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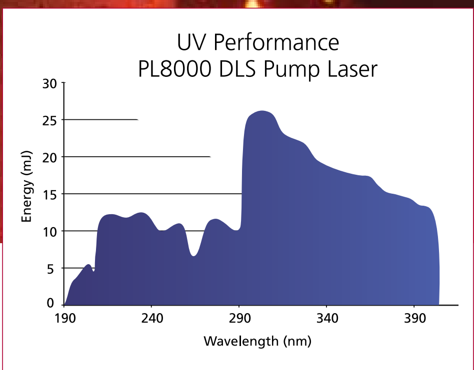

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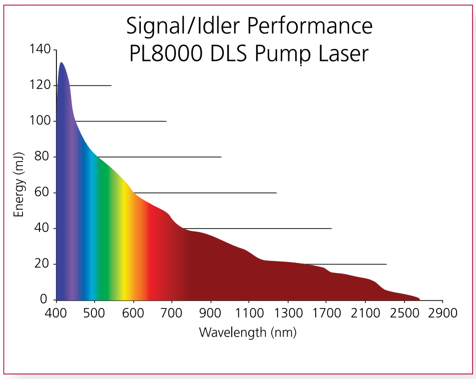

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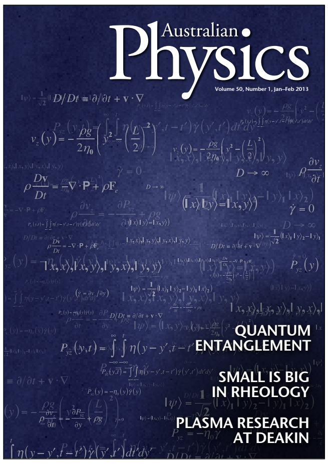

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EDITORIAL

Diversity

Welcome to the first issue of Australian Physics in our 50th Anniversary year.

You may have noticed that the Editor for Australian Physics has been a moving feast for the past few issues with Peter Robertson stepping down after issue 49-5 and Brian James (Chair of the Editorial Board) acting in the role for issue 49-6. Late last year Brian persuaded me to take on the role commencing with this issue and I must admit it is with considerable trepidation that I try to fill the very large shoes that Peter and Brian have vacated. I sincerely thank Peter Robertson, Akin Budi, Brian James and Marc Duldig for their support during the transition. This issue also marks several changes in the AIP Executive and Council – in particular Robert Robinson is taking over from Marc Duldig as President, Warrick Couch stepping up as Vice President and Joe Hope as Secretary.

Many if you will have attended the very successful AIP Congress in December and enjoyed the re-invigorating experience that comes from mixing with physicists from a wide range of disciplines and backgrounds. Personally, I was quite surprised by the diversity of physics represented and the quality of the sessions I was able to attend. Over the coming year we plan to publish articles relating to some of the plenary talks as well as items from the 2012 AIP Medal winners.

Continuing the trend set at the Congress, this issue contains 3 diverse articles:

The theme that has pervaded several recent issues relating how Australian physicists have played significant roles in various scientific developments is continued in this issue with the article from Frank Duarte (University of New Mexico) describing the largely unrecognised role played by Australian physicists in the development of the quantum entanglement probability amplitude equation for the polarisation of photons travelling in opposite directions.

Billy Todd (Swinburne University of Technology) provides an introduction to the field of Nanorheology which also serves to introduce one of our new cognate societies – The Australian Society of Rheology.

An overview of the activities of a newly-established plasma laboratory at Deakin University is given in the article by Jane Dai – the team leader. This team is developing non-equilibrium plasma technology for the production of functional surface/interfaces and fabrication/doping of nano-materials.

With continuing help through contributions from AIP members, we will endeavour to maintain the high standards set by the previous editorial team and provide you with articles and items of interest to the broad Physics Community in Australia in 2013 and beyond.

Tony Farmer

Happy New Year and Looking Forward to 2013

It is a great pleasure and honour to be the incoming president of the Australian Institute of Physics, and to be joined by Warrick Couch (of Swinburne University), the incoming Vice-President. We and the rest of the Executive are in these roles to serve the interests of you, our members, and to advance the cause of Physics in Australia. I recently had the privilege, part way through 2012, to show the Federal Minister for Science, Senator Chris Evans, around my own Institute, and we let slip that I would be assuming this role with the AIP – Senator Evans immediately quipped, "how on earth did you get sucked into that?" not without some admiration or appreciation, I think. I responded that "well, it's really community service, and an effort to put something back into society". And that is how I really see it, together with some nervousness about how much work will be involved.

For me, one of the highlights of 2012 was to help organise the recent Congress in Sydney. We had a large team of people, primarily from Sydney, the ACT and Melbourne, along with wonderful support from our professional conference organisers, Waldron Smith Management, who also provide the secretarial and administrative support for the AIP itself. One of my main roles was as overall Scientific Program Chair, and I got to know more about the wide range of physics activities, beyond my own interests in condensed-matter physics. I also got to know some of the key players in the other fields, primarily in greater Sydney but also in Melbourne and from the ANU. The cultures in the different fields of physics can be surprisingly different, something that I knew from my time at Los Alamos in the USA, but which is still sometimes a shock. I like to think that the Congress was a tremendous success, with around 850 registered attendees, a very modest surplus, and anecdotal feedback that was largely, but not entirely, positive. Certainly my own impression was very positive, and I am proud to have been so closely involved in this key event.

Since then, a number of physicists have been recognised in the 2013 Australia Day honours, most notably Brian Schmidt with Companion of the Order of Australia, and Bob Clark (former Chief Defence Scientist) with Officer of the Order of Australia. The Institute congratulates both.

My own journey in physics started in the home, with a father who worked on the boundary between physics and engineering with Ford Motor Company, and at school in London, where I loved mathematics, but found physics hard. I did both my bachelors and PhD degrees in the Cavendish Laboratory in Cambridge, interspersed with 3 years teaching science including physics to 11-18 year olds in the North of England. After Cambridge, I moved to Los Alamos in New Mexico to do a postdoc, and stayed there for 17 years. The move to Australia, in 1999, came as a consequence of the government's decision to build a new world-class research reactor on a green-field site in Sydney. The opportunity to help define things right from the beginning and to start a new Institute from scratch was simply too good to turn down.

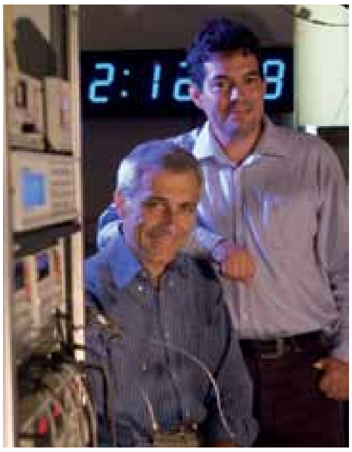
Of course, doing physics in a multi-purpose inter-disciplinary organisation like ANSTO, Los Alamos (or even industrial laboratories like Bell Laboratories in its glory days) is a bit different. Our present team at ANSTO also includes chemists, crystallographers, molecular biologists, engineers, computer scientists, earth scientists, and so on, all doing real research. Physics is actually part of a continuum, including all of the above along with all of materials science and overlapping into medicine and engineering. In practice, we often care little which professional label the practitioners actually use. I therefore believe in a "big physics" that asserts inclusion of all of this overlap. The alternative of a small "ivory-tower" of pure research will lead, I fear, to marginalisation of our subject. So I think that we need to be relentless in promoting ourselves to physicists (and others who are really doing physics) as broadly in society as possible.

Finally, I would like to thank the outgoing President, Marc Duldig, for his mentoring and friendship over the last two years – I will surely be reliant on his advice and counsel in the coming years. And it has also been a privilege to work with Brian James as well as Cathy Foley, who I suspect dobbed me in for this job!

Rob Robinson

NEWS & COMMENT

Alan Walsh Medal for 2012



The AIP's Alan Walsh Medal for Service to Industry for 2012 has been awarded to Laureate Fellow Michael Tobar and Winthrop Professor Eugene Ivanov of the University of Western Australia for their work on precision electromagnetic measurement. The award recognises their outstanding research in the development of ultra low noise sapphire microwave oscillators, and their contributions to, and continuing involvement in, the realisation of commercial applications of this technology. The Western Australian company Poseidon Scientific Instruments has commercialised the technology for applications in advanced radar systems. The award was accepted by Professor Tobar at the 20th AIP Congress in December 2012.

Professor Brian Schmidt awarded

We are proud to report that AIP member Professor Brian Schmidt was awarded Companion in the General Division of the Order of Australia (AC) in the Australia Day Honours List.

He was recognised "For eminent service as a global science leader in the field of physics through research in the study of astronomy and astrophysics, contributions to scientific bodies and the promotion of science education."

The Companion of the Order is awarded for eminent achievement and merit of the highest degree in service to Australia or humanity at large. The Companion is Australia's greatest civic honour.

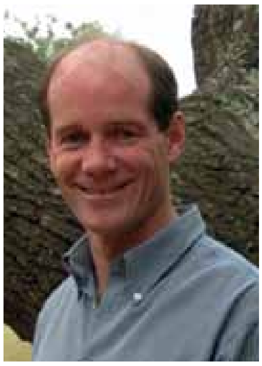
Brian's appointment is a testament to the outstanding achievements he has made in astronomical research as well as his tireless commitment to popularising science in our community and highlighting the importance of science education and research funding.

