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CONTENTS

42 Editorial
AIP Awards & Prizes

43 President’s Column
A new President: looking ahead

44 News & Comment

46 Branch News

47 Metamaterials, metasurfaces, and metadevices
Yuri S. Kivshar

51 Inquiry-oriented learning in the first year physics laboratory
Les Kirkup

56 Physics as a career?
Sam Picton Drake

59 Conferences

60 Samplings
Physics news that caught the eye of the editor

64 Book reviews
Paul Edwards reviews MASKELYNE Astronomer Royal
by Rebekah Higgitt (ed)

65 Product news
New products from Coherent Scientific, Lastek, and Warsash Scientific.

69 Obituary
George Andrew Collins, 1955-2014

70 Obituary
James Dumitru Mitroy, 1957-2014

Cover
Artist’s impression of a functional metasurface” (courtesy A. Tokarev). See article by Yuri Kivshar.

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PHYSICS AS A CAREER
METAMATERIALS, METASURFACES AND METADEVICES
INQUIRY-ORIENTED LEARNING IN FIRST YEAR LAB

Volume 52, Number 2, Mar–Apr 2015

For all information about the Australian Institute of Physics, visit:
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AIP Awards & Prizes

One of the important functions of the AIP is the recognition of significant accomplishments in the field of physics in Australia and by Australians, via the award of prizes and medals. There are the biennial research awards, the Boas Medal, the Alan Wash Medal for Service to Industry, and the Harrie Massey Medal (awarded jointly by the AIP and the IOP). Recipients are required to give a talk at the following AIP Congress, and write an article for *Australian Physics*. In this issue there is an article by Prof Yuri Kivshar (ANU), recipient of the Harrie Massey Medal for 2014, on the topic for which he received the award, *Metamaterials, metasurfaces and metadevices*.

Awarded annually are the Bragg Medal for the best PhD thesis and the Education Medal. While these do not include the obligation of an article for *Australian Physics*, I, nevertheless, invite recipients to write an article. Hence, in this issue, Prof Les Kirkup (UTS), recipient of the 2014 Education Medal, has written an article, *Inquiry-oriented learning in the first year physics laboratory*, describing the introduction of such a course at UTS.

The third article, *Physics as a career?*, is by Dr Sam Drake, a physicist at DSTO with an adjunct position at the University of Adelaide. Sam makes the point that in seeking practical applications of physics as a means of enthusing students, traditional examples may in some cases be better replaced by more modern, and perhaps less widely appreciated, examples. He uses the Doppler effect as an example: GPS positioning systems may well be a better contemporary application than 'train whistles' for today’s students.

Over many years I spent considerable time seeking advertisement for jobs for which a physics graduate would be a suitable applicant. I was particularly interested in jobs that did not mention physics or physicist, but for which a physics training would provide very relevant skills. I was particularly attracted to jobs that could be categorised under the broad heading ‘operations research’. No doubt a mathematical training would also be suitable, but it seemed to me that numerical competency combined real world application (capabilities provided by a physics training, I would contend) were probably even more appropriate. I invite any members with a physics training but now working in operations research to contact me with the view to writing an article for *Australian Physics*.

Brian James
A new President: looking ahead

With this being my first column as the new AIP President, having taken over from Rob Robinson at the Council Meeting held at the Australian Synchrotron on 2 February, it is appropriate that I introduce myself and outline what I see as being the most important priorities for the AIP during my 2 year term.

I am currently the Director of the Australian Astronomical Observatory, which is Australia’s national optical astronomy observatory and a division within the Federal Department of Industry and Science. I have been in this position for just under 2 years, having spent most of my working life as a research/teaching academic in the university sector — most recently at Swinburne University in Melbourne, and at UNSW before that. Being an astronomer, some of you may well view me as an imposter in being president of Australia’s professional society of physicists, but let me assure you that my training was in physics, I am very much a physicist at heart, and I see my time as President being an opportunity to bring the physics and astronomy communities in Australia closer together. This notwithstanding, I am very honoured and humbled that the AIP has entrusted me to serve as its President!

In receiving the presidential ‘baton’ from Rob Robinson, I am very mindful of how much he accomplished during his term as President in addressing what are the most important and challenging issues for the AIP right now — its falling membership and hence diminishing financial resources, its relevance and perceived value across the Australian physics and broader science communities — particularly amongst those at the early-career stage — and the need for a stronger international focus, particularly in our neighbouring Asia-Pacific region. The AIP is indebted to Rob for his leadership and contributions across all these areas, and I would also like to acknowledge what a pleasure it was to be his Vice-President and work with him and the rest of the Executive on these important matters.

In looking to the future, there is still much to be done and achieve in ensuring the AIP has a bright and sustainable future, where it not just serve the needs of its members well, but also properly fulfils its mission of “promoting the role of physics in research, education, industry, and the community both in Australia and internationally”. As President, I see the following being the highest priorities if we are to do this: (i) significantly grow the membership of the AIP; both by attracting early- and mid-career participants, and broadening and diversifying the membership base into fields allied to physics; (ii) modernize and update the AIP Constitution; (iii) strengthen the AIP’s linkages and influence in the national science-policy domain, exploiting its strong connections with the relevant government departments, the Australian Academy of Science, the university sector, and Science and Technology Australia; and (iv) continue to raise its profile and engagement in the Asia-Pacific region, particularly through the successful hosting of the next Asia-Pacific Physics Conference (APPC) in conjunction with the next (22nd) AIP Congress in Brisbane in December 2016.

While these represent significant challenges, we have an excellent team in the current Executive that is very well placed to tackle them. Here I also note that every AIP Branch and Education and other science agencies, as well as the national research facility perspective. Andrew’s primary responsibility as VP will be to develop and implement initiatives that will specifically address the aforementioned membership issues, with a particular emphasis on developing ‘value propositions’ for potential members. As Registrar, Ian McArthur will continue implementing the roll-out of the recent changes we have made to the various membership categories, as well as his excellent work in streamlining the membership application and renewal processes. Judith Pollard (Treasurer) and Joe Hope (Secretary) will, respectively, continue to provide the financial and administrative support so important to the operation of the AIP. As their title suggests, our two Special Project Officers have special roles to play — Olivia Samardzic, who manages all the AIP prizes and awards, and Halina Rubinsztejn-Dunlop, who will be the primary point of contact for the joint APPC/AIP-Congress meetings in Brisbane next year (who along with myself will be co-Chair). Finally, I have asked Marc Duldig (former AIP President) to remain on the Executive, in order to provide support for me as President, and to take responsibility for the review and modernization of the AIP Constitution that will be undertaken this year.

Warrick Couch
International Year of Light

The Opening Ceremony of the International Year of Light and Light-based Technologies 2015 was held on 19-20 January 2015 at UNESCO HQ in Paris, France. Over a thousand participants attended the two-day event, which brought together decision-makers, industry representatives and leading scientists from around the globe. The event included lectures by five Nobel Prize laureates, including Ahmed Zewail, Steven Chu, William Phillips, Serge Haroche and Zhores Alferov.

Launch of the IYL, Paris

In proclaiming an International Year focusing on the topic of light science and its applications, the UN has recognized the importance of raising global awareness about how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health. Light plays a vital role in our daily lives and is an imperative cross-cutting discipline of science in the 21st century. It has revolutionized medicine, opened up international communication via the internet, and continues to be central to linking cultural, economic and political aspects of the global society.

The IYL coincides with the 1000th anniversary of Kitab al-Manazir (Book of Optics) by Ibn Al-Haytham, a 10th century scholar from Basra (Iraq), who is considered to be the father of modern optics and of the present-day scientific experimental method.

2015 Pawsey Medal

The Pawsey Medal for 2015 has been awarded to Dr Naomi McClure-Griffiths, Australia Telescope National Facility, CSIRO Astronomy and Space Science. Dr McClure-Griffiths is an internationally recognised radio astronomer, who has used the Parkes radiotelescope and other Australian telescopes to make new discoveries about the Milky Way Galaxy. Her research has provided unprecedented insights into how the Milky Way is structured, lives its life, and interacts with its neighbours. She has unravelled the complicated pinwheel-like structure of our Galaxy and has helped explain how the Milky Way keeps finding fresh gas to make new stars.

Dr Naomi McClure-Griffiths

The Pawsey Medal is awarded annually by the Australian Academy of Science and recognises outstanding research in physics by scientists under the age of 40 years. The award is named after Australian scientist, radiophysicist and radio astronomer, Dr Joseph Pawsey.

2015 Nancy Millis Medal for Women in Science

The Nancy Millis Medal for Women in Science for 2015 has been awarded to Associate Professor Tamara Davis, School of Mathematics and Physics, University of Queensland. Associate Professor Davis uses astrophysics to test the fundamental laws of physics, and study the nature of dark energy and dark matter. She is one of the most highly cited astrophysicists in the world. Her contributions include testing advanced theories of gravity, measuring time-dilation of distant supernovae, using galaxies to measure the mass of the lightest massive particle in nature (the neutrino), and discovering that active galaxies fuelled by black holes can be used as standard candles.

A/Prof Tamara Davis
AO for Mike Gore
Mike Gore, science communicator and AIP member, was made Officer (AO) of the Order of Australia in the Australia Day Honours list. This award recognises his decades of work in public outreach and education and his roles in setting up the Questacon National Science Centre, the travelling Shell Questacon Science Circus and the Centre for Public Awareness of Science at ANU. Mike has been involved in establishing other science centres around Australia and internationally (countries in Asia, the Pacific and Africa). Has also been a regular participant in the National Science Summer School. Mike is currently an adjunct Professor at the ANU.

Academy’s Climate Update
The Australian Academy of Science released its latest update on the state of climate science on 16 February.

*The science of climate change: Questions and Answers* aims to counter confusion and misinformation on this important scientific topic. It examines nine key questions, including what the science says about options to address climate change.

