Autumn 2014, Number 5

Department of Physics Newsletter

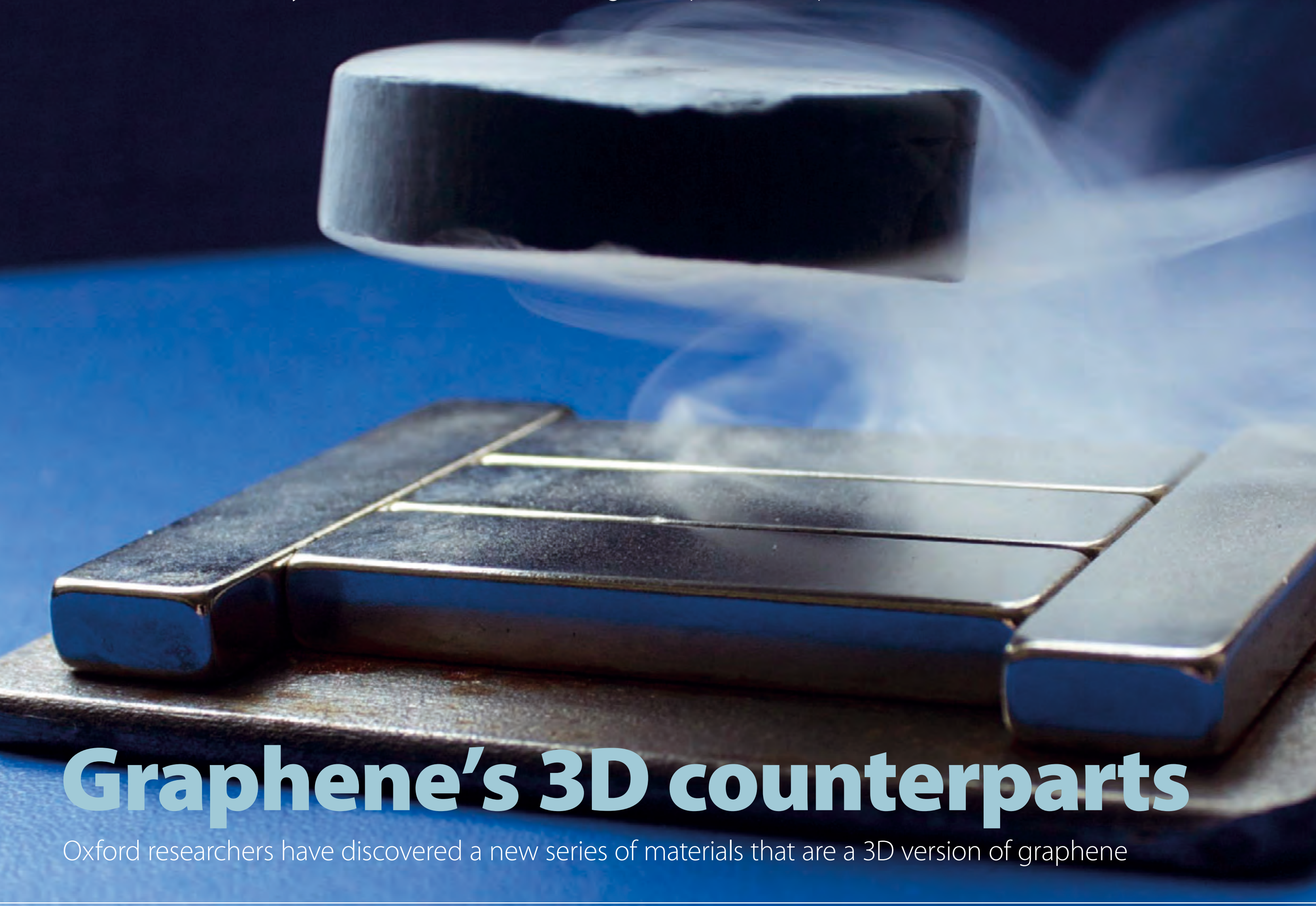
UNIVERSITY OF OXFORD

Beyond the boson

The next steps for particle physics

Superconductivity: Strike while the iron is hot

Oxford researchers synthesise new iron based high temperature superconductor



Graphene's 3D counterparts

Oxford researchers have discovered a new series of materials that are a 3D version of graphene

ALUMNI STORIES
Jean Chu (Holmes) reflects on life as a female physics student at St Hugh's, 1956–59

EVENTS
Alumni day at the Clarendon Laboratory; Bonn in Oxford; Alumni experience the LHC

MOSELEY & X-RAYS
Part II of Prof Derek Stacey's remarkable story celebrating Henry Moseley's work

PEOPLE
Five minutes with David Lloyd; Comings, Goings and Awards

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SUPERCONDUCTIVITY:
STRIKE WHILE THE IRON IS HOT

A little over a century after the discovery of superconductivity we are still missing some vital clues in understanding how and why the effect comes about. Over the years, the most important and interesting superconducting materials have all been found by chance, and so the discovery of a new family of superconductors always generates great excitement. That is exactly what has happened in the last few years following the unexpected discovery of superconductivity in a series of iron-containing compounds. Iron is magnetic and, so it had been thought, was the last element you would want in a superconductor because magnetism tends to break apart the electron pairs, which are the building blocks of the superconducting state.

Before describing these latest developments, let's step back a bit. What is superconductivity? When Kammerlingh Onnes discovered superconductivity in mercury in 1911 the defining feature was the vanishing of all electrical resistance below a critical temperature which, in the case of mercury, is four degrees above absolute zero (4 Kelvin). This lossless conductivity gave rise to the name: 'super-conductor'. It means that an electrical current set up in a loop of superconducting wire will continue to flow round and round forever, without need of any electrical power to keep it going. What Onnes had found was a quantum mechanical 'stationary state', like an electron orbiting the nucleus of an atom, that does not need to be sustained by an external driving force, but just exists in isolation, its internal motion simply part of its own intrinsic nature.

PERFECT DIAMAGNETISM

We now think of the zero resistance property as a secondary consequence of the eternal 'coherent' nature of the superconducting state, which is more directly manifested through the complete expulsion of magnetic flux when a superconductor is cooled below its transition temperature, a phenomenon known as the Meissner–Ochsenfeld effect. This 'perfect diamagnetism' is responsible for the counterintuitive ability of superconductors to levitate on the top of permanent magnets and, even more remarkably, to hang beneath a magnet without any physical means of support (see figure 1). Superconducting levitation offers a route to frictionless trains called MagLevs.

It wasn't until the late 1950s that a microscopic theory of superconductivity was developed which accounted for both for the zero resistance state and the Meissner-Ochsenfeld effect. This theory, formulated by Bardeen, Cooper and Schrieffer (known in the trade as 'BCS'), introduced the notion of superconductivity as a quantum coherent state, a concept also applicable to superfluids and Bose-Einstein condensates of cold atoms. According to the BCS theory, lattice vibrations induce an attractive interaction between electrons that then form 'Cooper pairs', and these pairs in turn condense at low temperature into a superconducting state. The pair condensate is a coherent state of matter since, as for singers in a well-trained choir performing an oratorio, the individual components are performing 'in phase' and lose their individual identity in the service of the joint enterprise.

Oxford has been a major centre for superconductivity research ever since Frederick Lindemann (later Lord Cherwell) attracted a number of brilliant émigré scientists from Germany in the 1930s. Fritz and Heinz London made the most important theoretical contribution to the field in the first half of the twentieth century while working here, and the low-temperature physics of Kurt Mendelssohn and Nicholas Kurti yielded valuable experimental data. It was Kurti's technician, Martin Wood, who in the 1960s commercialised the then emerging technology of superconducting magnets and, together with his wife Audrey, founded Oxford Instruments, one of the world's leading companies making cryogenic and superconducting magnet systems. These magnets have had many uses, from leading-edge experiments in research labs, to steering the beams around particle accelerators (such as the Large Hadron Collider at CERN) and confining the plasma in a fusion reactor. But perhaps their most important application has been in magnetic resonance imaging (MRI), the extraordinary technique that allows clinicians to examine salami slices through a living human body with very high resolution and without harming the patient in any way. This is made possible by placing the patient inside a very homogeneous magnetic field of several Tesla, which would be impossible inside an electromagnet wound with copper wire because the electrical current needed would be sufficient to melt the copper due to its electrical resistance. With a superconducting magnet there is no heating because the resistance is zero, and generation of the field straightforward. If you ever have an MRI scan, it's intriguing to contemplate that your whole body will be encircled by a coherent quantum wave function, every bit as perfect and unchanging as that describing an electron in an atomic shell! The MRI magnet business is a billion-dollar industry, and much of it is based in Oxfordshire as a direct result of work done in the Clarendon half a century ago.

Prof Stephen Blundell and Prof Andrew Boothroyd

Below: Molecular structure of newly discovered iron-based superconductor $Li_x(NH_2)_y(NH_3)_{1-y}Fe_2Se_2$.

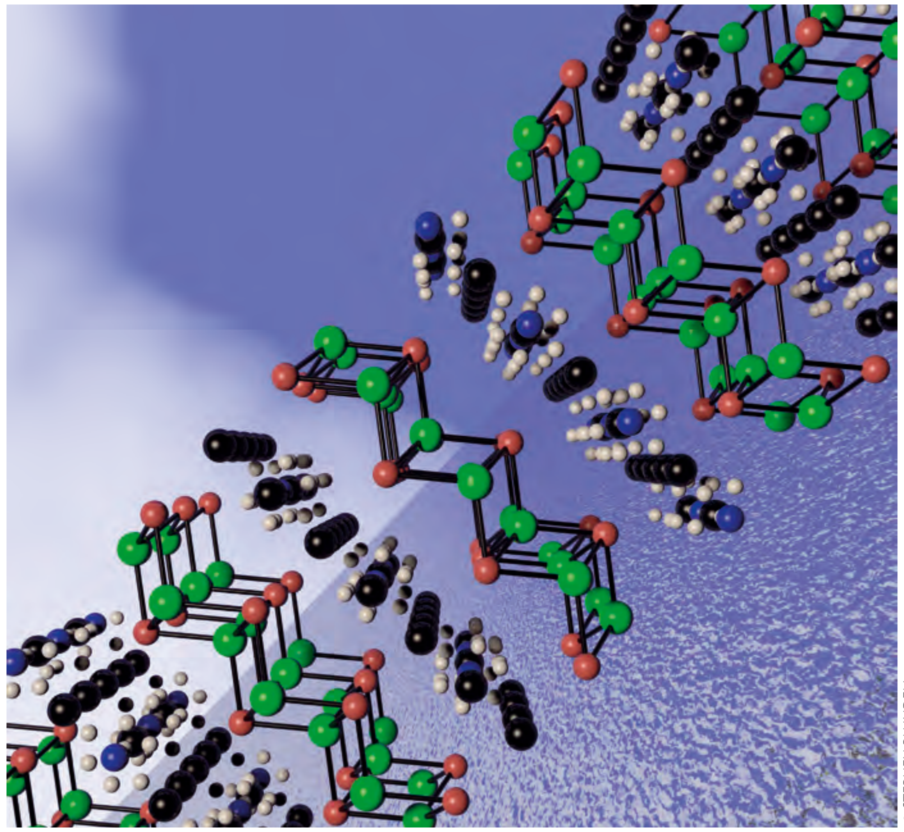

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Figure 1: Levitation by the Meissner effect: a block of copper oxide superconductor floats above an array of permanent magnets.

