



CAVMAG

News from the Cavendish Laboratory



New Cavendish construction begins
P.C. Ho research studentships

The construction of the New Cavendish Laboratory is underway in no uncertain terms, as recorded on these pages. These are very exciting and challenging times. As we keep emphasising, the future will be different from the past, but the opportunities for new areas of research and new collaborations are to be greatly welcomed. At the same time, the show goes on with excellent new science, generous benefactions and inspiring outreach.

It is with great sadness that we report the loss of James Stirling, formerly Jacksonian Professor of Natural Philosophy and Head of Department, whose early death robs us of an individual of outstanding academic and personal qualities.

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FRONT AND BACK COVERS: A view of the New Cavendish site showing, from left to right along JJ Thomson Avenue, the Computer Science Laboratory with the 'tented' bicycle park in front, the Maxwell Centre and the Physics of Medicine Building.

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Ground-breaking for the New Cavendish Laboratory

The formal start of the construction phase of the New Cavendish Laboratory took place on 10 January 2019 with a ground-breaking ceremony, hosted by the main contractor Bouygues. The photograph shows the ground-breaking team led by Vice-Chancellor Stephen Toope.



FIG 1

The formal ground-breaking was followed by speeches in the nearby Maxwell Centre. Andy Parker, Head of Department of Physics, said

'This is a great step in the development of physics research and learning at the University of Cambridge. We look forward to moving in to our new facilities and opening our doors to the wider research community and the public to increase understanding and foster discovery.'

Fabienne Viala, Chairman of Bouygues UK and UK Country manager for Bouygues Construction, said:

'Bouygues UK and our sister company Bouygues Energies & Services have been involved from the start on this exciting scheme, working alongside the University of Cambridge's existing project team to develop proposals for a new world-class laboratory. It is exciting to break ground on this project that will see us bringing innovation, a collaborative approach and our technical expertise to create a new home for major academic research.'

In fact, ...

Preliminary work on the site had begun in September 2018 with infrastructure works to install an underground drainage system. Drilling then commenced to install 112 boreholes, up to 180 m in depth for ground-source heat-pumps to provide the most eco-friendly means of heating and cooling the new buildings. Work on these installations will

continue into the Spring of 2019. These are located in the flattened, rather wet-looking area at the bottom of Figure 2.

Bouygues, the main contractor for the building, were able to make an early start on levelling the site and had completed the piling to enclose the low-vibration basement area for the most sensitive experiments. This required the boring of 272 piles, up to 20 m deep, and was completed by the end of January 2019. This area can be seen clearly in the centre of Figure 2.

This stage of the project involved the installation of two large piling rigs and a huge amount of steel reinforcement and poured concrete. At maximum there were up to 600 lorry movements per week. This important phase is completed and now the boring equipment has been removed. The facilities for the excavation of the low vibration basement area are now moving on-site, involving the installation of a number of large cranes.

The very large scale of the development of the site can be appreciated by comparing the size of the site with the Vet School to the right of Figure 2. The cover spread shows the site with the Laboratory's Physics of Medicine and Maxwell Centre Buildings in close proximity to the New Laboratory.

January saw the completion of the site hoarding securing the site boundary. The installation of the site internal access road, site welfare and the site office cabins will take place during February 2019. Temporary cabins have been placed on the site for the early works packages.

The current programme of construction is as follows:

- Enabling Works & Surveys – early 2018 to end 2018
- Shared Facilities Hub Construction – mid 2019 to early 2021
- Cavendish III Construction – late 2018 to early 2022
- Infrastructure – late 2018 to early 2022

Because of the early start to the construction programme, the project is currently ahead of schedule.

All the Committees involved in managing this very large project are in full operation. In particular, on the date of the ground-breaking, the third meeting of the Facilities Steering Committee met to continue the preparations and planning for the operational phase of the new Laboratory.

FIG 1, left: The ground-breaking team. From left to right: Caroline Buckingham, Royal Institute of British Architects, Vice President; Andy Parker, Head of the Cavendish Laboratory; Neil Pixley, Project Director, Bouygues UK; Stephen Toope, Vice Chancellor, University of Cambridge; Fabienne Viala, Chairman of Bouygues UK; Beverley Weston, Head of Estate Projects, University of Cambridge

FIG 2, below: An aerial drone photograph of the part of the New Cavendish site. JJ Thomson Avenue runs along the left of the picture. By this stage, the drilling and piling had been completed. The rectangular area in the centre of the site will house the lowest vibration basement laboratories, used for the most sensitive measurements.



FIG 2

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Opening of the Henry Royce Institute facilities in West Cambridge



The Henry Royce Institute was created as the UK's national institute for materials science research and innovation in 2016, through the allocation of £235 million capital for the provision of a new building at the Royce hub in central Manchester and for capital equipment at all partner institutions.



The funding for the purchase of advanced scientific equipment supports the research in the nine partner Royce institutions – the Universities of Manchester, Cambridge, Oxford, Sheffield, Liverpool, Leeds, Imperial College London, the National Nuclear Laboratory and the UK Atomic Energy Authority. As part of the Henry Royce Institute capital spend, £10 million was awarded to the University of Cambridge for the purchase of state-of-the-art research equipment, focussing on the theme of **Materials for Energy-Efficient Information and Computing Technology (ICT)**. Royce Cambridge is a collaboration between the Materials, Chemistry, Physics, Engineering and Chemical Engineering Departments of the University and is based in the Cavendish Laboratory's Maxwell Centre. The organisation of this collaboration has been driven by Isabelle de Wouters, who runs the Energy@Cambridge Interdisciplinary Research Centre, Lata Sahonta and Richard Friend.

2018 was a busy year on the West Cambridge site, with the continued installation of equipment

into the Henry Royce Institute facilities, primarily located at the Maxwell Centre, and distributed around other West Cambridge laboratory spaces. The equipment for research into Materials for Energy-Efficient ICT includes state-of-the-art deposition, nanofabrication, characterisation and packaging facilities for a broad range of technologies that promote energy generation, energy storage, and efficient energy use.

On 17th October 2018, the Cavendish Laboratory hosted the official opening of the Cambridge Royce facilities, the formalities being performed by Julia King, Baroness Brown of Cambridge, who unveiled an official plaque at the Maxwell Centre. The Vice-Chancellor of Cambridge University, Professor Stephen Toope gave a welcome address, highlighting the breadth of the research areas supported by the Cambridge Royce facilities, and its role as the centre of a bold vision for future materials research at the University.

The event also featured a series of short talks from early career researchers who highlighted the new cutting-edge science that is being enabled by the new facilities. The Henry Royce Institute's Chief Scientist, Regius Professor Philip Withers, gave an overview of the national programme of activities undertaken by the Henry Royce Institute's nine partner institutions. Industrial researchers also gave their perspective on the



benefits of interacting with the Henry Royce Institute, and how Royce has provided them with an opportunity to engage more closely with University research groups.

All the equipment suites are now installed and are being booked by University, external, and industrial scientists, taking advantage of the world-class facilities, expert technical support, and access to a vibrant user community associated with each equipment suite. A fine example of this is the Royce Ambient Processing Cluster Tool, a ten-glovebox suite with a robotic transfer system that allows a range of deposition, printing, testing and packaging of novel devices in an inert environment. Thanks to this system we can now fabricate devices with a mix of inorganic and organic layers, enabling new types of applications for future energy-efficient technologies.

Cambridge Royce operates as a national facility, and the equipment is available for use by all research institutions and industry. The equipment suites are all well-supported by expert technical staff, and also provide access to powerful materials analysis software.

All equipment suites are available for booking by all academic and industrial users. Please contact **Lata Sahonta**, Programme Manager of Cambridge Royce (royce@maxwell.cam.ac.uk),



or visit the Maxwell Centre website for more information.

www.maxwell.cam.ac.uk/programmes/henry-royce-institute

LATA SAHONTA AND RICHARD FRIEND

FIGS, left to right:

Julia King carrying out the formal opening of the Cambridge Royce facilities with Richard Friend in the Maxwell Centre.

The Vice-Chancellor of Cambridge University, Professor Stephen Toope, giving the welcome address in the Pippard Lecture Theatre.

Royce Ambient Processing Cluster Tool, a ten-glovebox suite with a robotic transfer system.

Henry Royce Institute's Chief Scientist, Professor Philip Withers, reviewing the national programme of the Henry Royce Institute in the Maxwell Centre.