Academy President, Professor Andrew Holmes, said “The evidence is clear: climate change, caused by human activities, is real. The vast majority of scientists and scientific organisations in this field are in agreement on this.”

“Climate change is not something happening in the far off future, it’s happening now. 2014 was the hottest year on record, and 14 of the 15 warmest years on record have occurred during the first 15 years of this century,” Professor Holmes said.

Australian breakthrough sets new solar photovoltaic record
A University of New South Wales group and the Australian company RayGen Resources combined to produce the highest-ever efficiency rate for the conversion of sunlight into electricity. The breakthrough came after testing in Sydney achieved an unparalleled 40.4% conversion rate for photovoltaic (PV) efficiency, and has been independently verified at the US National Renewable Energy Laboratory in Colorado.

The Director of the UNSW Centre for Advanced Photovoltaics Professor Martin Green said, ‘This is the highest efficiency ever reported for sunlight conversion into electricity. The new results are particularly relevant to PV power towers being developed in Australia.’ In 1989 the UNSW group developed the world’s first PV system to convert sunlight to electricity with an efficiency greater than 20%. The new result doubles this earlier record.

The system uses a PV power tower where sunlight is reflected from a field of sun-tracking heliostats to a dense photovoltaic array mounted on a central tower. The sunlight is split into spectral bands and each band is directed to a dedicated solar cell of an appropriate energy bandgap to efficiently convert this band. In this system, the improved efficiency not only reduces costs by increasing energy output for a given investment, but also reduces unwanted heat generation at the central tower.

In March 2015 RayGen will complete commissioning of a prototype power tower at a site near Bendigo in central Victoria. Plans are also in place for RayGen to build a 10 MW commercial-scale operation in China in 2016.
The proof-of-concept testing that produced the record 40% conversion rate was funded by the Australian Renewable Energy Agency (ARENA) and supported by the Australia–US Institute for Advanced Photovoltaics.

**BRANCH NEWS**

**New South Wales**

The New South Wales Branch has instituted an annual award, *NSW Community Outreach to Physics Award*, as a means of recognising the work of individuals for community outreach in relation to the discipline of physics. This Award seeks to acknowledge an individual, with a clearly notable record of work in contributing to outreach, physics education, who has demonstrated passion for the study of physics in New South Wales. The Award is open to everyone in NSW and will consist of a $500 monetary award, and a certificate citing the achievements of the individual.

Nominations for this Award will close on **9th October 2015**. A statement of up to 500 words outlining the work for which the nomination seeks recognition should be lodged by mail or email: Dr Frederick Osman, NSW Branch Secretary, Australian Institute of Physics, PO Box 649, Moorebank NSW 1875; fred_osman@exemail.com.au

**Western Australia**

An hour’s drive from Perth lies the Gravity Discovery Centre (GDC), home of a gravity wave detector and also public exhibits of astronomy and science. These interactive exhibits include the world’s tallest purpose-built leaning tower from which visitors can drop water-filled balloons (testing a Newtonian law and observing impact craters). A coach with passengers from the both AIP and RACI and their families made an excursion to the GDC on 15th February. The laboratories where the gravity wave detectors are being constructed were specially opened for the day, with guided tours by Prof David Blair.

For those who were unable to join the excursion a pictorial report of the tour was presented at a general meeting of the AIP branch on 18th February. The meeting also included a presentation on a tourist’s visit to CERN and the demonstration of an app – CosmicEye – which graphically shows the scale of objects from quarks to the universe. Additionally a video was shown of the runner-up winner of last years’ ‘Frame Your Physics’ competition, run by the ACT branch.
Metamaterials, metasurfaces, and metadevices
Yuri S. Kivshar*
Nonlinear Physics Centre and CUDOS@ANU, Research School of Physics and Engineering, Australian National University, Canberra ACT 0200

Metamaterials are artificial electromagnetic media that are structured on the subwavelength scale. Such structures were initially suggested for achieving negative index of refraction, but later they became a paradigm for engineering electromagnetic space and controlling propagation of waves through transformation optics and optically-induced magnetic response. The research agenda is now shifting towards achieving tunable, switchable, nonlinear and sensing functionalities of metamaterials, and it involves the fields of metasurfaces and metadevices where the Nonlinear Physics Centre in Canberra is playing an important role, with the recent demonstrations of breakthrough results in nonlinear metamaterials and tunable metasurfaces. Here we discuss briefly the basic concepts of this rapidly growing research field highlighting the recent developments in the physics of metamaterials and subwavelength nanophotonics.

What are metamaterials?
It is well known that the response of any material to applied electromagnetic radiation can be characterized by two electromagnetic parameters, magnetic permeability and electric permittivity. These two physical characteristics are combined in a product to define the square of a refractive index, which measures how fast the material transmits light and how light is bent on entering the material — the higher the refractive index, the slower the propagation and the stronger the deflection. However, a material whose permeability and permittivity become simultaneously negative, termed a left-handed material, would also allow the propagation of electromagnetic waves with many unusual properties [1-5].

In a left-handed material the Poynting vector of a wave is anti-parallel to the wave vector and, therefore, the basic feature of light is reversed: that is, light propagates in the opposite direction to the energy flow. This leads to some very interesting effects such as the reversal of the Doppler shift for radiation, and the reversal of Cherenkov radiation. In addition, one of the most basic principles of optics, Snell’s law, is “reversed” at the interface of a left-handed medium with a normal right-handed material, so that the electromagnetic waves experience negative refraction, and this property can be employed for flat-lens focusing [1,4].

Creation of novel composite materials demonstrating the left-handed properties at telecommunication and visible frequencies required the development of novel concepts and novel nanofabrication techniques. Very few theoretical concepts that have been suggested so far are based around nanofabricated composites. One of the example is nanowire plasmonic materials where nanowires arranged into parallel pairs can act as a left-handed material with the effective magnetic permeability and dielectric permittivity both negative in the visible and near-infrared spectral ranges [6]. Various composites based on metallic and dielectric nanostructures have been recently suggested and developed to achieve left-handed materials with macroscopic negative refraction [7-10] (see Figure 1).

![Figure 1: Examples of metamaterials fabricated through composition and periodic repetition of metallic and dielectric elements —“meta-atoms” or “meta-molecules” (adopted from Ref. [10]).](image)

During last 8-10 years, the field of metamaterials has developed as a novel approach for engineering the electromagnetic response of passive micro- and nanostructured materials by engaging resonance excitations such...
as localized plasmonic modes and Mie-like resonances. Remarkable results have been achieved including negative-index media that refract light in the opposite direction from that of conventional materials, chiral materials that rotate the polarization state of light hundreds of thousands of times more strongly than natural optical crystals, and structured thin films with remarkably strong dispersion that can slow light. A list of only few such remarkable highlights demonstrated with metamaterials during last 10 years includes: optical magnetism, negative index of refraction, invisibility cloaking, optical circuit components, and improved imaging. A few examples of fabricated nanostructured metamaterials are presented in Figure 2.

**Figure 2:** Examples of metasurfaces with optically resonant electric and magnetic response: nanoantenna oligomers, regular arrays of silicon nanoparticles, and magnetic metamaterials.

**Metamaterials Down Under**

The Nonlinear Physics Centre in Canberra has been involved in studies of metamaterials since 2002 [11] and it became one of the leaders in the physics of nonlinear and tunable metamaterials [12,13]. Starting from the initial theoretical proposal for the enhancement of nonlinear properties of metamaterials, the Centre investigated a wide range of nonlinear phenomena, both theoretically and experimentally. Recent studies cover several topics of magneto-elastic metamaterial and tunable metamaterials for terahertz applications.

As emphasized above, the advent of metamaterials provides novel methodologies in controlling light-matter interaction. With proper design and fabrication of the metamaterial units - so called meta-atoms and metamolecules, exotic properties unavailable with natural materials can be realized. These studies have inspired many unconventional ideas in optics and photonics, promising various ultra-compact and highly efficient metadevices [14]. Today, an important direction in the development of meta-devices is achieving dynamic control over their exotic properties. This can be done by including nonlinear or tunable elements into passive metamaterials, such as, e.g., liquid crystals; alternatively, one can design meta-molecules with deformable structures. For example, mechanical tuning is now widely used in THz metamaterials. We have recently proposed a post-processing approach for mechanical tuning of the electromagnetic properties of metamaterials, which may be used in applications which require precise engineering of metamaterial resonances.

Structural tuning shows advantages in modulation contrast and the ability to manipulate meta-molecules individually. However, deformation based on static electric or magnetic forces is not so straightforward for optical metamaterials with sub-micrometer features. To solve this problem, our research team from the Nonlinear Physics Centre at the Australian National University jointly with the University of Sydney introduced the concept of magnetoelastic metamaterials [13], where the meta-molecules can be deformed by the resonantly enhanced electromagnetic force. Importantly, this is a scalable solution of “light controls light” concept over a wide frequency range, and the interaction between electromagnetic resonance and structural dynamics can demonstrate novel effects beyond a simple modulation of parameters.

To achieve strong electromagnetic-to-elastic interaction, we have introduced an optimized design by exploiting the torsional deformation of chiral meta-molecules [15]. We have demonstrated giant bistable effect and dynamic nonlinear optical activity due to self-oscillation effect. An important breakthrough we got recently is the prediction and observation of spontaneous chiral symmetry breaking effect (see Figure 3) in a metamaterial composed of enantiomeric torsional meta-molecules, i.e. chiral meta-molecules with opposite handedness. In such a scenario, the initial configuration of the system is achiral due to chiral symmetry. However, due to the intermolecular electromagnetic (EM) interaction, the system stability changes, and such symmetry can be broken spontaneously when the incident power exceeds a certain threshold value, which further leads to abrupt nonlinear polarization change and mode splitting. The predicted effect is an artificial achiral-chiral phase transition and it was successfully demonstrated in a microwave experiment. As shown in the figure, the single resonance under the chiral symmetry configuration splits into two new resonances in the power regime of broken symmetry.

