the Department provides a welcoming and supportive environment for our female staff and to remove barriers to their progression. It is very clear that these measures have benefited all of our staff. I am proud that our efforts have been recognised by the Athena Swan panel."

The objectives of the Equality Challenge Unit (ECU) are described on their web-site. It works

"...to further and support equality and diversity for staff and students in

higher education across all four nations of the UK, and in colleges in Scotland. ECU works closely with colleges and universities to seek to ensure that staff and students are not unfairly excluded, marginalised or disadvantaged because of age, disability, gender identity, marital or civil partnership status, pregnancy or maternity status, race, religion or belief, sex, sexual orientation, or through any combination of these characteristics or other unfair treatment."

Val and David have spearheaded the Cavendish's efforts to implement these ECU policies since the scheme started almost ten years ago. It is worth highlighting the many changes which have been made to bring the culture in the Laboratory into concordance

phy.cam.ac.uk

with the high expectations of the scheme. In the Cavendish's submission, our application highlighted our main successes over the last 5 years as follows:

- a 64% increase in the number of women academic staff (3.2 FTE women appointed to Lecturer/Reader compared to 4 men);
- all female academics, eligible for promotion, have been promoted at least once;
- positive impact from the re-design of our undergraduate Physics course and an action plan to address the performance of women undergraduates at the end of their first year;
- a requirement that all staff undergo Equality and Diversity (E&D) training;
- a significant expansion in career advice activities for research staff;
- a review of the Staff Review and Development scheme, resulting in an increased coverage from 40% to 80% of the target cohort;
- the formation of a very active Research Staff Committee (meeting termly) and associated events (monthly postdoc teas and targeted workshops);
- a Workload Model for academic and senior research staff, in its second year of operation;
- formation of the Cavendish Social Committee and associated events (meeting termly, with 2 or 3 events held each year); and
- influential engagement with Athena SWAN and other gender equality activities at both the University and national levels.

Our full submission can be found at: www.phy.cam.ac.uk/Women-in-Physics/ WiPFiles/athena-swan-gold-application

University of Cambridge Vice-Chancellor Professor Sir Leszek Borysiewicz described the Department of Physics as a "beacon" within Cambridge:

"The Department was the first to gain an Athena SWAN Award in the University in 2010 and leads the way for other University departments who now hold, or are working towards, Athena SWAN Awards. The University is extremely committed to progressing gender equality and we are beginning to see the impact of the significant resources and initiatives dedicated to improving the numbers of women across all career stages. The Department of Physics has played and will continue to have a key role in supporting and promoting women in STEMM (science, technology, engineering, maths and medicine)."





Top and left: **Practical physics classes**. Bottom right: **Aziza Suleymanzade (AMOP) and Anna-Lena Redman (BSS) having completed their workshop training course**.

Athene Donald said:

"I am delighted that the Department of Physics has been awarded Cambridge's first Athena Gold. As the University's Gender Equality Champion, as well as a member of the department, it is excellent to see this recognition of all the hard work and far-sighted action being carried out by Physics. I hope this will act as a stimulus and inspiration for other departments in the University."

The February 2014 edition of CavMag (number 11) highlighted some of the many areas of physics in which women

staff members are involved. These are wonderful achievements and an inspiration for young women thinking about careers in the physical sciences. Whilst we can relish the moment of success, we are well aware that the award is for three-years and we need to continue all our efforts to maintain and enhance our present status so that it can be renewed in three years' time. This is indeed as it should be and we can only applaud the continued efforts of everyone in the Laboratory in contributing to our Gold status.

Malcolm Longair

The Top Quark and Going Beyond the Standard Model



We are delighted to welcome Alexander Mitov who joined the Laboratory in 2013 as a University Lecturer in Theoretical High Energy Physics. Here he reflects upon his career to date and his future programme.

Born in the land of the mythical and enigmatic Thracians, Alexander (Alex) Mitov received his Master's degree in Physics from Bulgaria's oldest national university, named after St. Clement of Ohrid - a IX-th century Bulgarian scholar, prolific writer and translator, often linked with the invention and popularization of the Cyrillic alphabet.

Upon graduating from Sofia University, Alex was offered one of only two national scholarship awards that supported young Bulgarian researchers in the field of Mathematical Physics. A couple of years later he received a research fellowship from the University of Rochester in Rochester, NY, which offered him the opportunity to pursue research directly related to elementary particle colliders, such as the Large Hadron Collider (LHC) at CERN near Geneva, Switzerland.

He obtained his MA and PhD degrees in four years, working with three different groups on independent research topics. Upon graduation, he accepted the offer of Kirill Melnikov, a prominent young scientist, to join his team as a post-doctoral research fellow at the University of Hawaii. It was in this tropical paradise that Alex became acquainted with the spirit of Aloha, the beauty of the endless Pacific and the thrill of surfing. He also managed to write several papers that led to the subsequent derivation of one of last decade's strongest constraints on the possible existence of Physics beyond the Standard Model, which has so far proved so elusive. To date, this work has been cited close to 700 times.

Subsequently, Alex received a Humboldt Fellowship and the Inaugural LHC Theory Initiative Fellowship from the USA, both of which presented him with the opportunity to pursue independent research and join forces with some of the leading research centres in Germany and in the USA. He was then offered a 3-year fellowship at CERN to continue his work on the top quark, at that time among the least-known of elementary particles. It was at CERN that Alex's innovative projects came to fruition and he, together with his long-time close collaborator Michael Czakon, published one of the most anticipated works in collider physics (Fig. 1). His groundbreaking papers on top-quark physics have the distinction of several 'first-ever' attached to them.

Going beyond these purely theoretical breakthroughs, Alex's scientific results have empowered experimental collaborations at the LHC by offering new, qualitatively different tools. By now his work has been utilised by these collaborations in their extensive searches for physics beyond the Standard Model and in their attempts to clarify with ever-increasing precision the ultimate validity of the fundamental laws of physics, as embodied in the Standard Model of the Elementary Particles.