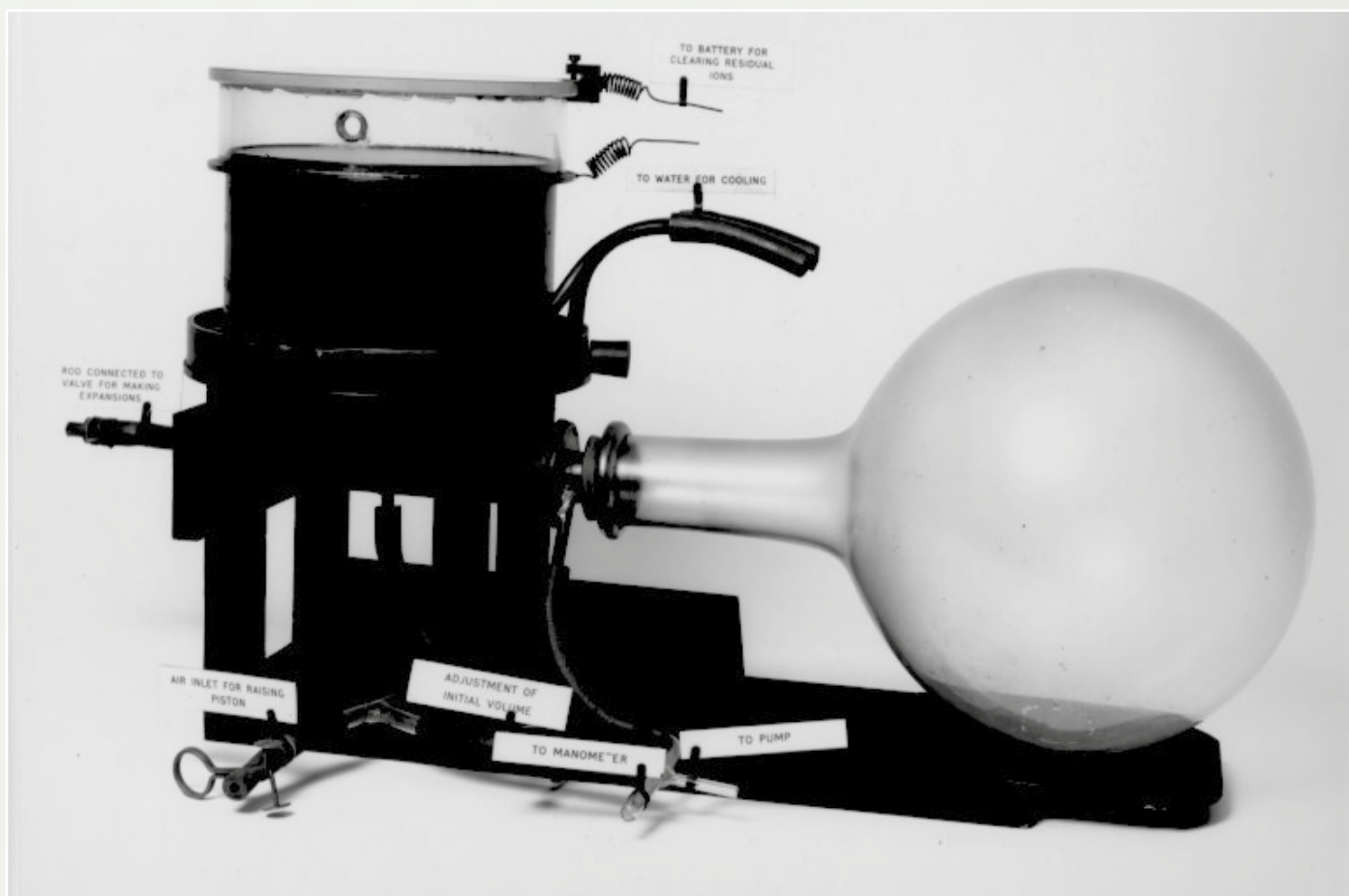
P.C. Ho and the evolution of the Wilson cloud chamber



In the famous photograph of the staff and students of the Cavendish Laboratory in 1932, there are nine Nobel Prize winners. Among the students is the Chinese graduate student P.C. Ho. He came from China funded by the Hubei provincial government. Unfortunately, his funding stopped after 2 years and he could not complete his PhD. He returned to China where he became a distinguished professor of physics.

In 2014, we received a request from Ho's grandson Yan Huo to visit the Cavendish museum and understand more about his grandfather, who had been very reticent about his work at the Cavendish. In the summer of 2018, this resulted in a study of what Ho actually did during his time at the Cavendish.

C.T.R. Wilson was the inventor of the Wilson Cloud Chamber. His primary interest was in understanding the process of cloud formation from super-saturated water vapour. He was inspired in these studies by the cloud and atmospheric phenomena he observed as a 'temporary observer' for two weeks in the summer of 1894 at the meteorological observatory on the summit of Ben Nevis in Scotland. In particular, he was struck by the beauty of coronas and 'glories', coloured rings surrounding shadows cast on mist and cloud, such as the Brocken spectre. In a brilliant series of experiments, Wilson worked out the precise degrees of super-saturation necessary to condense water vapour into tiny water droplets. In 1898, Thomson used this technique to make one of the very first estimates of the charge of the



electron, finding a value within about 50% of its present value.

By the late 1900s, it was realised that the paths of charged particles could be traced by the condensation tracks they produce in the supersaturated water vapour. Wilson greatly enhanced the performance of the condensation apparatus, resulting in the famous Wilson Cloud Chamber shown in Figure 2. With this apparatus, Wilson took the first images of the tracks of the high energy electrons and α -particles released in radioactive decays – the images were of exceptional quality. This instrument became the workhorse of studies of particle tracks for the next 40 years. As Patrick Blackett wrote in his Memoir of C.T.R Wilson in 1960,

‘There are many decisive experiments in the history of physics which, if they had not been made when they were made, would surely have been made not much later by someone else. This might not have been true of Wilson’s discovery of the cloud method. In spite of its essential simplicity, the road to its final achievement was long and arduous: without C.T.R. Wilson’s vision and superb experimental skill, mankind might have had to wait many years before someone else found the way.’

Once Rutherford had discovered evidence for what he called the disintegration of nuclei by fast particles in 1919, he challenged his research students to use the Wilson Cloud chamber to photograph these events. First Takeo Shimizu, a research student from Japan,

FIG 1 (left). Staff and research students of the Cavendish Laboratory in June 1932. Of special interest for this essay are P.C. Ho (enlarged in the insert), C.T.R Wilson (fifth from the right in the front row) and Patrick Blackett (second from the right in the front row).

FIG 2 (right). The perfected Wilson Cloud Chamber of 1912. Photographs of the high energy particle tracks were photographed through the glass upper disc.

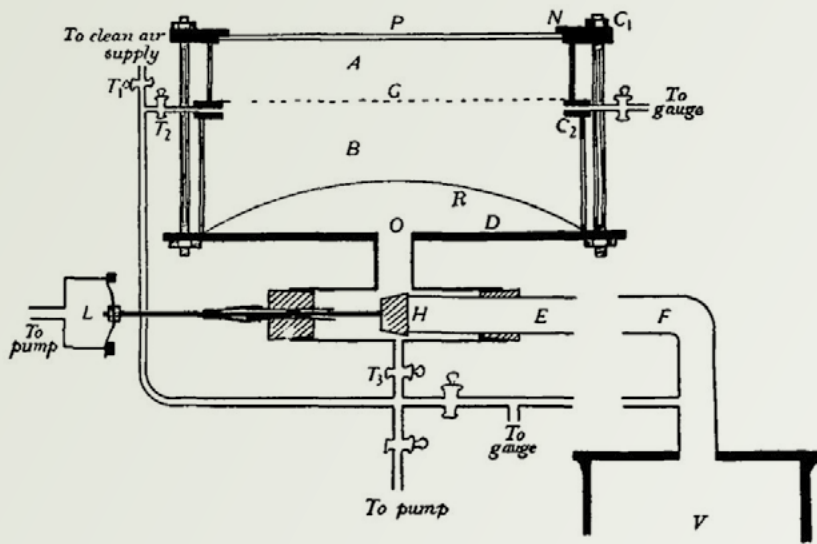


FIG 3. A diagram showing the operation of the Ho cloud chamber.

and then Blackett automated the operation of the cloud chamber in order to take the many cloud chamber photographs needed to observe these rare 'nuclear disintegrations'. This was successfully achieved by Blackett in 1925. On the 23,000 images of particle tracks taken with the automated chamber, there were 270,000 particle tracks, among which 8 nuclear interactions were observed showing the transformation of a nitrogen into an oxygen nucleus – this was not 'disintegration' but 'nuclear transmutation'.

The apparatus was somewhat bulky and inflexible and so in 1933, C.T.R Wilson suggested a different approach to the construction of the Cloud Chamber. In the classical cloud chamber, the cooling of the supersaturated vapour is achieved by very rapid adiabatic expansion of the sensitive volume. Rather than using the expansion ratio V_1/V_2 to cause the condensation of the water droplets, he suggested keeping the volume fixed and using a pressure change p_1/p_2 which would have exactly the same effect in condensing water droplets onto charged particles by adiabatic cooling.

When P.C. Ho arrived in Cambridge as a research student, his project was to build and assemble this new type of cloud chamber in the Cavendish workshop. Figure 3 shows the new variable pressure cloud chamber built by Ho.

In Figure 3, A is the fixed volume, G is a wire gauze and the curved surface R is a rubber diaphragm. The gas could be introduced into the volumes A and B at higher than atmospheric pressure and then expanded into air. The change of pressure was achieved by making the 'floor' of the chamber A out of wire gauze G through which a portion of the air would escape without turbulence. It also provided an electrode so that electric fields could be applied to remove residual charged particles. In operation, the rubber diaphragm R begins in the distended parabolic shape shown in Figure 3 and then, when valve H is released, the gas is rapidly expelled from the lower part of the volume and the diaphragm collapses onto the bottom of the chamber D, causing the adiabatic cooling.

Preliminary tests by Ho showed that this form of expansion chamber was capable of producing just as high quality photographs as the traditional cloud chamber and was easier to use. C.T.R Wilson described what Ho did in the paper:

- On a New Type of Expansion Apparatus, *Proc. Roy. Soc.*, **142**, 88-91, 1933.