Our studies provide a novel paradigm to achieve artificial nonlinear and phase transition effects in metamaterials via EM-elastic coupling. The realization of these effects at infrared and optical frequencies can greatly enrich the functionalities of future meta-devices.
One of the important directions in the physics of metasurfaces is the use of graphene as a component of metadevices. Graphene is a two-dimensional array of carbon atoms arranged in a honeycomb lattice, which has remarkable electronic and optical properties. Recently, its unique optical properties have generated significant interest in the research community revealing its great potential for applications in photonics and optoelectronics. The optical response of graphene is characterized by a surface conductivity which is determined by the chemical potential. For photon energies below a certain level defined by a chemical potential, graphene exhibits metal-like conductivity. In this regime, similar to metals, graphene can support transverse magnetic (TM) electromagnetic surface plasmon polaritons, and they represent a coupled state of the electromagnetic field and electrons. For the range of frequencies above the chemical potential, graphene has dielectric characteristics and it supports transverse electric (TE) surface waves. The study of plasmonic effects in graphene structures has attracted a special interest from the nanoplasmonics research community due to novel functionalities delivered by such systems, including a strong confinement of electromagnetic waves by a graphene layer and tunability of graphene properties through doping or electrostatic gating. Now, graphene plasmonics is a rapidly growing new field of physics which utilizes concepts of conventional metal plasmonics combined with unique electronic and optical properties of graphene. Being guided by a graphene monolayer, TM-polarized plasmons with subwavelength localization have an extremely short wavelength, and that is why their excitation is rather challenging. Nevertheless, recent experiments provided evidence of the existence of such plasmons by means of scattering near-field microscopy and nanoimaging.

In our work, we have studied both linear and non-
linear effects in graphene structures, including nonlinear propagation and switching of light in two coupled layers of graphene [see Figure 4(a)], and demonstrated that this simple double-layer structure can operate as an efficient optical coupler for both continuous plasmon polaritons and for subwavelength spatial solitons. We have shown that multi-layer graphene structures can be employed to increase plasmon wavelength thus increasing plasmon propagation length [see Figures 4(b,c)] and also predicting the existence of plasmon solitons in graphene [see Figures 4(d-g)].

Towards metadevices

The ever-increasing demand for faster information transfer and processing drives efforts to remove the bottleneck between fibre-based optical telecommunication networks and electronic data handling and routing, improving data storage and developing parallel data processing operating in a compact space. Fulfilment of these tasks will require strong and fast nonlinearities for switching light with light, and much improved control of the electromagnetic properties of matter with external stimuli such as electric signals. Many of these functionalities may be greatly enhanced by hybridizing functional matter with metamaterials and graphene, by exploiting nonlinearity of the metamaterial framework itself, and by taking advantage of the changing balance of forces in systems with building blocks smaller than the wavelength of light. This leads to the concept of metadevices, a logical extension of the metamaterial paradigm, where interactions are nonlinear and responses are dynamic. We envisage that the future platform for highly integrated electromagnetic signal processing and distribution will emerge that will combine nonlinear, memory and switchable functionalities with the ability of transformation optics to guide light via the engineered electromagnetic space, using metamaterials with spatially variable parameters.

Outlook

Future technologies will demand a huge increase in photonic integration and energy efficiency far surpassing that of bulk optical components and silicon photonics. Such an integration can be achieved by embedding the data-processing and waveguiding functionalities at the material level, creating the new paradigm of metadevices. It is now believed that robust and reliable metadevices will allow photonics to compete with electronics not only in telecommunication systems, but also at the level of consumer products such as mobile phones or automobiles. The main challenges in achieving this vision will be in developing cost-efficient fabrication and device integration technologies.

References

Inquiry-oriented learning in the first year physics laboratory

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Learning science through inquiry has gained momentum in recent years with many people, including Australia’s Chief Scientist, promoting the value of inquiry in secondary and tertiary education. Learning through inquiry encourages student engagement giving students a real sense of what scientists do and how they do it. In this article I describe how the first year physics programs at UTS, beginning in the early 1990’s, explored and then embraced inquiry in the undergraduate physics curriculum. I describe the processes we adopted to develop and deliver a laboratory program consisting of inquiry-oriented experiments and the challenges we faced by delivering such a program.

Introduction
I graduated with a BSc in physics from Sheffield University in the UK in 1979. Though detailed recollections of my experiences have predictably dulled, I do remember the anxiety I experienced when, as part of the third (and final) year of my degree, I was required to complete a semester-long honours project involving an amount of laboratory-based research. Prior to the honours project, the laboratory-based ‘experiences’ in my degree consisted of orthodox physics experiments furnished with detailed instructions. To be unleashed on an open-ended project was challenging, exciting and daunting. I didn’t stop to wonder at the time why project-type experiences were not a more common feature of the undergraduate physics curriculum. I reflect now that it was unlikely physical or human resources were limiting factors; there were only 20 students enrolled in the third year of my physics degree in Sheffield, laboratories were well equipped and, by today’s standards, student-staff ratios were small.

I became a physics lecturer in Paisley College (now the University of the West of Scotland) in 1983. In the time I worked there, which was up till 1990, the undergraduate physics curriculum had much in common with the physics curriculum in Sheffield University, especially with respect to project work which was a feature confined to the final year of the degree. Though there were many dedicated lecturers in Paisley, I don’t think it occurred to them (and certainly not to me) that we were not making the most of students’ emerging capabilities in the early years of their degree to ‘do science like scientists’. I think I believed that students had to complete an apprenticeship largely consisting of consuming a goodly fraction of physics principles supplemented by laboratory work before moving on much later to designing and carrying out investigations of their own.

UTS in 1990
In 1990 I moved to the Department of Applied Physics (DAP) at UTS. The undergraduate physics curriculum at UTS bore a strong resemblance to physics curricula the world over, but with perhaps a stronger emphasis on applied physics. The physics laboratory experiments, especially in the first year at UTS, were very similar to those given to my students in Scotland. One major difference was that, at UTS, there were many more students taking physics as a ‘service subject’. The students themselves could be majoring as examples in engineering, the environmental or biological sciences, or nursing. Another major difference between Paisley College and UTS was that by the early 1990’s UTS had introduced student feedback surveys.

What emerged from the surveys was that, though the first year physics subjects at UTS were quite well regarded, the laboratory programs were consistently criticised. One student wrote:

In prac. experiments I was totally lost. I didn’t understand what the concept was or what we were supposed to do. It just gives you some theory and a picture of what you are supposed to do, but it was unclear what I was looking for........ when you don’t know what you are doing, you think “I just want to get out of here”.

(Student enrolled in Physics 1C in 1991)

This comment tallied with anecdotal feedback we received about students’ laboratory experiences. This finding was echoed many years later when a national study, completed as part of an Australian and Learning and
Teaching Council (ALTC) project, explored students’ experiences of first year physics subjects. Findings of the project revealed that the lack of positive learning experiences in the first year physics laboratories across many universities in Australia was not unusual[1].

At UTS we might have dismissed criticism of the laboratory program with the familiar (and not always unjustified) judgment, ‘we know best’. However, about this time we were fortuitously sharing a floor of a UTS building with the recently created Centre for Learning and Teaching (CLT). This meant that we had convenient access to critical expertise we lacked on student learning and the work done in other institutions to reconceptualise learning in the laboratory and similar settings. Also, there was a new head of DAP who, dissatisfied with the ‘we know best’ approach, wanted to examine the issue of the student experience of first year physics laboratories at UTS more closely. This, allied with academics in the DAP strongly committed to undergraduate education and the availability of competitive national funding for curriculum reform, meant that the climate favoured serious reconsideration of the laboratory components of our physics subjects. We first turned our attention to ‘Physics 1C’ which was a first year physics subject for students majoring in the physical sciences (eg applied chemistry, applied physics and materials science).

Revitalising Physics 1C

In the early 1990s 150 students (typically) would enrol in Physics 1C in their first semester at UTS. The delivery of Physics 1C consisted of, on average, 3.5 hours of lectures/tutorials each week for 13 weeks. Students working in pairs completed one experiment of duration 2.5 hours each week for 10 weeks. A laboratory group would typically consist of 16-20 students supported by one demonstrator. Students were subjected to a ‘circus’ of experiments recognisable to almost anyone who has taken a first year physics subject; students would carry out a recipe-based electricity, optics, and thermal experiments over a semester, very often out of step with material presented in lectures. The systemic disconnect between ‘theory’ and experiment was palpable and generally not conducive to enhanced student understanding and engagement.

In developing the Physics 1C laboratory program, the simple question we asked was what do we want students to get from laboratory work? In answering his question we were influenced by the work of Boud et al. [2]. A team was assembled, led by the head of the DAP, which assumed shared responsibility for the development, implementation and evaluation of the new laboratory program. The people drawn into the team which consisted of full time academics, demonstrators, technical staff, an educational researcher (from the CLT) and an educational developer brought invaluable experience and insights which enhanced the development process [3].

It was clear from early in the reviewing process that there were key elements of laboratory work that we valued as practising scientists that were absent from the Physics 1C laboratory program. For example, there was little opportunity for students to be inventive in their approach to an experiment, which was not surprising as each experiment prescribed the tasks that had to be carried out and how they were to be carried out. In contrast to the discussions that are routine between scientists as they attempt, as an example, to explore whether a particular experimental method can be improved, there was little or no encouragement for students to present and discuss their ideas or findings with their peers during the laboratory session.

We began the process of reform by examining the existing Physics 1C experiments and making judgments as to whether a student, in carrying out each experiment would have to [4]:

- a) engage in scientific inquiry by exploring a phenomenon, developing a procedure, or designing apparatus;
- b) demonstrate experimental skills or use an instrument or device;
- c) use data reduction skills such as graphical or error analysis, and;
- d) demonstrate enhanced physics knowledge by doing the experiment.