Alex's work has been generously supported by a number of research agencies. At present, he is supported by an Ernest Rutherford Fellowship from the UK Science and Technology Facilities Council (STFC). Thanks to additional financial support from the STFC, as well as from Cambridge's Newton Trust, he has been able to increase significantly the footprint of Theoretical Particle Physics in the Cavendish Laboratory with the establishment of the new *Centre for Precision Studies in Particle Physics*. The Centre's mission is the development of a new generation of precision phenomenological particle physics applications and, ultimately, their incorporation in the most important analyses of data expected from the LHC and future high-energy colliders.

In addition, he has just been offered a prestigious Senior Research Fellowship at Durham University that will give him the opportunity to spend a few weeks at the UK's premier particle physics Institute (IPPP) in Durham.



Fig. 1. Measured and predicted top-antitop production cross sections in proton-proton and proton-antiproton collisions from Tevatron to LHC energies. The theoretical curves were generated using the predictions by Czakon, Fiedler and Mitov (see M. Czakon, P. Fiedler and A. Mitov, 2013. The total top quark pair production cross-section at hadron colliders through O(a,⁴). *Physical Review Letters*, 110, 252004 and the *Particle Data Group Review 2013*.)

Phase Transiting to a New Quantum Universe









Fig. 1. The strontium titanate perovskite lattice. Titanium ions (red) and oxygen ions (gold) form electrical dipoles which line up in a ferroelectric state.

Recent insights and the discovery of a new class of quantum transition open the way for a whole new subfield of materials physics and quantum technologies.

A recent article in *Nature Physics* [1] reports results on the quantum properties of ferroelectric crystals. In this project, led by Stephen Rowley (top) and Siddharth Saxena (middle) with Gilbert Lonzarich (bottom) of the Quantum Matter Group in the Cavendish, a new type of *quantum phase transition* is explored in these seemingly 'inert' materials.

Quantum phase transitions are subtly different from the familiar classical phase transitions, an example of which would be the freezing of water or the melting of ice as the temperature is changed. In such a transition, matter transforms into a more or less ordered state depending on whether its temperature is decreased or increased. If, however, the temperature was hypothetically fixed at absolute zero and another parameter, such as pressure, was applied to bring about a transition, this would occur without any change in entropy, that is, it would be an 'order-to-order' transition. In the neighbourhood of such a zero entropy phase transition one often finds the emergence of superconductivity or other forms of novel quantum order.

Ferroelectrics are materials comprising electrical dipoles in the unit cells of the crystalline lattice (Fig. 1). Due to interactions between them, these dipoles

may line up resulting in ordered electric fields permeating the crystal. By using pressure, chemical, or isotopic substitution, ferroelectrics can be tuned into the quantum critical regime where dipole fluctuations exist in an effective four-dimensional space and arise due to criticality of the quantised polar lattice vibrations. This physics is very different to that found in other quantum critical systems which focus on electronic or spin degrees of freedom. Intriguingly the fluctuation spectrum found in guantum critical ferroelectrics is the same as that in elementary particle physics – propagating modes in three spatial dimensions plus one time dimension.

The article in *Nature Physics* highlights the amazing transformation of the crystal properties as a ferroelectric approaches its quantum critical point. It describes how a theory was developed to understand the phenomena successfully and quantitatively in a number of materials without adjustable parameters (Fig. 3). The theory included the effects of coupled fluctuating polarisation and quantum strain fields which explained the observation of small peaks in the measured dielectric susceptibility below a temperature of 4 K.

The most striking effects were observed in the mineral strontium titanate $(SrTiO_3)$ using custom-built high-precision measurement apparatus developed in the Laboratory. $SrTiO_3$ crystals may be cut into beautiful gems, as shown in Fig. 2, and have been used by artisans and jewellers for decades. They have a range of important technical applications in optics and electronic devices. When cooled below 50 K the crystals begin vibrating with highly anharmonic quantum fluctuations which drastically change the measured physical properties (Fig. 4). Crucially the thermodynamic properties depend upon the time dependent properties of the fluctuations, which is not the case near a classical critical point.

Going beyond ferroelectric insulators, electron charge carriers may be introduced, for example, by voltage gating or chemical substitution. The first of the oxide superconductors - doped SrTiO₃, discovered in the 1960s - is of this kind. Superconductivity appears to arise in the intriguing anti-adiabatic limit which poses a major challenge to theory. The understanding of superconductivity in SrTiO₃ and KTaO₃ have remained particularly elusive. New measurements and theory led by the Cambridge team have shown how the novel polar optical phonons existing close to the ferroelectric quantum critical point can mediate this type of superconductivity. This involves a gap function that oscillates in time to avoid repulsive parts of the time dependent electron-electron interaction potential. Such knowledge is already guiding the search for new types of superconductor and other correlated states of quantum matter.

Further unravelling the quantum nature of ferroelectrics not only elucidates the missing pieces in our understanding of phenomena ranging from high temperature superconductivity to emergent effects



Fig. 2. SrTiO, crystal gems.

in insulators. It also allows us to think about how this can inform developments in quantum computing and on-chip refrigeration of electronic devices.

This work has significant implications for the collaborative network of theorists and experimentalists within the Cavendish. For example, it provides experimental examples of the types of phenomena developed theoretically in an early form by David Khmelnitskii, while he was working in the Soviet Union in the 70's. Jim Scott's canonical understanding of ferroelectrics provided basic understanding of ferroelectric materials for the development of this experimental programme.

Collaborations and funding support ranging from US, Japan, Kazakhstan, Uzbekistan, Brazil, Greece and Singapore not only made this work possible, but are also helping expand the scope and broader utility of these findings. In particular, the idea of multiferroic quantum criticality, where melting of both the spin and the charge order occur simultaneously, gives rise to entirely new states of matter. Intriguingly, the models constructed by Rowley and his collaborators provide paradigms for developments in fundamental physics through analogies with phenomena found in particle physics and cosmology.

[1] S. E. Rowley, L. J. Spalek, R. P. Smith, M. P. M. Dean, M. Itoh, J. F. Scott, G. G. Lonzarich and S. S. Saxena, 2014. Ferroelectric Quantum Criticality, *Nature Physics*, **10**, 367-372.



Fig 3. Calculated and measured phase diagram for quantum critical ferroelectrics.



Fig 4. Melting of spin and charge quantum order in the same phase space - the new scenario of Multiferroic Quantum Criticality.