The Companion of the Order of Australia is a beautiful badge with a gold insignia of the Order in the centre. It will sit very well alongside Brian's Nobel Prize medal and the many other medals and awards he has received and richly deserved.

Physics Decadal Plan launched

The Physics Decadal Plan 2012-2021, Building on Excellence in Physics, Underpinning Australia's Future was launched on 6 December at the Australian Academy of Science. It presents the Australian physics community's strategic vision for the 10 years, from 2012–2021. The Plan will ensue that the process of strategic investment in teaching and research in physics in Australia continues for the next 10 years, allowing Australia to build on present excellence, to remain a strong member of the world's physics community and to enjoy the associated intellectual, economic and social rewards. The Plan was prepared by a working group under the auspices of the Academy's National Committee for Physics and chaired by Professor David Jamieson of the University of Melbourne. An electronic copy of the plan can be obtained from **www.science.org.au/natcoms/physicsdecadal-plan.html.** The plan itself is accompanied by a Research Report that includes all the data that was collected and used in developing the report.

The Harrie Massey Medal and Prize



The Harrie Massey Medal and Prize for 2012 has been awarded to Dr Anthony Murphy, a chief research scientist at CSIRO Materials Science and Engineering, for his "outstanding research in the field of thermal plasmas, in particular his work on computational modelling and measurement techniques and their application to the development of industrial processes". The biennial award, which is given jointly by the Institute of Physics and the AIP is made for contributions to physics or its applications. The award was presented to Dr Murphy at the 20th AIP Congress in December 2012.

NSW Science and Engineering Award

Professor Peter Robinson, from the School of Physics University of Sydney, has been awarded a NSW Science and Engineering Award for Emerging Research. The awards for 2012, announced in November recognise and reward the State's leading researchers in science and engineering

for cutting edge work that generates economic, health, environmental or technological benefits for NSW.

Professor Robinson received the award for pioneering work in the emerging area of physiologically-based quantitative brain modeling and its applications. The main areas are brain dynamics, sleep and alertness, networks and brain structure, and development of data and imaging analysis methods and technology. The research has succeeded in bringing hard-core theoretical physics techniques, such as field theory, wave physics and nonlinear dynamics, to bear on problems of practical interest in brain dynamics.

ANSTO to manage Australian Synchrotron

The Australian Nuclear Science and Technology Organisation (ANSTO) took on operational management of the Australian Synchrotron from 1 January this year. The Synchrotron, located in Clayton, Melbourne, is an integral part of Australia's critical scientific infrastructure serving thousands of Australian and New Zealand academic and industrial users. This follows the announcement by the Australian Government in March 2012 that the future of the Synchrotron had been secured through a $100 million, four-year funding arrangement between the Australian and Victorian State Governments.

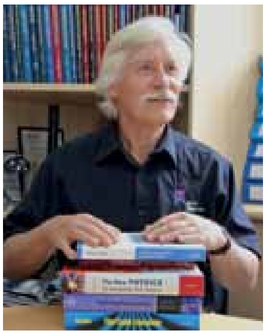
To ensure continuation of world-class science and innovation for Australia, New Zealand and regional partners, and finalise the integration process between ANSTO and the Synchrotron the following new appointees have been announced: Professor Andrew Peele, who has been appointed interim Director of the Synchrotron; Professor Michael James, who has been appointed interim Head of Science; and Michael Beckett, who has been appointed the General Manager of Operations.

Prof. Andrew Peele, interim Director

Prof. Michael James, interim Head of Science

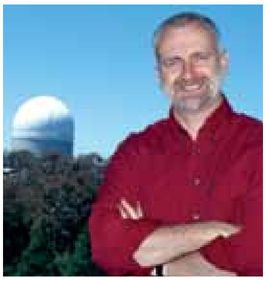
Michael Beckett, General Manager of Operations

New chair for National Committee for Physics



Professor Hans Bachor is the new chair of the National Committee for Physics of the Australian Academy of Science AAS. It is one of 22 national committees of the Australian Academy of Science. They foster a designated area or theme of (natural) science in Australia, provide liaison with appropriate international scientific bodies and advise the Council of the AAS on these matters. They respond to Council initiatives create their own initiatives. For 2013 the main priority is the implementation of the Decadal Plan of physics. Other members of the National Committee for Physics are Professor Nanda Dasgupta (ANU), Professor David Jamieson (Melb), Professor Ian McArthur (UWA), Professor Tanya Monro (Adel), Professor Rob Robinson (ANSTO) and Associate Professor Kevin Varvell (Syd).

New director of RSAA



Professor Matthew Colless, Director of the Australian Astronomical Observatory from 2004 to 2012, has been appointed Director of the Research School of Astronomy and Astrophysics at the Australian National University (ANU). Professor Colless obtained a BSc (Hons) at the University of Sydney in 1982 and his PhD at the University of Cambridge in 1988. He carried out research at Kitt Peak National Observatory, Durham University and Cambridge before returning to the ANU in 1993. In recognition of his work on the large-scale structure of the universe and galaxy evolution, Professor Colless was elected a Fellow of the Australian Academy of Science in 2004 and an Honorary Fellow of the Royal Astronomical Society in 2009. He currently serves as Vice-Chair of the Board of the Giant Magellan Telescope (GMT) project, a next-generation 25-metre optical telescope in which Australia has a 10% share. The Research School of Astronomy and Astrophysics is currently designing major elements of the adaptive optics system for GMT, as well as one of the first-light instruments.

Prof Warrick Couch appointed AAO Director

Professor Warrick Couch, currently the Director of Swinburne University of Technology's Centre for Astrophysics and Supercomputing, has been appointed Director of the Australian Astronomical Observatory (AAO).

One of the first priorities for Professor Couch as Director of the AAO will be to work with the Australian National University on the recovery of Siding Spring Observatory, which was recently ravaged by a major bushfire. While the AAO's two telescopes sited at the Observatory were unscathed, several buildings were damaged.. Professor Couch is Chair of the AAO Advisory Committee, a Fellow of the Australian Academy of Science, and Vice-President of the Australian Institute of Physics. Professor Couch will continue his association with Swinburne with an appointment as an Adjunct Professor.

2013 Pawsey Medal Awarded

Associate Professor Christopher Blake from Swinburne University of Technology's Centre for Astrophysics and Supercomputing has been awarded the 2013 Pawsey Medal by the Australian Academy of Science. Professor Blake received the award for his research into dark energy and the expansion of the universe. His particular expertise is constructing large maps of how galaxies are scattered through space, and determining what their distribution tells us about the physics of the universe, His contribution to the dark energy field over the last ten years has been to lead Australian-based research that exploits a different probe of dark energy that is independently sensitive to cosmic gravity, expansion and homogeneity. The Pawsey Medal is awarded annually 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.

Branch News

NSW

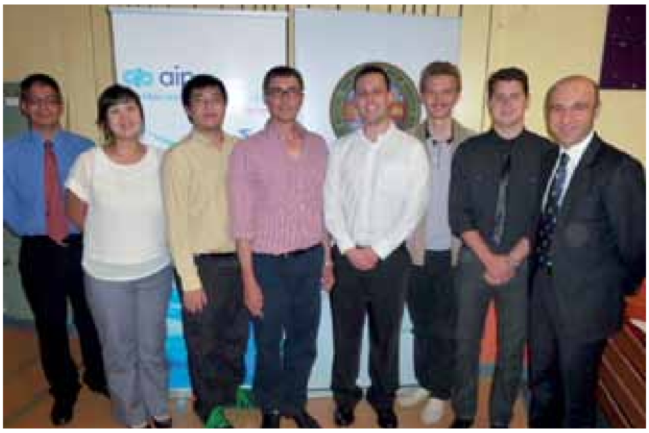
Australian Institute of Physics and the Royal Society of New South Wales Postgraduate Awards Day Report

The NSW Branch of the AIP in conjunction with the Royal Society if NSW held its annual Postgraduate Awards Day on Tuesday 20 November 2012 in the Slade Lecture Theatre, University of Sydney. Each New South Wales University was invited to nominate one student to compete for the $500 prize and Postgraduate medal on that day.

This year we would like thank the generous support of The Royal Society of NSW as the co-sponsor to award the Jak Kelly Scholarship prize of $500 as a separate award category for this event.

Students were asked to make a 20-minute presentation on their postgraduate research in Physics, and the presentation was judged on the criteria (1) content and scientific quality, (2) clarity and (3) presentation skills. The nominated speakers for 2012 were:

- **Andrew Ong**, University of New South Wales - *Single-ion Atomic Clocks using Highly Charged Ions: Detecting the Variation of Fundamental Constants*
- **Nick Cvetojevic**, Macquarie University - *From Photons to Planets: Finding a Second Earth using the Integrated Photonic Spectrograph*
- **Jung-Ha Kim**, University of Sydney - *Motion Correction in x-ray CT: First Practical Demonstration*
- **Peter Lazarakis**, University of Wollongong - *The biological effect of static magnetic field on irradiated cells*
- **Alexander Solntsev**, Australian National University - *Nonlinear Quantum Walks*



2012 Postgraduate Group Photo: Dr Scott Martin (AIP), Jung Ha Kim (USYD), Andrew Ong (UNSW), Dr Stephen Bosi, Peter Lazarakis (UOW), Alexander Solntsev (ANU), Nick Cvetojevic (MAQ), and Dr Frederick Osman (AIP Branch Postgraduate Coordinator)

The winner of the AIP Postgraduate Presentation for 2012 was awarded to Alexander Solntsev, Australian National University for his talk on Nonlinear Quantum Walks. Alexander received the 2012 Crystal Postgraduate figurine, and a $500 cheque from the AIP.