Of the 14 first year experiments reviewed, 100% satisfied b) and c) above. Only 21% of the experiments required exploration, none required students to work collaboratively to design apparatus or develop a procedure, and only 7% required students to demonstrate enhanced physics knowledge.

We were determined to reform the Physics 1C laboratory program in order to make it more engaging, stimulating and relevant to student lives. We also wanted to build on concepts introduced or elaborated on elsewhere, for example in lectures. Educational research offered evidence that an inquiry-oriented approach to teaching and learning could accommodate those aims as well as expose students to experiences such as curiosity.
perseverance, experiencing failure and dealing with doubts [5]. We made the decision to place inquiry-oriented experiments at the heart of the new laboratory program.

I should say at this point that I don’t believe that all student experiences in the laboratory should be ‘inquiry-oriented’ and that in some sense recipe-based experiments should be considered an anathema to good laboratory programs. There are techniques and skills that students taking physics subjects, depending on their circumstances and career trajectory, should grasp and practice. Indeed it can be argued that such skills are the basis of the scaffolding that students need if they are to carry out inquiry-oriented experiments successfully. It is when student experiences begin and end with recipe-based experiments that we need to ask ourselves if this is likely to lead to engagement and learning and whether such experiments will stimulate or inspire the next generation of scientists.

We examined the openness to scientific inquiry of each experiment using the scheme illustrated in table 1, adapted from [2]. The table relates the level of scientific inquiry inherent within an experiment to the extent of student autonomy.

<table>
<thead>
<tr>
<th>Level</th>
<th>Aim (Is the aim of the investigation given to students or is it open?)</th>
<th>Materials (Do students select their own materials or are the materials provided?)</th>
<th>Method (Is the method given or do students develop their own method?)</th>
<th>Answer (Is the outcome given to students, or is the outcome open?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
</tr>
<tr>
<td>1</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
<td>Open</td>
</tr>
<tr>
<td>2A</td>
<td>Given</td>
<td>Given whole or part</td>
<td>Open or part given</td>
<td>Open</td>
</tr>
<tr>
<td>2B</td>
<td>Given</td>
<td>Open</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>3</td>
<td>Open</td>
<td>Open</td>
<td>Open</td>
<td>Open</td>
</tr>
</tbody>
</table>

Table 1: Level of openness in scientific inquiry

An experiment in which students follow instructions to reach an outcome or answer that is already known, is classified a level 0 experiment. At the other extreme a level 3 experiment is one in which the student devises the aim, the means by which the aim will be achieved, and is responsible for advancing and defending an answer. Most (12) of our Physics 1C experiments in 1991 were found to be at level 1, while the remainder (2) were at level 0. We considered this as unsatisfactory and set about making radical changes to the laboratory program and its philosophy.

We took the bold step of setting aside all the existing experiments in Physics 1C, in order to create new experiments aimed to be at level 2A as described in table 1. We also brought an abrupt end to the circus of experiments such that, in the new laboratory program, all students worked on the same experiment at the same time. This provided natural opportunities for meaningful discussions between students and demonstrators of the various experimental approaches adopted. Students were able to present the methods they had devised and their findings to their peers in the laboratory.

Example of an inquiry-oriented experiment: planning a film stunt

The ‘planning a film stunt’ experiment was carried out by students in their first week at UTS, usually before any consideration of the principles of mechanics had been considered in lectures. Intended outcomes of this experiment were that students understand the value of being systematic in the way they devised and performed an experiment, were able to communicate their findings to their peers and were conscious of physics being applied in a real world context. See Figure 1

The experiment was a significant departure from the conventional mechanics-based first year experiments, and was based on the work of a physics academic at UTS regularly retained as a technical consultant by a movie company. The company’s major business was to devise and perform spectacular stunts such as those involving motorbikes leaping between buildings or over obstacles.

As part of the introduction to the experiment, a video clip of a stunt was shown to students in which a small truck takes off from a ramp then crashes through a neon sign. A whole-of-class activity was to identify factors to consider when designing the stunt. The factors were recorded, reviewed and discussed in the laboratory.

We found that students, irrespective of their physics background, were able to bring ‘common-sense’ notions as what parameters would be important to consider in the design of the stunt. The discussion progressed to consideration of which of these parameters could be successfully explored in the laboratory which, in due course, they proceeded to do.

Student reaction to the stunt experiment and the new laboratory program in general, evaluated through student interviews and anonymous surveys, was generally favourable [3]. Feedback included:

Following a method given word for word isn’t really thinking for yourself and you are never going to develop experimental skills for yourself.

and

I find that (fewer instructions) are better than someone giving us the instructions and saying, do this and do
that. If you have a problem you actually work hard at working it out and you feel you have accomplished something at the end. It’s better than someone saying calculate this, calculate that.

During the early stages of the development and trial of the new laboratory program, academics responsible for the development of the program took on role of demonstrators in the laboratories. This had the advantage that we were able to respond in a timely fashion to teething problems that naturally beset new experiments. The other advantage was to illuminate the fact that the role of the demonstrator in laboratory was obliged to change due to changed philosophy of the laboratory program. The demonstrator was no longer the interpreter/decipherer of the step by step instructions contained in the laboratory manual, but was now a facilitator, monitoring and advising on (sometimes) quite different approaches being adopted by students as they carried out their experiments. Such a change in role had (and continues to have) significant implications for the professional development of demonstrators.

Since the mid 1990s
We were encouraged by the successful revitalisation of the Physics 1C laboratory program to apply the approach, with some adaptations, to our large enrolment first year physics subject for engineers [6] in the late 1990’s and after that to our (also large enrolment) first year physics subject for medical, biological and environmental sciences students [7]. In each case, special consideration had to be taken of the contexts in which the inquiry-oriented experiments were placed. However the same general methodology was adopted, consisting of:

• assembling a diverse team which included academics, technical staff, demonstrators and educational developers
• reviewing the place of the laboratory components in the curriculum
• assessing existing experiments with respect to their emphasis or otherwise on inquiry, as described in table 1
• implementing changes and assessing the student experience using surveys, observations and focus groups.

Not all academics within the DAP at UTS were involved in developing the new laboratory program but we understood the importance of having the majority of faculty positively disposed towards the revitalisation of the laboratory programs. Through whole of department workshops in which the goals of the new laboratory program were explored, academics not directly involved with the innovations could bring their perspectives of the new program. Perhaps inevitably there were academics (few in number) who could see little value in changing the program. The input of such academics was vital as a reality check as it made the laboratory program developers ask: are we convinced of the value of the approach(es) we are adopting?

Figure 1: Les looks on as students carry out the stunt experiment

Figure 2: First year students at UTS carrying out an inquiry-oriented experiment into the relative efficiencies of silicon and organic solar cells.

Inquiry oriented learning in 2015
Calls for a greater emphasis on science students engaging in the processes of inquiry have grown over decades [8]. The DAP at UTS, prompted by student feedback and close consultations with education researchers and developers, embarked on reform of its laboratory program in the early 1990’s.
Inquiry oriented experiments remain at the heart of laboratory programs at UTS in 2015. Challenges remain, not least through the increase in student enrolments requiring we continue to innovate, and most importantly support our demonstrators, as they strive to assist students carrying out inquiry-oriented experiments.

In the 20 years or so since we began our reforms, a number of factors have conspired to promote such engagement on a wider scale in primary, secondary and tertiary education in Australia and elsewhere. Those factors include a shared commitment to promoting and embedding inquiry in the curriculum from national and institutional policy makers and those that engage directly with students on a day-to-day basis [9]. While inquiry-oriented learning, especially in first year physics laboratories has yet to become fully established, there are promising signs that it has gained a foothold and that its influence is expanding [10].

Acknowledgements

I wish to thank the following people who made major contributions to the evolution of the laboratory programs at UTS The late Bob Cheary, David Green, Walter Kalceff, Maree Gosper, Elizabeth Hazel, Sue Johnson, Nirmala Maharaj, Jenny Pizzica, Lakshmi Srinivasan, and Katrina Waite.

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AUTHOR BIOGRAPHY

Les Kirkup was born in the UK. He studied for degrees in England and Scotland before joining UTS in 1990. He is currently a professor in the School of Physics and Advanced Materials at UTS.

Many of his educational development activities have focused on enhancing the student experience in laboratories. His contributions to teaching and learning nationally have been recognised by the award of national fellowships, the latest being, in 2011, an ALTC National Teaching Fellowship.

In recognition of his contribution to physics education in Australia, Les was awarded the AIP Education Medal in 2014.

Outstanding Service to Physics

The AIP Award for Outstanding Service to Physics will recognise an exceptional contribution on the part of an individual who gives great amounts of time and effort to the furtherance of Physics as a discipline. Nominations may be made by a Branch Committee or by three members of the AIP. There will be no more than three awards nationwide in any one year.

The deadline for nominations is 1 July 2015.

Further information can be found at www.aip.org.au/content/medals or obtained by email from the AIP Special Projects Officer Olivia Samardzic (olivia.samardzic@dsto.defence.gov.au or by phone on (08) 7389 5035). Nominations should be sent by email attachment to the above email address or to the Special Projects Officer at: Olivia Samardzic, 205 Labs, EWRD, DSTO, PO Box 1500, Edinburgh, SA 5111.
Preamble:
When a student decides to enrol in a science degree and major in biology or chemistry they know that, upon completion, there are a number of clearly defined career options. However, if a student decides to major in physics then the skills they acquire appear to be applicable only to teaching, academia and a few jobs in Defence. A consequence of this is that those who enrol in a physics major do so because their interest in physics outweighs their career aspirations. Is it surprising then that so few students decide to major in physics?

“I believe that the concepts and mathematics taught in classical mechanics are fascinating but I know that for many students that is not a good enough reason for studying them”

When I was in the final year of my science degree (majoring in physics) I attended a lecture on the career prospects for physicists. The key points that I remember from that lecture were that when compared with other disciplines in science 1) physicists are more likely to go onto a higher degree, 2) physicists are considered good problem solvers, 3) physicists have a higher than average salary immediately after graduation, and 4) physicists are “most likely to do anything”, (which is to say that they get a job that is not related to their specific training).