Ho published three papers involving this new type of Cloud Chamber:

- Experiments with a simple type of cloud chamber, (with E.C. Halliday). *Proc. Camb. Phil. Soc.*, **30**, 201-205, 1934.
- Investigations on condensation phenomena in mercury vapour, 1934. *Proc. Camb. Phil. Soc.*, **30**, 216-224, 1934.
- An investigation of the upper limit of the thorium C+C'' β -ray spectrum by means of the Wilson Cloud Chamber. *Proc. Camb. Phil. Soc.*, **31**, 119-124, 1935.

From 1934 onwards, this was the preferred type of Cloud Chamber. It could be miniaturised and, in particular, it could be oriented on its side, unlike the traditional Wilson chamber in which the vacuum seals were provided by the water vapour itself. As a result, the new version of the Cloud Chamber was ideal for cosmic ray studies in which coincidence counters (C) could be placed

above and below the chamber so that only penetrating radiation coming from above would set off the cloud chamber (Figure 4).

Again quoting Blackett, 'Among the many discoveries made by the use of Wilson's cloud chamber, outstanding were those of:

- The positive electron (1932)
- Pair production and cosmic ray shower phenomena (1936)
- The β -meson and its spontaneous decay (1937)
- The charged and neutral V-particles (1947),
- The negative cascade hyperon (1959).'

Unfortunately, P.C. Ho had to end his PhD studies in Cambridge due to the lack of funding from the Chinese government. His experience in Cambridge, however, enabled him to pursue further research and teaching on his return to China. He was subsequently awarded professorships in various Chinese universities and engaged in research on cosmic rays and high energy physics. He was widely recognised for his contribution to research and education of generations of physicists in China.

KRZYSZTOF ZAMARSKI AND MALCOLM LONGAIR

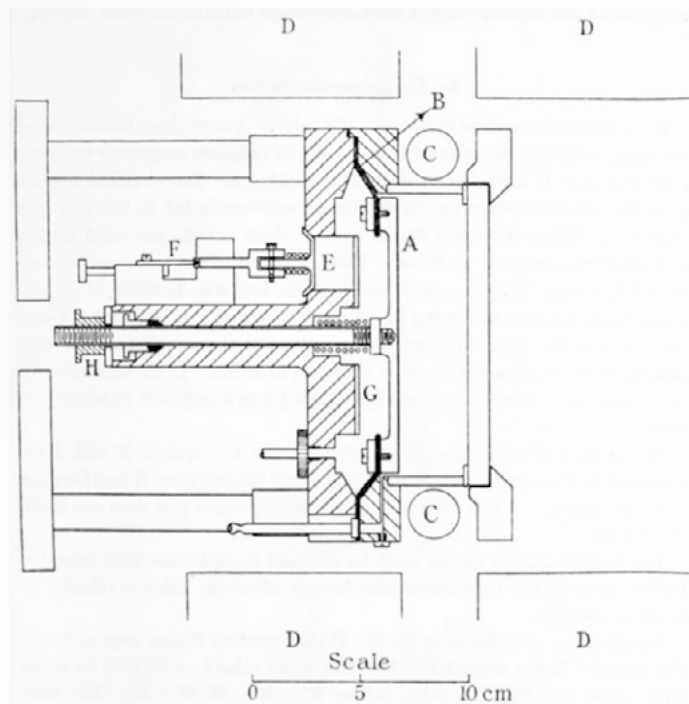


FIG 4. The variable pressure version of the cloud chamber, with the sensitive volume A lying between a pair of coincidence detectors C. A cloud chamber photograph was only taken when a coincidence event occurred in the detectors C. This was an ideal configuration for cosmic ray studies.

P.C. Ho Ph.D. Studentships

We are delighted to report a magnificent gift by the Huo Family Foundation to support graduate studentships in the Laboratory. Yan Huo, his wife Xue Fang and their fellow trustees have generously endowed these studentships in perpetuity in memory of Yan's grandfather P.C. Ho whose work in the Laboratory is described in the accompanying article. The Grace to set up the **P.C. Ho Fund** was submitted to the Regent House on 7 November 2018 and approved later that month.

It is planned that the fund will support three studentships in the Laboratory each year in the longer term. The first P.C. Ho Studentship will be awarded to an outstanding applicant for a PhD programme starting in October 2019.

Yan did a PhD in Electrical Engineering at Princeton University on the quantum Hall effect and then moved very successfully into the finance sector. He co-founded Capula Investment Management in 2005.

We are profoundly grateful to the Huo Family Foundation for their generosity.

Dislocation plasticity and the Cavendish Laboratory



MICK BROWN describes a remarkable study of the application of the concepts of self-organised criticality to the understanding of the physics of plastic deformation.

The equation of state of an ideal gas has prompted attempts to find similar constitutive equations for more complicated materials. The Cavendish Laboratory has played a prominent part in this endeavour. Viscoelastic behaviour inspired James Clerk Maxwell's 'spring and dashpot' models which are still used to characterise rubbers and tars. David Tabor's demonstration of rolling friction caused by hysteresis in rubbers, which plays such a prominent role in the design of tyres, is on display in the Cavendish museum. But the behaviour of metals is not viscoelastic, but plastic, meaning that they can suffer a 'permanent set' – a change of shape which is not reversed when the load is released. Bragg's X-ray diffraction experiments showed that such plastically deformed metals were still crystalline, although the diffraction peaks were characteristically streaked.

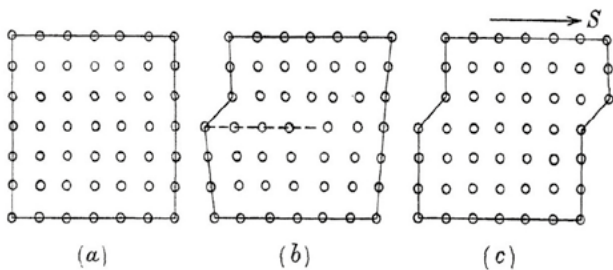


FIG 1.

A breakthrough in understanding came with Geoffrey (G.I.) Taylor who introduced the idea of dislocations which could traverse a crystal to change its shape, but still leave an undistorted crystal behind (Figure 1). Although the study of dislocations was delayed by the war, Nevill Mott, then at Bristol, pioneered the application of physics to them, and soon many of the features became clear: the dislocations could bend, and had a line tension. One could begin to see how alloying the metal strengthened it and also how it could creep by the diffusion of vacancies to the dislocations. Taylor did not consider screw dislocations at all. Famously, Mott identified the cross-slip of screw dislocations with the basic mechanism of the initiation of fatigue cracks in repeated alternating plastic flow. On his migration to the Cavendish, Mott attracted a brilliant team to develop these ideas, aiming to find, if possible, 'constitutive equations' of engineering utility describing the complex behaviour of crystalline flow.

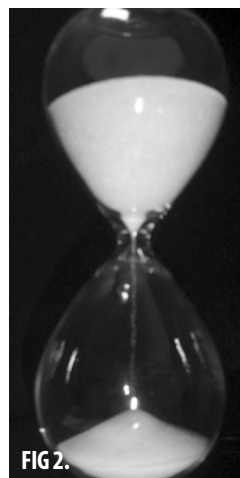


FIG 2.

One of the most compelling developments was the first observation by electron microscopy of moving dislocations in simple ductile metals. The team led by Peter Hirsch opened up an enormous field of applied research which continues to this day in departments of materials science, chemistry, mechanical engineering and mineralogy. The pioneering text *Electron Microscopy of Thin Crystals* (1965) by Hirsch, Howie, Nicholson, Pashley and Whelan laid the foundations for a detailed study of dislocations and crystal rotations in plastically deformed materials. It seemed only a matter of time before a sound

understanding of plasticity would be achieved. But the field became mired in controversy and disillusion as the German school under Seeger fought with the English school headed by Mott and Hirsch.

The tussle concerned how to explain 'work-hardening' – the phenomenon whereby a ductile metal becomes harder when it is deformed. Experimentally, it had become clear that when strained in tension a ductile single crystal displays several stages of deformation: elastic at very small strains; plastic but showing little resistance, so called 'easy glide' or Stage I at modest strains; plastic showing marked resistance in which the stress required to continue straining increases nearly linearly with the plastic strain, called Stage II, up to strains around 20%. Stage II has a slope tied to the elastic shear modulus but about 1/400 of its value. Then one arrives at Stage III, a stage with progressively diminishing slope; then finally fracture. As demonstrated by Peter Hirsch (1975), what is most remarkable is that, although there are variations depending upon temperature, the behaviour in Stage II is universally observed in all ductile metals, as is the sequence of stages. But to paraphrase Basinski: 'the problem of work-hardening in metals was the first to be tackled by the new concepts of dislocations, but will be the last to be solved'.

Meanwhile, the concepts of 'complexity' were being developed to explain the behaviour of a wide variety of systems, from earthquakes to stock-market crashes. 'Avalanches' play a central role. The paradigm is the sandpile, as famously studied by Per Bak. Simple computer models of sandpiles show 'self-organised criticality'

whereby avalanches with a wide range of sizes course down the sides as sand is added to the pile. As Sam Edwards has emphasised in his studies of granular matter, what one sees is the 'angle of repose', namely the characteristic slope of the sides of sand dunes observed on all scales, from giant structures in the desert to the modest piles produced by childrens' crumbling castles on the beach.