The winner of the Royal Society of NSW Jak Kelly Scholarship prize for 2012 was awarded to Andrew Ong, University of New South Wales for his talk on Single-ion Atomic Clocks using Highly Charged Ions: Detecting the Variation of Fundamental Constants.

Dr Frederick Osman with Mr. Andrew Ong (UNSW) - 2012 Royal Society of NSW Jak Kelly Scholarship winner

TASMANIA

The Tasmanian Branch has instituted the Ken McCracken Award for high performance in Physics Honours. The inaugural award, to Daniel A Macdonald was made at the Branch AGM in late November.

Following the award, Dr McCracken gave an interesting, and at times provocative, public lecture on Cosmic Ray and Solar Variability in the past 9400 years and some speculations about their origins. Ken, an Honours and PhD graduate of the University of Tasmania, has a habit of asking questions and seeing opportunities that no one else has thought worth considering. The ideas discussed in his talk originate from a paper by Dicke (1978) entitled "Is there a chronometer hidden deep in the sun?" Ken provided evidence from 10Be ice-core records and elsewhere that appear to support Dicke's hypothesis of long-lasting periodicities within the sun. He then went on to speculate about possible physical causes which might give rise to such effects. It's a complex situation and we'll watch further developments with interest.

Dicke, RH, (1978) Nature, **276**, 676-680

Conferences in Australia 2012-13

8–12 April 2013
2nd Heavy Ion Accelerator Symposium on Fundamental and Applied Science
Canberra, ACT
http://hias.anu.edu.au/2013/

6 - 9 May 2013
17th International Conference on the Use of Computers in Radiation Therapy
Melbourne Convention & Exhibition Centre, Vic

15-17 May 2013
CRCA Collaborate | Innovate | 2013 Conference – the Cooperative Research Centres Association conference
Melbourne, Vic
http://conference.crca.asn.au/

4-9 August 2013
21st International Symposium on Plasma Chemistry (ISPC 21)
Cairns Convention Centre, Qld
http://www.ispc21.com/

7-11 December 2014
21st Australian Institute of Physics Congress
ANU, Canberra, ACT

The probability amplitude equation of quantum entanglement: the Australian connection

F. J. Duarte

Interferometric Optics, Rochester, New York, USA
University of New Mexico, Albuquerque, New Mexico, USA

The origin of the ubiquitous quantum entanglement probability amplitude equation, for the polarisation of photons traveling in opposite directions, is described.

In a recent paper [1], originally written to explain the origin of experimental configurations to determine the quantum entanglement of photons traveling in opposite directions, the issue of the corresponding probability amplitude surfaced. As it turns out, Australian physicists J C Ward and R H Dalitz played key roles in this field, roles that are largely unrecognised, or unknown, by the physics community. Here, a succinct description of these crucial contributions is provided.

The initial discussion on the use of quantum theory to describe the polarisation correlation of quanta propagating in opposite directions was given by Wheeler in 1946 [2]: "According to the pair theory, if one of these photons is polarized in one plane, then the photon that goes off in the opposite direction with equal momentum is linearly polarized in the perpendicular plane." This is the essence of entanglement. The pair theory that Wheeler refers to is the Dirac theory of electron-positron pairs [3].

Ward in 1949 [4] mentions Wheeler's contribution and then continues to explain that Wheeler did attempt to calculate this effect *but* "through the neglect of interference terms he derived an incorrect, and in fact, far too small value for the angular correlations of the scattered quanta" [4]. Ward's thesis [4] includes the physics used to derive the quantum formula for correlated polarisations published by Pryce and Ward in 1947 [5] which was also independently published by Snyder *et al.* [6] in 1948.

Figure 1. J. C. Ward (1924-2000), one of the contributors to the Standard Model and the creator of the Ward identities. His momentous physics career began in 1947 with a brief paper in Nature that correctly predicted the polarisation correlation of entangled photons propagating in opposite directions. English born, and Oxford educated, John Ward first traveled to Sydney in 1947, returned a few years later to Adelaide, for brief period, and finally accepted a professorship at Macquarie in 1964. Between Adelaide and Macquarie, he had several positions in the United States and one in New Zealand. In later years, he traveled extensively with an Australian passport.

Ward's approach begins by listing the polarisation alternatives related to x and y polarisation axes related to two counter propagating photons: $|x,x\rangle, |x,y\rangle, |y,x\rangle, |y,y\rangle$ [4]. Here, the first coordinate refers to photon 1 and the second coordinate to photon 2. Eventually, Ward [4] arrives at the probability amplitude for entangled polarisations $|\psi\rangle = (|x,y\rangle - |y,x\rangle)$. Using the identity given by Dirac $(|x\rangle|y\rangle = |x,y\rangle)$ [7] , once normalised, this expression can be restated as

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|x\rangle_1|y\rangle_2 - |y\rangle_1|x\rangle_2\right) \qquad (1)$$

This is the probability amplitude used, to derive the polarisation correlation of two propagating quanta in opposite directions, by Pryce and Ward [5] and Snyder *et al.* [6].

Moreover, this is also the famous probability amplitude for entangled polarisations as utilised in optical EPR-Bell type experiments [8].

In his memoirs Ward [9] also mentions that, following the Price-Ward disclosure in *Nature* [5], a young Australian physicist, and Ward's friend, R. H. Dalitz independently derived these results and presented them at a seminar in Cambridge, late in 1947, thus making "quite a name for himself" [9] (Note: for the sake of completeness, Dick Dalitz is known in particle physics for the *Dalitz plot, Dalitz poles*, and the *Dalitz pair*).

In 1950, Wu and Shaknov [10] reported measurements on polarisation correlation of counter propagating photons which agreed, within ~ 2%, with the theoretical value applicable to the geometry of their experimental configuration. In their paper, Wu and Shaknov [10] explicitly state: "As early as 1946 J. A. Wheeler proposed an experiment to verify a prediction of pair theory, that the two quanta emitted in the annihilation of a positron-electron pair, with zero angular momentum, are polarized at right angles to each other... The detailed theoretical investigations were reported by Pryce and Ward and Snyder *et al.*" Further, in 1975 Wu and colleagues wrote: "the explicit expression for the probability of detecting a pair of scattered photons in this geometry... as in eq. (1) was first worked out by Pryce and Ward" [11].

Bohm and Aharanov [12] in 1957 state that the Wu and Shaknov [10] experiment is considered as an example of an EPR type experiment. When this interpretation was brought into question [13], Bohm and Aharanov rejected such criticism [14]: "In a previous paper [12] we have discussed the paradox of Einstein, Podolsky, and Rosen (EPR) [15], and we have shown that the Wu-Shaknov experiment [10]... provides an experimental confirmation of the features of quantum mechanisms which are the basis of the above paradox" [14].

It should be pointed out that current expositions of this subject begin with the EPR paper [15], followed with the 1957 paper of Bohm and Aharonov [12] that refers to the polarisation of two quanta, propagating in opposite directions, produced in an annihilation process (this paper [12] also includes the probability amplitude for the polarisation of entangled photons, in the form of equation (1)). Next, the famous paper of Bell [16] is mentioned followed by the literature of polarisation correlation measurements of photons.

In contemporaneous EPR research, relevant to optical experiments, the entanglement probabilities are derived from the polarisation probability amplitude given in equation (1). Then, it is shown that these probabilities do violate the relevant Bell-type inequalities [8].

This brings us to a possible explanation of why the excellent contribution to physics of Pryce and Ward [4, 5] has remained shrouded in obscurity for such a long time. First, and obviously, Pryce and Ward neglected to place their work in the context of EPR. Secondly, Ward neglected to publish in the open literature the explicit *bra-ket* quantum polarisation expressions included in his 1949 thesis and that he applied to derive his 1947 final result published in *Nature* with Pryce. In retrospect, this is not surprising given the reluctance of Ward to publish [17].

Beyond the EPR implications, and Bohm and Aharanov's interpretation, the experiment seeded from Dirac's ideas [3], discussed by Wheeler [2], illustrated and described with the correct quantum physics by Pryce and Ward [5] had all the ingredients of quantum entanglement as previously mentioned by Dalitz and Duarte [18]. On a broader perspective, the evidence presented here tends to indicate that the physics of quantum entanglement, as initiated by Dirac, discussed by Wheeler, and resolved by Pryce and Ward, and Snyder *et al.*, would still be here even in the apparent absence of interpretational questions.

Thus, the probability amplitude of entangled polarisations should be added to the other momentous J. C. Ward contributions to statistical mechanics, the Standard Model, and renormalisation theory. In this regard, the sentence: *He has drawn attention to fundamental truths, and has laid down basics principles, which physicists have followed... often without knowing it, and generally without quoting him* [19] is not hyperbole.

Note added in proof: it should be noted that the probability amplitude for entangled polarisations can also be derived, in addition to Ward's approach, using Dirac's notation, from a Hamiltonian approach and from an interferometric approach [20].