Tony Hewish at 90



Above: Tony Hewish with Lord Sainsbury (left) and Humphrey Battcock (right) at the opening of the Battcock Centre for Experimental Astrophysics in October 2013.

This year's Hewish Lecture was a very special occasion. It was the fifth of the series and was timed to coincide with Tony's 90th Birthday. We send Tony our very warmest greetings on this auspicious birthday.



It was an enormous pleasure to welcome **Tony Readhead**, one of Hewish's most distinguished former graduate students, Robinson Professor of Astronomy at the California Institute

of Technology and Director, Owens Valley Radio Observatory, to deliver the lecture on the subject of *Back to the Beginning in Cosmology and Experimental Radio Astronomy.*

The discovery of pulsars in 1967 will always be associated with the names of Antony Hewish and Jocelyn Bell-Burnell, but the seeds of their achievement were sown long before [1]. Hewish began his lifelong involvement in studies of rapidly fluctuating radio signals caused by irregularities in the intervening ionospheric, interplanetary and interstellar media in the late 1940s. These resulted in a series of important contributions to many different aspects of radio astronomical science. The discovery of pulsars was a huge bonus in a sustained campaign of outstanding science.

[1] for more details, see: M.S.Longair (2011), The Discovery of Pulsars and the Aftermath, *Proc. Amer. Phil. Soc.*, **155**, 147-157.

Siddharth Saxena and Stephen Rowley

Nano-spintronics



Andrew Ferguson, Hitachi Senior Fellow in the Microelectronic Group, describes some remarkable recent advances in the burgeoning field of nanospintronics in his research group.

How does electricity affect a magnet? So goes one of the questions that is currently occupying my research group. The interaction of electricity and magnetism is an important topic in technology, especially in data storage where nano-scale magnets store information in hard-drives and are expected to do likewise in emerging magnetic memories. Perhaps surprisingly, given the long history of electromagnetism, this question underlies a fast moving area of experimental and theoretical physics research.

A bar-magnet can be oriented with its magnetisation in one of two directions (the magnetisation is a vector that points from the South to North poles) giving the magnet the ability to store a single bit of information. To write that information, the magnet could be physically rotated by 180 degrees, but since that's not a scalable solution for data storage we need to turn to physics. One solution is to generate a magnetic field from a nearby electric current carrying wire. This applies a torque to the magnetisation, causing it to rotate or even switch. More recently it was discovered that, by passing electricity directly through certain magnets, a new type of torque with quantum-mechanical and relativistic origins could act on the magnetisation. We believe that the physics found in this 'spin-orbit torque' may enable new ways in which to write information into magnetically stored data. The name 'spin-orbit' refers back to atomic physics in which case an electron bound by an electrically charged nucleus feels a component of magnetic field due to its orbital angular momentum - it is moving around an electrical charge. This affects the microscopic magnetic moment of the orbiting electron and causes the fine structure in atomic spectra.

Special relativity is famously responsible for time-dilation and length contraction. It also mixes up electric and magnetic fields - if you move past an electric field it partially changes into a magnetic field and vice-versa. This is important in our context since electric currents consist of moving electrons and if they move past electric fields in the crystal structure of their wire, they feel an additional magnetic field. Since each electron itself is a tiny magnet they experience a torque, and if the wire is a magnetic material, this tiny torque experienced by each electron affects the larger-scale magnetisation of the magnet. This is the principle behind the spin-orbit torque.

The spin-orbit torque has been observed at room temperature in layers of magnetic cobalt with non-magnetic materials such as tantalum and platinum, materials which are suitable for memory devices. However, we work with (Ga,Mn)As, a ferromagnetic semiconductor which becomes magnetic below about -100 °C, as a model system. We believe it is the simplest material in which to study these effects.

If the magnetisation of a magnet is slightly disturbed, it orbits around its initial position billions of time each second before regaining its original position after 10's of orbits. Our approach to measuring the spin-orbit torque is to use microwave frequency electricity to repeatedly apply







Fig. 1.



Fig. 3.

kicks to the magnetisation at this GHz orbiting frequency. In this way, we create a stable orbit for the magnetisation, allowing us to measure the magnitude and symmetry of the spin-orbit torque [1]. Further measurements enabled us to find a so-called anti-damping contribution to the spin-orbit torque [2]. Together with theorists at the Czech Academy of Sciences and at Johannes Gutenberg University in Mainz as well as with collaborators at the Hitachi Cambridge Laboratory and at the University of Nottingham, we understand this effect in terms of the quantum mechanical phase accumulated by electrons as they accelerate though the material. As its name suggests, the anti-damping torque opposes the magnetic damping of the magnetisation, giving the possibility to create a microwave oscillator with a direct current.

Reciprocity appears throughout physics. For example, electricity drives mechanical motion in a motor but the same device when driven mechanically creates electricity and it becomes a dynamo. Reciprocity is relevant to our latest experimental advance. After we published our first paper on spin-orbit torque, together with theorists from NTNU in Trondheim, we started to explore the reciprocal effect of the spin-orbit torque, whereby orbiting magnetisation creates an alternating electrical current [3]. It took us about 3 years to realise the first demonstration of this physical phenomenon which we refer to as magnonic charge pumping, and it couldn't have been achieved without the innovations of Chiara Ciccarelli, a talented junior research fellow in my group.

What does the future hold for us in this field? As a physicist, I view our job to be to investigate new phenomena related to spin-orbit torque, and new materials which display this effect, rather than to engage in technical developments towards magnetic memory. Over the next few years we will set up new microwave measurements and collaborate with material growers in Canada, Germany and in the UK, using the experimental tools we build to measure new magnetic materials. There are guestions that need to be answered, particularly in more complex cases of magnetic metals. No doubt there will be a few surprises too.

Fig. 1. An electromagnet that has been configured for microwave frequency measurements on magnetic systems at room temperature.

Fig. 2. As microwave frequency electricity is passed through a ferromagnet, a torque is applied to the magnetisation, causing it to orbit its equilibrium position.

Fig. 3. A micrograph showing one of the nanoscale ferromagnetic wires through which an electric current is passed. This one is etched from a crystal of Ga(Mn,As) grown on an epitaxial substrate.