One very striking feature of these structures is that they must undergo three phases: a precursor phase, in which they build up, then a self-organising-critical phase in which the angle of repose acts as an attractor, so that as the dune develops, steeper bits collapse and less inclined bits build up, perpetuating an uneven surface lying on average at the angle of repose. Finally, there must always be an exhaustion phase, in which the sand runs out or the edges of the dune encounter different conditions at the boundary. These phenomena can be directly observed in the behaviour of the flow of sand in an egg timer. Because in the self-organising critical phase there is a wide range of avalanche sizes, from atomic to macroscopic, with no input from any other dimensional quantities, one expects and finds simple power-law relations between the variables. One characteristic feature of such avalanching systems is that static observation reveals only a residual structure: there is a palimpsest effect, whereby each unpredictable avalanche overwrites the remains of its predecessors.

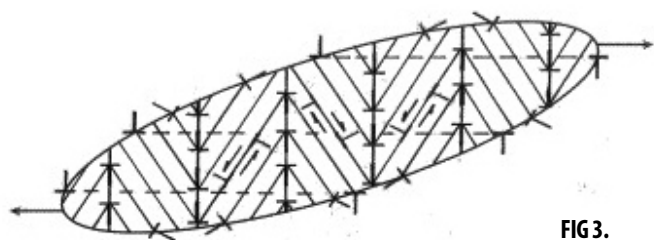


FIG 3.

To turn the sandpile analogy into a useful algebraic model of work-hardening much detail needs to be added. The crucial step is to find an acceptable model for an avalanche. Here one can make use of a powerful theorem due to Eshelby: in an elastic medium containing an embedded inclusion which has suffered a transformation strain, the resulting strain inside the inclusion will be uniform if and only if the inclusion has an ellipsoidal shape. In plastic shear, this means that the shape of an avalanche caused by the collective motion of dislocations must be ellipsoidal. The dislocations all move together, so they must all feel the same stress, which can only happen if they propagate in an ellipsoidal envelope (Figure 3). Then one must understand how each avalanche can be brought to a halt. Why doesn't one of them run away entirely? The answer lies in the slight tilts that they suffer, statistically misinclined to the crystallographic shear plane, some steeper than it and others shallower. This causes secondary slip which brings the runaway shear to a halt. The geometry of the resulting dislocation arrays agrees in detail with the painstaking observations by electron microscopy over many years. It induces slight rotations of the crystal lattice and accounts for the blurring of the x-ray patterns observed by Bragg and his students.

Finally, one needs to be able to calculate the 'emergent properties' of the process: pre-eminently the slope of the work-hardening curve in Stage II. Here one needs to look at the self-organising critical state: it is a state of maximum suppleness of response, wherein each element over time is equally likely to participate in an avalanche, and to be stopped. The idea of maximum suppleness in these complex systems is closely related to ideas of maximum

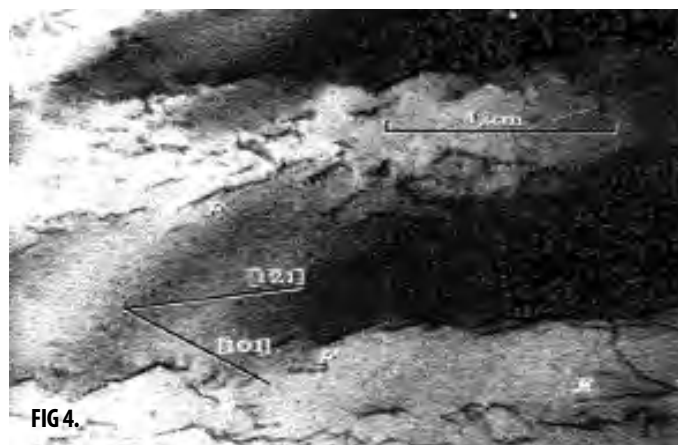


FIG 4.

entropy, but it is not related to temperature and only indirectly to heat. In conventional thermodynamics one can think of the equilibrium state as an attractor, the state to which the system always returns after fluctuations. In complex systems suffering an increase in intensive force (stress) the state of maximum suppleness is the statistically uniform state to which the system returns after avalanches. It enables one to calculate the increase in irreversible plastic displacement - the extensive variable - without a detailed knowledge of microscopic mechanisms. It comes as no surprise to find that in Stage II the system obeys a kind of equation of state, as beautifully demonstrated at the Cavendish by Wyatt in 1953. Using these ideas, one can calculate the exponents of all the statistically related variables encountered in plastic flow.

There is an interesting sequel to this story. Dislocations require a certain time to synchronise their movements. They must come to a kind of murmur, like starlings. Exchange of stress waves to communicate between all parts of the array requires time. It follows that at very high strain rates the collective motion must cease, and it will be more difficult to accomplish plastic displacement. This effect, the striking increase in flow stress at high rates of strain, was observed some years ago and variously interpreted. Very recent work by Lewis Lea in the Cavendish Laboratory has confirmed that it is caused by an increase in work-hardening, and that the progressive failure of collective motion is a very likely cause of the effect. In his award-winning thesis, he has derived the power-law which the increase obeys on the basis of the known power laws obeyed by avalanching dislocations.

References:

- Per Bak, *How Nature Works*, 1997, Oxford University Press.
- Wyatt, O. H., Transient Creep in Pure Metals, *Proc. Phys. Soc. B* 66 (1953) pp 459 – 480.
- Brown, L. M., Power laws in dislocation plasticity, *Phil. Mag.* 96 (2016) pp 2696 – 2713.
- Taylor, G. I., The Mechanism of Plastic Deformation of Crystals, *Proc. Roy. Soc. A* 145 (1934) pp 362 – 387.
- Hirsch, P. B., Chapter 5 in *The Physics of Metals*, P. B. Hirsch, Ed., (1975) pp 189 – 246, Cambridge University Press.
- Eshelby, J. D., The determination of the elastic field of an ellipsoidal inclusion, and related problems, *Proc. Roy. Soc. A* 241 (1957) pp 376 – 396.
- Mott, N. F., A theory of the origin of fatigue cracks, *Acta Met.* 6 (1958) pp 195 – 197.
- Blumenfeld, R., Edwards, S. F., and Walley, S. M., Physics of Granular Systems, in *Oxford Handbook of Soft Condensed Matter*, (2015), pp 183 – 248, E. Terentjev and D. A. Weitz, eds, Oxford University Press.
- Lea, L. J., (2018) Structural Evolution in the Dynamic Plasticity of FCC metals (doctoral thesis) <https://doi.org/10.17863/CAM.20971>.
- Steeds, J. W., Dislocation Arrangements in Copper Single Crystals as a Function of Strain, *Proc. Roy. Soc. A* 292 (1966) pp 343 – 373.

FIG. 1. G. I. Taylor's (1934) conception of an edge dislocation deforming a crystal by its motion across it.

FIG. 2. Sandpile in an hour glass.

FIG. 3. Brown's 2016 two-dimensional model of an ellipsoidal dislocation avalanche or slip band. Taylor's edge dislocations are denoted by 'T' symbols, angled or upside down. As the band shears, the tilt causes it to elongate along its major axis, thereby activating secondary slip (angled T's) and alternating misorientations within it and across its boundary.

FIG. 4. Steeds' demonstration of rotation axes perpendicular to the primary slip plane within slip bands. In this 1966 image, alternating rotations are caused by arrays of secondary dislocations in deformed copper. They take on interpenetrating, roughly ellipsoidal shapes.

Making Quantum Mechanics work – Interferometry with atoms



BILL ALLISON was awarded the 2018 British Vacuum Council Senior Prize and Yarwood Medal for his work on surface dynamics using atomic interferometry. He describes the major challenges involved in making this technique a reality.

The best ideas, they say, are always simple. What's not said is that simple ideas are not always easy to implement. In the present case we set out to make the 'spare neutron' in the nucleus of a ^3He atom scatter strongly at a surface. Surfaces are all but invisible to free neutrons so neutron scattering is strictly limited in its application to surface science. An analogy helps: we recognise that the motion of a model-ship in a bottle is determined by the bottle. In the same way the neutron at the centre of the ^3He atom is constrained to move with its 'bottle' of electrons. The idea enables us to benefit from the strong surface interaction of the electrons, while the spin of the 'neutron' allows us to exploit various techniques established in neutron-optics. The viability of the technique as a method to gain detailed information on surface dynamics was first demonstrated at the Cavendish Laboratory. The method has been applied successfully to many systems and has hugely extended our knowledge of the behaviour of atoms and simple molecules at surfaces.

Surfaces are central to many practical phenomena but our knowledge of behaviour at surfaces is limited by the means we have to explore them. For example, how do oxygen and carbon monoxide react at the surface of a car's catalytic converter? We know the steps in the interaction and have a good idea of the energetics but know little about the mobility of the species involved. What we lack is a picture of the dynamics of the atoms and molecules on a microscopic distance-scale and an atomic time-scale. It is a tall order for an experiment to resolve processes separated by both nanometres and picoseconds. Usually, one has to choose between time-resolution and spatial-resolution. Microscopy, for example, generally favours resolution in space over resolution in time. The Helium Spin-echo method is an approach that creates an atom-optical interferometer that delivers both space and time resolution – though in a rather complicated package!