Figure 2. R. H. "Dick" Dalitz (1925-2006) the creator of the Dalitz plots, a tool of crucial importance to high-energy physics in the search of new particles, such as the Higgs boson. Born in Dimboola, Victoria, he was educated at the Universities of Melbourne and Cambridge. Late in 1947, while at Cambridge, Dalitz independently derived the probability amplitude of entangled polarisations for counter-propagating photons and the corresponding polarisation correlations and disclosed the results at a physics seminar [9]. Ward and Dalitz met sometime in the late 1940s and remained close friends for life. Dalitz spend most of his career at Oxford.

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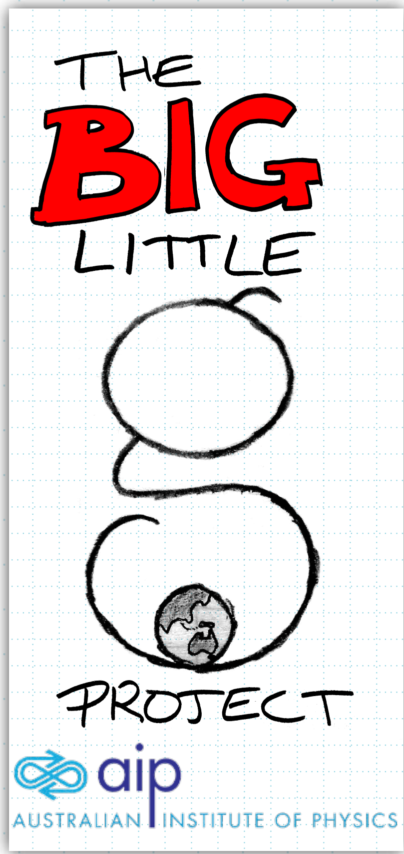
AUTHOR BIO

F. J. Duarte is a research physicist based in Western New York, USA. He has made key contributions to the physics and architecture of high-power tunable narrow-linewidth laser oscillators. This research allowed him to discover the generalized multiple-prism dispersion theory which is applicable to both tunable narrow-linewidth emission and laser pulse compression. He has also pioneered the use of Dirac's quantum notation in the description of *N*-slit interferometry and diffraction phenomena. Duarte is author and editor of several well-known books on tunable lasers. Presently, he is working on very large *N*-slit interferometers and on his new book *Quantum Optics for Engineers*.



As part of the celebrations for our 50th Anniversary, the AIP plans to involve school children around the country in what will be one of the largest (in terms of number of participants) physics experiments ever – measurement and mapping of the local variations in little g, the acceleration due to gravity.

In 1581, a young medical student was watching a chandelier moving. He noticed the regularity of its motion and realized that the period of its oscillation was more accurate than the most accurate time keeper he had available: his pulse. That man was Galileo Galilei, and his thirst for knowledge and free thought revolutionized science and society.

The motion of a pendulum is incredibly accurate, and the period of its motion depends on the length of the pendulum and acceleration due to the Earth's gravitational field. Because the Earth is not the same everywhere, this acceleration varies from place to place. We will be inviting students to measure the gravitational field across Australia using pendula – repeating Galileo's historic discovery.

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Small is Big in Rheology

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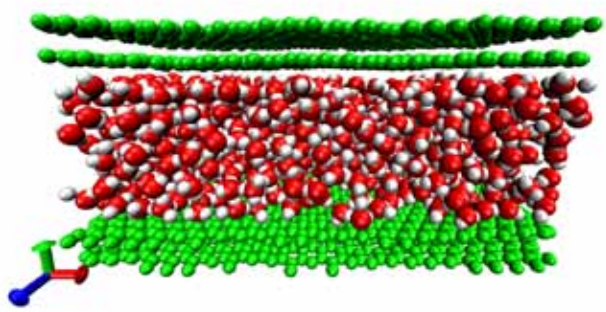
Rheology is the science of the flow and deformation of matter. Traditionally it has its roots in the dynamics of macroscopic fluids. However, as a major technological drive over the past two decades has been towards the miniturisation of devices, traditional rheology has likewise followed suit with significant new advances in both micro- and nano-fluidics. In the case of nano-fluidics, computer simulation – and particularly molecular dynamics – has become an invaluable tool in understanding the physics of flow at the molecular level. It has allowed physical insight into systems that experiment cannot yet resolve due to the confinement of such systems to nanometer length scales. It also allows us to detect and rectify errors in existing theoretical treatments dating back to the 19th century which break down at nanometer length scales. This article attempts to give a perspective of some of these challenges and solutions in a field that is rapidly gaining momentum and technological relevance.



A snapshot in time of a molecular dynamics simulation of water molecules confined to nanometre sized graphene slits. Image provided by S.K. Kannam.

INTRODUCTION

The Greek philosopher Heraclitus of Ephesus (536–470 BCE) is credited with the quote: *"Everything flows and nothing abides; everything gives way and nothing stays fixed."* In the 1920s the renowned American scientist Eugene Bingham, along with his equally renowned Israeli colleague Markus Reiner, drew inspiration from Heraclitus and coined the term "rheology" to depict that field of science dealing with the flow and deformation of matter ("rheos" being the Greek word for stream or flow). Thus the multidisciplinary field of science known as *rheology* was officially born, though of course scientists since the ancient Greeks and beyond had been practicing and trying to understand this science long before the name was ever coined.

Rheology has always been studied by diverse groups of people ranging from mathematicians interested in purely mathematical problems associated with solving the complex coupled differential equations describing the conservation laws of mass, momentum and energy, to industrial engineers whose primary interest is focused on practical and efficient technologies to transport sludge from mines, or recover oil from drill sites, or process polymer melts into cling wrap or the plastic chairs we sit on as we enjoy our barbecues, and the like. Whether the problem be purely abstract and mathematical, or highly applied and practical, the science is highly non-trivial and, in many instances, absolutely fascinating. For one thing, flow is not just confined to liquids and gasses. "Solids" can also flow, albeit on macroscopically large timescales, the most notable being glasses and gels. Furthermore, the molecular structure of the material under flow has an enormous impact on the properties of the flow. Liquid argon, for example, has a relatively simple Newtonian flow behaviour under experimentally accessible flow rates (i.e. the shear stress behaves linearly with the applied rate of strain and the fluid has a constant viscosity), whereas molten plastic or DNA, consisting of polymers of high molecular weight, are non-Newtonian in general (shear stress is a nonlinear function of applied strain rate and so has a viscosity that is a function of strain rate) and can display some rather surprising physical properties when under flow conditions. Examples of quirky non-Newtonian fluids include oobleck, which flows like a liquid yet acts like a solid when acted upon by a force, and flubber (yes, there really is such a substance, albeit inspired from a Hollywood film), which behaves as a flowing fluid under low stress conditions, yet breaks up like a solid under higher stresses. Most fluids are non-Newtonian in general and their nonlinear behavior as a function of strain rate can be used to practical advantage in many technological processes.

Up to about the 1980s rheology was largely focused on macroscopic flows: industrial processing, geophysical

flows (e.g. the flow of lava, modeling the mantle of the earth, etc), food rheology, pharmaceuticals and the like. In the 1980s new experimental techniques opened up the field to microfluidics, in which behaviour at the micron scale could be studied. At this length scale traditional methods of driving fluid flow, such as pressure gradients, may no longer be applicable due to the relatively high surface frictional forces compared to the inertial forces of viscous fluids. Instead, new methods such as optical tweezers, magnetic fields or electrokinetics, were developed to actuate or manipulate these fluids. The motivation for microrheology (or microfluidics) to takeoff as a field was overwhelming: lab-on-a-chip devices are prominent examples of practical microrheology, as is the study of the circulation of blood in the human body in micron-scale arteries, and the transport mechanisms of inter- and intracellular processes. Indeed, microfluidics is a key enabling technology in molecular biology since ultimately all living biochemistry is undertaken in solution, and much of the chemistry – physical and organic – is under conditions of high confinement (i.e. within cells, arteries, glands, etc) and/or flow. Despite this, one may be surprised to know that inkjet printers are perhaps the most commercially widespread application of microfluidics, though that will undoubtedly change as medicine continues to evolve rapidly.

As important and interesting as macro- and microscale rheology is, in this article we focus on what is perhaps the next major frontier in rheology, namely rheology at the *nanoscale*, or nanofluidics/nanorheology. The main technologically motivating reasons for the rise of nanofluidics are threefold: separation science (e.g. desalination by passing brackish water through membranes with nano-scale pores), chemical storage (e.g. storage of hydrogen in nanopores composed of functionalized materials to increase the adsorption capacity of hydrogen), and next-generation medical devices. Indeed, the discovery of buckyballs and carbon nanotubes has had a profound influence on the development of this field, and the flow properties of fluids inside such structures are often counter-intuitive with enormous potential benefits for the flow of highly confined fluids, as we will see a little later.