[1] D. Fang, H. Kurebayashi, J. Wunderlich, K. Výborný, L. P. Zârbo, R. P. Campion, A. Casiraghi, B. L. Gallagher, T. Jungwirth and A. J. Ferguson (2011) Spin–orbitdriven ferromagnetic resonance. *Nature Nanotechnology* **6**, 413–417.

[2] H. Kurebayashi, Jairo Sinova, D. Fang,
A. C. Irvine, T. D. Skinner, J. Wunderlich,
V. Novák, R. P. Campion, B. L. Gallagher,
E. K. Vehstedt, L. P. Zârbo, K. Výborný, A.
J. Ferguson and T. Jungwirth (2014) An antidamping spin–orbit torque originating from the Berry curvature. *Nature Nanotechnology*, **9**, 211–217.

[3] C. Ciccarelli, K. M. D. Hals, A. C. Irvine, V. Novák Y. Tserkovnyak H. Kurebayashi, A. Brataas and A. J. Ferguson., submitted (2014).

Members of Andrew Ferguson's Nanospintronics Group include: Dr Chiara Ciccarelli (Junior Research Fellow at Caius College), Dr Nick Lambert (Post-doctoral Research Assistant), Tim Skinner (Ph.D. student), Megan Edwards (Ph.D. student), Vahe Tshitoyan (Winton Ph.D. studentship), Adam Esmail (Ph.D. student) and Zhou Fang (Ph.D. student).

Physics and Industry: Past, Present and Future



Andy Jardine reflects on the long term impact of basic theoretical research in Condensed Matter Physics and describes innovative research in the Surface,

Microstructure and Fracture Group (SMF) of immediate interest to industry.

In the Surface, Microstructure and Fracture Group, one of the 'condensed-matter' based groups in the Cavendish, most research activities focus on different aspects of material dynamics. Broadly speaking, the group works in two major areas – firstly, characterising and understanding atomic scale dynamics at surfaces, including adsorption and desorption, quantum motion of atoms, and atomic-scale friction; and secondly, studying the response of larger scale, often meso-structured materials at the continuum level - these include pure, composite, granular and even geological materials. Together, these activities span an unusually wide range of length- and timescales, from nanometres and picoseconds upwards.

Many of these areas are of direct importance to industry, and the group has a long history of working with industrial organisations. Here, we describe several examples of fundamental research with industrial links, to highlight the impact of past and present industrially collaborative research, as well as looking forward to new challenges in the future.

JKR Adhesion: A longstanding but increasingly important theory

Contact and adhesion between different materials is fundamentally important to any mechanical system, and particularly so in modern advanced material composites. The 'JKR theory for adhesion' was developed in the 1970s by Ken Johnson, Kevin Kendall and Alan Roberts, in a collaboration between what was then the Physics and Chemistry of Solids group, the predecessor to the current SMF group and where Kendall and Roberts obtained their PhDs, the University Engineering Department and the British Railways technical centre in Derby.

The JKR theory quantifies the energy balance between surface energies and elastic deformation energies when two elastic spheres are brought into contact. It allows the contact area to be calculated, which means the theory can be used to interpret a wide range of experiments and to study a variety of adhesive and contact effects. The original work was published in the *Proceedings of the Royal Society* [1] but, despite the originality of the ideas, it received little attention.

As the importance of adhesive contact in technological problems has grown, the significance of the JKR theory has finally been realised. Fig. 1 shows the history of citations of the work. At the present day, when immediate impact is so highly valued, it is interesting to note that more than 20 years of relative obscurity passed before the true significance and impact emerged. The approach provides a valuable foundation, upon which many modern experiments are based, including ongoing research within the SMF Group. It is clear that the combination of fundamental physics research, with an applied industrial context has stimulated a rather important theory, which after 40 years continues to have an increasing impact.

Energy Efficiency in the Mining Industry

Current industrial collaborations in the SMF group include ongoing projects with the mining industry. Primarily, these interactions are focussed on a better understanding



Fig. 1. Published work referring to the original 'JKR' paper by Johnson, Kendall and Roberts. After a slow initial reception, the citation rate began to increase dramatically 20 years after publication (data obtained from the Web of Knowledge).

of the mechanisms of rock mechanics, with long term aims related to improving efficiency - other projects have included developing approaches to the removal of lead from mining consumables. The scale of the mining industry, with a global market capitalisation of 750+ billion dollars, means that even small improvements in efficiency through better understanding of the underlying physical processes, can have substantial impact. For example, roughly 13.5% of Australia's final energy consumption is in mining, and much of that is associated with the comminution of rock, meaning its reduction from one average particle size to a smaller value.

Recent experimental results from the group have developed a small scale physical model of rock fragmentation, at pressures comparable to those in a typical borehole. The model has revealed how increasing the rate of dynamic loading in a prototypical rock causes the material to fracture on progressively finer length-scales, eventually reaching the mesoscopic grain size of the material. Much of the analysis was made possible by the combination of analysis facilities available within the department and the wider University, as well as the comprehensive workshop facilities required for difficult sample preparation. An example of the tomographic reconstruction of rock microstructure is shown in Fig. 2.

The results promise to allow the efficiency of blasting operations to be



Fig. 2. X-Ray tomographic reconstruction of the microstructure of a sample of Gosford Sandstone. The grey regions show the granular structure, primarily quartz and muscovite, while the dark regions correspond to internal void.

improved, for example, by tuning the rock blasting process to modify the internal microstructure and so reducing energy requirements later down the line. The work also promises to bridge the mesoscale gap between fundamental simulations of material fracture, which can now be performed with quantum mechanical precision, and the large scale continuum level simulations widely used in industry.

CavMag AUGUST 2014

Richard Hills FRS



TEM Grid

Tin spheres on carbon

Scale bar = 30um

Fig. 3. The first helium atom images obtained using the prototype neutral helium atom microscope. Left: comparison of a TEM grid with optical and neutral helium imaging. Right: Calibration sample of tin spheres on carbon, illustrating the different contrast mechanisms.

Looking forward: New microscopy with neutral helium atoms

Most recently, the group is planning to develop new industrial links through a completely novel form of microscopy using neutral helium atoms. Atoms offer a quantum probe of a surface that is non-destructive, yet potentially with higher resolution than optical microscopy. The technology has emerged from a combination of helium beam production and measurement techniques developed within the group over the past 10 years. The group has been able to assemble a lowresolution prototype instrument in a new 'microscope geometry' on something of a shoestring by re-tasking existing equipment. Fig. 3 shows some of the first images obtained, compared with conventional optical images.