Figure 1 illustrates the principle of the method. A beam-splitter manipulates the helium wavepacket into two parts separated in space, though both travel along the same path (see Figure 1). In that way the first packet creates a scattered field that represents the state of the surface at one instant. The second part of the wavepacket arrives after a short delay, τ_{se} , typically a few picoseconds. If the surface is unchanged then the second part scatters identically to the first part and, on recombining with the outgoing waves, one returns to the initial polarisation state. If, however, there has been some

motion of surface atoms between the arrival of the two wavepackets then recombining the outgoing wavepackets results in a change in the resulting polarisation. Thus, measurements of the polarisation as a function of the time delay, τ_{se} , allow us to extract the nature and extent of the motion.

Converting these ideas into a working instrument was far from a simple task. The demands of precision in manufacture and of operation in a molecular-beam environment generate special technical challenges. Indeed, earlier attempts elsewhere had failed precisely because these technical problems were not overcome. Components are needed to polarise and analyse the ^3He atoms as well as to control the relative phase of the spin-components. In addition, an intense beam of atoms and a highly efficient helium detector are needed. Each of these requirements resulted in a mini engineering-marvel built largely in house by the excellent staff of the Cavendish workshop. One example is illustrated in Figure 2, which shows the atom-optical element that creates the polarised ^3He beam. It is based on a magnetic-field with a hexapole configuration that is generated using permanent magnets. It acts both as a lens, to focus one spin-component, and as a polariser, since the other spin component is defocused (Figure 2(c)) and hence removed from the beam.

The instrument is illustrated in Figure 3. The polarising hexapole, described above, is the first component after the beam source (top right). The analysing hexapole (bottom centre) works on similar principles, though its design and fabrication reflect the different environment in later stages of the experiment. Wavepacket splitting and recombination (Figure 1) takes place in solenoidal magnetic fields placed before and after the scattering surface. The final component is the helium detector, a highly sensitive ioniser and mass selector. It too is a Cavendish speciality.

The Cavendish instrument is the first of its type and has been developed over a number of years (Figure 4). Its use, in collaborations with groups in Europe and the USA, has generated many scientific highlights. Initial experiments demonstrated how atomic motion on surfaces could be understood. The energy landscape, in which the surface atoms move, can now be measured with great precision and cooperative effects in the motion, arising from surface forces, observed from a fully atomic perspective. More recently, work on molecular systems has shown that surface forces are not

necessarily pairwise – a result that changes one’s perception of how chemical reactions might take place. The importance of molecular conformation and its effect on the way molecules move at surfaces has also been revealed with stunning detail. Finally, we have begun to understand and quantify the interaction between the surface atoms and the rest of the solid. This adsorbate-surface interaction acts as the heat-bath that generates surface motion; however, the precise source of the interaction and the extent to which phonons or electrons contribute remain open questions.

With the building of the new Cavendish Laboratory, there are opportunities to develop the method further and move towards the next generation of instrument. Improvements in helium detection together with opportunities to seek higher resolution as well as extending the spin-echo time, τ_{SE} will allow observations of a wider range of surface systems. Supramolecular interfacial systems and the growth of novel 2D materials will be accessible, as well as opening up the possibility of observing surface-templated chemical reactions. The future for experiment is bright especially when coupled with improved methods that give a more holistic analysis of the quantity of high-quality data that new instruments will deliver.

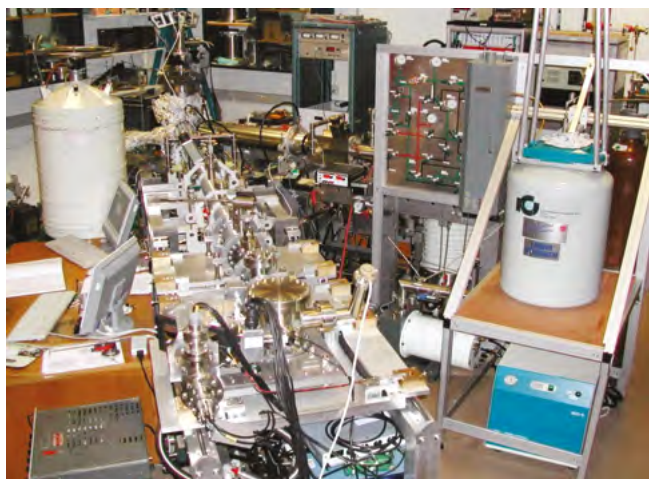
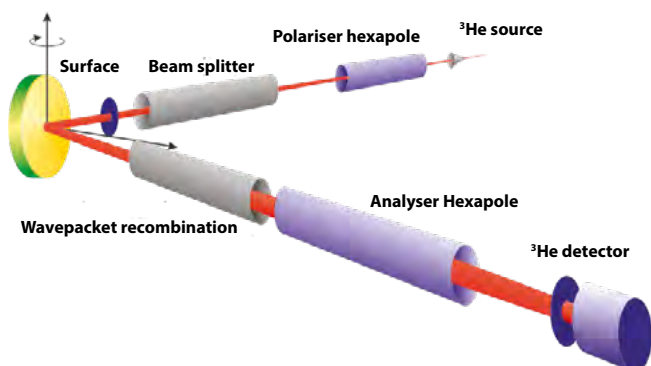
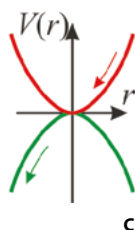
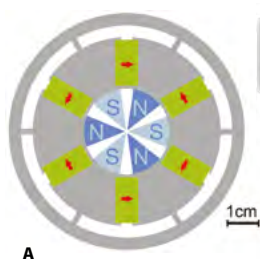
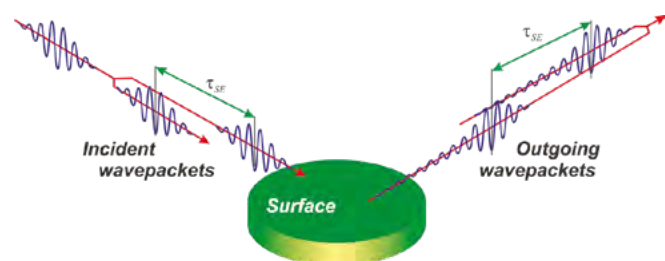
FIGS left, top to bottom:

1. The spin-echo technique represented as an atom interferometer. The incident wavepacket enters the system, top left, and is coherently split into its two spin-components. The resulting wavepackets follow the same trajectory but, in the figure, are illustrated with a lateral offset, for clarity. A delay between the components ensures that they scatter from the surface, centre bottom, with a time difference, τ_{SE} . The outgoing wavepackets are recombined before entering the detector, top right. Differences between the outgoing wavepackets, due to surface motion, give rise to a loss of coherence, which is detected through a change in the polarisation state of those atoms reaching the detector.

2. The polarising hexapole for the ^3He atoms, in which permanent magnets generate pole-tip fields in excess of 1T; (a) shows the construction method, with the pole-pieces (blue) and permanent magnets (yellow-green) assembled inside the soft iron yolk (grey), which also acts as a support, and a magnetic screen. Wire erosion methods were used to guarantee the necessary manufacturing precision; (b) a partly assembled view of the resulting device. Gaps between the 6 component parts and within each part cope with the high gas-load of the ^3He beam; (c) illustrates the polarising principle. One spin-component in ^3He seeks the low-field region (red curve) and, like a snow-boarder in a half-pipe, experiences a force towards the axis. The other spin-component (green curve) experiences an outward force, which dilutes its contribution to the outgoing beam. Thus, the emerging beam is predominantly made up of the first component (red).

3. Arrangement of the components to create the atom-interferometer. A supersonic expansion in the ^3He source creates an unpolarised beam of atoms. The polariser hexapole, described in Figure 2 generates a parallel beam of polarised atoms that pass to the beam splitter, which is a solenoidal magnetic field. Here, the helium atom is split into two spatially separated wavepackets (see Figure 1), before scattering from the surface. In the outgoing leg of the apparatus the wavepackets are recombined in a second solenoidal field before analysis in a second hexapole. Atoms having a particular polarisation state then enter the detector (bottom right).

4. The completed interferometer viewed along the outgoing arm of the apparatus. The view is towards the scattering chamber (centre left at the top). The incoming arm, with polariser and beam-splitting solenoid, can be seen directed from the right of the picture towards the scattering chamber.



2018 Winton Symposium

Machines: from cosmic to the nanoscale

The 7th Annual Winton symposium explored the chemically-powered world of living systems alongside the man-made world of electrically and optically coupled devices, from electric motors to detectors of gravity waves, from nanoscale devices to those spanning kilometres to explore our universe.

Richard Friend, Director of the Winton Programme, welcomed the audience to the 7th Winton Symposium on 'Machines: from cosmic to the nanoscale' held in the Cavendish Laboratory on 1 November 2018. This proved to be an outstandingly successful day highlighting the diversity of approaches to machines and inspiring interdisciplinary approaches.



Sheila Rowan, Director, Institute for Gravitational Research, University of Glasgow, discussed the fundamental physics that can be explored with gravitational wave detectors and the engineering challenges of constructing these machines. Gravitational waves predicted by general relativity result from mass changes that cause extremely small ripples in space-time. The first gravitational waves first reported in 2016 were generated in the collision and coalescence of two black holes. The details of the observed oscillations encode information related to this event that took place 1.3 billion light years away.