If you ever have an MRI scan, it's intriguing to contemplate that your whole body will be encircled by a coherent quantum wave function, every bit as perfect and unchanging as that describing an electron in an atomic shell.

MATERIALS DISCOVERY – A HOT TOPIC

So what is the current challenge? Well, the problem with superconductors is that they only work at low temperatures (usually less than 100 Kelvin), and this is why they have not so far been used to transmit power along the national grid or why levitating trains have not become all the rage for HS2. However, there are a vast number of ways to combine atoms to form different alloys and compounds, and imaginative chemical synthesis has led to all sorts of new surprises, which is why 'materials discovery' is a hot topic at the moment.

The physicist Wolfgang Pauli (famous for his Exclusion Principle) was famously sceptical of this approach and derided what he called 'dirt physics', maintaining that physicists should concentrate on pure elements (in his day, impurities in semiconductors were being shown to determine properties; he didn't like this, but of course 'n' and 'p' doped semiconductors are fundamental to the transistor, integrated circuits and the whole of modern electronics). Oxford research in the '30s, '40s and '50s helped to show that certain superconducting alloys could be used to make materials with very high critical fields (and the current MRI magnets utilise this basic insight). More recently, the discovery of high temperature superconductivity in 1986 arose because certain copper-containing oxides were shown to exhibit superconductivity at temperatures well above 100 Kelvin (a phenomenon which is still far from understood).

EXPLORING NEW PHYSICS

Here in Oxford our current focus is on the newly discovered materials that contain iron. Some of these have transition temperatures above 50 Kelvin, respectable but not yet record breakers. However, they are more ductile than oxides and so may be easier to fashion into wires and tapes. Moreover, they seem to be more amenable to theoretical analysis than the copper oxides while veering away from the basic paradigm of BCS that describes the 'traditional' materials.

A consensus is emerging that the magnetic behaviour of iron in the new superconductors, rather than being detrimental, is actually a key component of the pairing interaction required to form the superconducting state. This contrasts with simple BCS superconductors, in which the pairing force derives from vibrations of the crystal lattice, but bears some resemblance to a type of fluctuating magnetism found in the copper-oxide superconductors. However, there are differences too. In the copper oxides, the electrons form a so-called 'd-wave' pairing state, which has non-zero angular momentum and is analogous to an atomic d orbital, whereas the pairs in the iron-based superconductors seem to be predominantly in a type of s-wave state with zero angular momentum. Moreover, superconductivity is thought to derive from multiple iron orbitals. The theoretical challenge is to develop a multi-orbital model incorporating the electronic correlations needed to account both for the superconducting pairing interaction and the observed magnetic fluctuations.

On the experimental side, scientists are searching for new iron-containing superconductors and exploring the link between their atomic arrangements and their physical properties. Together with Simon Clarke in the Inorganic Chemistry Laboratory in Oxford, we have been attempting to make and study new iron-containing superconductors that incorporate molecules and have recently found that this approach turns iron selenide (FeSe, an 8 K superconductor) into a new molecular iron-based superconductor with a critical temperature of 43 K (a picture of the molecular structure of this newly discovered material is shown opposite). This molecular route has the potential to open up new avenues in materials discovery and provides an alternative strategy for optimising superconducting properties.

Superconductivity has just entered its second century, but we are beginning a new era in which theoretical advances and imaginative chemistry are being combined to design superconducting materials that work at higher temperatures. We may not be in time for HS2, but we are hopeful that as the science takes off, then in time, so will the trains. ■

SCIENCE NEWS
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BEYOND THE BOSON

The next steps for particle physics

THE DISCOVERY OF A NEW FORCE OF NATURE

On 4 July 2012, in a watershed moment for physics, the spokespeople of CERN's two largest experiments announced the discovery of an entirely new type of particle – a Higgs boson. This historic moment was the culmination of decades of work by particle experimentalists. What was found was not just a new particle, but the first evidence for an entirely new force of nature – one different from anything seen before.

The presence of the Higgs boson at the party was not unexpected. As long ago as 1964, Peter Higgs and others had solved a tricky problem – how to give mass to elementary particles. The implications of the Brout-Englert-Higgs theory are both precise and profound. A crucial prediction of the theory is that if enough energy is concentrated together, excitations of the vacuum can produce a new massive particle: the Higgs boson. Uniquely amongst all fundamental particles, this Higgs particle should have no intrinsic angular momentum (spin). It should interact with other particles with a strength that is proportional to their mass, rather than their charges. Finally, the Higgs field ϕ must interact with itself, generating a potential $V(\varphi) = -\mu\varphi^2 + \lambda\varphi^4$. The potential's particular shape means that the field does not vanish in the vacuum (at the minimum of V). The result is a non-zero field φ which extends universally throughout what is apparently empty space. All the other fundamental particles, which would otherwise be massless, then acquire their masses from their interactions with that residual field.

The Standard Model of particle physics predicts only one type of Higgs boson, and makes very precise predictions about how it should be born, interact and decay. Now that some sort of Higgs boson has been found, testing those predictions is one of the driving forces for particle physics. The Higgs particle has thus itself become a tool for discovery: any deviation of its properties from the Standard Model expectations would unambiguously indicate the presence of some new physics.

FINGERPRINTING THE HIGGS PARTICLE

A spin-less particle like the Higgs boson should appear exactly the same from all directions. The ATLAS collaboration, of which the Oxford group is a member, reported the particle's consistency with zero spin on 4 July 2013. The timing was apt, coming exactly one year after the original discovery announcement.

Over the last year we have also measured the Higgs boson's interactions with the heavy W and Z bosons with a precision of about 30–40%. We have found that it also interacts with tau leptons, again as predicted in the Standard Model. These measurements, made by ATLAS analysis teams that included Oxford academics and graduate students, are a beautiful demonstration that the Higgs field interacts both with fermions (matter particles) and gauge bosons (force particles). Together with the spin measurements, they indicate that this new particle is, if not the Standard Model Higgs boson, then a closely related sibling. Many other interactions are still to be explored, and any of them might yield surprising and unexpected results.

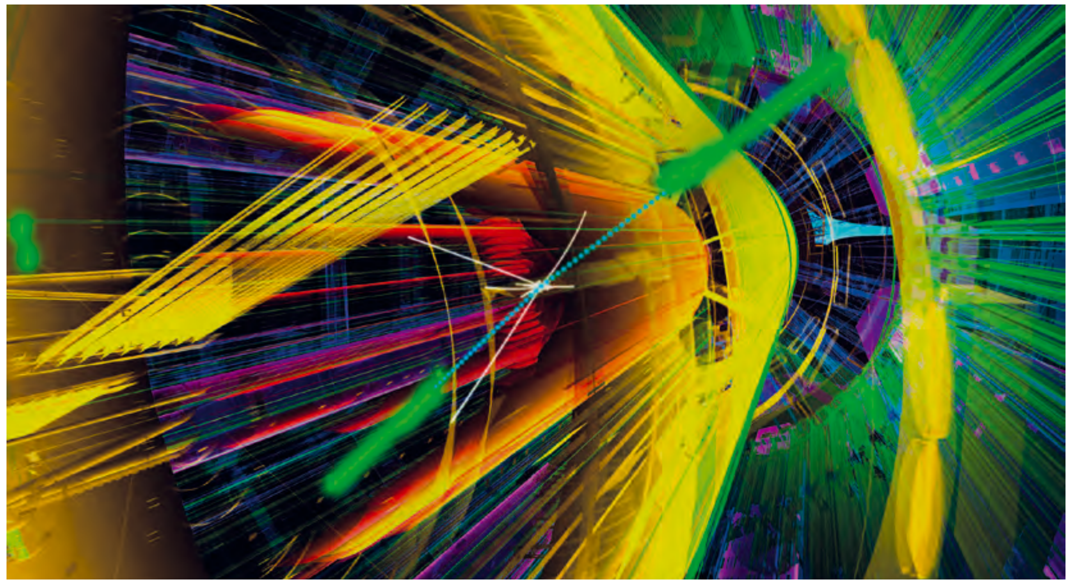
To determine the interaction strength of the Higgs to other particles, it is crucial to provide accurate predictions for all the relevant production and decay modes. Oxford academics in the Particle Theory group are playing a major role in these efforts. Their contributions include an improved determination of the structure of the proton using artificial intelligence techniques, and precise calculations for a variety of different processes in which the Higgs is produced.

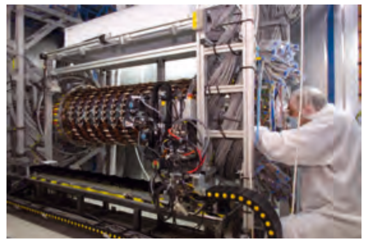
Prof Alan Barr and Dr Juan Rojo

> Unlike the electromagnetic, strong and weak forces, the force-carrying particle of the Higgs force (the Higgs boson) does not have any angular momentum (spin). Unlike them its interactions are not set by a symmetry principle. Nor is it similar to the gravitational force.

FORCE	FORCE-CARRYING PARTICLE	IMPORTANT EFFECTS
Electromagnetic	Photon Spin=1	Binds atoms together. Creates light, electricity, and magnetism.
Strong nuclear	Gluon Spin=1	Holds the proton and the neutron together.
Weak nuclear	W and Z bosons Spin=1	Transmutes the elements by changing neutrons into protons (and vice versa).
Higgs	Higgs boson Spin=0	Extends throughout the vacuum of space. Gives mass to the elementary particles.
Gravity	Graviton? (as yet unobserved)	Binds galaxies, stars and planets. Responsible for the evolution of the universe as a whole.

Right: The ATLAS detector records a collision which has produced a pair of energetic photons.





Above: At the heart of the ATLAS detector lies the semiconductor tracker barrel. Assembled in Oxford before final installation in CERN, it makes forty million precision measurements per second. By analysing the resulting data, we can reconstruct the positions and momenta of particles created in the LHC collisions.