Apart from the technological drivers for nanofluidics, there is an equally important scientific and intellectual motivation, which is what will be discussed in more detail in this article. Traditionally, when solving a problem in fluid dynamics one takes the appropriate conservation equation, say for example the classical continuity equation for momentum, which is always exact if we can assume the fluid molecules behave within the laws of classical mechanics (for most fluids, this is an accurate assumption to make; liquid hydrogen or helium are obvious exceptions where quantum effects cannot be neglected). For a classical fluid, we can therefore express the momentum continuity equation as:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla \cdot \mathbf{P} + \rho \mathbf{F}_e \quad (1)$$

where $\mathbf{v}$ is the fluid streaming velocity, $D/Dt \equiv \partial/\partial t + \mathbf{v}\cdot\nabla$, ρ is the fluid density, $\mathbf{P}$ is the pressure tensor and $\mathbf{F}_e$ is any external body force per unit mass acting on the system. This is nothing more than Newton's second law of motion expressed in terms of internal stresses and external forces. In order to make use of this expression, for example to solve for the flow velocity profile, one needs two additional pieces of information: a closure relation expressing a thermodynamic flux to its conjugate thermodynamic force, and boundary conditions. To see how this works, lets consider the simple case of a fluid in a planar channel with width in the y-direction, under gravity acting in the z-direction (perhaps water confined between two parallel solid sheets). If we assume incompressibility of the fluid, that the channel is exactly vertical, and the flow is laminar, then Eq (1) simplifies to

$$\rho \frac{\partial v_z}{\partial t} = -\frac{\partial P_{yz}}{\partial y} + \rho g \quad (2)$$

Remember, we want to solve for the velocity profile, $v_z(y)$. If we are in the steady-state (time independent flow) then the left hand side of Eq (2) is zero, so where has the velocity term gone? This is where closure comes in: we express P_{yz} (which is nothing other than the negative of the shear stress, the internal response of the fluid to the applied field) in terms of a *constitutive equation* relating the thermodynamic flux (shear stress) in terms of its driving thermodynamic force (in this case, the velocity gradient). This law was devised by Newton and is of course his law of viscosity:

$$P_{yz} = -\eta_0 \dot{\gamma} \quad (3)$$

where η_0 is the shear viscosity and $\dot{\gamma}$ is the strain rate $(\dot{\gamma} = \partial v_z/\partial y)$. Substitution of the constitutive equation into Eq (2) and solving with the so-called "no-slip" boundary condition (velocity at the channel walls is zero), leads to the classical quadratic solution for Poiseuille (or gravity) flow:

$$v_z(y) = -\frac{\rho g}{2\eta_0}\left(y^2 - \left(\frac{L}{2}\right)^2\right) \quad (4)$$

where L is the channel width and our coordinate system is such that y = 0 is the centre of the channel. This, of

course, is just one simple application of the immensely useful Navier-Stokes approach towards solving problems in fluid mechanics. It has been one of the outstanding successes in classical physics since the 19th century. It is used in all manner of scientific and engineering applications from predicting the flow patterns of microfluidic circuitry to the design of aerospace vehicles and the prediction of global climate patterns and oceanic current systems. But it has failed, and failed spectacularly, for one particularly important new technology for the 21st century, namely nanofluidic systems.

THE PROBLEM WITH RHEOLOGY AT THE NANO-SCALE

There is not just one solitary reason why classical hydrodynamics fails at the nano-scale. To be more precise, classical Navier-Stokes hydrodynamics begins to break down when the scale of confinement is less than approximately 10 molecular diameters [1]. For water, this equates to roughly 2.9 nm. At this length scale, three peculiarly nano-scale phenomena kick in that make the classical formulation inadequate. However, these three effects are still *strictly classical*! Classical hydrodynamics fails due to purely classical reasons – it has nothing to do with quantum effects, though of course (and as already mentioned) quantum effects are important for certain kinds of fluids. However, for many people working in rheology, this limitation of classical hydrodynamic theory is such a new concept that it is largely unknown amongst practicing engineers.

The best way to illustrate the failure of classical Navier-Stokes hydrodynamics at the nano-scale is through example, and all the examples that follow are taken from the molecular dynamics literature. Indeed, molecular dynamics is an ideal tool to investigate the fundamental physics occurring at the nano-scale. Laboratory experiments in nanofluidics are still in the stage of infancy, with many technological breakthroughs yet to appear on the horizon due to significant technical challenges of measurement at the nano-scale. But the theoretical and simulation tools to study these systems have existed since the 1970s and, coupled with the doubling of computational power every two or so years, the scientific armoury available to study very detailed and experimentally inaccessible nanofluidic systems by a range of molecular simulation methods now exists, of which molecular dynamics is one of the most powerful. In molecular dynamics one solves effectively 6N classical equations of motion for the positions and momenta of N particles that interact via some intermolecular potential energy function. There are a host of techniques that allow one to constrain molecular architecture to the known molecular structure, to keep the temperature or pressure controlled, and the like, so that the simulations faithfully model laboratory conditions. The main limitations to molecular dynamics are (1) the accuracy of the intermolecular potential, (2) the degree of 'coarse-graining' required for large molecular systems such as high molecular weight polymers (including biopolymers such as DNA and proteins), and (3) computational cost. Nevertheless, as computational resources continue to grow, the accuracy and reliability of molecular dynamics continues to grow.

"… classical Navier-Stokes hydrodynamics begins to break down when the scale of confinement is less than approximately 10 molecular diameters."

Molecular dynamics simulations conducted in the 1990s first hinted that classical hydrodynamics did not quite work at high degrees of confinement. But the first unambiguous simulations to demonstrate this were conducted by Travis and Gubbins in 2000 [2], in which an atomic fluid was confined to flow in a channel of width < 5 atomic diameters. If classical Navier-Stokes hydrodynamics works for this system, it means that Newton's law of viscosity must hold at every location in the channel, i.e. $P_{yz}(y) = -\eta_0(y)\dot{\gamma}(y)$. In other words, a direct, spatially local proportionality should exist between the strain rate and the shear stress. However, it was clearly demonstrated that this proportionality did *not* exist! In fact, if one was to naively try to estimate the viscosity profile by dividing the shear stress by the strain rate at each spatial location, one would find a viscosity that is singular at all places where $\dot{\gamma} = 0$ (of which there could be several for highly confined fluids). But this simply does not make physical sense, so the only reasonable conclusion one can make is that Newton's law of viscosity, and hence the Navier-Stokes equations themselves, break down for such a highly confined system.

But this is just the first of three major inconsistencies indicative of the breakdown of classical hydrodynamics at the nano-scale. The second major problem has to do with the no-slip boundary condition assumption, i.e. that the fluid velocity is zero at the walls. For macroscopic systems this is usually true, but for nano-scale fluids there can often be significant slip at the walls, where the layer of fluid immediately adjacent to the wall actually moves. At the

nano-scale, the so-called "slip length" (the extrapolated distance into the wall at which the fluid velocity would be zero) can be of the same order as the channel width, or even greater, which means that the slip becomes as significant as the flow itself. In the case of high-slip systems, such as water flowing in carbon nanotubes, the degree of slip is extraordinarily high due to the extreme hydrophobicity of the carbon-water interaction. This leads to very little friction between liquid and solid, and hence very little viscous dissipation, which in turn gives a velocity profile that is almost flat and displaying a very weak quadratic dependence. Slip thus becomes a major issue in nanofluidic systems, and over the years several theoretical models have been developed to predict this slip [3-6]. High slip is believed to be the most important reason behind extraordinarily large flow enhancement factors experimentally measured in water flow in carbon nanotubes, compared to the flow rates predicted by classical Navier-Stokes theory, but the quantification of this enhancement by both experiment and simulation is still hotly debated, with results varying by orders of magnitude in some instances [7-9].

"… the transport properties of fluids are not static – they have wavelength and frequency dependences ..."

The third – and only recently quantified – problem with classical hydrodynamics is that at the nano-scale the *molecular structure* of the fluid molecules itself becomes important. It is not widely known that Max Born first predicted this in 1920 [10]. For a uniaxial molecule, he demonstrated that the angular velocity is one half the curl of the linear velocity (the vorticity). The significance of this is that the fluid's linear and angular momenta are coupled, with the coupling constant known as the rotational or vortex viscosity. In addition, the transport of angular momentum by diffusion is governed by an additional set of spin viscosities [11-13].

The importance of the spin viscosities in predicting hydrodynamics at the nano-scale has however only very recently been appreciated. For macroscopic flows, they are largely irrelevant and thus seldom invoked. However, their importance increases to the point of being indispensible to describe nano-scale flow. In work we have recently performed, we demonstrated that ignoring the molecular structure of a fluid confined to a nano-scale channel can result in overestimating the flow rate by up to almost 20% for liquid buta-triene [14] and as much as 50% for water [15, 16].

These types of overestimates are too great to be ignored, but the fact is that many researchers do not yet appreciate that these effects exist and so continue to use the traditional Navier-Stokes equations to make flow rate estimates. Little wonder then that for nanofluidic systems there can often be large discrepancies between the predictions of theory and the data of simulation and experiment. These spin-coupling effects decrease monotonically as the width of confinement increases and become negligible for widths of several hundred nanometers in general.