The measurements are performed using a Michelson light interferometer. The waves produce path length changes in the two orthogonal arms of the interferometer, but these relative distance changes are less than 10^{-22} . The challenge is to maximise the signal and minimise the noise from various

sources including, photons, radiation pressure, seismic, thermal and gravitational noise. Two LIGO observatories have been built in the US involving over 1000 scientists from across the world. The mirrors are 40kg in weight, the arms of the interferometer 4km long, and are kept under vacuum to reduce scattering. Improved sensitivity and directionality will allow a wide range of new observations, including neutron star collisions, the first of which was observed last year.

The high precision technology developed has found a number of applications. Work at Glasgow has led to fabrication of MEMS-based gravity sensors for gravity imaging and navigation. These are being trialled with arrays on Mount Etna and on devices on drones. Another application is in healthcare where stem cells can be stimulated to form bone cells by exposing them to precisely controlled vibrations.



Mark Kasevich discussed the atom interferometry system he has built with his group in the Physics Department at Stanford University and how this can shed light on the link between gravitation and quantum mechanics. An ensemble of rubidium atoms is created that is cooled to picokelvin temperatures. The atoms are launched vertically into the system and then individual atoms are separated with light pulses. Two ensembles of

atoms are thus created which are spatially separated and then are recombined. This is the equivalent of Young's double slit experiment which was first used to explore interference with light waves.

He has shown that even with spatial spacing of 54 cm between the two ensembles, interference effects can be observed when the atoms are recombined. This ability to demonstrate quantum effects on such macroscopic scales has invalidated some models that predict that coherence cannot exist when atoms experience a different gravitation force (the KTM model) or when the spacing between atoms that are in coherence is large (the Ellis model).

The ability to measure gravitation effects with great precision can have practical applications. The company AOsense is developing products for geophysical mapping, including an application to monitor water tables. On the fundamental physics front, atom interferometry offers a way to measure the frontiers between gravity and quantum mechanics.



Adrian Thomas from the Zoology Department at the University of Oxford discussed flying machines in his talk, 'Taking inspiration from biomechanics to engineering, dragonfly drones and other bio-inspired vehicles'. Through a series

of videos he demonstrated the different design concepts utilised by various species of birds and the trade-offs between efficiency and performance.

Experiments performed on airflows show that flyers produce wingtip vortices that lead to areas of downlift and uplift. By flying in the regions of uplift, following flyers can be more energy efficient - fliers in the 'V' formation are able to be 10-20% more efficient. This is commonly seen in the flight of birds; planes can follow this principle but it requires accurate control of flight to maintain position in the vortices.

Although birds come in a wide variety of sizes and shapes, the wing area scales surprisingly well with body mass. The shape of the wings is however dependent on the need for speed; birds with long and narrow wings are faster. Evolution is based on a number of selection pressures, including sink rate, glide speed, and turn radius as well as efficiency. Locusts are migratory and so efficiency is important whereas the main requirement of bumblebees is to collect nectar from flowers so they are relatively inefficient flyers.

The ability of birds to flap their wings gives relatively efficient flight. This is one of the principles that is being adopted by Animal Dynamics Limited, established by Adrian to produce improved drones.



Barrie Mecrow from Newcastle University discussed the limits of performance of current electric motors. Motors are integral to our energy infrastructure - the vast majority of electricity is generated by electric machines and more than half of this is then used to drive electrical motors.

Modern DC motors using rare earth lanthanide permanent magnets require complex drive electronics. The most

complex part of the drive electronics needs to change the current based on the precise position of the rotor. This is an area that has seen considerable advances and current motors now achieve up to 98% efficiency.

To improve the power to weight ratio, electric motors need to be operated at high speeds; for example, the motors in Dyson vacuum cleaners operate at 100,000 rpm. High magnetic fields are now provided by rare-earth permanent magnets and further improvements may be achieved using superconductors. This would generate a real application for high temperature superconductors.

One of the biggest challenges is the electrification of flight and this may soon be realistic for short distance travel using batteries. For longer flights hybrid electric distributed propulsion systems are required. Siemens and Airbus are teaming up to produce planes by 2030. Barrie concluded by stating that the future is bright and electric.



Mark Allen from University of Pennsylvania discussed the Micro-electro-mechanical systems (MEMs) technology and their applications. MEMs make use of micro fabrication technologies first developed in the semiconductor industry to make mechanical structures and transducers. These are already used in a host of applications including microphones in mobile phones, accelerometers and pressure and chemical sensors. Mark's lecture focused on their use for medical applications. For example, remote monitoring is now possible due to three main changes; MEMS fabrication, low power circuitry and high sensitivity wireless communication.

He is exploring sensors for monitoring heart condition, where the intra-cardiac pressure is measured with an implant placed inside

the pulmonary artery. Clinical trials showed that patients who were treated based on the additional information provided by the sensor had 40% reduction in hospitalisation compared to control patients.

Another application is the use of implantable neural micro-electrodes to measure activity in the brain. The first trials with silicon-based sensors showed a degradation of the signal to noise ratio suggesting a bio-compatibility issue. To overcome this a collagen based device was made, for which a MEMs process had to be developed. Surprisingly, the devices showed an improvement in performance with time indicating that the neurons in the body are adapting to the collagen implants.

He concluded that medical treatment can be greatly augmented by information from implantable devices and will be widely adopted, starting with cases where the rewards outweigh any risks.

Carlos Bustamante, Professor of Chemistry, Molecular and Cell Biology, and Physics at University of California, Berkeley explored nm scale molecular machines. Cells are neither isotropic nor homogenous and require active motion to function, and not by diffusion alone. There are many examples of directional movement - neutrophils chasing bacteria, mitosis of cells and bacteria with flagella.

The molecular motors operate at just above the energy of the thermal bath and experience large fluctuations resulting in stochastic motion. Experimentally these can be directly manipulated using optical and magnetic tweezers and atomic force microscopes. Studies of a range of systems have been performed, one studied in detail being the virus phi-29. This is found to generate very large forces up to 70pN. The virus has a highly coordinated structure and packaging cycle, and an energy efficiency, which at 63%, is very high for a biological system.

Consequently, we are now able to analyse in detail how molecular motors operate, and learn from them how they have evolved with the aim of imitating these in the laboratory.

RICHARD FRIEND AND NALIN PATEL

James Stirling 1953–2018

It is with great sadness that we report the death of James Stirling on 9 November 2018. James came to the Laboratory as Jacksonian Professor of Natural Philosophy in 2008, becoming Head of Department in 2011. He then moved to the newly-created position of Provost, the chief academic officer, at Imperial College, London, from which he retired in August 2018. He moved back to Durham where his retirement was tragically curtailed by illness.

His wide-ranging contributions to the development and application of quantum chromodynamics were central in verifying QCD as the correct theory of strong interactions, and in computing precise predictions for all types of processes at hadron colliders like the LHC.

James was born in Belfast, Northern Ireland, and educated at Peterhouse, where he obtained his PhD in 1979. After post-doc positions at the University of Washington in Seattle and at Cambridge, he worked at CERN, first as a Fellow and then as a Staff Member, leaving in 1986 for a faculty position at Durham University, where he remained until 2008. He was elected a Fellow of the Royal Society in 1999. He played a major role in the foundation of the Institute of Particle Physics Phenomenology in 2000, and served as its first Director. In 2005 he was appointed Pro-Vice Chancellor for Research at Durham.

James was a prolific and meticulous researcher, publishing more than 300 papers, including some of the most highly cited of all time in particle physics. His research, always full of insight, focused on the confrontation of theoretical predictions with experimental results. Over the years he performed frontier research on a vast range of phenomenological topics. Already during his graduate studies at Cambridge, in the early days of QCD, he clarified in detail the connection between deep inelastic lepton-hadron scattering and hadron-hadron processes such as lepton pair production, which led to his later work on parton distribution functions at Durham.



James (far left) with Peter Higgs (second right), Andy Parker (far right) with their HEP colleagues on the occasion of the award of an honorary Cambridge Doctor of Science degree to Peter.

A typical example of his pioneering research is the first computation of the resummed transverse momentum distribution of W and Z bosons in hadron collisions at next-to-leading logarithmic order, performed with Christine Davies in 1984. Another is the development of the powerful helicity amplitude method, completed with Ronald Kleiss while they were at CERN. This enabled them to show that the 'monojet' events at the CERN proton-antiproton collider, which had been thought to be a possible signal of new physics, could be explained by vector boson plus jet production. The method has since facilitated the calculation of many other important Standard Model processes.

After moving to Durham in 1986, James formed a very long-standing and successful research collaboration with Alan Martin, Dick Roberts and later Robert Thorne. Among other projects, they set the standard for determining the quark and gluon distributions in the proton, which led to the widely used MRS, MRST, MSTW parton distribution functions. Later, when James returned to Cambridge, he became interested in double parton scattering, bringing a new level of rigour to the analysis of such processes.

James had the gift of being able to explain complicated concepts and ideas simply. He was highly sought after as a plenary or summary speaker at the major international particle physics conferences. His textbook *QCD and Collider Physics* written with Keith Ellis and Bryan Webber

has been a standard reference for more than 20 years.