It is this last point that I think is the greatest hindrance to getting students to enrol in a physics major. Why should one spend so many hours trying to understand the use of Lagrange multipliers and holonomic constraints in classical mechanics if this knowledge is never used?

Don’t get me wrong, I believe that the concepts and mathematics taught in classical mechanics are fascinating but I know that for many students thinking about their future that is not a good enough reason for studying them, that is a sort of “art for art’s sake” argument. If we want more students to enrol in physics we have to show how it is used, and we cannot do this alone. We need to offer courses relevant to other disciplines. For example chemists should take a course on quantum mechanics and that course should be taught by physicist, but it must be tailored to what is relevant to chemist, i.e. it should spend more time explaining the link between the solutions of Schrödinger’s equations and spectroscopy and less time on Schrödinger’s cat.

There are many examples of how physics is applied to design and build devices and algorithms that are used today. I would like to collect them so that I have real life examples that I can provide students or employers who ask “Why should I become/hire a physicist instead of an engineer?” More than just providing hand waving arguments I would like to collect specific case studies that show how the physical concepts and mathematics are applied. To set the ball rolling let me give an example from my own experience at work of using a fundamental physical concept in a practical application.

Doppler Positioning
The teaching of the Doppler Effect is a classic example of how we fail to show how physics is used in practice. Most text books derive the Doppler Effect by considering how the distance and time between successive wave fronts depends on the velocity of the emitter and receiver. They describe how the Doppler Effect causes the pitch of a siren to change as an emergency vehicle moves towards and then away from us. The student is then asked to use the Doppler shift formula to calculate something like the frequency of a bat’s echo location signal as it travels towards a wall. How many textbooks or
lectures discuss how the Doppler Effect is used in Global Navigation Satellite Systems (GNSS) [1] or for Doppler imaging of the heart [2]? Most recently it has been used to refine the estimated location of the missing Malaysian airlines flight MH370 [3].

Prior to the development of the global positioning system (GPS) the job of determining the location of a ship or aeroplane on the surface of the earth was a difficult one that required specialist skills. A good account of the history of navigation is found in Sobel’s popular science book *Latitude* [4]. As you might imagine navigation for submarines is particularly tricky. It is very difficult for a submarine to determine its position under water but if it needs to surface to get a position fix it wants to do this as quickly as possible, otherwise what is the point of being submersible?

**TRANSIT** (see Figure 1) was a global satellite navigation system designed by the US Navy so that users could determine their position quickly anywhere on Earth without requiring the visual identification of landmarks or stars, it is based on the Doppler positioning [5].

![Figure 1: A backup Transit 5-A satellite from the 1970s. Origin: National Air and Space Museum, Smithsonian Institution. http://timeandnavigation.si.edu/multimedia-asset/transit-satellite](http://timeandnavigation.si.edu/multimedia-asset/transit-satellite)

The Doppler shift formula describes how the received frequency differs from the emitted one depending on the location and velocities of the emitter and the receiver [6].

\[
    f_r = \frac{1 - \frac{v_e^2}{c^2} (u^2 - v_e^2)}{1 - \frac{v_r^2}{c^2} (u^2 - v_r^2)} f_e
\]

where \(c\) is the speed of light in a vacuum, \(f_e\) is the emitted frequency of the signal, \(f_r\) is the received frequency, \(u\) is the phase velocity of the signal, \(v_e\) is the velocity of the emitter, and \(v_r\) is the velocity of the receiver. Note that I have used the convention that a bold lower case letter is a column vector, a normal font is a scalar, i.e., \(u^2 = u^T u\) and superscript \(T\) denotes the transpose.

Assuming that the refractive index \(n\) is constant, the signal will travel in a straight line from the emitter to the receiver

\[
    u = \frac{r - p}{\sqrt{(r - p)^T (r - p)}} \frac{c}{n}
\]

where \(r\) and \(p\) are the receiver and emitter locations respectively.

If the locations, velocities and frequencies of \(N\) emitters are known it is possible to determine the location and velocity of the receiver by solving the \(N\) simultaneous equations

\[
    f_{r1} = \frac{\sqrt{1 - \frac{v_{e1}^2}{c^2} (u_1^2 - v_{e1}^2 u_1)}}{\sqrt{1 - \frac{v_r^2}{c^2} (u^2 - v_r^2)}} f_{e1}
\]

\[
    \vdots \quad \vdots \quad \vdots
\]

\[
    f_{rN} = \frac{\sqrt{1 - \frac{v_{eN}^2}{c^2} (u_N^2 - v_{eN}^2 u_N)}}{\sqrt{1 - \frac{v_r^2}{c^2} (u^2 - v_r^2)}} f_{eN}
\]

for the unknown receiver location \(r\) and velocity \(v_r\), where the subscripted index refers to a particular emitter and

\[
    u_i = \frac{r - p_i}{\sqrt{(r - p_i)^T (r - p_i)}} \frac{c}{n}
\]

If we wish to determine both the location and velocity of the receiver in three dimensions then at least six emitters are required (\(N=6\)). If, on the other hand, the velocity of the receiver is known, for example from the submarine’s, ship’s or aeroplane’s inertial navigation system (INS) then only three emitters (satellites in the case of GNSS) are required.

As a pedagogical example consider determining the location of a receiver that is known to be on the equator from two TRANSIT satellites that are in orbit in the equatorial plane

”...Doppler Effect is used in Global Navigation Satellite Systems... Doppler imaging of the heart ... Most recently has been used to refine the estimated location of the missing Malaysian Airlines flight MH370.”
In the situation depicted in Figure 2 the positions and velocities of the two satellites are given by

\[
p_1 = \begin{bmatrix} \sqrt{2ah + h^2} \\ a \end{bmatrix}, \quad v_1 = \frac{GM}{(a + h)^2} \begin{bmatrix} -a \\ \sqrt{2ah + h^2} \end{bmatrix}
\]

\[
p_2 = \begin{bmatrix} 0 \\ a + h \end{bmatrix}, \quad v_2 = \frac{GM}{(a + h)^2} \begin{bmatrix} -1 \\ 0 \end{bmatrix}
\]

where \(a\) is the Earth’s equatorial radius, \(b\) is the satellite’s altitude, \(G\) is the gravitational constant and \(M\) is the mass of the Earth. In determining the satellite’s speed we have used the fact that for circular orbits \(v_e = \sqrt{GM/(a + h)}\). If a receiver is stationary in the Earth centred Earth fixed (ECEF) coordinate system (denoted by \(x\) and \(y\) in Figure 2) then \(r' = [0,a]\) and its velocity is \(v'_e = \omega_e [-1,0]\) where \(\omega_e\) is the Earth’s rotation rate.

As the speed of the satellite and the receiver are significantly less than the speed of light, the Doppler shift formula can be approximated by

\[
\Delta f \equiv f_r - f_e \approx \left(-\frac{u^T v_r}{c^2} + \frac{u^T v_e}{c^2}\right) f_e
\]

The transit satellite emitted a signal at a frequency of about \(f_e \approx 450\) MHz and were in an orbit about 1.075 km above the surface of the Earth, which corresponds to a Doppler shift of 8696 Hz for the satellite at \(p_1\) and 0 Hz for the satellite at \(p_2\).

Lines of constant Doppler shift are shown in Figure 3, the blues lines correspond to constant Doppler shift frequency for the satellite at \(p_1\), and the red lines to constant Doppler shift for the satellite at \(p_2\). We can see from this figure that the predicted Doppler shifts intersect at the receiver’s true location, signified by the filled triangle.

**Figure 2:** Diagram of the positions of two TRANSIT satellites in equatorial orbits.

**Figure 3:** Lines of constant Doppler shift in a region denoted by the shaded area in Figure 2. The filled triangle is the true receiver location.

TRANSIT operated as a global navigation satellite system (GNSS) for 32 years and was eventually replaced by the global positioning system (GPS). GPS uses a combination of time delay and Doppler shift to determine the receiver’s location from the known satellite locations.

It would be hard to overstate the impact GNSS has had on our lives. These days we expect to be able to determine our location to within a few metres wherever we are in the world. The technology is so pervasive that it is not only used for navigation in aeroplanes and cars but we now expect most modern phones to also be GPS receivers.

The fact that GPS receivers use the Doppler effect to help determine their location should be emphasised when that topic is taught. Furthermore we need to highlight that physicists are employed to design these systems and that such careers are the optimal combination of being both interesting and rewarding. Global satellite navigation systems have been developed by other countries, such as the Russian GLONASS, the European Galileo and the Chinese Compass. With Australia’s new space research program there may be even more career opportunities for Australian physicists.

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AUTHOR BIOGRAPHY

Sam Drake is a senior research scientist at the Defence Science and Technology Organisation (DSTO), an adjunct associate lecturer at Adelaide University, and on the editorial board of the American Journal of Physics. He completed his undergraduate degree at Melbourne University, his PhD at Adelaide University, and did post-doctoral research at the Padua University, Italy.