SOLUTIONS TO THE PROBLEMS

Fortunately, in recent years there have been significant advances in both theory and simulation that allow us to rectify the deficiencies in classical hydrodynamics at the nano-scale. The first of these, which relates to the breakdown of Newton's law of viscosity, was actually known before the simulations of Travis and Gubbins, but had never been clearly demonstrated. The solution lays in the theory of generalized hydrodynamics, which has its origins in the work of pioneers dating back to the 1970s [17-19]. The basic idea here is that the transport properties of fluids are not static – they have wavelength and frequency dependences, and in general all transport "coefficients" are not really coefficients at all, but rather space and time dependent kernels of integral constitutive equations. In short, all thermodynamic fluxes are *non-local functions* of their conjugate thermodynamic forces, in both space and time. This means that the shear stress at some point in space and time depends not just on the immediate spatial location and moment in time, but on the entire temporal history and spatial distribution of the strain rate. Generalizations along the same line can also be made for all other transport properties. So, for a homogeneous fluid, Newton's law of viscosity can be generalized (for the system geometry as given in Eqs (3-4)) as [20]

$$P_{yz}(y,t) = \int_{-\infty}^{\infty}\int_{-\infty}^{t} \eta(y-y',t-t')\dot{\gamma}(y',t')dt'dy' \qquad (5).$$

A similar generalization can be made for inhomogeneous fluids, but is more complex to analyse [21, 22]. In 2008 this was convincingly demonstrated for the first time [23, 24], as shown in Fig. 1. Here a homogeneous fluid (i.e. not spatially confined by walls, but rather a 3 dimensional atomic fluid fully periodic in space) is subjected to a sinusoidally varying external field in space, such that a sinusoidal velocity profile results, in which the wavelength of the profile is of the order of the range of the intermolecular interaction (thus mimicking the behaviour of a highly confined fluid, but without the complication of walls). Fig. 1

shows the shear stress computed by Eq (3) (local, Newtonian viscosity) and Eq (5) (non-local, generalized viscosity kernel) and compared to the molecular dynamics data (measured exactly). The local (classical Navier-Stokes) prediction clearly breaks down, whereas the generalized hydrodynamics prediction gives perfect agreement with the simulation results. As the wavelength of the field increases, the classical Navier-Stokes prediction converges to the exact result, as expected [21].

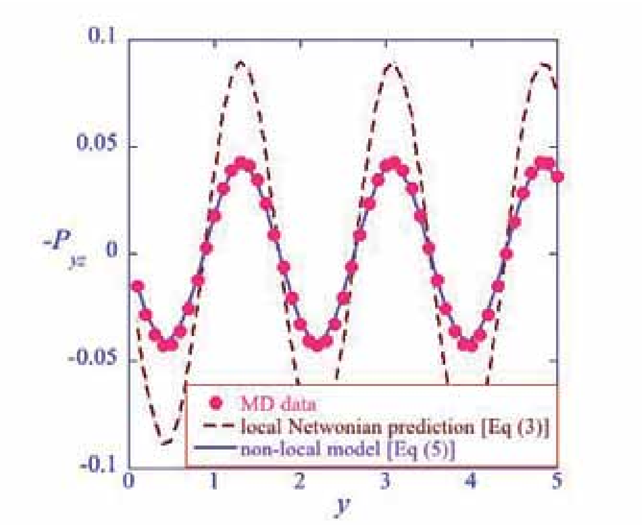


Figure 1. Shear stress for a fluid of Lennard-Jones atoms under the application of a sinusoidally transverse external field with shear gradient in the y-direction and flow in the z-direction. The wavelength of the applied field is of the order of 2 atomic diameters. The dots are the molecular dynamics data, whereas the dashed curve is the stress predicted assuming Newton's law of viscosity, Eq (3). The solid curve is the stress predicted assuming the non-local constitutive equation, Eq (5).

The solution to the problem of slip is actually well developed now, and theoretical models can accurately predict the slip without the need for computationally expensive non-equilibrium molecular dynamics simulations (see for example Ref [25]). What remains is to link the slip theories with generalized hydrodynamics so that velocity profiles (and hence accurate flow rates), shear stress fields and the like, can be accurately predicted for highly confined fluids. This is still a work in progress. A further extension of this formalism should include the prediction of angular velocity slip (where the angular velocity of molecules is not assumed to be zero at the walls).

THE FUTURE FOR NANO-RHEOLOGY

Considering the wealth of useful applications in separation science, medical technology and nanotechnology in general, the future looks very bright indeed for this fledgling science. Couple this to the advances that will be made in the next decade in theoretical and experimental developments, and the ever-increasing power of computers, makes nanofluidics a highly attractive field for those interested in the interplay between physics, chemistry and engineering. The interesting and unusual properties of carbon nanotubes provide one such example of this interplay. Intuitively one would expect that as one decreases the diameter of a carbon nanotube the frictional forces between the tube and the fluid (for example water) should increase and the resistance to its motion likewise increase, leading to lower flow rates. However, as depicted in Fig. 2, precisely the *opposite* feature is observed, namely decreasing the tube diameter actually results in an increase in the flow rate [26] (even though this figure is for methane inside a carbon nanotube, exactly the same reasoning applies to water inside a carbon nanotube [27, 28]). The reason for this is the nature of the carbon hexagonal honeycomb structure, which leads to an extremely dense, smooth surface. So much so that the frictional forces between the wall of the tube and the fluid molecules are less than the viscous forces between fluid molecules themselves. Thus, as one reduces the tube diameter, each fluid molecule 'sees' more carbon atoms than neighbouring fluid molecules, and so resistance to its motion is reduced. This of course means that, for the same magnitude of external force, fluid will actually flow faster in a small diameter carbon nanotube than confined to one with a larger diameter, allowing for higher volumetric flow rates in miniturised nanofluidic circuitry.

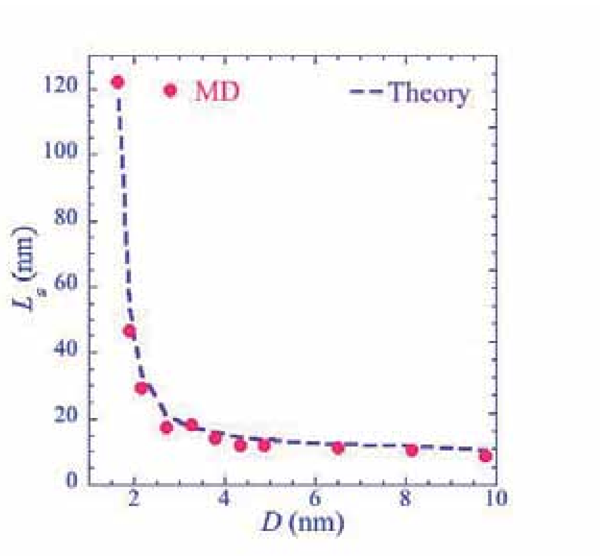


Figure 2. Slip length as a function of diameter (D) for methane flowing in carbon nanotubes [26]. The dashed curve is theory prediction using the model of Hansen et al [6, 26], whereas solid circles are actual molecular dynamics data. The limiting slip length for the methane/nanotube system in the limit as $D \to \infty$ is 5.9 ± 0.6 nm.

Such effects do not occur on macroscopic length scales and are an example of the rather strange but extremely useful properties of nanofluidic systems. There are a number of good reviews (see for example Refs [29, 30]) that provide many other interesting examples of the current state of the field and the exciting prospects that lay ahead in terms of technological applications in a world where shrinking devices is now the norm. This article has only focused on certain important challenges in nanofluidics, and is by no means a thorough review of the field. The understanding and useful application of electrokinetic flow, electric double layers, functionalized surfaces, ionic liquids, nanoscale pumps and other novel features of nano-scale fluids are all extremely important with many problems waiting to be solved. The field is certainly a promising area for bright young physicists to focus their attentions on, both in terms of applications and fundamental physics. Australia is very well established, both in the broad field of rheology and in micro/nano-fluidics, with world-class research groups in theory, experiment and simulation established across a number of universities and CSIRO. As in many things, Australia punches well above its weight, in this case in a relatively fluid field!

AUTHOR BIO

Billy Todd did his undergraduate and postgraduate studies in physics at the University of Western Australia and Murdoch University. He then completed postdoctoral appointments at the University of Cambridge and the Australian National University, before moving to CSIRO in Melbourne in 1996. In 1999 he took up an academic appointment at Swinburne University of Technology, where he is currently Professor and Head of Mathematics. His research specialty is in statistical mechanics and non-equilibrium molecular dynamics. He is a Fellow of the Australian Institute of Physics and a former President of the Australian Society of Rheology.

The Australian Society of Rheology (ASR) has recently become a cognate society of the AIP, with reciprocal arrangements for the benefit of both AIP and ASR members.

The ASR coordinates the activities of the rheology community in Australia and is open to membership by all those with an interest in any aspect of rheology.

Details of its activities and membership can be found at **http://www.rheology.org.au/.**

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Plasma Research at Deakin University: Diverse Applications and Team Spirit

Xiujuan Jane Dai

A new plasma laboratory has been established in the Institute for Frontier Materials (IFM) at Deakin University, Geelong. The two major research themes are (1) tailoring of surfaces/interfaces with new functionality; and (2) fabrication/doping of nanomaterials. The aim is to meet the challenge of better performing materials in applications ranging from energy, biomedicine and nanotechnology to composites, transport and textiles. Plasma technology offers an alternative to conventional approaches and its success depends on an improved understanding of the underlying mechanisms. We promote a team spirit in which different experts harmoniously work together. More than thirty PhD studies and collaborative projects have been undertaken and proposed since 2009 - within IFM, across the University and with outside research organisations nationally and internationally.

Introduction

As the fourth state of matter, plasma shows its splendour in nature, e.g. shimmering aurora and lightning flashes; but plasma also brings convenience to human life, e.g. plasma TV and fluorescent lamps. It is at the heart of Tokamaks for fusion energy and also in many environmentally friendly and more benign scientific and industrial applications.