The ultimate validation of the Brout-Englert-Higgs theory will also require the measurement of the self-interactions of the Higgs field. These are, however, extremely difficult to access experimentally. To measure Higgs self-interactions we need to find two or more Higgs bosons being produced in the same collision. This has not yet been seen, which is not a surprise – it is expected to be an extremely rare occurrence, happening in less than one in a trillion collisions. Several of us in Oxford are working on improved ways of making this measurement possible. Still, it seems likely that an increase by about a factor of about 100 in the total number of collisions, as well as a higher collision energy will be required. Fortunately CERN plans to upgrade its accelerator complex, so that the proton collision rate can be increased. One benefit should be to allow us to investigate Higgs-Higgs interactions, and so explore the potential of the vacuum.

THE HIGGS BOSON AND NEW PHYSICS

The Standard Model of particle physics cannot be the final word. While it does a superb job of explaining an impressive range of measurements, it is incomplete in crucial ways. It does not explain the observed pattern of three families of quarks and leptons, nor why neutrinos have tiny masses. It has nothing to say about the Dark Matter and Dark Energy which seem to be required to explain astronomical and cosmological observations. Nor can it explain why matter dominates over anti-matter. Finally, it does not provide any microscopic explanation for the force of gravity. Extensions of the Standard Model which tackle these problems have been proposed by many physicists, including by leading Oxford particle theorists. Among other implications, these modified models typically increase the numbers of Higgs fields (and therefore Higgs particles) and alter their properties. To distinguish between these models it is crucial to look for the additional Higgs particles. Just as importantly, we must make the most precise measurements possible of the existing Higgs boson.

COLLIDER

is a mobile application that lets you view high energy particle collisions directly from the Large Hadron Collider, making it simple to understand what's going on at a glance.

- View live events, straight from the ATLAS Detector at CERN
- Find out how to identify different particles
- Hunt for the Higgs Boson

Developed by physicists from the University of Oxford, with support from STFC, the Android version is now available (for free) from http://collider.physics.ox.ac.uk/

How to find a Higgs boson

Finding a Higgs boson is far from easy. The Large Hadron Collider (LHC) must first accelerate bunches of protons to unprecedented energies by driving them through the equivalent of four trillion volts. When the proton beams smash head-on, only **one in a billion** collisions will create a Higgs boson. Once created, the Higgs boson has short lifetime, travelling only about a trillionth of a millimetre before decaying. Many of its decays appear difficult to isolate, but some, like decays to a pair of photons with particular energies, are distinctive.

Multi-layered detectors the size of cathedrals are needed to accurately measure the particle debris emitted. Data from the precision semiconductor tracker, assembled at Oxford, is put together with information from other parts of the ATLAS experiment to reconstruct particles' energies and momenta. The particles are then calibrated, and the collisions analysed and categorised by a dedicated global computing grid of more than 170 computing centres in 40 countries.

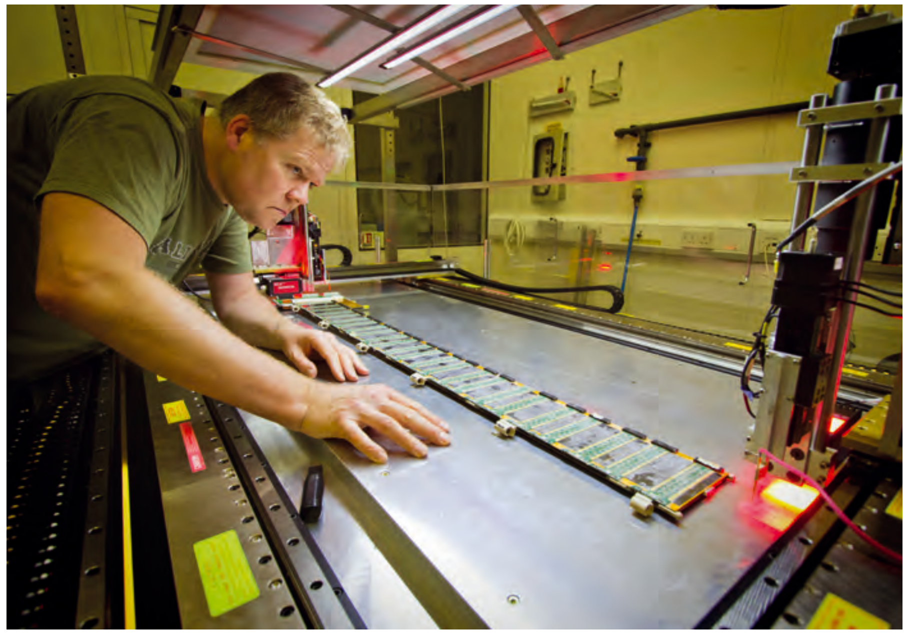
The resulting distributions are compared to state-of-the-art computer simulations, making use of sophisticated statistical techniques. Only after analysis of more than two hundred trillion proton-proton collisions, could we be sure that the distinctive debris from Higgs boson decays had been observed.

There is another big problem with the Standard Model, one which is related to the Higgs boson's own mass. We know that the Standard Model cannot be the final theory of nature. To fix its shortcomings, some deeper, more wide-ranging theory must eventually take over. With this in mind, theorists only require that the Standard Model need do a good job up to some energy Λ. This cut-off energy could be as large as the Planck energy E_{Planck}, where we know the Standard Model should be replaced by some quantum theory of gravity. Calculations show that if we take this perspective, the natural mass for the Higgs boson should be around Λ/c^2. This is an extraordinary finding. The Higgs boson should really be about one hundred thousand trillion times heavier than is measured. The dangerous sensitivity that Higgs suffers to physics at the highest energies is a disease which affects only spin-zero bosons. The other Standard Model particles, which do have spin, are immune. Fortunately there exist theories, such as supersymmetry, which can protect even the spin-zero bosons. These 'natural' theories predict additional new particles which could well be discovered at an upgraded LHC. One of these additional particles might even be responsible for the Dark Matter that seems to dominate the universe.

UNCOVERING THE FULL POTENTIAL OF THE LHC

Until now, the LHC has been running at just over half of its design energy. Over the last 16 months, CERN has put its accelerator complex through a major programme of maintenance and upgrades. The upgraded machine is being commissioned, with restart planned for early 2015. The Oxford team intends to be amongst the first to hunt for signs of new particles in the new high-energy data.

As well as an increase in energy, more proton-proton collisions are needed if we are to maximise our sensitivity to new particles. Over the next ten years, the CERN accelerator complex will be upgraded further to enable the LHC to deliver a factor of 100 more collisions. The ATLAS experiment in its current form cannot cope with the increased collision rate, so engineers, technicians and academics from Oxford Physics are working with their partners to develop new technologies to replace its sensitive tracking detector. Research and development is well under way on state-of-the-art silicon detectors, electronics, computing and data-acquisition systems. We aim to design and build the new tracking detector, ready for installation at CERN by 2023, when the LHC is planned to reach its maximum collision rate. ■

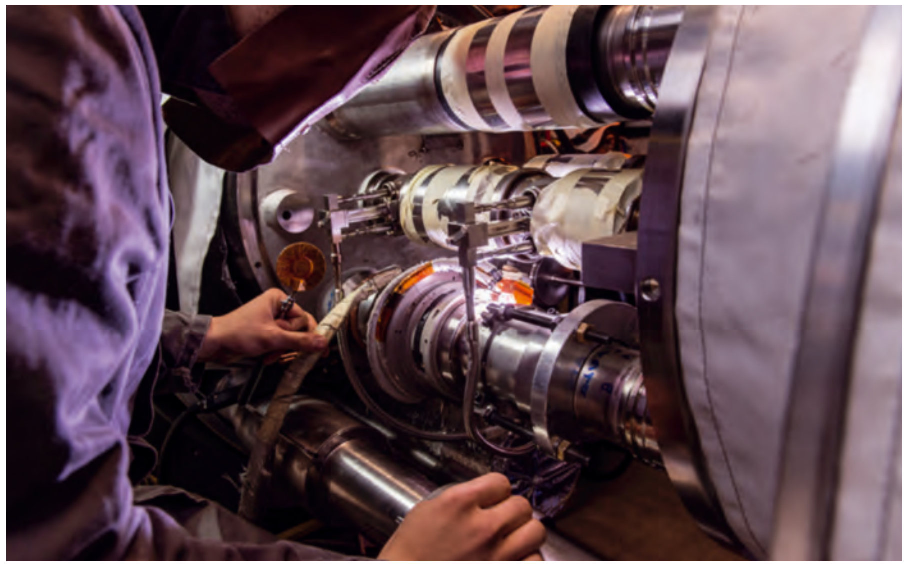


Shaping the future of particle physics

Regardless of the findings of the LHC in the next few years, it is highly unlikely that all the pressing problems of particle physics will be solved there. For example, subtle differences in Higgs couplings at the percent level would be too small to detect even at the upgraded LHC. Various facilities are being discussed to shape the post-LHC future. To probe the Higgs in this fine detail would be possible only in the clean environment of a future electron-positron collider.

The two leading proposals here are the **International Linear Collider** (ILC) and the **Compact Linear Collider** (CLIC). For the latter, Phil Burrows of Oxford has recently been appointed the new spokesperson. In addition, if other new particles are found at the LHC, then ILC or CLIC could be the ideal laboratory in which to explore their properties too.

In the longer term, an even bigger proton collider, tentatively known as the **Future Circular Collider** (FCC), could reach energies of up to 100 TeV, charting further unknown territory in our efforts to find an answer to the fundamental questions that the Standard Model leaves open.



Top: Researchers at Oxford Physics are performing detailed electrical and mechanical tests on prototypes for the ATLAS upgrade tracker.

Bottom: CERN engineers have consolidated some 10,000 superconducting magnet interconnections to allow the accelerator to operate at collision energies of up to 13 trillion electron volts.

SCIENCE NEWS
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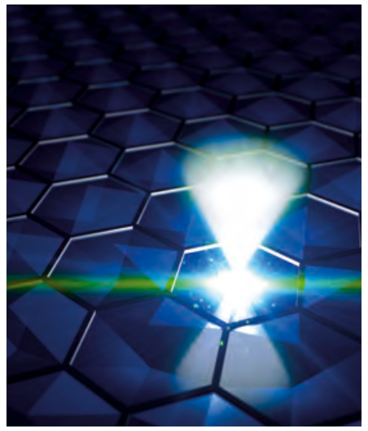
Prof Yulin Chen

GRAPHENE'S 3D COUNTERPARTS



Nope, they are not graphite. Oxford researchers have discovered a new series of materials that are 3D versions of graphene – the atomically thin sheet of carbon, on which the motion of electrons (in contrast to the standard situation in solids) is characterized by a dispersion relation of the form $E=v|\mathbf{p}_{2D}|$. This looks like the dispersion of massless relativistic particles (e.g. photons), but with a velocity v that is smaller than the velocity of light in vacuum by a factor of 300. Similarly, 3D counterparts of graphene ought to have a dispersion relation $E=v|\mathbf{p}_{3D}|$, but now the momentum p has three spatial components (p_x, p_y and p_z) instead of the two (p_x and p_y) seen in graphene. This is very different from electrons in graphite, which do not satisfy $E=v|\mathbf{p}_{3D}|$. In the newly discovered materials, named '3D topological Dirac semimetals' (or 3DTDS in short), electrons can travel along any direction in its 3D bulk with energy linearly dependent on its momentum. Furthermore, the electrons in 3DTDS can race at much higher speeds than in silicon, which promises not only new physical insights, but also exciting applications for the high-tech industry such as much faster transistors and far more compact hard drives.