The technology is particularly exciting as we expect new contrast mechanisms and, perhaps more importantly, the energy of neutral helium atoms is roughly six orders of magnitude lower than in an electron microscope, meaning that beam-induced sample damage does not take place and so enables experiments on whole new classes of delicate materials to be carried out. The group has recently been awarded an EPSRC Impact Acceleration award to take the project further towards a commercially viable proposition, by dramatically improving both the resolution and imaging rates. We have already had interest from the industrial microscopy sector, which is actively following progress with a view to taking the work further. To complement the instrumentation, a new PhD research project beginning in October 2014 will explore the fundamental contrast mechanisms in atom based imaging.

In summary, the two-way flow of research results between industry and academia has proved to be particularly fruitful over many years, and goes far beyond simply selling university generated Intellectual Property to the highest bidder. With new initiatives such as the Maxwell centre, we look forward to even greater successes in the future.

[1] K. L. Johnson and K. Kendall and A. D. Roberts, 1971. Surface energy and the contact of elastic solids, *Proceedings of the Royal Society of London*, **A324**, 301-313



Richard Hills, Emeritus Professor of Radio Astronomy, has been elected to Fellowship of the Royal Society.

We are delighted to congratulate Richard Hills on his election to the Royal Society of London. The citation for his election to the Society is as follows:

'Since the early 1970s Richard Hills has played a leading role in the development of radio astronomy at millimetre wavelengths, an essential zone of the spectrum for the study of star formation in galaxies. As Project Scientist of the James Clerk Maxwell Telescope on Hawaii he was closely involved with the design and operation of this highly successful telescope. For his outstanding contribution to this project he was awarded the Jackson Gwilt Medal and Gift of the Royal Astronomical Society in 1989. From 2007 to 2012 he was Project Scientist of the Atacama Large Millimetre/Submillimetre Array (ALMA) in Chile. The first scheduled observations at 345 GHz using 16 of the planned 66 antennas took place in September 2011. These demonstrated the full angular resolution obtained by phase-coherent aperture synthesis which requires continuous monitoring of atmospheric absorption along the line of sight above each antenna. The outstanding scientific leadership shown by Richard Hills undoubtedly played a major part in the success of this challenging international project.'

Furthermore...



We also congratulate **Peter Littlewood** on his appointment as the new director of the Argonne National Laboratory. Argonne has an annual budget of \$722 million and a staff of 3350. Peter was Head of the Cavendish from 2005 to 2011.

Rutherford Schools Physics Project - An update



In the July 2013 issue of CavMag, we announced the beginning of an exciting five-year project aimed at developing the skills of 16–19 year old potential physicists, funded by a £7 million grant from the Department for Education. The aim is to provide support and extension materials for students and their teachers across the whole of the UK. Mark Warner and Lisa Jardine-Wright report on progress.

University physics and engineering require students to be fluent in mathematics and in physics problem-solving. Being able to apply physics with the tools of mathematics is a measure of how deeply you understand the subject. Universities want to admit students who are beginning to think like physicists. The most important skill is the ability to deconstruct a problem through sketching diagrams to digest the information within it, assembling ideas from different areas of physics and using mathematical skills to understand the phenomenon guantitatively and symbolically. The Rutherford Schools Physics Project (RSPP) provides extension materials for students aged 16-19 to develop these key skills within areas of the existing A level curriculum, enabling students from all backgrounds to gain expertise beyond school level which will help them to apply for physics, engineering and mathematics courses at universities throughout the UK.

Delivery of the RSPP

Hub events are held in partner schools, typically a half day, with a theme - for example, physics and vectors, exponentials, and so on. Organisation and materials are provided by the RSPP, as well as collaborating in the delivery of the material with our partner teachers. To support the teachers' Continuing Professional Development (CPD), residential courses for them have been held in Cambridge and in future these will take place elsewhere.

The on-line platform MOOC, standing for Massive Open On-line Course, is both for student self-directed learning, and as additional materials and lessons directed by teachers. Graded problems in 6 levels spanning the GCSE/AS transition to the A2/university transition are available in





mechanics, and soon will include waves, optics and electric and gravitational fields, as well as the mathematics relevant for physics at this level. Hints for each question, both text and scribble videos, will be available for consultation, along with the relevant physics and mathematical concepts linked to each question. A pilot resource website was launched towards the end of 2013 and is available at **http://isaacphysics.com**

Getting involved with the project

Within the project there are opportunities for teachers, graduate students and undergraduates to get involved. The RSPP wishes to engage with enthusiastic physics teachers to help the team expand, delivering more face-to-face events all around the UK for students aged 16-19 and their teachers. A partner school acts as a central location so that multiple schools can attend the events. Typically we deliver two or three, half or one day events per year in each of our partner school locations, each event focussing on a specific topic within the A-level curriculum. An example of a half-day event (3 hours) would typically include:

- 15 min introduction.
- 45 min of problem solving (including a 5 min demonstration).
- 15 min break for drinks
- 45 min of problem solving (including a 5 min demonstration).
- 50 min lecture (for example, vectors and spin)

Acting as one of our lead teachers can vary in commitment from helping us identify a room or rooms in your area and which schools to invite from the locality, to suggesting new topics and developing content and problems in that area.

What is involved?

Specifically, what is involved in these events includes:

 Identification of surrounding partner schools and teachers to invite to events.



<text><equation-block><equation-block><equation-block><equation-block><equation-block><equation-block><equation-block><equation-block><equation-block>

ilibrium

vsics Concep

- Liaising with the project's administrator to choose suitable dates for events.
- Discussion with the project's physicists about suitable programmes and content.
- Booking a local venue and suitable room(s).
- Liaising with the project administrator who will publicise the events and register students. And the option to:
- Create content for new topic workshops and events from within the curriculum.

Support is provided by the RSPP team and there are lots of benefits for you, your students and your school.

Access to the materials is location- and school-independent. The only requirement is access to the internet and so can be accessed from a library, at home, on a mobile on the bus from school and so on. Access does not require input from teachers, although of course we positively encourage teacher input. There will be project support for students who engage with the problems but who don't have access to help from a physicist teacher.