In addition to his brilliance as a physicist, James was an outstanding scientific leader and manager. His intention on accepting the Jacksonian Chair was that he could devote much more of his energies to his research, but this intention was thwarted when he took over as Head of Department only three years after his arrival in Cambridge. He carried out this demanding role in an exemplary manner, his fairness, humanity and good sense shining through. His brilliance and natural ability at management made him the prime target for the post of Provost of Imperial College, an offer he could not resist.

James was basically a humble and modest person but his intellectual brilliance, coupled with a very strong work ethic and exceptional organizational skills, meant that his advisory and administrative services were always in great demand. In 2006 he was awarded a CBE for his services to science.

In addition to the great respect in which he was held as a scientist, James was much loved as a friend, colleague and mentor. He treated everyone with the same respect, courtesy and attention, whatever their status. His warmth, kindness and fundamental humanity made a deep impression on all who came into contact with him. We pass on our deepest condolences to Paula and their family.

ALAN MARTIN, BRYAN WEBBER AND MALCOLM LONGAIR

Aston's Positive Ray Spectrograph Chemistry Breakthrough Award

It is a great pleasure to report that the Laboratory was selected to receive one of 2018 **Chemical Breakthrough awards** of Division of the History of Chemistry of the American Chemical Society (ACS). This award programme honours publications, patents and books that have made breakthroughs in chemistry and the molecular sciences that have been revolutionary in concept, broad in scope, and long-term in impact.

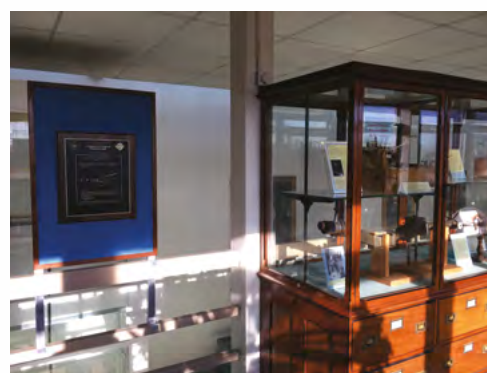
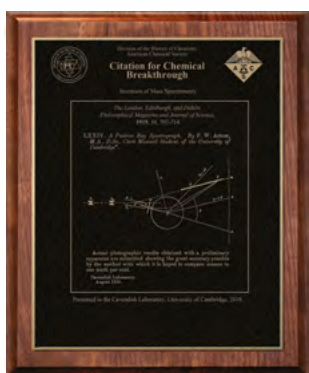
The award cites Francis Aston's 1919 paper "A positive ray spectrograph," *Philosophical Magazine*, **38**, 707-714 (1919) as a major breakthrough in the technology for measuring accurate masses of atomic nuclei. Earlier in 1912, JJ Thomson and Aston had used a prototype version of the positive ray tube to discover the non-radioactive isotopes of neon, ^{20}Ne and ^{22}Ne . Aston set about a major programme of the precise measurement of the masses of atomic nuclei through a series of three mass spectrographs, the ultimate third version having a mass resolution of about one part in 100,000.

The plaque was unveiled during in the Annual Winton Symposium on 1 November 2018, with Dr. Peter Morris, historian of chemistry and member of the ACS, representing the Society. The plaque is now on display in the Cavendish Collection of Scientific Instruments, next to the cabinet which includes both the Thomson and Aston 1912 positive ray apparatus and Aston's third mass spectrograph of 1938.

We are most grateful to the ACS for this award which symbolises the remarkable symbiosis between physics and chemistry in current frontier areas of research.



Left to right: Malcolm Longair, Andy Parker, Peter Morris and Richard Friend following the unveiling of the plaque.



The plaque in place in the Cavendish collection of scientific instruments. In the display case to the right of the photograph are Thomson and Aston's positive ray tube (top shelf) and Aston's 3rd mass spectrograph (bottom shelf).



Data-Driven Molecular Engineering of Functional Materials

The Royal Academy of Engineering has awarded Jacquie Cole a prestigious 5-year Fellowship under their Research Chair and Senior Research Fellowship scheme, only the second time this award for senior-researchers has been bestowed on a Cambridge researcher.

Jacquie Cole is Head of Molecular Engineering at Cambridge. She leads a 22-strong interdisciplinary research group, as well as the University initiative in Molecular Engineering, through her joint appointment between the Cavendish Laboratory and the Department of Chemical Engineering & Biotechnology, as well as external partnerships.

The founding external partner is the ISIS Neutron and Muon Source at the STFC Rutherford Appleton Laboratory. This Royal Academy of Engineering award enables Jacquie to welcome a new external partner to join this University initiative, BASF, the world's largest chemical company. BASF and the Royal Academy of Engineering share the title of Jacquie's Fellowship and will work together with continuing support from the STFC Rutherford Appleton Laboratory. Jacquie will lead this synergetic collaboration between industry, a government laboratory, and academia, with the endorsement of the learned society, to provide a world-leading platform for Data-Driven Molecular Engineering of Functional Materials.

This platform engages a data-driven approach to materials discovery. The team will apply the latest advances in artificial intelligence to predict systematically new chemical materials that are tailored to suit a given device application. Lead candidates from these predictions will then be experimentally validated by concerted team efforts in synthesis, advanced materials characterization, device fabrication and testing. This systematic approach overcomes the traditional 'trial-and-error' methods to materials discovery and is an important paradigm shift for industry. Through this Fellowship, Jacquie aims to deliver new materials for three key industrial application areas: solar cells, magnetic devices and catalysts.

This strong endorsement from the Royal Academy of Engineering together with substantial industry and government support, positions Molecular Engineering @ Cambridge firmly on the world stage.

Impulse

The Cambridge Entrepreneurship Programme for Tech Innovators

Impulse is an Entrepreneurship Programme specifically designed for individuals - PhDs, postdocs, researchers, and early stage entrepreneurs - and organisations - researchers, engineers, and managers of large corporations - across the different fields of Physical Sciences and Technology including the Life Sciences.

The programme is about strong action learning and results driven outputs where participants bring their innovative ideas to the table. It acts as a learning vehicle, with a sharp focus on prioritising and developing "high-potential" business cases. The core of Impulse's approach is to engage experienced entrepreneurs amongst others, Hermann Hauser, Andy Hopper, David Clevely, Richard Friend, and Florin Udrea, to act as role models and to provide guidance to our delegates at the heart of the Cambridge Phenomenon.

Through Impulse, the participants get the opportunity to develop commercialisation strategies for their novel ideas. They receive expert advice and mentoring from successful entrepreneurs, innovators and investors, and benefit from networking with over 80 contributors from the Cambridge entrepreneurial community and Maxwell Centre's industry partners.



"I believe we need to encourage the brightest people with the big ideas and create a truly inspirational environment and provide the correct support. I fully support Impulse which will allow researchers and innovators to test their clever ideas and execute them successfully."

Hermann Hauser (Serial entrepreneur, Impulse board member) with Yupar Myint (Head of Impulse)



The programme consists of two intensive residential modules with individual assignments in between. Its nature allows considerable flexibility in defining aims and workflow. Are you ready to take the next step to making your big idea a reality?

Apply now to be part of Impulse 2019. The application deadline is 31 March 2019. Our partners sponsor places on Impulse. Check your eligibility on our website or get in contact with Alexandra Huener, Impulse Coordinator (Email: ah930@cam.ac.uk, Tel: 01223 747368).

For more information about the programme please visit our websites www.maxwell.cam.ac.uk/programmes/impulse-programme.



The Cambridge Entrepreneurship Programme for Tech Innovators

- PhDs, Postdocs and researchers
- Early stage entrepreneurs
- Researchers/engineers and managers from large corporates

MODULE A

25 April – 2 May

INDIVIDUAL ASSIGNMENTS

May – July

MODULE B

10 – 12 July

Apply Now!

Deadline 31 March 2019
www.maxwell.cam.ac.uk/programmes/impulse



Brenda Jennison's Legacy

Lisa Jardine-Wright reflects upon Brenda Jennison's extraordinary legacy as a physics teacher trainer and her major impact upon physics outreach in the Laboratory.



Thanks to pioneering work by Brenda Jennison, the Cavendish Laboratory is recognised as a leader in physics outreach internationally. The Cavendish Outreach Programmes are focussed on addressing a very specific need, educational outreach, meaning working with teachers and their students to raise their aspirations and attainment.

I began running the Cavendish's outreach programmes in 2006, and even in the last 12 years I have seen what it means to 'do outreach' evolve significantly. When I began, I undervalued the importance of enabling students and teachers to visit the Department and the University. Arranging a scientist to visit a school is logistically a lot easier for teachers than asking them to arrange a trip. But it is clear from our work that a key factor in encouraging future undergraduates is changing the perspective that 'it's just not for me'. Students have to be able to picture themselves studying in an environment in which they would feel at home and be surrounded by cutting edge research.