WHY ARE 3DTDS EXCITING?

Two of the most exciting new materials in the world of high technology today are graphene and topological insulators, another class of novel materials that are electrically insulating in the bulk but possess conducting surface electrons similar to those in graphene. Featuring 2D Dirac fermions (i.e. electrons with $E=v|\mathbf{p}_{2D}|$), both graphene and topological insulators can give rise to extraordinary and highly sought after physical properties.

The 3DTDS are natural cousins to both graphene and topological insulators. Because of its 3D Dirac fermions in the bulk, a 3DTDS is naturally an efficient optical sensor material. But 3DTDS can also process many unusual properties, such as the intriguing non-saturating linear magnetoresistance (magnetic field dependent resistance) that can be orders of magnitude higher than the materials used in hard drives nowadays – thus promising higher density magnetic recording devices. In addition to its unconventional useful properties, the 3DTDS is the neighbour state to various intriguing quantum states ranging from regular band insulators to topological superconductors.

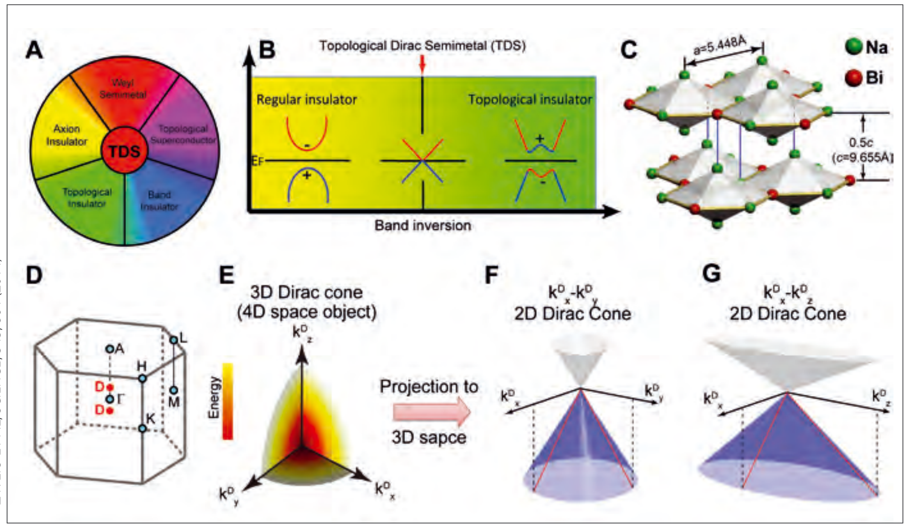
HOW 3DTDS WERE DISCOVERED

Discovery of the first 3DTDS was made on sodium bismuthide (Na_3Bi)[Z K Liu et al, *Science*, 343, 864 (2014)]. This established the existence of the novel 3DTDS state, that was only recently proposed by theorists. Soon after Na_3Bi, another 3DTDS, cadmium arsenic (Cd_3As_2), which is more stable in ambient environments (and thus more suitable for practical devices and applications), was discovered by the same group of researchers [Z K Liu et al, *Nature Mat.*, 13, 677 (2014)].

In both Na_3Bi and Cd_3As_2, the researchers found that their bulk conduction and valence bands touched only at discrete points and disperse linearly along all three momentum directions to form bulk 3D Dirac fermions. The Oxford-led research team first developed a special procedure to properly synthesize and transport the materials (especially Na_3Bi), then determined their electronic structure using Angle-Resolved Photoemission Spectroscopy (ARPES), in which samples are irradiated with high-intensity X-rays, which cause the photoemission of electrons along different angles and kinetic energies that can be measured to obtain a detailed electronic spectrum.

From a technological viewpoint Na_3Bi, Cd_3As_2 and other 3DTDS offer some distinct advantages over graphene, in particular given that preparing large-size atomically thin single domain graphene films remains a challenge. Most importantly they could provide significant improvements in efficiency in many applications because of their 3D volume. ■

Below: (**A**) Topological Dirac semimetal (TDS) state and its various neighbouring states of matter. (**B**) The TDS state occurs at the topological quantum phase transition from a conventional insulator to a topological insulator. The '+' and '–' signs denote the even and odd parity of the bands at the time reversal invariant point, respectively. (**C**) Crystal structure and (**D**) Brillouin zone (BZ) of Na_3Bi. Cyan dots indicate the high symmetry points of the BZ; red dots highlight the 3D Dirac point positions. (**E**) Visualisation of a 3D Dirac fermion dispersion ($E = V_x \cdot \overrightarrow{k^D_x} + V_y \cdot \overrightarrow{k^D_y} + V_z \cdot \overrightarrow{k^D_z}$); different colours are used to represent energy. (**F**, **G**) Projection of the 3D Dirac fermion onto (k^D_x, k^D_y, E) and (k^D_x, k^D_z, E) spaces. Red lines outline the linear dispersions along the k^D_x, k^D_y and k^D_z directions.



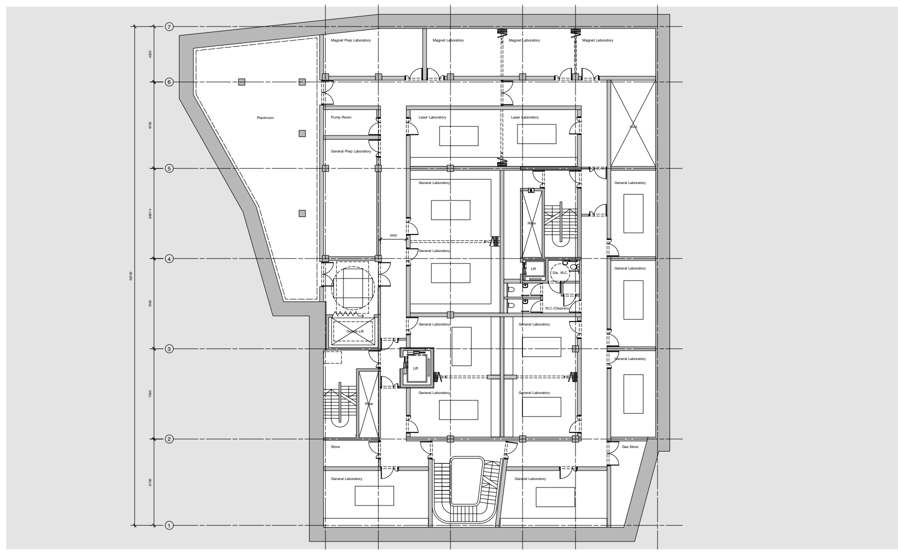
Above left: Crystal structure of Na_3Bi (background); the bright cone represent the Dirac fermions formed by its electrons.

NOTES FROM THE HEAD OF PHYSICS

Prof John Wheater, Head of Department

PROGRESS ON THE NEW BUILDING

I've written in previous newsletters about the New Clarendon Laboratory project to replace the department's outmoded infrastructure and in particular about our plans for the first new building on the car park (where else?) in front of the Lindemann Laboratory. The building will house the theorists above ground and have high-tech laboratories in the basement where it is easiest to arrange ultra-stable conditions. It will be the future Oxford home of aspects of physics ranging from the theories of fundamental particles such as the Higgs boson to understanding the behaviour of fusion plasmas in tokomak devices, from the atomic force microscopy of biological molecules to the development of quantum computing technology. Planning permission was obtained in 2011 and the last six months have seen some definite progress towards turning this project into concrete. The University has allocated £1.6m to the detailed design phase which is now underway and has set us a target to raise £8m by 31 January 2015 as a condition for approval of construction. At the time of writing the fund stands at £5.9m and you can see an update on progress at www.physics.ox.ac.uk/alumni. This project is crucial to the Physics Department's ability to remain at the forefront of research for the next few decades; if you are able to contribute to building the future now is the time to do it – every gift, large or small, will make a difference. You can make a gift by using the form enclosed with this newsletter, by going to https://www.campaign.ox.ac.uk/physics, or by contacting William Thomas by email william.thomas@devoff.ox.ac.uk or phone +44 (0)1865 611547.



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The new building: crucial for keeping Oxford Physics at the forefront of research.

NEW MASTERS IN MATHEMATICAL PHYSICS

Sometimes people ask me whether there is any external evaluation of our undergraduate degree courses. In fact there is; the Institute of Physics accredits physics degree courses in the UK in much the same way as the professional engineering bodies do engineering degrees. Since our last accreditation review six years ago the courses have changed substantially, so the successful renewal of our accreditation this May was certainly not a formality. Next time the review takes place the new Masters in Mathematical Physics programme will have been up and running for several years; together with colleagues in the Mathematics Department we are now in the final stages of preparation to make this a reality and the first real applications will soon be made for admission to take the course starting in October 2015. This is an exciting development and for the first time we will have provision for Mathematical Physics which is directly competitive with the place in the Fens.

EVENTS HIGHLIGHTS

There has been a full programme of alumni events over the past year and it has been a pleasure to meet many of you at them. Among the highlights were Alan Barr's talk on the Higgs boson discovery at the North American reunion held in New York at Easter; he filled a very large room at the Waldorf Astoria – there are barely enough Physics alumni in North America altogether to do that, so the excitement of a cutting edge physics discovery has spread well beyond the practitioners.

Closer to home, this year's garden party was held in the very beautiful gardens of St Hugh's College. The sun shone despite the downbeat weather forecast and the topics of conversation ranged very widely – interestingly mostly with a physics slant from reminiscences of the old days to wild speculation about what the future holds in store!

I'd like to take this opportunity to thank for their generosity all those alumni who have helped run our events this year. If you haven't yet been to a physics alumni event then perhaps the 2014/15 academic year is the time to take the plunge. The next major event is the alumni weekend in Oxford on 19–21 September 2014, which is now open for booking at https://www.alumniweekend.ox.ac.uk. We have an exciting programme in physics and I look forward to seeing you there. ■

Above: The physics garden party. Below: Alan Barr in action at the North American reunion. Click here for more photos of the North American reunion.

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Prof Derek Stacey, Emeritus Professor, Atomic and Laser Physics

MOSELEY AND X-RAYS

In the second of three articles to mark the centenary of Henry Moseley's seminal work, Prof Derek Stacey tells the remarkable story of an unusual graduate student.