What is plasma and how does it work are questions often asked by newcomers to the technology. The plasma, used by our group, is a partially (or weakly) ionised gas generated by an electric or electromagnetic field. It is electrically neutral (the number of positive charges is equal to the number of negative charges). It is a "cold" or nonequilibrium plasma where electrons get energy directly from the field and so can have a much higher temperature (~10^4 K) than the gas, including the ions, which have the ambient temperature of 300 K. Therefore it is possible to avoid thermal damage of materials during the process. In this weakly ionised gas, the electrons mostly collide with neutral molecules and atoms which results in ionisation, excitation, and dissociation (gas phase reactions). During these reactions, various reactive species are generated, including charged particles (positive and negative ions and electrons), free radicals, neutral particles, and UV photons. These species will react with the material surface (top down) so that the surface/interface will be changed (gas-interface reactions), or the reactive species will link and grow into a nanostructured material (bottom up). In a plasma process, the electron energy distribution function ($f(\varepsilon)$) and electron number (N_e) play critical roles. They are determined by the external parameters (frequency, power, pressure etc.), and they determine what chemically reactive species are generated. The reactive species are chosen to match the application (or final product). The gas used may also be the vapour of a monomer, typically a larger chemical unit containing a desired functional group. The key issue and challenge is how to design the parameters, and hence select and control the reactive species for a specific application. This demands a deep understanding of plasma physics, plasma chemistry, material science, biology, and devices.

To meet the challenge, plasma research at Deakin University has focused on development of novel plasma technologies and methodologies and the understanding of the underlying mechanisms. We are applying these developments and understanding to diverse applications in energy, biomedicine, composites, nanotechnology, sensing, transport and textiles. A key focus has been to bring different experts together in a harmonious environment.

Stable interfaces with a higher density of required functionality for biomedicine

For applications in biomedicine and nanocomposites, a challenge has not only been to control the selection and level of functional groups but also to have the newly tailored surface strongly attached to a relatively inert substrate.

Continuous wave (CW) plasmas are commonly used for surface treatment. However, it is difficult to control both the gas phase and gas-interface processes. The continuous electron-atom and electron-molecule collisions, ion bombardment and UV radiation in a CW plasma can destroy the required functional groups and damage the newly formed surface. Particularly when a monomer is used, a CW plasma causes fragmentation of the monomer, degradation of the newly formed polymer surface, and produces a cross-linked structure. To overcome this disadvantage,

pulsed (P) plasma is used. In a pulsed plasma, the short plasma "ON" time generates gas phase reactions, giving the required reactive species, and the long "OFF" period allows gas-interface reactions to be undisturbed. The design of duty cycle *(DC=T_{ON}/(T_{ON}+T_{OFF})* and the plasma "ON" time *(T_{ON})* is one of the keys to controlling the balance between high retention of the required functional groups and deposition rate. Through carefully designed pulsed plasma parameters (duty cycle and input power), we have achieved well-controlled and selected functionalities [1] on polymers which have mainly C-C/C-H bonds. However, for metals and semiconductors, the surfaces produced by a pulsed plasma are not stable in an aqueous environment due to weak bonding.

We have developed a combined plasma mode (continuous wave plus pulsed, CW+P mode, shown in Figure 1) that enjoys the CW mode advantage of markedly higher stability in aqueous solutions and the pulsed mode advantage of a higher density of required functional groups. If a monomer is used, the CW plasma first produces a very thin plasma polymer layer with strong cross-linking and attachment to the metal or semiconductor surface which provides a good foundation and better bonding of a pulsed plasma polymer layer. The pulsed plasma enables a higher retention of the functional groups of the chosen monomer.

In biomedical applications, this combined mode gave an approximately 3-fold higher density of the required functional groups (primary amines) than the CW mode, and a 20% higher density of the functional groups remained after sterilisation than for the P mode [2]. This was demonstrated to give a boosted (approximately six times higher) cellular response of osteoblasts in their initial adhesion stage on titanium (a common material for dental and hip implants). A reduced growth of fibroblasts, was also observed, which may be advantageous in preventing the formation of fibrous capsules. These factors should increase the formation of new bone around implants (reducing healing time), promoting osseointegration and thereby increasing implantation success [3]. Similar results were also achieved for boron nitride nanotubes (BNNTs) for biomedical application [4]. This method has also been used in the development of a surface-stress-based microcantilever aptasensor. An aptasensor is a biosensor that employs aptamers as the biorecognition element. Biosensors based on microcantilevers convert biological recognition events into measurable mechanical displacements. The immobilised biorecognition elements on the sensor surface determine the specificity of the biosensor. This was the first such sensor with the aptamer immobilised on a plasma functionalised bare SU-8 surface [5].

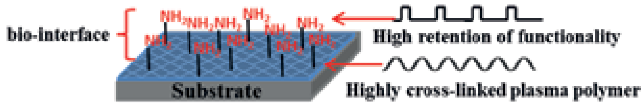

Figure 1. A schematic of the CW+P mode developed for achieving stable interfaces with higher density of a required functionality on inert material surfaces.

Improved mechanical properties of nanocomposites for the transport industry

It is routine now to make lightweight carbon fibre/epoxy composites to replace metal components in planes and cars. Such composites could also be reinforced at a much finer scale using carbon nanotubes (CNTs). However, two particular difficulties are that the nanotube surface is relatively inert and that the nanotubes tend to stick together due to Van der Waals forces. To improve the dispersibility of nanotubes and the interfacial bonding between nanotubes and epoxy, and hence improve the mechanical properties of nanocomposites, we developed a specific stirring plasma system. The reaction chamber sits on a magnetic stirrer that allows speed and temperature control of the stirring of the powders during plasma treatment. This enables easy handling and uniform treatment of powders with a high density of functional groups. The combined plasma mode was then used to modify both CNT and BNNT surfaces by nitrogen containing gases (N_2/H_2:85/15). Figure 2 shows a schematic of the process.

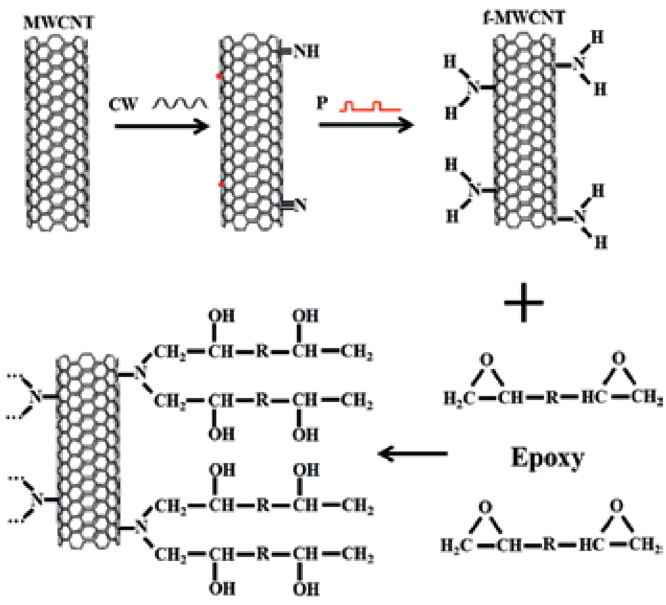

Figure 2. Scheme of the CW+P plasma functionalisation of MWCNTs and the formation of nanocomposites with epoxy

The CW gas plasma firstly creates active sites on the nanotube surface, which makes it easier for the following pulsed plasma to graft the NH radicals to form primary amine groups on the surface. The NH radicals are generated in the pulsed N_2/H_2 plasma during the 'ON' time. The 'OFF' period then provides sufficient time for them to form amine groups on the surface with minimum destruction by charged particles and UV photons. H radicals created in the 'ON' time can further improve selectivity for the required functionality [6,7]. The T_{ON} used was sufficiently short to avoid recombination in the gas phase reactions but longer than that required for the plasma to reach a steady state [8]. A higher level of primary amines than previously reported for any nitrogen-containing gas plasma treatment as well as CW mode or P mode alone, was achieved. The integrity of the nanotube structure is also maintained during the process and the functionalised surface greatly improves the dispersion of the nanotubes and their interfacial bonding with epoxy. The incorporation of only 0.1wt% of functionalised multiwalled CNTs (MWCNTs) leads to marked increases in both nano- and macro-mechanical properties compared to neat epoxy [9]. This controllable and selectable plasma functionalisation is a promising method for capturing the excellent properties of difficult substrates for practical applications. Figure 3 shows the superior nanoindentation performance of the composites with the plasma functionalised CNTs [10].

Figure 3. SPM images of the nanoindentation for the epoxy and MWCNT reinforced composites (smaller the area, harder the material), from left to right: neat epoxy; 0.1 wt% unmodified MWCNTs; 0.1 wt% plasma modified MWCNTs.

Oxygen doping of boron nitride nanotubes (BNNTs)

A BNNT can be thought of as a CNT in which alternating B and N atoms (group III and group V elements) substitute for C atoms. To better capture the potential of BNNTs, their optical, electrical and magnetic properties need to be tunable. According to theoretical predictions [11] this should be possible by oxygen doping (O-doping), but it had not been experimentally achieved. The challenge was to overcome their chemical inertness while being able to control the doping process without damaging the BNNT surface.