Current and Forthcoming Events

The schools listed here for the partner workshops are kindly acting as hosts for all surrounding schools. The teacher CPD days venues are to be confirmed but the dates are fixed.

Events already held:

- Exponentials Partner workshop 24th June – Highgate School, London – AS students
- Exponentials Partner workshop 27th June – Netherhall School, Cambridge – AS students
- Teacher residential 28th-30th June Cambridge
- Senior Physics Challenge 30th June -3rd July – AS students – Cambridge
- Exponentials Partner workshop 7th July – Queen Elizabeth Grammar School, Kent - AS students

- Exponentials Partner workshop 9th July – Ermysted Grammar School, Skipton – AS students
- Vectors Partner workshop 9th July Southend High School for Boys – AS students

Upcoming events:

- Teacher CPD Day 26th/27th
 September Venue one of (London, Cambridge, York, North West)
- Teacher CPD Day 23rd /24th October– Venue one of (London, Cambridge, York, North West)
- Teacher CPD Day 19th/20th December – Venue one of (London, Cambridge, York, North West)
- Teacher CPD Day 13th/14th February 2015 – Venue one of (London, Cambridge, York, North West)

If you would like to register for one of these events, or find out further information, or wish to contact the project team, please e-mail the project manager and administrator, Mr David Taylor (**dst28@phy. cam.ac.uk**).

Maxwell, the Ether and the Michelson-Morley Experiment

While studying the papers of James Clerk Maxwell published during his period as Cavendish Professor, I was intrigued by the title of his last posthumous paper of 1880 with the title, On a Possible Mode of Detecting a Motion of the Solar System through the Luminiferous Ether [1]. The paper was in fact by George Stokes, reporting a letter which Maxwell sent to Mr. D.P. Todd of the Nautical Almanac Office in Washington dated 19 March 1879. The main body of the letter concerns the use of accurate timing of the eclipses of Jupiter's satellites as a mean of measuring the speed of light plus the Earth's motion through the ether. This required an accurate knowledge of the orbits of Jupiter's satellites. Maxwell writes,

'I have therefore taken the liberty of writing to you, as the matter is beyond the reach of anyone who has not made a special study of the satellites.'

But, more germane is the remark in an earlier paragraph.

'... in the terrestrial methods of determining the velocity of light, the light comes back along the same path again, so that the velocity of the earth with respect to the ether would alter the time of the double passage by a quantity depending on the square of the ratio of the earth's velocity to that of light, and this is quite too small to be observed.'

This statement is somewhat more specific than its first appearance, which is in his remarkable essay Ether in the great ninth edition of the Encyclopaedia Britannica [2]. Maxwell contributed regular essays: atoms, attraction (1875); capillary action (1876); constitution of bodies, diffusion, diagrams (1877); ether (1878); Faraday (1879). The alphabetical series terminated with his death in 1879. The essay is a tour de force of simple, logical and clear thinking, in which he established the necessary physical properties of the ether, given the known facts of the modes of propagation and polarisation of light. The question of determining the Earths' motion through the ether is discussed, his preference being for 'one-way' tests using the eclipses of the satellites of Jupiter as the best stable clocks available. In an earlier paragraph, he wrote about the terrestrial tests:

'... the increase of this time (of the double journey) on account of the

relative velocity of the ether equal to that of the earth in its orbit would be only about one hundredth million part of the whole time of the transmission, and would therefore be quite insensible.'

This fractional time difference is just the square of the aberration, $\Delta \theta \approx$ (v/c).

Albert Michelson recognised that, contrary to Maxwell's assertion, very small path differences could be detected by optical interferometry. In his paper on the first version of the experiment of 1881 [3], Michelson states explicitly that:

'The following is intended to show that, with a wave-length of yellow light as a standard, the quantity [the path difference between the light rays] — if it exists — is easily measurable.'

Interestingly, in this paper Michelson carried out the first estimate of the time-delay between light propagating parallel and perpendicular to the motion of the ether, but made an error in his calculation in which the expected difference was overestimated by a factor of two. This was quickly corrected by Alfred Potier and in more detail by Hendrik Lorentz. The result was that the 1881 result had lower significance and the need for an improved experiment was recognised in the introduction to the 1887 paper by Michelson and Morley.

Fig. 1 shows the much improved Michelson-Morley experiment of 1887 [4]. In Michelson's own words,

'... the interferometer was mounted on a block of stone 1.5 m square and 0.25 m thick resting on an annular wooden ring which floated the whole apparatus on mercury.'

The experiment was performed by observing the movement of the central fringe of the interferometer as the apparatus was rotated 'fairly uniformly and continuously' through 360° and measurements made every onesixteenth of a revolution. In Fig. 2, the mean displacements of the central fringe during rotation through 360° are compared with the expected sinusoidal variation if the Earth moved through a stationary ether at 30 km s⁻¹, the dotted sinusoidal line corresponding to only one eighth of the theoretical displacement. Again, in Michelson's words,



'It must be concluded that the experiment shows no evidence of a displacement greater than 0.01 fringe ... With v/c = 1/10,000, this gives an expected displacement of 0.4 fringes. The actual value is certainly less than one-twentieth of this actual amount and probably less than one-fortieth.'

The statistical significance of the null-result was quite enormous. The experiment was repeated at different times of the year by Morley and Miller, in case the motion of the Earth about the Sun was cancelled out by the drift of the ether, but the same null result was found.







Fig. 1. Left: The mounting of the Michelson-Morley experiment. Right: the reflections involved in the interferometer [4].



Fig. 2. The null result of the Michelson-Morley experiment [4]. The solid line shows the average movement of the central fringe as the apparatus was rotated through 360°. The dotted line shows *one eighth* of the expected sinusoidal variation if the Earth moves through the stationary ether at 30 km s⁻¹.

Centre: Portrait of James Clerk Maxwell by his cousin Jemina Blackburn (née Wedderburn). © Cavendish Laboratory.