AN INDEPENDENT SPIRIT

'The Professor showed a marked inclination to keep this particular magnet for himself, and it is only after much importunity that I have got him to give it up.' So wrote Henry Moseley to his mother in October 1912, after scarcely more than two years in Ernest Rutherford's group in Manchester. One might think that Rutherford, as Head of Department, had a perfect right to use his own equipment. But Moseley got his way, as usual.

Why? First of all, of course, his personality – we all know people like that. But there is also a clue in another letter home, written at around the same time: 'Today I was surprised to find a sad blunder in Rutherford's latest paper…I fear his calculations are all wrong, but when I demonstrated it to him he philosophically acknowledged his error…' Rutherford knew quality when he saw it. Moseley may have made a nuisance of himself, but Rutherford appreciated what an asset he was.

Rutherford, 'Papa' to his group, was the genial and generous-hearted son of a New Zealand farmer. He was a man of great drive and energy; he had the affection and respect of a first-class team of young researchers and they were happy to follow his lead. Moseley was of a different stamp. He certainly admired his mentor, but he was playing for higher stakes. He wanted independence, as quickly as possible. He was not a team player; his passions outside physics were the family garden and bird-watching, not ideal topics for the tea-time social gatherings in the Rutherford group.

Ernest Rutherford, Head of Department in Manchester during Moseley's time. He was responsible for the nuclear atom and is often called 'the father of nuclear physics' in recognition of his later work. He tried unsuccessfully to keep Moseley in Manchester, and later to prevent his being sent to the front in the Great War.

WHY MANCHESTER?

So why was he there at all? In 1910, the year he graduated, a new and exciting era in physics was opening up, and Moseley was determined to be part of it. This was not going to happen in Oxford, where change was what one got when buying a bottle of port with a fiver. Rutherford, on the other hand, personified the new physics. Famous scientists came and went as his guests; Moseley made himself known to them, and found out what they were up to.

Rutherford suggested an initial project for Moseley, but had expected him to be fully occupied with teaching duties for the first term at least. In fact, Moseley had a working experiment by Christmas, which involved remaking much of the apparatus himself rather than wait for the laboratory assistant to finish repairing Rutherford's car. We can follow his progress through his letters[1], which are mainly to his mother and sisters, to whom he was devoted. They show a self-assured young man with a dry humour and a sharp intelligence, influenced strongly by his Christian upbringing and education, and with a mind always working overtime, restlessly switching between topics. Typically, he wrote to his mother after that first term: 'I have got my examination papers off my hands…one man, who has been taking the same course for at least four years, got but three marks out of a hundred…I fear he will be an old man before he succeeds in passing. I find the experiments I did…give a result quite satisfactory and interesting. I am now writing up the paper for the Royal Society but I must do a few more experiments as I go. Please tell Babey [the gardener] to mulch the lawn with manure…'

MOSELEY, THE BRAGGS AND X-RAYS

His work during his first two years in Manchester is characterised by originality and ingenuity, but also clear scientific thinking. The beginning of his involvement with X-rays shows all these qualities. X-rays had been around since 1895, but their nature was not understood. Some, including William H Bragg, Cavendish Professor in Leeds, believed them to be particles, others inclined to a wave theory. There was no X-ray work in the Rutherford group. Then, in April 1912, Friedrich and Knipping in Munich carried out their famous experiment, which gave clear evidence of diffraction of X-rays by a crystal. The theorist von Laue, who had suggested it, published his own analysis of the results. Bragg of course pounced on the discovery. Together with his son, he made abortive attempts to explain the data through a corpuscular theory. Eventually, Bragg the younger persuaded his father that there had to be something wave-like about X-rays, but there were

1 Published in *H G J Moseley, the Life and Letters of an English Physicist, 1887–1915* (Univ. of California Press, 1974), the splendid biography by John Heilbron, which I am glad to acknowledge as the source of much of my factual information. He is also responsible for the terms 'apprentice' and 'master', which I cannot better. I am grateful to him, to Mike Glazer and to Liz Bruton for helpful comments and to Lucy Blaxland of the History of Science Museum at Oxford for the new pictures of Moseley's apparatus.

clear objections to von Laue's interpretation. He then took the lead in deriving the celebrated Bragg condition for diffraction maxima, which gives a very simple picture of the underlying physics. But what of Moseley? He seems to have come across the Laue paper in September 1912, and, lateral thinker that he was, he reckoned that if a crystal gave interference effects with X-rays it could maybe form the basis of energy measurements on his gamma rays. He studied von Laue's analysis and also saw its flaws. Together with Charles Darwin, another student (and the grandson of his famous namesake), he worked out a theory which turned out to be essentially the same as that of the Braggs. He presented it in a lecture on 1 November 1912, attended by the great man. The upshot can be understood from one of Moseley's letters home: 'You know that the main discovery was made by a German, who found spots when X-rays were photographed through a crystal. We worked out the cause of these spots, but left the publication to Bragg, who was a day or two ahead of us'. Not bad for a couple of graduate students, starting late, and working in a laboratory with no interest or expertise in X-rays. Bragg's son presented his results to the Cambridge Philosophical Society on 11 November 1912.

With the self-confidence of a man at the top of his game, Moseley left Manchester to continue in Oxford, despite having no post to go to.

APPRENTICE TO MASTER

Moseley then came into his own. In no time, he was building X-ray equipment in Rutherford's laboratory, drawing heavily on Bragg's expertise, which was generously shared. He wrote to his sister in February 1913: 'We have now got what seems to be definite proof that an X-ray which spreads out in a spherical form from a source as a wave through the aether can when it meets an atom collect up all its energy from all round and concentrate it on the atom… Mechanically, of course, this is absurd, but mechanics have in this direction been for some time a broken reed. There is some mysterious property…which we see no immediate hope of comprehending'.

By May, he had settled on his long-term project: 'The whole subject of the X-rays is opening out wonderfully… We find that an X-ray bulb with a platinum target gives out a sharp line spectrum which the crystal separates out as if it were a diffraction grating. Tomorrow we search for the spectra of other elements. There is here a whole new branch of spectroscopy, which is sure to tell one much about the nature of an atom'. Darwin describes him at his bench: 'Working day and night by himself with a very characteristic excess of energy, and in spite of constantly pulling his apparatus to pieces in order to improve it, he quickly got his main results…'

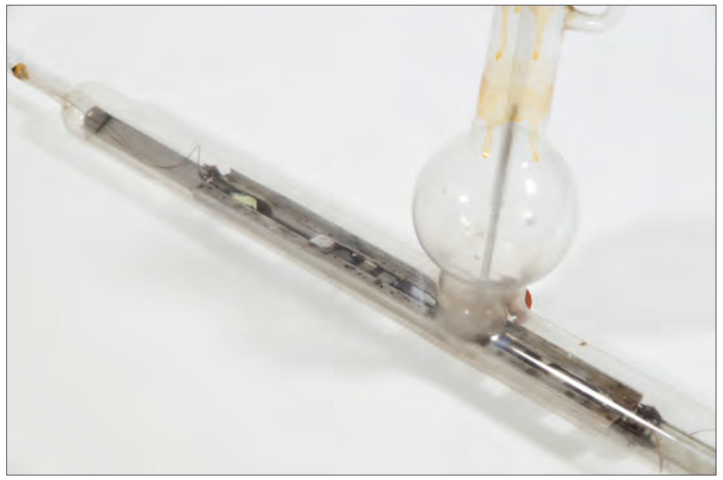
He certainly did. In November of that year he wrote to Niels Bohr, with whom he was on friendly terms, the pair having met in Manchester: 'So far I have dealt with the K series from calcium to zinc…the results [which he gives] are exceedingly simple and largely what you would expect'. He comments that they prove Bohr's 'condition of constant angular momentum', and writes down what we now know as Moseley's Law, adding 'I feel that they lend great weight to the general principles which you use, and I am delighted that this is so, as your theory is having a splendid effect on Physics, and I believe that when we really know what an atom is, as we must within a few years, your theory even if wrong in detail will deserve much of the credit'. Just so.

With the self-confidence of a man at the top of his game, Moseley left Manchester to continue in Oxford, despite having no post to go to. The work continued apace and his reputation grew; he applied for the Chairs at Oxford and Birmingham, but both elections were postponed due to the war, which of course he did not survive. What more he might have achieved, no-one knows; of what he actually did, Bohr commented many years later: 'You see, actually the Rutherford work [on the nuclear atom] was not taken seriously… There was no mention of it in any place. The great change came from Moseley'. ■


William Lawrence Bragg, born in 1890, son of W H Bragg. Although still an undergraduate, he was the driving force in their derivation of the Bragg diffraction law.


Niels Bohr, born two years before Moseley, produced the first atomic theory to account successfully for an observed spectrum, that of hydrogen. Moseley interpreted his own X-ray measurements in the light of Bohr's theory, demonstrating that the frequencies were determined by the charge on the nucleus rather than by the atomic weight. Bohr wrote enthusiastically to Moseley, calling his results 'most interesting and beautiful'.

Moseley's apparatus



PHOTOGRAPHS COURTESY OF THE HISTORY OF SCIENCE MUSEUM, OXFORD

ALUMNI STORIES


Jean Chu, photographed by Gillman and Soame at her graduation in 1959.

JEAN CHU (HOLMES) ST HUGH'S COLLEGE (MT 1956), BA, MA, DPHIL

Probably very few readers will know what Llwyn-y-Bryn means. Roughly translated from the Welsh (not my mother tongue although Wales is the land of my fathers) it is 'grove on the hill'. It was the name of my wonderful high school in Swansea, a training ground for 11–18 year old girls who had passed what was then the dreaded 11+ examination. It was at Llwyn-y-Bryn that I first developed an interest in physics and mathematics, and I am eternally grateful to the demanding teachers (affectionately known as Tommy Tweet and Dilly Willy, among others) who both trained and encouraged me. Although I eventually came up to Oxford from another all-girls' state school in London (too long a tale for these pages), I doubt I would have succeeded without those five formative years of excellent Welsh education.

I entered St Hugh's in 1956 to read physics. It was a tough transition on a number of counts. I was the first in my family to go to college; my closest relatives (while they were proud and supportive) seemed in a permanent state of bewilderment at what I was about. Oxford seemed about as far from South Wales as the moon – and why did women need a college education anyway? Second, there were five women reading physics in my year and close to 120 men, many of whom had completed national service and seemed to know all about electronics and other (to me) foreign practical domains that would come to good use in the lab. And there was that constant, nagging fear that I might not be up to the intellectual challenges of an Oxford degree, an imposter soon to be found out.