Sadly, the problems for physics education in schools have not evolved as significantly as has the effort going into outreach over the last 30 to 40 years. The number of students studying physics remains lower than they were in the 1950s with the proportion of women remaining at 20-22%. There

continues to be a shortage of physics graduates going into teaching, resulting in 20 years of under-recruitment and too many of those leave after a relatively short time. The National Foundation for Educational Research school workforce census data shows that about 10% of Science and Mathematics teachers leave the teaching profession each year.¹

On her appointment in 1970, Brenda Jennison's aims to address these problems were:

- Create more good physics teachers.
- Provide schools with lectures on cutting edge science to inspire students and teachers alike.
- Enable students to experience 'the point of physics' and its wide range of potential applications.
- Show that physics is for everyone, irrespective of background, gender, ethnicity and so on.

In an interview for the Institute of Physics (IOP)² Physics Education Journal Brenda was asked, "What are the characteristics of an excellent physics teacher?" Her response was:

- A love of physics and wanting to learn more
- Enthusiasm to hold a conversation about physics

School student comments:

"Now I am definitely likely to pick physics for my GCSE's. Also the speeches which were given really inspired me to actually try really hard in my physics."

"I found out that Physics has a huge variety of uses that I never knew about. I am definitely more interested in it and I really enjoyed the visit."

"It showcased what living in a university would be like, which I found incredibly inspiring."



- To get involved beyond the school walls so that ideas can be taken back to keep you alive
- To be self-motivated and enjoy it. It's fun. But don't be too serious.

The Cavendish Outreach Programme began with a series of meetings, organised by Brenda, for local physics teachers to discuss teaching ideas, and to provide mutual support and enthusiasm. These meetings later developed into a lecture series for teachers and their students – the Cambridge Physics Centre lectures, still going strong 34 years on. [For this year's series of 6 lectures see <https://outreach.phy.cam.ac.uk/programme/cpc>].

In 1984, Mick Brown returned from an IOP meeting and told Brenda about the idea of running exhibitions at universities to demonstrate to school students the applications of physics in research and industry – Physics at Work³ was born and continues 35 years on. When I was first introduced to the idea of hosting 2000 students over three days in a research department I wasn't sure what to expect – but Brenda had the logistics down to a fine art and a plan for me to take it over. For the last 35 years the plan is still the same – with a few small tweaks in technology around the edges.

I met Brenda during my first week, and it was clear that I was following a formidable

Outreach Opportunities for Everyone



woman and an extremely experienced teacher of physics. It was also clear in the years to come that, while Brenda's expectations and standards were extremely high, whether you were a school student or a Senior Professor giving a schools' lecture, she was always the first to congratulate you on a job well done.

In the 30 years following her appointment, Brenda trained almost 350 physics teachers which can be compared with the national annual recruitment numbers between 1980 and 2005 which were between 200 and 500 a year⁴. In 1996 she was awarded the Institute of Physics Bragg Medal for her outstanding service to physics education, and in 1999 was awarded an MBE.

Long after her retirement, Brenda continued to attend all of the Cavendish flagship events until she became too ill to take part. Brenda passed away in March 2017 but her mission and practical support continues. Her lasting legacy is not only in the extremely strong foundations that she put in place through all her work but also through a benefaction which provides financial assistance for those who otherwise could not come to the Cavendish to be inspired. If you are a teacher and want to find out more about the funding available please contact Jacob Butler.

1. <https://www.nfer.ac.uk/media/2044/nufs01.pdf>
2. <http://iopscience.iop.org/article/10.1088/0031-9120/37/4/603/pdf>
3. <https://outreach.phy.cam.ac.uk/programme/physicsatwork>
4. statistics provided by the Institute of Physics (IOP)

Above left: Brenda & Mick Brown in 2009 celebrating the 25th Anniversary of Physics at Work.

Above right: Dara Ó Briain getting in on the 25th Anniversary Physics at Work action.

The Cambridge College Physics Experience has been running for eight years providing school students with the opportunity to learn what undergraduate physics is really like at Cambridge. The map shows the wide geographical distribution of the schools which have taken advantage of this opportunity.

For the 2018/19 period, the programme has undergone a revision that puts greater focus on the Cavendish Laboratory, allows a later start to help our more distant visitors, and has meant that the 2019/20 timetable can already be published. Thanks to a generous bursary, we are now able to offer schools in the lower three POLAR4 quintiles assistance with travel and teacher cover costs. This has already increased the number of booked places and, at a time when schools are finding it more difficult to engage with extra-curricular events, will hopefully maintain the momentum of the project into the future.

For more information, including dates and booking, please visit <http://outreach.phy.cam.ac.uk/cpe>

Cambridge Science Festival

2019 will be the third year that the Teaching and Outreach Office has run the Cavendish contribution to the Cambridge Science Festival. Following previous years' format, the main event will take place on the afternoon of Saturday 23rd March 2019 and feature a programme of talks and activities for all ages. These aim to show the importance and impact of physics in a variety of ways, from lectures given by leading academics to hands-on activities for families.

There will be an emphasis on unconventional ways of promoting physics in order to engage with those that might not typically attend science events. Last year's SciArt exhibition at the Cavendish (<https://sciart.org.uk/cavendish/>) was met with great interest from a broad range of people, and there are plans to hold another in 2020. This year's programme will feature a talk on the science of football and an interactive exhibit on the physics of music. If you have any ideas for speakers, workshops, or events, please get in touch with the Outreach Office (jbb48@cam.ac.uk).



Cambridge College Physics Experience school attendees from 2011 to 2018

Physics at Work

Dr Steve Martin and I recently returned from the annual Association for Science Education conference. This is Europe's largest science education conference and is aimed at spreading best practice and connecting teachers with the science engagement opportunities available. It is also a chance for us to discover new exhibitors for Physics at Work (<http://outreach.phy.cam.ac.uk/paw>). This three-day event, which will be held in September 2019, has over 2000 student attendees viewing around 25 exhibits, and we are always interested in new exhibitors. Please let us know if you have any contacts that may be interested in taking part.

JACOB BUTLER



Artist Nicolas Strappini demonstrates the physics behind his work during a public evening lecture (Credit: Redmonk Images)

New appointments

We are delighted to welcome three new University Lecturers:



Marco Bettler, High Energy Physics, LHCb, Lecturer
Diana Fusco, Biological and Soft Systems, Lecturer
Melissa Uchida, High Energy Physics, DUNE PI, MicroBooNE PI, Lecturer

Research Fellowships

We warmly congratulate the following on winning research fellowships:

Dhiren Kara, Royal Society University Research Fellow, Atomic, Mesoscopic and Optical Physics
Stephen Rowley, Royal Society University Research Fellow, Quantum Matter
Katarzyna Macieszczak, JRF Selwyn College, Theory of Condensed Matter
Rohit Chikkaraddy, JRF Trinity College, NanoPhotonics
Leah Weiss, JRF Clare College, Optoelectronic

We welcome **Leigh Whitehead**, HEP Senior Research Associate supporting the DUNE Project.

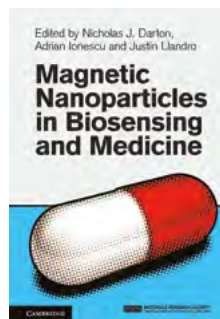
The following have joined the Laboratory in Administrative and Technical Roles:

Richard Allison, Finance, Accounts office
Christopher Burling, Workshop, Principal Technician
Peter Dean, Maintenance, Senior Buildings Services Technician
Olivia Matthewson, Rutherford Hub, General Administrator
Matthew Molloy, Stores, Stores Technician
Peter Norton, Maintenance Senior Buildings Services Technician
Giovanni Orlando, Nanophotonics, Research Laboratory Technician
David Robson, Mott Finance, Administrator

We wish all of them success in their new positions.

Acknowledgement: We are most grateful to the Mistress and Fellows, Girton College, Cambridge for permission to publish the image of Helen Megaw which appeared on page 13 of CavMag20.

Books



Adrian Ionescu and collaborators have published *Magnetic Nanoparticles in Biosensing and Medicine*, drawing together topics from a wide range of disciplines and providing a comprehensive insight into the fundamentals of magnetic biosensors and the applications of magnetic nanoparticles in medicine. The highlighted topics range from the basic physical principles of magnetism to the detection and manipulation, synthesis protocols and natural occurrence of magnetic nanoparticles. This Cambridge University Press monograph is a thorough introduction to the topic aimed at graduate students, lecturers, medical researchers and industrial scientific strategists.



Shirley Fieldhouse 1935–2019

Members of the Department will be saddened by news of the death of Shirley Fieldhouse (centre above). She came to the Department in 1959 as secretary to Professor Sir Nevill Mott, intending to stay only three years while her younger brother Martin studied mathematics at the University. Instead, she remained in the Department for forty years, acting as secretary to the Head of Department and then as the secretary to the Secretary of the Department, John Deakin. She will be remembered as a tower of strength in the running of the Department. She was passionately dedicated to the preservation of the countryside, becoming a very active member of the Campaign for the Preservation of Rural England. The photograph shows Shirley's retirement party in 1999 at which the secretaries of the research groups and assistants presented her with a bedspread consisting of patchwork squares, sewn by each of them with their names.

How you can contribute

Online Giving

The University's Office for Development and Alumni Relations (CUDAR) 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/graduate-support**

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 described in this edition of CavMag and is also available at: **www.phy.cam.ac.uk/development**

A Gift in Your Will

One very effective way of contributing to the long-term 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 Malcolm Longair (**msl1000@cam.ac.uk**) or Gillian Weale (**departmental.administrator@phy.cam.ac.uk**) who can provide confidential advice.

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

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