In the 1962 reprint of Michelson's book *Studies in Optics*, Harvey B. Lemon wrote in his introduction:

'To the complete astonishment and mystification of the scientific world this refined experiment also yielded absolutely negative results. Again must we note at this point the universal confidence with which any experimental fact announced by Michelson was instantly accepted. Not for twenty years did anyone have the temerity to challenge his conclusion.' that there is no explicit reference to the Michelson-Morley experiment in Einstein's great paper of 1905 on the Special Theory of Relativity - Michelson's null result instantly became one of the established facts in the thorny problem of understanding the nature of the ether. Evidently, Maxwell's words had stimulated Michelson to carry out one of the great experiments of physics.

 Maxwell, J.C., (1880). On a Possible Mode of Detecting a Motion of the Solar System through the Luminiferous Ether, *Proceedings of the Royal Society of London*, **30**, 109—110. [2] Maxwell, J.C., (1878). Ether, *Encyclopaedia Britannica*, Ninth edition, **8**, 568-572.

[3] Michelson, A. A. (1881). The Relative Motion of the Earth and the Luminiferous Ether, *American Journal of Science*, **22**, 120-129.

[4] Michelson, A. A. and Morley, E.W. (1887). On the Relative Motion of the Earth and the Luminiferous Ether, *American Journal of Science*, **34**, 333-345.

Malcolm Longair

This may well be part of the reason

AUGUST 2014 CavMag

Upcoming changes to the Physics curriculum



The government has recently announced reforms to the current GCSE and A level qualifications. With these modifications the former Secretary of State for Education, Michael Gove, aims to reduce grade

inflation, introduce more rigorous content and stretch the more able students. These provide the outreach team with new challenges.

These changes come about after a lengthy consultation process, which involved both schools and universities, and which led to a series of recommendations.

A level Physics will be first to be given a shake-up, the new proposals coming into effect in September 2015. The course will include the introduction of 12 assessed pieces of practical work which will be a requirement for A level Physics. At the end of the year, students will receive either a pass or fail grade for these practicals as well as a tiered grade for their written examinations. This proposal responds to concerns from the university sector that students are entering higher education without the necessary experimental skills. Otherwise, the content of the Physics A level course will not see any major overhauls. There will however be greater emphasis on mathematical skills, especially the concepts underlying calculus. This mirrors a general trend to increase the level of mathematical awareness within all the sciences.

The overall structure of A levels will also change with the decoupling of the A level and AS level examinations. These two qualifications will become stand-alone courses, rather than one as part of the other. The exams will be sequential with students sitting one examination at the end of the AS level year and one examination at the end of the two years of study for the A level qualification.

GCSE's will not change until September 2016 and consultations are still in progress. It is however apparent from preliminary considerations that the new science GCSEs will require much more scientific knowledge and detail with clearer mathematical requirements for each topic. Additional content will include nanoparticles and space physics.

New projects for the Outreach Team

The department has recently received additional funding for a set of new and exciting outreach projects. The funding will be used specifically to implement strategies to encourage more girls into physics. A new series of school workshops has been planned that will build upon the success of previous workshops and will also allow more direct provision for girls. The workshops will run during the school holidays with the hope that parents will accompany students and thus also gain an awareness of both physics and the University. There will be sessions dedicated exclusively to girls based on topics that they find particularly interesting.

A pilot project will also be started that aims to identify the different attitudes of girls and boys to physics. Students at participating schools will be sent a 'toolkit' and asked to complete a practical task. Some students will have prescriptive manuals whilst others will only have minimal instruction. A questionnaire will accompany the toolkit and will be used to help assess the different techniques used by different genders alongside differences in beliefs and confidence.

Outreach News from the Institute of Physics

New 'opening doors' project to address gender imbalance in Physics

A pilot project called Opening Doors has been initiated at the IoP. The project, funded by the Government Equalities Office, will seek to eradicate gender stereotypes that are detrimental to the uptake of A-level physics amongst girls. It will build upon previous work carried out under similar schemes such as the IoP Juno project that concentrated upon the under-representation of women within university Physics departments.

3-minute wonder winner announced

This May, the final of the IoP's 3-minute wonder competition was held in the Faraday Theatre at the Royal Institution in London. Hannah Wakeford from the University of Exeter took home the top prize of £500 for her 3-minute explanation of how to search for water in the atmosphere of other planets. Regional finals had previously been held around the country including here at the Cavendish Laboratory.

Stimulating Physics Network programme extended after boost in funding

The IoP has received £4.3 million in funding to continue its Stimulating Physics Network programme. The new funding will allow the Institute to continue supporting physics teachers and will also finance two new initiatives called *Improving Gender Balance* and *the Maths & Physics Chairs* scheme. The first will be a pilot project that aims to identify and then overcome the factors that are currently discouraging girls from studying physics at A-Level. The second scheme will recruit top PhD students into physics teaching with a tempting benefits package.

Forthcoming Events at the Cavendish

Physics at Work

The 30th Physics at Work exhibition will be taking place from Tuesday 23rd September 2014 - Thursday 25th September 2014 here at the Cavendish Laboratory. The event will see research groups from across the department come together with their counterparts from industry to showcase the application of Physics within the workingworld. Unfortunately Physics at Work 2014 is now fully booked. Please email **outreach@phy.cam.ac.uk** to be added to the waiting list for places.

Cambridge Physics Centre Lectures

A new series of CPC lectures has been confirmed for the beginning of the next academic year. The lectures take place at 6pm in the Pippard Lecture Theatre and are free to attend!

Tuesday 14th October 2014 **Physics of Juggling** – Dr Colin Wright

Thursday 13th November 2014 **Relativity - understanding the connection between space and time** Dr Julia Riley

Tuesday 2nd December 2014 **Can science make a cyclist faster?** Professor Tony Purnell

Lizzie Bateman

Keeping the show on the road

With approximately 1000 people working on site and about 850 undergraduates passing through the Laboratory each term, it is a major challenge to keep everything up to the standards expected of one of the largest physics departments in the country.

This is where the 'behind the scenes' support staff who do all the really physical hard work of implementing all the changes and keeping the Laboratory in its 'ideal normal' state come in. We have been very lucky to have an excellent staff of cleaners and maintenance crew. They have been particularly busy with all the changes which have taken place with the move of the Astrophysics Group to the Battcock Centre and the consequent 'musical chairs' as groups move from one location to another. The same process will continue with the construction of the Maxwell centre and ultimately the planned move of the rest of the Laboratory to the Paddocks site.