LIFE AS A FEMALE UNDERGRADUATE

On the latter count, I received some initial reassurance from my first tutorial partner assigned from another not-to-be-named women's college (because there was no one else at St Hugh's) who, in spite of a privileged public school education, seemed rather clueless and was in fact sent down after our first year (a consequence, I suspect, of too many weekends in London). My tutor, Dr Madge Adam (a mild middle-aged single woman who had happily devoted her life to solar physics and, I think with many years of hindsight, may have hoped I would follow in her footsteps) gave me a mixed-message report after my first Michaelmas term: 'You have worked perhaps too hard, but keep it up'. So I

St Hugh's College garden, c.1958. Jean Chu is third row from back, 7th from right.

WITH THANKS TO J CHU FOR SHARING THIS PHOTO, TAKEN BY GILLMAN AND SOAME

A 50th mini-reunion of physics alumni, Lincoln College, 2006. Jean Chu is seated in the middle. Derek Stacey (Christ Church) is second from left, standing.

struggled on through Honour Moderations at the end of the first year and was much relieved to get a second.

Unlike my fellow non-scientist freshers at St Hugh's, I seemed to spend a great deal of each day in a very structured academic fashion. The first lecture in the Clarendon was at 9am, followed by another at 10am. I biked there (sometimes under umbrella), dutifully attended, took notes, and (like everyone else) asked no questions of the lecturer, ever. If you didn't understand, it was your responsibility to go and figure things out. At 11am it was time to make for the Cornmarket and indulge in coffee and walnut cake at Fuller's. Since there were so many more men than women, I soon (out of necessity) became good friends with three men at Lincoln (they remained life-long friends; alas only one is alive as I write). They had all completed national service and seemed very worldly; our foursome had great fun over regular coffee conversations, very little of which was devoted to physics apart from a few jokes about the morning's lectures (and lecturers). By noon we were back at the Clarendon for lecture number three, and then it was another quick bicycle ride up the Banbury Road for lunch at St Hugh's. (Beets in white sauce and mince anyone?)

As I remember from this considerable distance in time, two full afternoons each week were also spent at the Clarendon, this time for lab experiments. I don't know how it came about, but for this I was paired with Ann from St Anne's (also a life-long friend and subsequently one of the bridesmaids at my wedding in Balliol Chapel). We muddled through our experimental assignments, measuring e/m or whatever, dutifully writing our results in a lab book and offering each other consolation for our varying degrees of klutziness. (Always keep one hand in pocket when assembling electronic circuits.) It was in the lab that I experienced one of my few sexist comments at Oxford: the demonstrator du jour came by, eyed our work and commented in all seriousness, 'Now if there was a young man doing this experiment…' Of course, in good 1950's female fashion, neither Ann nor I even thought of objecting; but I have not forgotten (even his name!).

The biggest personal challenge of the week was the formal, hour-long tutorial with Dr Adam at St Hugh's. Surely in such close quarters I would be found out as an admissions mistake. I spent many very late nights determined to complete the week's problem set. In retrospect, one of the mysteries of our physics degree work was why there was so little apparent correlation between the lectures and tutorial work. In the latter, I could be studying optics, e.g. properties of thick lenses (not very useful but dear to my tutor's heart and interests), while the weekly lectures were on nuclear physics, mechanics, or E & M. I do not have the faintest recollection of how/what I studied for the Honour Moderations examinations, but it certainly would have been helpful if there had been more coordination in the subject material.

We muddled through our experimental assignments, measuring e/m or whatever, dutifully writing our results in a lab book and offering each other consolation for our varying degrees of klutziness.

SPORT RELIEF

When I was not hard at work with physics, I spent my spare time playing netball. There was a court at St Hugh's where we had regular practices for any interested players from all five of the then-women's colleges. I had always loved sports and also messed about with tennis and field hockey at Oxford. My reward was to captain the Varsity team in netball, alas, once losing to Cambridge on the court of Newnham College, one of the few times I wept as an undergraduate. It did not matter to me then that women varsity players were only awarded a half-blue; I believe times have changed. In addition to providing some good exercise, I attribute my keen participation in sports to surviving the considerable male competition in physics.

EXAMINATION SCHOOLS

But back to physics at Oxford. By the time Schools came around in 1959, I was feeling somewhat more confident academically although I remember vividly the stress of those final exams, a measure of one's life's work crammed into that one week. It is (was) not a good system, I think. The first paper (Properties of Matter?) was cause for despair since almost none of the questions seemed to cover material I had studied, e.g. 'Explain what causes tidal variations' (or something like that). Fortunately, everyone else who took the exam felt the same so the examiners could not have been pleased with our attempts. I found the rest of the papers much better – apart from the absolutely dreaded two required practical exams that came a week later. 'Construct a phase shift oscillator to operate at 0.5 cycles/sec' and 'Determine the viscosity of air'. I was so traumatised that I still remember the questions almost 60 years later. But my Schools results were pleasing enough to my tutor that I was immediately offered a position to work as her DPhil student at the Observatory.

My graduate experience began with the immediate assignment of a problem in solar physics: a determination of velocity fields in sunspots, a subject about which I then knew nothing. The following six straight months I peered not-so-patiently at photographic plates to measure minute Doppler shifts in high dispersion sunspot spectra. (I refer the reader wishing more detail in the results to the Monthly Notices of the Royal Astronomical Society, 1962–3!). It took less than a year after my DPhil, by which time I was married and living in the United States, to realise that my career in physics could have benefited greatly by a year or more of graduate course work in a range of subjects. Studying for Schools had simply confirmed how little I knew about physics. While it was gratifying in 1962 to know more about sunspot velocity fields than few others on this planet, the lack of more formal and less specialised training did not serve me well in the long run.

A CAREER FORGED

I have not followed the changes in the physics curriculum at Oxford since I left in 1962, but I am sure there have been many. I suspect (hope) there are also more than five percent women reading physics and an increase in the number of lecturers (the latter would not be difficult since I never had a woman lecturer). Nevertheless, my six years at Oxford was life changing in ways both personal and professional – as most graduates would undoubtedly attest – and I am indebted for a memorable experience that set me off on a great adventure (including two children and six grandchildren). It paved the way for several years teaching college physics in California followed by 25 challenging, but enormously rewarding, years in the administration at Stanford University where I was one of a few to wear the scarlet and navy-trimmed Oxford DPhil gown at annual commencements. It is a long way from Llwyn-y-Bryn. ■

Emerging from the dreaded Schools papers

'FIVE MINUTES WITH'…DAVID LLOYD

Fourth year DPhil, Atomic and Laser Physics

Tell us a little bit about your background

I grew up in London and received an MSci degree in physics from Imperial College in 2010. The same year I joined Prof Simon Hooker's research group in Oxford, studying for a DPhil in Atomic and Laser Physics. I am currently in my fourth year at Oxford and am hoping to submit my thesis in the near future.

When/how did you decide to become a physicist?

I have always been a curious person. In sixth form college I was interested in both philosophy and science. I chose to study physics because it had the potential to provide answers to questions with more certainty than philosophy could offer. I realised that through physics I could start addressing all the questions, big and small, about the world around us that I had long wished answered.

Why do you think it is important to study Physics?

A physics degree is more than just a gateway into an academic career. Skills like problem solving and programming are very employable in a wide range of areas. Physics degrees produce employable and skilled people, and I think the country (and the economy) benefits greatly from the contribution physics graduates make.

Can you explain the work you do?

My research centres on characterising ultrafast bursts of X-rays produced by the interaction between intense laser pulses and gaseous matter. Particularly, I am interested in a quality called coherence and how non-linear interactions can influence and degrade this particular property. Experimentally, we use a technique known as high harmonic generation (HHG) as a test-bed for characterisation tools we have developed in Oxford.

What are the current challenges in this field?

The field of ultrafast science is reasonably mature now. For many years, groups around the world have dedicated time and resources to building light sources with unique and scientifically desirable properties, in terms of wavelength, pulse duration, energy and coherence. Now the challenge lies in applying light from such sources to probe the behaviour of physical systems of interest, be they light harvesting molecules, metal alloys or even biological samples. With these new tools, scientists can for the first time map charge migration in excited molecules or image the internal structure of cells. Further systematic studies should have far reaching implications in fields as diverse as medicine and materials science.

Can you describe your day to day routine at Oxford?

When I am conducting experiments, I will arrive in the morning to switch the laser system on, as some time is required for the laser to warm up and the temperature in the laboratory to stabilise. I will speak to the post-doctoral researcher (Dr Kevin O'Keeffe) about what plans we both have for experiments that day and how we might be able to help each other. The properties of the laser need to be tested to ensure they are on specification and the system is then externally stabilised. Experiments typically involve focussing the laser into a gas cell filled with a noble gas. The non-linear interaction produces a beam of ultrafast X-rays that we are interested in. Using tools designed and constructed in our lab, we are able to characterise a wide array of properties of the produced radiation.

What other interests do you have besides physics?

I am a keen fan and participant in sports. I am part of a local football club and occasionally play for St John's college MCR team. In the summer I play cricket for the physics department team.

What scientific breakthrough would you like to see in your lifetime?

We use 3D printing in our lab for prototyping parts to be used in experiments. Recently, the prospect of printing biological samples, perhaps even organs, has been raised. The ability to produce safe, unique, made-to-measure parts fit for transplantation would be revolutionary.

What are your plans for the future?

I have been applying to post-doctoral positions in research groups based in the UK and Europe. I would like to continue working in research, either in academia or in industry.

Can you share the main positives of being a physics student at Oxford?

The diversity of the people I get to share my working day with is definitely a positive aspect of the physics department. During term time the weekly seminars held by the department are a fine way of hearing first hand of the latest developments at laboratories around the world. ■

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David Lloyd

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The Physics team playing against Admins in May, at the University Club

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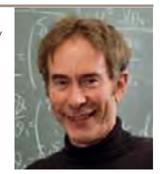
3D printing exhibition at the Science Museum, February 2014

ALUMNI EXPERIENCE THE LARGE HADRON COLLIDER

Prof Ian Shipsey



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One evening last March 80 physics alumni and 20 guides gathered at the London Science Museum to take a simulated journey inside CERN's Large Hadron Collider (LHC), the largest scientific experiment ever constructed. Prof Neville Harnew (Head of Particle Physics) welcomed the group before Prof Sir Christopher Llewellyn Smith (a former Head of Oxford physics and Director of CERN when the LHC was approved for construction) told the inspiring story of the laboratory and Oxford's role from the early days to the LHC: the work of 10,000 men and women from across the globe, united in their quest to uncover the fundamental building blocks of the universe.

The guides (a team of enthusiastic Oxford academics, postdocs and graduate students working on the ATLAS and LHCb experiments at the LHC and from Theory) and our alumni are magically transported deep under the border between Switzerland and France, to the LHC. The immersive exhibition blends theatre, video and sound art with artifacts from CERN. Behind the scenes we witness the moment of discovery of the Higgs boson, and its subsequent announcement to the scientific community and the world's press. We explore the 27km collider, and meet the engineers that made the vision a reality. We see how a proton beam is made, starting from the bottle of hydrogen gas used during the LHC run. We walk the LHC tunnel alongside the superconducting magnets that steer the beams and focus them, enter the cathedral-sized detector caverns, walk inside one of the detectors and stand at the heart of a simulated collision.