Conferences 2015

13-17 April 2015
3rd International Workshop on Rock Physics (3IWRP), Fremantle, WA 6160
info@3iwrp.org

15-17 May 2015
Astronomy from the Ground Up Teacher Workshop
Parkes Radio Telescope, NSW

18-22 May 2015
VIII Southern Cross Conference Series: Multiwavelength dissection of galaxies. Sydney, NSW

8-10 July 2015
13th Australasian Environmental Isotope Conference
Sydney, NSW 2000

19-23 July 2015
2nd Asia-Oceania Conference on Neutron Scattering Saturday, Manly, NSW
www.aocns-2015.com/

19-23 July 2015
IEEE International Conference on the Properties and Applications of Dielectric Materials (ICPADM). University of NSW, Sydney
www.icpadm2015.org

20-24 July 2015
The 10th Principles and Applications of Control in Quantum Systems (PRACQSYS) Workshop 2015, UNSW, Kensington, NSW

17-21 August 2015
Elizabeth and Frederick White Research Conference: Quantum astronomy and stellar interferometry: celebrating the 5th anniversary of the Narrabri Stellar Intensity Interferometer
Darlington Centre, University of Sydney, NSW 2006

13-17 September 2015
IBIC 2015 - International Beam Instrumentation Conference
Melbourne Convention & Exhibition Centre, Vic
ibic2015.org

31 August - 4 September 2015
Conference on Laser Ablation (COLA) 2015
Pullman Cairns International Hotel, Cairns, Qld
cola2015.org/

17-24 October 2015
ICALEPCS 2015: International Conference on Accelerator and Large Experimental Physics Control Systems
Melbourne Convention & Exhibition Centre, Vic

25-30 October 2015
ADASS XXV: The 25th Annual Astronomical Data Analysis Software & Systems Conference
Rydges World Square, 389 Pitt Street, Sydney NSW 2000
http://www.caastro.org/event/2015-ADASS

7-11 February 2016
International Conference on Nanoscience and Nanotechnology
 ICONN2016), National Convention Centre, 31 Constitution Avenue, Canberra, ACT
http://www.ausnano.net/iconn2016/
Cellular model of tissue growth could shed light on metastasis

A simple yet potentially very useful model of how living cells interact to create tissue has been created by Anatolij Gelimson and Ramin Golestanian of the University of Oxford in the UK. The simulation considers how individual cells in a colony are simultaneously drawn together by chemical signalling and driven apart by cell division and death. The research suggests that below a certain rate of division and death, the colony tends towards a compact and tissue-like steady state. Above this optimum rate, however, the cells spread increasingly far apart. Although the researchers stress that the model is highly schematic, they hope it could one day provide insights into what causes cancer cells to spread around the body.

As they grow, living cells communicate with each other by excreting chemicals that attract or repel neighbouring cells – a process called chemotaxis. While some bacteria and other single-celled organisms can respond to these chemicals by swimming, the cells that make up the tissues in our bodies move by complex mechanisms that are not well understood. The rate at which the cells move depends on the concentration of the chemical signal in the surrounding environment. Cell movement is also affected by the local density of cells, with cells moving from regions containing lots of cells – such as the bulk of a tissue – to regions with fewer cells, such as the surface of a tissue. This means that the faster the cells divide and die, the faster the cells will expand outwards from the surface of the tissue.

Dark matter seen in the Milky Way’s core

An international team of astronomers has found the best evidence yet that the inner core of the Milky Way contains significant quantities of dark matter. The result confirms the long-standing belief that the centre of the Milky Way is rich in dark matter, just like its outer regions. While the researchers have deliberately avoided using any specific models of dark matter in their analysis, they are confident that further studies of the galactic core could help identify which models are most viable.

Scientists first inferred dark matter’s existence from the fact that galaxies such as the Milky Way rotate faster than would be expected if they were held together by just the gravitational forces between visible matter such as gas, dust and stars. While it is apparent that the gravitational attraction of invisible dark matter is holding galaxies together, it has proved very difficult to measure the distribution of dark matter in the core of the Milky Way. This is because the complicated distribution and dynamics of conventional matter in the core makes it very tricky for astronomers to work out exactly where the dark matter should be.
In the new research, Fabio Iocco of the ICTP South American Institute for Fundamental Physics in São Paulo and colleagues in Sweden and the Netherlands have combined data from several recent observations of the Milky Way and compared it with theoretical predictions of how fast the core should be rotating.

The team calculated the difference between the observed and theoretical rotation curves at a large number of different radii between 3–20 kpc. Differences are seen at all radii and although the statistical significance is relatively small at 3 kpc, it rises to above 5σ beyond 6–7 kpc.

This result means that there are significant quantities of dark matter well inside the 8 kpc radius of the Milky Way, provided that Newtonian dynamics holds true. This last qualification is crucial, because a minority of astrophysicists argue that the discrepancies between predicted and observed rotation curves are better explained by modifying Newtonian dynamics at large distances, rather than the presence of invisible matter. The researchers believe, however, that by examining the galactic dynamics on comparatively small scales, their results will shed some light on this debate. Indeed, the team plans to address this issue in the future.


Extracted with permission from an item by Tim Wogan at physicsworld.com

New optical fibre shortens laser pulses the easy way

A simple and efficient way of creating ultrashort infrared laser pulses has been unveiled by an international team of physicists. The technique reduces the length of a pulse by simply passing it through a specially structured, low glass fibre filled with a noble gas. The researchers say that the new method should make it easier for laboratories to produce pulses for studying chemical reactions on very short timescales.

The details of chemical reactions are often studied by “pump–probe spectroscopy”. This involves firing an attosecond-long (10–18 s) “pump” X-ray pulse at a sample to activate a reaction, followed a tiny fraction of a second later by a second, “probe”, pulse. By measuring the interaction between the probe pulse and the reacting chemicals, researchers can gain insight into the state of the reaction at the time it was hit by the probe. By varying the time gap between the pump and probe pulses, the progression of the reaction can be mapped out in time. Similar attosecond pulses can also be used to measure interactions between electrons in a molecule.

Attosecond pulses are produced in the lab by a process called high-harmonic generation. This involves firing an intense infrared laser pulse into a gas, where its powerful oscillating electric field drags electrons away from their atoms. The electrons then snap back to the atoms, producing an attosecond X-ray pulse.

The process of high-harmonic generation requires ultrashort infrared pulses that are no longer than one cycle of the average frequency of the infrared light – longer infrared pulses will produce ill-timed sequences of attosecond pulses. This means that the infrared pulse needs to be less than about 5 fs (5 × 10–15 s) in duration. Such extremely short pulses cannot be produced directly by conventional lasers because confining light energy into such a narrow time interval requires a source that delivers light over a wide range of frequencies – something a laser cannot do. Instead, sophisticated and expensive optical equipment is used to shorten pulses from an infrared laser.
Now, scientists at Vienna University of Technology, together with colleagues in France, Germany, the UK and Russia, have demonstrated a simple and ingenious technique for compressing the energy in an infrared pulse into a single cycle. Ironically, the technique works because of dispersion, which usually causes pulses to spread out in time. In most materials, dispersion causes light at low frequencies to travel faster than higher frequency light. However, in materials with “anomalous dispersion”, light at higher frequencies travels faster than its low-frequency counterpart.

The researchers took advantage of these two types of dispersion within an intricate “kagome optical fibre”. The central portion of the fibre is a void that is filled with a noble gas such as argon or xenon and has normal dispersion. This region is surrounded by a delicate kagome structure that resembles woven fabric – kagome is a traditional Japanese basket weave – and has anomalous dispersion. The combined effect of both regions on an 80 fs infrared pulse passing along the fibre is to squash all its energy into just 4.5 fs. Indeed, using the kagome fibre, the team could produce an output pulse with peak power of more than 1 GW, which is enough to pull electrons away from atoms.

The researchers focused their shortened pulses on a sample of xenon gas and used an interferometry technique to observe the movement of the individual electrons as they were torn away from the atoms. From these measurements the team was able to show that the pulses contained only one cycle of the infrared field. [T. Balciunas et al., Nature Communications, 6, 6117 (2015); doi:10.1038/ncomms7117]

Extracted with permission from an item by Tim Wogan at physicsworld.com

**Photons simulate time travel in the lab**

Physicists in Australia claim to have simulated time travel using fairly standard optical equipment on a lab bench. They say they have prepared photons that behave as if they are travelling along short cuts in space–time known as “closed time-like curves”, and add that their work might help in the long-sought-after unification of quantum mechanics and gravity. Others, however, argue that the research does little or nothing to establish whether time travel is possible in nature.

Although everyday experience suggests the impossibility of travelling backwards or forwards in time, Einstein’s general theory of relativity does not rule it out. The theory allows for loops in space–time called closed time-like curves that could be created by very powerful sources of gravity such as black holes. These structures would bring an object back to a place and a time that it had already passed through, typically via a short cut between the two separated regions of space–time known as a wormhole.

In classical physics the existence of closed time-like curves would lead to a number of paradoxes. One of the best known of these is the grandfather paradox, in which someone who has travelled backwards in time kills their grandfather while he is still young, thereby preventing their own birth. In quantum mechanics, however, such paradoxes can be avoided.

The quantum-mechanical equivalent of the grandfather paradox involves a subatomic particle that has two states – one and zero – corresponding to “alive” and “dead”. The paradox emerges if the particle started out in state one, travelled backwards in time, met a younger version of itself and then flipped the value of its earlier self to zero.

But in 1991 David Deutsch of Oxford University showed that the probabilistic nature of quantum mechanics comes to the rescue. Deutsch found that there would always be a state that a quantum particle could assume that would make the particle’s trip back in time a safe one. For example, if the particle were to start out in an equal mixture of one and zero, when flipped it would remain in that state – a 50:50 mixture of one and zero.

**Caught in a loop: has time travel been simulated?**

Martin Ringbauer and colleagues at the University of Queensland in Brisbane set out to reproduce Deutsch’s model in the laboratory. But given the absence of any real closed time-like curves in the vicinity of their lab, they were not able to directly study the interaction between younger and older versions of the same quantum
particle. Instead, they used two separate particles. The idea is that the “younger” particle remains in normal space–time, while the “older” one disappears down a simulated wormhole, reappears in the “past” and then interacts with its junior partner.

To implement their scheme, the team generated pairs of single photons by shining a laser beam through a nonlinear crystal. The younger photon was encoded by polarizing it – with horizontal polarization representing zero, vertical polarization representing one and intermediate polarization representing superpositions. That photon then interfered with its older partner in a beamsplitter, and the outcome was recorded by a pair of detectors.