The Cleaning Team. Back row from left: Mark Threadgold, Gleb Tsumak, Algirdas Zilevicius, Zina Manekiene. Front row from left: Monika Nierodzinska, Marzena Kulma, David Rudderham, Liucija Zileviene, Xiuping Zhang.

David Rudderham supervises the work of all the cleaning staff and, as can be seen from the names of the excellent team, it is like managing a little United Nations. It is a great tribute to the team that, despite the constant comings and goings throughout the buildings, the Laboratory always looks well presented, particularly in the public areas where our prominent visitors and guests gain their initial impressions of the Laboratory. The team are also particularly popular since a number of them supervise the wine and canapé receptions after lectures to the Cavendish Physical Society and the Scott Lectures.



The Maintenance Team: Back row from left: Graham Cox, Nigel Dibden, Jeff Catlin, Graham Matthews. Front row from left: Mark Callaghan, Keith Matthews, Alan Turner, Dave Smith.

The maintenance staff have a huge operation to maintain. The fact that every area of the Laboratory has been refurbished so many times brings new maintenance challenges, and these are particularly demanding with the requirements of current Health and Safety legislation. Keith Matthews looks after the team who have to combine installing new equipment, services, furniture, and so on as well as dealing with the constant flow of requests for the repair and maintenance of all types of existing equipment and facilities. They have been able to take on important projects for the Laboratory because most of them have been here for a considerable time and have indepth knowledge of the place. We are one of the few departments in the University who have delegated powers to refurbish and maintain our own buildings. This is mainly due to the expertise of our Maintenance team and their commitment to looking after our ageing buildings.

The efforts of both these teams are essential to the operations of the Laboratory and we owe them all a great debt of gratitude for their sterling efforts.

How you can contribute

» Online Giving

The University's Office for Development and Alumni Relations has made it easier to make donations online to the Department and to two of our special programmes. If you wish to make a donation to the Department, please go to:

campaign.cam.ac.uk/giving/physics

If you wish to support the graduate student programme, please go to:

campaign.cam.ac.uk/giving/physics/ graduatesupport If you would like to discuss how you might contribute to the Cavendish's Development Programme, please contact either Professor Malcolm Longair (msl1000@cam.ac.uk) or Professor Andy Parker (hod@phy.cam.ac.uk), who will be very pleased to talk to you confidentially.

If you wish to support our outreach activities, please go to:

campaign.cam.ac.uk/giving/physics/outreach

If you would like your gift to be applied to some other specific aspect of the Development Programme, please contact Andy Parker or Malcolm Longair. The Development portfolio is at:

www.phy.cam.ac.uk/development

A Gift in Your Will

One very effective way of contributing to the longterm development of the Laboratory's programme is through the provision of a legacy in one's will. This has the beneficial effect that legacies are exempt from tax and so reduce liability for inheritance tax. The University provides advice about how legacies can be written into one's will. Go to: **campaign. cam.ac.uk/how-to-give** and at the bottom of the page there is a pdf file entitled **A Gift in Your Will**.

It is important that, if you wish to support the Cavendish, or some specific aspect of our development programme, your intentions should be spelled out explicitly in your will. We can suggest suitable forms of words to match your intentions. Please contact either Professor Malcolm Longair (msl1000@cam.ac.uk) or Mr Robert Hay (rach2@ cam.ac.uk) who can provide confidential advice.



News

2014 Institute of Physics medals and prizes: many congratulations to

Swan Medal and prize



Professor Mike Payne For the development of computational techniques that have revolutionised materials design and facilitated the industrial application of quantum mechanical simulations.

Franklin Medal and Prize



Professor Ben Simons For the application of non-equilibrium statistical mechanics to provide fundamental new insights into the mechanisms that regulate stem cell behaviour in tissue maintenance and disease.

Paterson Medal and Prize

Dr Sarah Bohndiek For her remarkable work in developing advanced molecular imaging techniques and applying them to address questions at the interface of physics, biology and medicine.

Personal Promotions



Many congratulations to our new Professors, **Crispin Barnes** (left), **Russell Cowburn** (below left) and **Zoran Hadzibabic** (below right).





Likewise, congratulations to our newly promoted Readers, **Ben Gripaios** and **Austen Lamacraft**.



Contacts

The Cavendish Laboratory JJ Thomson Avenue Cambridge CB3 0HE Tel: +44(0) 1223 337200 Fax: +44(0) 1223 363263 Email: hod@phy.cam.ac.uk www.phy.cam.ac.uk **Head of Department** Professor Andy Parker Tel: +44 (0)01223 337429 Email: hod@phy.cam.ac.uk

Director of Development Professor Malcolm Longair Tel: +44 (0)1223 765953

Tel: +44 (0)1223 765953 Email: msl1000@cam.ac.uk

applying them to a

New Appointments

We welcome the following new members of the Department:

Prof Pavlos Savvidis: Leverhulme Trust Visiting Professor, Nanophotonics Juan Benayas Sanchez: Facilities Manager, Semiconductor Physics Christopher Darvill: Instrument Maker Matthew Pluck: Instrument Maker David Smith: Plumber Linda Whyles: Project Coordinator, TFM, formerly in SMF

Leavers

We wish the following all best wishes in their next roles:

Sarah Adderley: PA to Prof Athene Donald, Alfonso Fernandez-Montenegro: Cook (Maternity Cover) Julie Kite: Project Coordinator, TFM Kavitha Nimaladevi: Assistant, HEP

Success for Jan Merens

The Parliamentary and Scientific Committee runs the SET for BRITAIN event in collaboration with seven scientific societies including the IoP and with private sector and institutional sponsorship. The winner of this year's Silver Medal and £2,000 was **Jan Mertens**, a PhD student in the NanoPhotonics Group of the Cavendish Laboratory. His research involves squeezing light into tiny gaps to produce powerful sensors.

Suchitra on her Soapbox

Recently **Suchitra Sebastian** (on the left) took part in an outreach event on the South Bank in London which involved female scientists getting on their soapboxes and talking about their research to passersby. She writes: 'It's really an awesome event! We should encourage more Cavendish members to participate.' Please consider getting on your own soapbox.