Leaving the exhibition it takes an instant to travel the 450 miles from Geneva to central London, and the now deserted Science Museum. We head back past marvellous exhibits of great steam engines and 3D printers, to the Smith Centre for drinks and canapés. Alumni and guides discuss how studying the subatomic world points the way to a more complete understanding of the birth of our universe, its evolution and ultimate fate. The conversation is animated, and many stay nearly an hour past the scheduled end of the event. ■

Top and bottom: Experiencing the LHC.
Middle: Prof Neville Harnew and Prof Sir Christopher Llewellyn Smith at the London Science Museum.

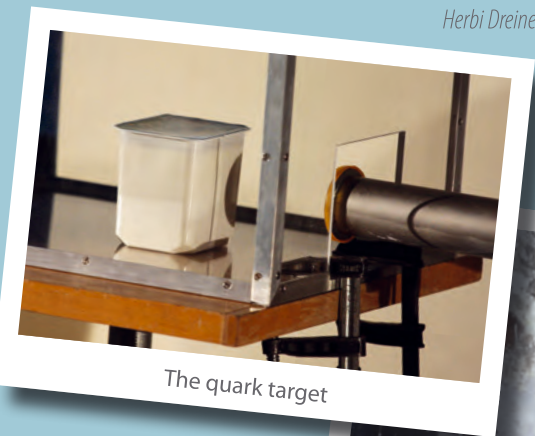
BONN IN OXFORD

Herbi Dreiner

On 16 March 2014 we rolled up to the Clarendon Laboratory with two vans full of equipment and a bus with 15 physics students from Bonn University. The Bonn Physikshow had arrived. Over two days we set up the demonstration experiments, rehearsed until just before the pubs' closing time and on Tuesday evening were ready to go. This was the world premiere of our brand new and entertaining show on particle physics. In three days there were four performances, two during the day for school classes. This included a live accelerator with a wooden projectile and a quark target, as well as a direct culinary read-out. (Quark is a German version of cottage cheese.)

The show was structured as a play, with two protagonists travelling back in time to visit Rutherford (Manchester), Lawrence (Berkeley), Wu (DESY) and finally CERN, where we produced the Higgs boson, represented by a green frog! The shows were well received in particular also by the younger audience. There was even a family from Bonn, living in Oxford: groupies! It was wonderful to visit Oxford again, especially to show our young gang my former haunts. I worked in Theoretical Physics with Graham Ross and Subir Sarkar from 1990–93 and from 1995–2000. Since 2000 I have been a professor in Bonn.

We thank Sian Owen and her team for the great local organisation and the entire department for their technical support and their warm reception. ■



The quark target

Splat!

Green frog representing the Higgs boson

universitätbonn
Rheinische Friedrich-Wilhelms-Universität Bonn

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A MORNING OF THEORETICAL PHYSICS

The fourth instalment of the 'Mornings of Theoretical Physics' (on 10 May 2014) was devoted to the physics of plasma – the fourth state of matter, the fabric of much of the visible universe (from stars to galaxies to intergalactic space), the fuel of fusion reactors – and a relatively recent addition to the core activities of the Rudolf Peierls Centre for Theoretical Physics.

The Culham Laboratory – one of the most famous plasma labs in the world and the site of both the UK's fusion programme and of Europe's flagship JET tokamak – sits only a few miles away from us in rural Oxfordshire and has been busy researching plasmas and designing the future fusion reactors for well over half a century. The University has a long history of collaboration with Culham – a collaboration that has intensified greatly over the last six years, with three new appointments at the Rudolf Peierls Centre for Theoretical Physics.

On the morning of 10 May, the focus was on the fundamental properties of plasma – what is it? how to make it? how to hold it in a laboratory device? why does it rattle its magnetic cage, seethes and boils and ever rushes to escape? – and on the practicalities of the world's combined effort to design a fusion power plant.

Felix Parra gave the audience a tutorial in the basic physics of plasma as a 'collective state of matter' involving charged particles (ions and electrons) moving in concert with electric and magnetic fields. Alex Schekochihin then talked about plasma turbulence – a chaotic multi-scale state into which the plasma inside a tokamak (as well as, not entirely dissimilarly, plasmas in space) is driven by the fundamentally unstable nature of its magnetically confined state. This was an opportunity to discuss not just plasma physics but also the universal physics of turbulence, often billed 'the last great mystery of classical physics'. Finally, Steve Cowley (CEO of the United Kingdom Atomic Energy Authority and Director of the Culham Laboratory) outlined the challenge of constructing a working, confined, energy-producing plasma device: how to tame the confined plasma, what the physics and technical issues are, and how they are being tackled both by the great engineering effort of the international fusion reactor ITER and by the application of analytical thought by theoretical physicists – not least here in Oxford. ■

Steve Cowley talking about plasma turbulence during the event.

The next 'Morning of Theoretical Physics' events will be in January and May 2015

ALUMNI DAY AT THE CLARENDON LABORATORY

'Thank you for last Saturday's event…the programme was well conceived and succeeded in giving us an overview of what the department is up to these days…' This is a quotation from just one of the appreciative letters and emails from alumni who visited the Clarendon Laboratory on 7 June 2014. About 80 visitors, alumni of the Physics Department, spouses and children, were welcomed by Prof Paolo Radaelli who gave an illustrated talk on the Clarendon Laboratory, past present and future. Ably assisted by most of the children present, Prof Paul Ewart reminded the graduates about atoms, molecules and photons as an introduction to the day's activities!

The programme included short lectures highlighting some of the exciting and wide ranging research in Condensed Matter Physics (CMP) and Atomic & Laser Physics (ALP). Prof Steve Blundell gave a very accessible talk on superconductivity and Dr Sonia Contera spoke about 'Physics and the future of Biology'. Convergence of research in the two sub-departments was illustrated by the talks on quantum technology (superconducting quantum circuits) by Dr Peter Leek (CMP) and quantum computers by Prof Jonathan Jones (ALP). Prof Justin Wark rounded off the lectures with a talk on the future of X-ray physics based on the next generation of free-electron lasers.

A parallel programme of 'hands on' demonstrations, a quiz and games entertained the children (and some grown-ups!) whilst also, it was hoped, educating and inspiring the physicists of the future. The afternoon programme of lab tours proved especially popular and, by public demand, had to be repeated several times as it seemed everyone wanted to go on every tour! 'Nanotechnology in medicine' and 'Microwaves at millikelvin' in CMP were presented by Dr Sonia Trigueros and Dr Peter Leek respectively. In ALP the tourists were shown 'Optics in action' by Dr Josh Nunn, and Dr David Lucas showed atoms making quantum jumps in his ion traps. Visitors to Paul Ewart's combustion physics lab and were treated to a 'controlled explosion'! A friendly and happy 'buzz' filled the Clarendon common room at the coffee breaks and lunch time, as alumni and current academics and students reminisced about the old days and renewed contacts with tutors, old and new. ■

Images top to bottom: Prof Taylor shows young visitors some experiments; old instruments from the archives on display; alumni enjoy afternoon tea in the Clarendon common room.

WOMEN IN PHYSICS

Thanks to the roaring enthusiasm and unwavering efforts of your fellow students, postdocs and professors, we would like to introduce the Oxford Women in Physics Society. The purpose of this society is to promote the career development of women in physics while providing a warm, welcoming environment to foster support networks.

Our mission

Specifically, we hope through our efforts that more undergraduate women will be encouraged to pursue 4th year master's programmes and eventually graduate studies in physics. We also provide graduate students and postdocs with resources to help develop leadership skills, while increasing awareness and support for career development.

Join the festivities!

The Oxford Women in Physics Society hosts monthly tea sessions for all members of the department to socialise over tea and chocolate covered fruit. This is an invaluable opportunity to meet other women in the department and ask them about their experiences, for example, when applying for jobs or grants. Each year we host a lavish champagne reception, followed by a delicious banquet dinner. Additionally, last year we hosted a beautiful lunch and garden party, complete with face painting!

Mentoring programme

During the 2014–15 academic year, we will introduce a new mentoring programme that will enable all women in the department to connect with potential mentors for personalised feedback to help them reach their full potential. This also offers women an opportunity to make a real difference in another woman's life by providing guidance and encouragement. Please get involved by contacting our mentoring programme organiser, Natalie Fuller, natalie.fuller@some.ox.ac.uk.

Contact us

For more information on our activities, please see our website and like us on facebook. If you would like to be a part of our society family, please contact Jena for available positions, jena.meinecke@physics.ox.ac.uk.

www.physics.ox.ac.uk/equality-and-diversity/women-in-physics-society

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2014 LEAVERS EVENT

The department marked the achievements of its 2014 graduates with its inaugural 'leavers' party'. More than 100 students attended and were treated to a delicious lunch, complemented by beer and cake. To celebrate the occasion students could, to the tune of 'physics-themed' songs, sign the leavers' book, write messages on a flip-chart, take 'selfies' at the selfies corner or be part of a group photo. The occasion also presented students with an opportunity to pick up their alumni cards.

PHIL BURROWS ELECTED SPOKESPERSON OF THE INTERNATIONAL COMPACT LINEAR COLLIDER

Congratulations to Prof Phil Burrows who has been elected Spokesperson of the international Compact Linear Collider (CLIC) accelerator collaboration, which is a multi-national consortium of 65 institutes in 29 countries. Over the next three years, Phil will engage with the institutes to ensure that CLIC's R&D programme pushes ahead during the critical phase ahead of the next update of the European strategy for particle physics.

EVENTS

The department offers a variety of events, lectures and opportunities open to all alumni (and guests on most occasions), enabling them to engage and keep connected. For a list of what's on, visit www.physics.ox.ac.uk/events regularly.

You can also register on our specific alumni section of the website: www.physics.ox.ac.uk/alumni or email alumni@physics.ox.ac.uk.

THE UNIVERSITY OF OXFORD CENTRE FOR ASTROPHYSICAL SURVEYS

Generous gift from Sir Michael Hintze's Family Charitable Trust

The University of Oxford Centre for Astrophysical Surveys has been established with the help of a £1.5m gift from the Hintze Family Charitable Foundation established by businessman and philanthropist Sir Michael Hintze.

The centre will fund a team of research fellows and graduate students, that will provide a focus for physicists at Oxford working on surveys searching for the invisible dark matter and dark energy thought to make up 95% of the universe, exploring transient sources such as pulsars, and looking at how galaxies evolve. The new centre will enable Oxford University scientists to play a leading role in the next generation of international sky surveys, probing fundamental questions about our universe.