One of these detectors constitutes the entrance to the “wormhole” and is used to record the state of the older photon to ensure that it is in the same state as it is at the beginning of the experiment – the point at which it emerges from the wormhole. In this way, the scheme satisfies the “consistency condition” that Deutsch imposed on his model to remove the paradoxes from time travel – that whatever goes into a wormhole emerges from it unchanged.

Encoding the younger photon arbitrarily with one of 32 different polarizations and fixing the state of the older photon to satisfy the consistency condition, the researchers showed that they could indeed meet this condition.


Extracted with permission from an item by Edwin Cartlidge at physicsworld.com.
BOOK REVIEWS

**MASKELYNE Astronomer Royal**
Edited by Rebekah Higgitt
Hardback, 208 pages

Reviewed by Emeritus Professor Paul Edwards, University of Canberra

This timely book follows, somewhat belatedly, a one-day symposium held in the National Maritime Museum (NMM) at Greenwich to mark the 2011 bicentenary of the death of the 5th Astronomer Royal, the Rev Dr Nevil Maskelyne, also the 250th anniversary of his 1761 voyage to St Helena to observe the transit of Venus. This year marks the 250th anniversary of Maskelyne’s appointment as Astronomer Royal by George III in 1765, a position he held for 46 years until his death.

Maskelyne has become a controversial figure in recent years, due in part to Dava Sobel’s portrayal of him as the villain of the piece in *Longitude*, her colourful version of the life and times of clockmaker George Harrison, marine chronometer pioneer. This book presents professional counter-narratives to Sobel’s popular misrepresentation of the development of the marine chronometer and the role and character of the 5th Astronomer Royal.

The book is edited by symposium organiser Rebekah Higgitt, now lecturer in the history of science at the University of Kent and a former NMM curator. It draws upon preliminary research into the history of the Board of Longitude currently being undertaken jointly by the NMM and the University of Cambridge under the direction of Professor Simon Schaffer, supplemented by the 2013 release of digitised archival material held at Greenwich and Cambridge. It comprises eight chapters, each by a different author, interspersed with concise, well researched “Case Studies” prepared by the editor.

In Chapter 1, *Revisiting and Revising Maskelyne’s Reputation*, Dr Higgitt examines how Maskelyne’s posthumous reputation has changed in the two centuries since his death. She concludes with the observation that “Maskelyne was unfairly maligned in Sobel’s account” and that, with the success of such popular narratives, “the casualty is the hard work of historians of science.” a view shared with other professional historians such as Professor John Gascoigne of the University of NSW.

Other chapters and case studies deal with Maskelyne’s role as an applied scientist (in the modern sense), working at the intersection of astronomy, navigation and scientific exploration, and his personal, professional and institutional relations. His role as founder and life-long editor of the *Nautical Almanac*, originally introduced to promote and facilitate the determination of longitude by astronomical means, is outlined, also his scientific and logistic support of Cook’s voyages.

This book helps to place Maskelyne alongside other European scientists associated with the early exploration of Australia and New Zealand. The names of botanists Daniel Solander, Robert Brown (of Brownian motion fame), Jacques Labilladière, and the avid collector and long-time Royal Society president Joseph Banks, are well known in this context. Not so well known is the scientific work of Maskelyne, “the seaman’s astronomer”, in underpinning Cook’s three voyages and those of other explorers and traders. Chapter 5, *Maskelyne’s Time*, also makes it clear that, far from opposing the introduction of marine chronometers for longitude measurement, he enthusiastically encouraged and supported their continued improvement.

I found one of the most interesting chapters to be *The Tempestuous Relationship between Nevil Maskelyne and Joseph Banks*. It addresses the uneasy professional and personal relations between the two men. Inevitably, it also deals with the bitter conflicts within the Royal Society between the professional mathematicians and natural philosophers (like Maskelyne, Cavendish and Hutton) on the one hand, and the natural historians (like Solander and Banks himself), on the other.

Overall, this book, an early outcome of The Longitude Project, is worth reading for its insights into 18th and 19th century British science, its re-examination of Maskelyne’s professional and personal life, and as a counterfoil to oversimplified popular accounts of the development of the marine chronometer. Hopefully there is more to come from this project.

**Book reviews & reviewers**

*Have you read a book recently that might be of interest to other members?*

Members are invited to submit reviews of books they have read for publication in the Book Reviews section of *Australian Physics*.

There is a backlog of books (some on specialised topics, others popularisations) for review. If you are interested in reviewing a book, contact the editor (aip_editor@aip.org.au) indicating your areas of interest.
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*HASS: Highly Accelerated Stress Screening

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Delivering over 2 W of sub 70 fs pulses at 1055 nm, the Fidelity fibre oscillator opens up a broad range of scientific and commercial opportunities in applications as diverse as optogenetics, terahertz generation and fundamental material research. Of course, for ultrafast pulses to be most effective in these types of applications, they must maintain their pulse width (maximum peak power) on target. By incorporating a user-adjustable dispersion compensation into the laser head, Fidelity delivers the shortest possible pulses to the sample.

For more information about these items please contact our ultrafast laser specialist: Dr. Dale Otten, dale.otten@coherent.com.au

For further information please contact Coherent Scientific at sales@coherent.com.au

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LASTEK

Flame: Next Generation Miniature Spectrometer from Ocean Optics

Ocean Optics has launched a spectrometer line that combines decades of miniature spectrometer design expertise with industry-leading manufacturing techniques. The Flame spectrometer delivers high thermal stability and low unit to unit variation without compromising the flexibility and configurability that are the hallmark of modular, miniature spectrometers. Features such as interchangeable slits, indicator LEDs and simpler device connectors provide great flexibility for a wide range of UV-Vis applications including OEM integration and lab, industrial and field use.

The Flame is fully configurable across the 190-1100 nm wavelength range for use in absorbance, transmission, reflectance, irradiance and colour applications. Spectrometers come preconfigured or custom configured, with interchangeable slits that enable users to adjust resolution and throughput on demand. For example, the user can reconfigure the same spectrometer from high resolution for absorbance to high throughput for fluorescence in seconds. To further increase measurement power, the Flame works seamlessly with the Ocean Optics range of light sources, optical fibres, sampling accessories and software.

Ekspla LightWire FF3000 Series
femtosecond fibre laser

Ekspla’s LightWire FF3000 femtosecond laser provides optimal solution for the applications where power of the standard femtosecond oscillators is not enough. Flexible repetition rate and higher pulse energy can give your non-linear experiments a required boost to achieve better results. Single box configuration makes the system very easy to install and operate.

LightWire FF3000 series femtosecond fibre laser features up to 4 W output power, < 300 fs pulse duration and 40 MHz repetition rate. Features:
- Up to 4 W output power
- Up to 1 µJ pulse energy
- Repetition rate from 1 MHz to 40 MHz
- 300 fs pulse duration
Quantum Composers DPSS Jewel Laser Release

Quantum Composers has announced that it will be releasing a series of diode pumped solid state lasers. The Jewel Laser is a rugged, Q-switch, Nd:YAG, DPSS laser with a compact, monolithic design. Reliable, lightweight, compact, with easy to swap components, the Jewel is ideal for commercial and OEM applications. The Jewel is just 6 inches long and weighs only 2.5 lbs, becoming one of the smallest, lightest, diode pumped lasers in its class. The Jewel will reduce the space and weight limits on laser systems and with its swappable resonator, downtime and production costs are reduced dramatically.

Created with extensive Built-In-Test, the USB or optional Bluetooth wireless interface may be used for programming and running diagnostics without ever touching the system, making it perfect for clean room applications. This unique option allows the user digital diagnostics and the ability to fire the laser remotely. With self-diagnosing software, the user can easily determine exactly where components have failed. With swappable resonators and diodes that can be replaced quickly and efficiently with minimal adjustment/alignment, users will be able to save time and money.

This laser will also be used for LIDAR, PIV, LIF, OPO, TFT-LCD repair, ablation and mass spectroscopy applications.

For further information please contact: Jeshua Graham, jeshua@lastek.com.au

For more information please contact Lastek at sales@lastek.com.au

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WARSASH SCIENTIFIC

All New ILT5000 Research Radiometer & Picoammeter

Warsash Scientific are pleased to announce the release of the all new ILT5000 Research Radiometer & Picoammeter from International Light Technologies (ILT), a leading designer and manufacturer of light measurement and detection systems.

The ILT5000 is “The ILT1700 for the 21st Century” improving on the industry standard with rapid measurements (up to 100 Hz), a broader dynamic range (100 fA to 1 mA), extensive supporting software apps, wireless communication, internal data storage, and a 4-20 mA output.

The broad linear dynamic range of the ILT5000 and the SMA input connector allow the meter to also serve as a highly sensitive and accurate picoammeter. The ILT5000 supports numerous light measurement applications including, but not limited to: Radiometry, Photometry, Research, UVGI-Sterilization, Solar, Photosist, Optical Radiation Hazard, Phototherapy, Photo-degradation, Plant Growth and more.

Key new features of the ILT5000 include Wireless, USB and 4-20 mA output, broader calibrated dynamic range, faster data transfer and easy-to-use software. Sys-
tem configurations are based on the industry standard ILT1700 Research Radiometer/Photometer.

The ILT5000 is backwards compatible with the ILT1700 “D” type sensors, as well as all of ILT’s vast supporting filters, input optics, integrating spheres and ISO 17025/NIST traceable calibrations.

The ILT5000 also doubles as a highly accurate picoammeter and has a SMA connector to allow connection of any current generating source including non-ILT photodiodes and sensors.

The ILT5000 is supplied with 4 versions of complementary software designed to cover a wide range of applications. A full API and LabVIEW™ start-up code are available for customers who want to write their own control software. The software and ILT5000 are produced in the USA at ILT’s Peabody, MA facility which allows ILT to rapidly customize system components to meet the needs of their customers and OEMs.

New Q-Motion Range of Miniature Positioning Stages

Warsash Scientific are pleased to announce the release of the Q-Motion series of miniature positioning stages from PI (Physik Instrumente).