For more information go to: http://www2.physics.ox.ac.uk/news/2014/02/26/generous-gift-from-sir-michael-hintze's-family-charitable-trust

Have you registered as an alumnus/na or friend on our website?

By registering, you will receive advance notice of events and other news, before it is published on the web. There is also a short questionnaire, which will enable us to plan events and services to your liking.

www.physics.ox.ac.uk/alumni/connect

Would you like to host an event for physics alumni?

It could be a drinks reception or dinner, a visit to a special place, to your company, for a small or large group…the possibilities are endless. We may be able to provide financial support and/or assistance, if required, but private sponsorship is always welcomed. Please get in touch for an informal conversation, we'd love to hear from you!

Do you have a photo from your time in Oxford? A story or anecdote that you would like to share?

The alumni office is looking for contributions of this kind, as we are working towards making the archives more accessible and interactive. Send your contributions, no matter how big or small, to Val Crowder, Alumni Officer: alumni@physics.ox.ac.uk.

THE HENRY MOSELEY SOCIETY

The Department of Physics has established the Henry Moseley Society to honour the memory of a truly great Oxford scientist and to help secure the future of Oxford Physics. By becoming a member of the Henry Moseley Society, alumni and friends of the Department can contribute to the next great breakthroughs made by Oxford Physicists.

The Henry Moseley Society enables donors to support the Department of Physics. Initially, all gifts will go towards the new Clarendon Laboratory building, which will house Theoretical Physics and provide a substantial number of high-tech laboratories for research in quantum optics, nanoscience and quantum materials. In the longer term, the Society will continue to encourage support towards other important initiatives such as graduate scholarships.

The aim is to raise a minimum of £250,000 towards the new building and further information about becoming a member can be obtained via the contacts listed on the right.

The department is seeking donations of £1,000 and above to become a member of the Henry Moseley Society and we hope members will give to the best of their ability. This can be a one-off gift or made over a period of time such as monthly or annually. If you would like to discuss this further, or have any questions, we can send you an explanatory leaflet, and/or would be delighted to speak to you.

Benefits associated with becoming a member:

- Group naming via a plaque of a significant space in the new building
- Henry Moseley Society benefactors book listing members
- Annual drinks reception with talks by Oxford physicists
- Invitation to the opening ceremony
- Other members only events

Who to contact:

Please contact Will Thomas about donations: will.thomas@devoff.ox.ac.uk or Tel: +(44) (0)1865 211547.

Alternatively, for general enquiries please contact Val Crowder: valeria.crowder@physics.ox.ac.uk or Tel: +(44) (0)1865 282065.

We take this opportunity to thank the many generous members who have already joined!

LETTERS TO THE EDITOR

Letters are welcome and should be addressed to newsletter@physics.ox.ac.uk

Rodney Linford, Brasenose, 1960–63
Sarasota, Florida, USA

I was fascinated to read the article by David Hills in the spring issue of the Department of Physics newsletter. Like David, I was a Brasenose man reading Natural Sciences, albeit some years later (1960–63). What a difference 17 years made! Although I was a youngster of 18, a considerable fraction of the matriculating class of 1960 was made up of ex-servicemen, many of whom had completed their National Service in Germany and elsewhere. How we envied their maturity, and their ability to consume large amounts of beer in the Buttery. They in turn admired our study habits that had not eroded two or three years out of school. The college had built new rooms behind the New Quadrangle and we had the luxury of running water in our rooms, except when the college froze in the winter of 1962–63.

My physics tutor, Dr D M S Bagguley, was also the Dean charged with student discipline. When I visited his rooms to request permission to join the Oxford-Cambridge lacrosse team touring US universities at Easter 1961, he reluctantly gave his permission, predicting that I would have ample opportunity to visit the USA in the future (I have lived here for 45 years!).

The other Oxford physicist who influenced my years at the Clarendon was Professor Nicholas Kurti, already a fellow of the Royal Society. A pioneer in the field of cryogenics (I think he held the record for the lowest temperature reached by adiabatic demagnetisation or something even more esoteric), he also had an occasional cooking show on BBC TV. He was a constant presence in our laboratory classes and helped me find my first research job after graduation. His influence continued when I wrote a thesis on superconductivity to gain a PhD at the University of Warwick in 1968.

Since then I have worked in and retired from the US aerospace industry. My physics training and the research skills learned at Oxford and Warwick served me well. My final project as a program manager of the International Space Station took me to the Kennedy Space Center on many occasions, to witness launches…on cryogen-fuelled rockets! ■

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Click here to see Kurti's laboratory as it is today

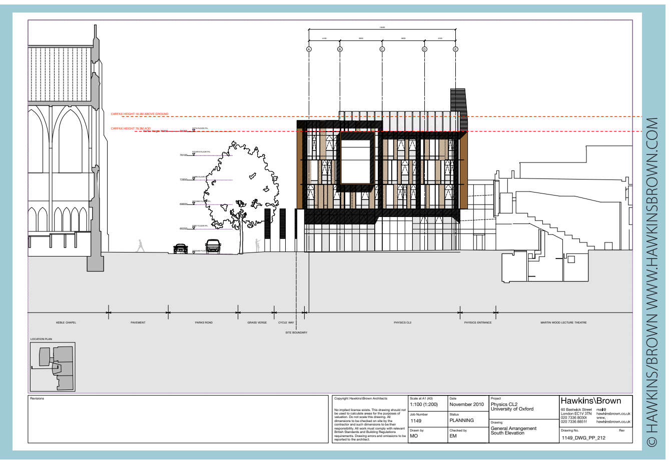
© HTTP://CURIOUSCOOK.TYPEPAD.COM/SITE/ERICE.HTML

Top: Rodney Linford and his wife Terri.
Bottom: Nicholas Kurti in 1969.

SUPPORT FOR THE NEW PHYSICS BUILDING

Thank You! to our generous alumni and friends of physics, for their donations, without whom the new building could not happen. All your gifts – no matter how big or small – make a huge difference.

Special thanks to Adrian Beecroft, The Alexander Trust, Dr Richard Golding, Dr James Dodd, Paul Bate, Dr John Moussoris, Martin Lueck, BNY Mellon Wealth Mgt, S Savage, Henry Moseley Society members, and those whose wished to remain anonymous, for their gifts towards the building and/or sponsorship for various alumni events this year.



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For latest news on developments at the Oxford Physics Department, see www.physics.ox.ac.uk/about-us.
To contact the alumni office: alumni@physics.ox.ac.uk

The Physics Department has a presence on Facebook, Twitter, and LinkedIn. Follow us, link to us and join the conversation:

University of Oxford Physics
https://www.facebook.com/oxfordphysicsalumni

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COMINGS, GOINGS & AWARDS...

COMINGS...

DR MICHAEL BARNES is a theorist working on kinetic dynamics and turbulence in magnetised plasma. He received his PhD in Physics from the University of Maryland before undertaking postdoctoral fellowships at the University of Oxford and the Massachusetts Institute of Technology. Most recently he has served as an Assistant Professor at the University of Texas. He has joined the Rudolf Peierls Centre for Theoretical Physics as a Senior Physics Lecturer.

GOINGS...

PROF NICK JELLEY, Particle Physics and a tutor at Lincoln College, retires in 2014.

AWARDS...

Congratulations to **PROF JOE SILK**, who has been elected to the US National Academy of Sciences. Joe is the former Savilian Professor of Astronomy and is an Emeritus Professorial Fellow of New College. He also has affiliations with the Institut d'Astrophysique de Paris and Johns Hopkins University. Joe has published widely in many different areas of theoretical astrophysics, and is especially well known for his contributions to cosmology, where he originated the idea of 'silk damping', a process important for setting the galactic mass scale. The effects of silk damping can be seen in the power spectrum of the microwave background.

The Plasma Physics Division of the European Physical Society has awarded **DR EDMUND HIGHCOCK** its prize for the best PhD thesis of 2012. Edmund, whose supervisor was Alex Schekochihin, is currently a Fellow by Examination of Magdalen College and works in the Rudolf Peierls Centre for Theoretical Physics. His thesis was entitled 'The zero turbulence manifold of fusion plasmas'.

All Souls Junior Research Fellow **DR TESSA BAKER** has won a gold medal and £3,000 in the SET for Britain poster competition finals held at the House of Commons on 17 March 2014. She was among 210 early career researchers who were shortlisted to display their work to politicians and a panel of expert judges. Her research, which looks at how the laws of gravity relate to the largest scales across the universe, was judged the best among entries from the 29 finalists in the physics category.

DR BOON KOK TAN has been awarded the 2014 MERAC Prize of the European Astronomical Society for the best doctoral thesis in the area of new technologies for his thesis in the field of sub-millimetre wave astronomy. The research has contributed significantly to the advancement of the state of the art of coherent detector technologies. This includes fully integrated SIS mixer chips with wide RF and IF bandwidth, which are suitable for future heterodyne arrays, and advanced designs such as balanced and single side-band mixers.

Congratulations to **DR ROGER JOHNSON** who has been awarded the IoP Physical Crystallography Prize 2014. This prize is awarded for the best recently published work by a person in the early stages of their career, working in the field of physical crystallography, and whose research is expected to make a significant impact in the field.

Congratulations to **ALEXANDER HEARMON** who has been awarded the PANalytical Thesis Prize 2014 for the best use of techniques or methods of physical crystallography in a successfully examined thesis. Alexander has recently completed his thesis 'Neutron, X-ray and Optical Studies of Multiferroic Materials' under the supervision of Paolo Radaelli.

DR SNEHA MALDE has been awarded one of this year's L'Oréal-UNESCO UK & Ireland For Women in Science Fellowships. Dr Malde received her award on 19 June 2014 at a ceremony held at London's Royal Society. The award will support her work investigating how the asymmetry between matter and anti-matter has emerged.

Congratulations to **PROF STEVE SIMON**, who has been awarded a 2014 MPLS Divisional Teaching Award. The MPLS Divisional Teaching Award Scheme celebrates success and recognises and rewards excellence in teaching. Awards are available to all those who teach, including graduate students, postdoctoral researchers and learning support staff. The Teaching Award Scheme is administered by the MPLS Divisional Office and awards are made, on merit, across the departments by a cross-departmental panel chaired by the Associate Head of Division (Academic).

Congratulations to **DR JOSEPH CONLON**, who has been awarded the 2014 Oxford University Student Union (OUSU) Outstanding Tutor Award for Mathematical, Physical and Life Sciences (MPLS). The Oxford University Student Union Teaching Awards are an opportunity to recognise really great teaching and student support in Oxford. The awards are entirely student-led and will go on to support good practice in teaching.

We hope you enjoyed reading this issue of the physics department's newsletter.

To contact the production team please email newsletter@physics.ox.ac.uk.