The Q-motion product line, incorporate a piezoelectric inertia direct drive designed by PI. This allows for very compact size, self-locking at rest with maximum force and nanometer resolution. The Q-Motion stages will be available as

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An idea for an article?

It could be about:

• your area of physics
• an unusual career for a person trained as a physicist
• an Australian company that grew out of physics research
• physics education,

i.e. anything that might let the physics community know about physics-related activities in Australia.

Suggestions for articles, and offers of authorship would be greatly appreciated. Contact the editor: aip_editor@aip.org.au
It is with the greatest of sadness that we mourn for Professor George Collins, who died suddenly and unexpectedly, at the age of fifty-nine on 15th November 2014. George was universally respected as a physicist, materials engineer, manager and leader, and by many of us as a friend. He was a member of the Australian Institute of Physics, and a former president of our sister society Materials Australia. At the time of his passing, George was Deputy Vice-Chancellor for Research and Development at Swinburne University of Technology in Victoria.

George studied physics at Sydney University, and did his PhD in plasma physics under the supervision of John Lehane. He then took off to the Centre for Plasma Physics Research in the École Polytechnique Fédérale de Lausanne in Switzerland and stayed there five years, before returning to Australia in the plasma fusion program and ANSTO. Soon afterwards, the Fusion research group was disbanded, and a new group formed using Plasma Physics for the purpose of modifying materials. This became the PI3 (plasma ion immersion implantation) group – through which George and John Tendys gained international recognition. But there was a minor set-back on Friday 13th 1992, with a fire in the lab – this was unprecedented at ANSTO, but the insurance payout meant the lab could be rebuilt in a new location, with the view to building a prototype of an industrial machine. George went on to lead this new group which built and sold PI3 systems worldwide. George was renowned at Plasma conferences for sitting at the piano after the conference dinner, taking requests and ending up running an all-in sing-along.

George soon came to the attention of the ANSTO senior management, due to something he coordinated called "the Pricing Review", which was Commonwealth government gobbledegook for something or other, which was at the time incredibly important. Anyway, he impressed ANSTO CEO Helen Garnett so much that when Adam Jostsons retired, George was plucked out from relatively low in the organisation to lead its most important division – Materials and Engineering Sciences. He was a "young-gun" back then and many of us still think of him as the soccer-playing, rogain-ing, deep-ocean sailing athlete – the eternal youth. He seemed (and seems) ageless with that boyish smile and a cheeky twinkle in his eye. But it is rumoured that George only applied for the Division Director job as a dare!

And then, on his very first day as Division Director, ANSTO was just about to clear the site for the new OPAL Reactor, when Greenpeace climbed over the back fence and hung a big banner on the old HIFAR Reactor, with TV crews coordinated to watch our embarrassment. Everyone evacuated the site, while the Security people and Police figured out what to do. So George simply held his first all-of-Division meeting in the open air, on the grass, by the swimming pool.

In spite of this, George succeeded in the position and rose to ever-higher levels of management. His final job at ANSTO was that of Chief of Research, as part of a triumvirate senior management team. He then left Sydney to become the CEO of the CAST-CRC based at the University of Queensland for 4 years (2008-12), which pursued industrially related research in light metals. Then he moved to Swinburne University of Technology in Victoria, where he spent his final two years as DVC Research and Development and contributed to research in the Australian Higher Education system through his membership of the Universities Australia DVCR Committee. Aside from his presidency of Materials Australia, George was for many years on the executive of the Australian Institute of Nuclear Science and Engineering. He also played a key role in growing closer links between ANSTO and both CSIRO and DSTO, and was a key player in setting up the Defence Materials Technology Centre, a kind of CRC for defence-related materials engineering.

By any account a highly successful career that ended far too soon.

We pass our sincere condolences on to his wife Evelyn and three children Chris, Elodie and Alexi.

Rob Robinson and Ken Short (ANSTO), Andrew Cheetham (University of Western Sydney)
James (Jim) Dumitru Mitroy, Professor in Physics at Charles Darwin University in the Northern Territory of Australia, unexpectedly passed away on August 28th, 2014 at the age of 57. Best known for his proof of the existence of positronic atoms, Jim published nearly 200 papers, and was still in full scientific flight at his end. A creative scientist with incredible capacity for work, Jim was one of the most formidable theoretical atomic, molecular and optical physicists of his generation.

Jim was born in Toorak, Melbourne on the 16th February 1957, to Nicolae Mitroy, a post-World War II refugee from Romania, and the late Dora Steele, a fourth generation Australian. Raised in a family of modest means, he won scholarships to attend The University of Melbourne. He received a first-class honours degree, and completed a PhD there on studies in atomic structure and (e,e') reactions between 1978-1983 under the supervision of Ken Amos. He took up postdoctoral research associate positions, first at Flinders University (1983-1986) with the late Ian Ellery McCarthy, then at JILA (1986-1988) with David W. Norcross, and thirdly as a Research Fellow at the Australian National University (1988-1989).

In 1989 Jim was hired as a lecturer by the fledgling University College of the Northern Territory in Darwin. The U.C.N.T. became the Northern Territory University and then Charles Darwin University. Along with the two other physics lecturers there, Jai Singh and Steve Shanahan, Jim was instrumental in establishing an undergraduate physics programme (which was short-lived due to the small number of physics students in the Northern Territory). Jim's distinctive manner of personal deportment was noted by all, and won him many fast friends. Jim managed to mostly avoid becoming, as he called it, 'a suit'. Amongst his most enjoyable such roles, however, was when helping graduate students as the Associate Dean of Research and Postgraduate Studies and as the University's representative on the Australian Council of Deans and Directors of Graduate Studies and the Australian Institute for Nuclear Science and Engineering.

In the early 1990's Jim began working on antimatter-matter interactions, the subject of his most noteworthy contributions to physics. On sabbatical with Andris Stelbovics at Murdoch University in 1993, Jim published a series of computational solutions to the collisions of positrons with atoms. His most striking physics discovery was that of positronic atoms. These atoms consist of positrons stably bound to neutral atoms (wherein they will eventually annihilate), analogous to negative ions where an electron is bound to a neutral atom. Although previous studies had suggested this possibility, in 1997 Jim and his postdoc Gregory Ryzhikh unexpectedly, yet variationally, computationally proved the existence of positronic lithium. Coincidentally, Krzysztof Strasburger and Henryk Chojnacki at the Wrocław University of Technology submitted a paper 19 days earlier proving the same result! This subject remains of current interest because, as of early 2015, no positronic atom has yet been seen in experiments. Jim was a core member of the Australian National Centre of Excellence for Antimatter-Matter Studies, which ran during 2006-2013, and he contributed broadly to its success.

In the past decade Jim moved relentlessly into studying photon-atom and atom-atom interactions. He was the leader of two separate collaborations that led to major review articles, one on atomic polarizabilities in 2010 and another on explicitly-correlated Gaussian basis functions in 2013. He had recently developed a fruitful scientific partnership involving regular visits to the atomic physics group of Ting-Yun Shi and Li-Yan Tang at the Wuhan Institute of Physics and Mathematics in Wuhan, China, whose hospitality he enjoyed immensely.

Jim was an idiosyncratic and sparkling character. He was first and foremost a consummate scientist who would not stand for anything but the best - and as many will attest, he took us to task when he thought we had things wrong or could do things better. He had a unique approach to educating his experimental colleagues - a combination of banter, badinage, and strangely appropriate Australian colloquialisms. He particularly liked to deliver his assessments to the students with a pointed, but always entertaining, twist. Jim's insight, formidable intellect, persistence, scientific rigour and wit will be sorely missed by all those colleagues who knew him.
THE 2016 BRAGG GOLD MEDAL
FOR EXCELLENCE IN PHYSICS

The purpose of the prize is to recognise the work done by a Ph.D. student in Australia that is considered to be of outstanding quality.

Background to the Award
The Bragg gold medal was established in 1992 as an initiative of the South Australian Branch, to commemorate Sir Lawrence Bragg (whose picture is inscribed on the medal) and his father Sir William Bragg.

Conditions of the Award
The medal is awarded annually to the student who is judged to have completed the most outstanding Ph.D. thesis under the auspices of an Australian university, whose degree has been approved, but not necessarily conferred, in the thirteen months prior to the closing date for applications to the State Branch (i.e., from the 1 June 2014 to the 1 July 2015). No candidate may be nominated more than once.

Nominations and Time Line
Each Australian university may nominate one candidate. These nominations must be submitted to Secretary of the local State Branch by 1 Jul 2015. An electronic copy of the selected nominations from the State Branches, accompanying documentation, should reach Olivia Samardzic, AIP Special Project Officer, by the 1 Sep 2015. The announcement of the winner shall be made by the end of Jan 2016.

Further information about these awards can be found at http://www.aip.org.au/ or obtained by phone on 0410 575 855 or by email from Olivia.Samardzic@dsto.defence.gov.au.

THE 2015 WALTER BOAS MEDAL
FOR EXCELLENCE IN PHYSICS RESEARCH

The aims of the award are to promote excellence in research in Physics in Australia and to perpetuate the name of Walter Boas.

Background to the Award
The Medal was established in 1984 to promote excellence in research in Physics and to perpetuate the name of Walter Boas (University of Melbourne 1938-47, CSIRO 1947-69). The award is for physics research carried out in the five years prior to the date of the award, as demonstrated by both published papers and unpublished papers prepared for publication, a list of which should accompany the nomination. Any AIP member may make nominations or may self nominate for the award. Information regarding the conditions of the award can be found at the AIP web site (see link below).

Time Line:
Nominations should be sent electronically to Olivia Samardzic, Special Project Officer olivia.samardzic@dsto.defence.gov.au by 1 July 2015.

Presentation of the Award
The award is conditional on the recipient delivering a seminar on the subject of the award at a meeting of the Victorian Branch of the AIP in November. The recipient is also expected to provide a manuscript based on the seminar for publication in Australian Physics.
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