The binding energy of a hexagonal B-N bond is 7-8eV. The first step is to break this B-N bond to create a nitrogen or boron vacancy, then allow oxygen substitution. We carefully designed the plasma conditions, in which the electron energy distribution function ($f(\varepsilon)$) had a modest higher energy tail (> 10eV) but with electrons having a mean energy that can generate the maximum atomic oxygen density [12] so that atomic oxygen could immediately substitute the N atom or the B atom at the site where a B-N bond had been broken. We have observed that a reduced percentage of N was accompanied by an increased percentage of O. This indicates that the oxygen plasma breaks the BN bond and creates a nitrogen vacancy (V_N) which is then replaced by an O [13]. This agrees well with the theoretical calculations that oxygen substitution for the nitrogen atom is more favourable than for the boron atom due to the lower formation energy [14]. The total input power was kept low enough to minimise damage to the tube surface by energetic electrons/ions and UV photons in the plasma. TEM images (Figure 4) show that a contaminating layer of amorphous BN (a-BN), which is normally present, was removed and the damage could be minimised while achieving a desired degree of surface oxygen substitution using the combined CW+P oxygen plasma mode. We also found that the doped-O density could be controlled by the total plasma energy input and argon plasma pre-treatment (which removes the amorphous BN and creates active sites). This development opens opportunities for making nanodevices using undamaged and functionalised nanotubes.

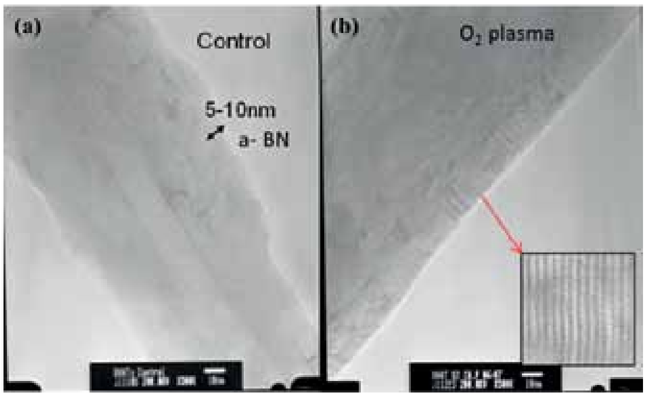

Figure 4. HRTEM images showing (a) amorphous layer (~5-10nm) in an untreated BNNT; and (b) after O2 plasma treatment, showing removal of the a-BN layer without damage to the nanotubes.

Energy applications (energy generation and energy storage)

Dye Sensitised Solar Cells (DSSCs) are the most promising third generation solar cells due to their lower production cost and because they allow flexible substrates. A typical DSSC consists of three parts: nanocrystalline TiO_2 electrode (electron acceptor), dye (electron pump), and electrolyte (electron donor). The photons interact with the dye molecules on the surface of the TiO_2 electrode. Upon absorption of a photon the dye generates an electron-hole pair (exciton). The electrons are injected into the TiO_2 network to give the photocurrent whereas the holes are transported to the cathode by means of the redox species present in the electrolyte. The challenge is that the efficiency (current record 11.1% [14]) needs to be significantly improved if DSSCs are to be successfully commercialised.

Our focused approach is (1) to increase dye absorption (to enhance the photon harvest) and (2) to improve electron transport through the interface between the excited dye molecule and the semiconductor electrode as well as within the semiconductor network. Oxygen plasma was used to treat TiO_2 nanoparticles. The reactive species from the oxygen plasma react with the TiO_2 surface to form oxygen functional groups (-OH, -OOH). These functional groups help the dye absorption by forming strong covalent bonds with the terminal COOH group in the dye molecules. This was confirmed by the absorption spectra of the dye desorbed solution, which showed a ~25% increase in the amount of dye loading after the O_2 plasma treatment. This resulted in an increase of the incident photon-to-current conversion efficiency (IPCE) to 34% and an increase of 13% in efficiency compared with untreated samples.

Nitrogen doping of the TiO_2 electrode is part of the second approach to improving efficiency. This aims firstly to alter the surface charge state of TiO_2 to improve the transport of the electrons between the excited dye molecule and the semiconductor interface, then secondly, to decrease the energy band-gap of TiO_2 in order to extend the absorption spectrum of photons to longer wavelengths. A unique plasma plus thermal (P+T) system has been developed and N-doping of TiO_2 has been successfully achieved. A nitrogen-containing plasma can break the Ti-O bond to create an oxygen vacancy, enabling nitrogen substitution.

This P+T system has also been used to successfully N-dope SnO_2 and nanofabricate SnON. SnO_2 has a significant potential advantage over the currently used carbon as the anode material for lithium batteries, but two main hindrances need to be overcome. They are an initial capacity loss due to the irreversibility of tin reduction and poor cyclability (performance over repeated charge and discharge cycles). The latter is due to structural damage caused by the huge volume changes (400%) during the alloying reaction of tin and lithium. N-doping of SnO_2 (addressing the first challenge) has improved ion diffusion rates, lowered the band gap and increased the reversibility of the reduction reaction while maintaining the initial capacity of the battery. At the same time, the plasma etching from the P+T system produces nanostructured SnO_2 (addressing the second challenge) with an increased surface area and better resistance to volume changes, allowing better cyclability. The preliminary battery tests are very promising.

New approaches in the textile industry

Conductive textiles have applications in sport and medicine by enabling sensors for performance feedback and bio-monitoring clothing for patients. The wear and tear of textiles, including cleaning, imposes severe performance requirements and improved interfacial bonding between the textile surface and the conducting polymer coating was essential. However, the bonding mechanism was not fully understood [15,16].

We have investigated the effect of different plasma gases and conditions together with comprehensive characterisation and surface analysis to understand and optimise the bonding and electrical conductivity of conducting polymers [16]. Electrical conductivity and interfacial bonding of polypyrrole (PPy) coatings on a polyester (PET) fabric and thin film (as reference) were significantly improved by plasma treatment using Ar, N_2 or O_2 gases (the effectiveness was $O_2 > Ar > N_2$). Figure 5 shows, after 2000 cycles of abrasion, that ~36% of the conductivity of the untreated sample was lost, but the conductivity of the oxygen plasma treated sample was hardly affected (~7% lost). The highest level of surface functional groups (COOH) and most uniform nano-scale surface roughness were achieved by the oxygen plasma treatment that gave the highest interfacial bonding and highest conductivity. The COOH groups that are acid catalysed (electrophiles) can attract the nucleophilic nitrogen atom of the pyrrole ring giving increased conductivity. This systematic approach has provided a better understanding of how and why the conductivity of PPy coated on a PET surface can be improved.

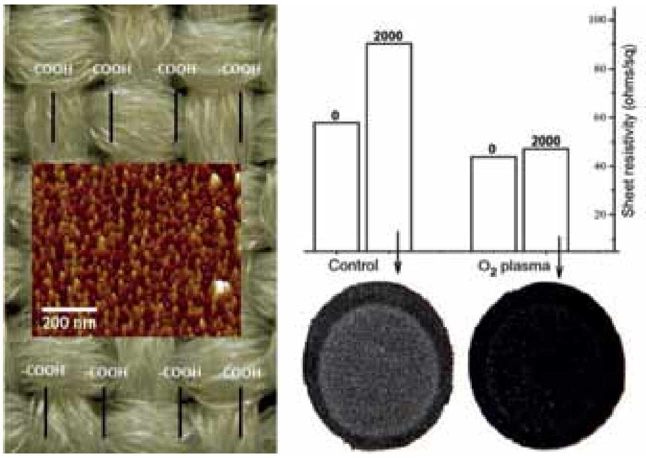

Figure 5. The COOH groups and uniform nano-scale surface roughness produced by O_2 plasma improved coating adhesion and increased conductivity

Pilling of wool knitwear during wear and laundering has been a serious problem for both industry and consumers. The initial pill formation involves the entanglement of free fibre ends on the fabric surface with anchoring fibres. Although many methods of improving pilling performance have been introduced, a completely satisfactory solution has not been achieved.

To meet the challenge, we developed a novel three step plasma treatment. The three steps are, surface activation with argon plasma, then surface functionalisation with pulsed oxygen plasma, followed by deposition of a thin film using pulsed plasma polymerisation of hexamethyldisiloxane (HMDSO). This method firstly produces a uniform and higher level of oxygen functional groups on the wool fibre surface, followed by the uniform deposition of a Si-O-Si thin film by pulsed plasma polymerisation. This strongly bonded silicone thin film covers the free fibre ends and loops on the fabric surface, reducing the possibility of entanglement, progressive migration and pull-off of protruding surface fibres. A substantial improvement in pilling resistance has been achieved using this method, with the pilling grade increased to 4, compared with 2 for untreated and 3 for other plasma methods.

We have also developed a nanosecond pulsed atmospheric pressure plasma (NPAPP) system for applications in wastewater treatment, biomedicine, and material surface treatment. The system consists of a nanosecond pulsed generator and several different electrodes for specific applications. A plasma can be generated in a liquid as well as gases. The advantage of using an atmospheric pressure plasma is that it does not require a vacuum system so that it can be more easily used at an industrial scale. The very short pulses prevent filament discharges which can give localised damage and highly uneven treatment in gas plasmas. This system combines a pulsed electric field, UV radiation, O_3, and free radicals. It has shown very promising results for textile wastewater treatment both in the bleaching of dye liquors and reducing total organic carbon content.

Summary and the Future

Understanding of plasma physics, plasma chemistry, materials science, biology, and the requirements of the specific application is vital to successful outcomes for plasma processing. Different experts harmoniously working together is the key to reaching our goals and making breakthroughs!

Improved pulsed plasma, the novel CW+P mode, and the novel three step plasma treatment can help tailor surfaces/interfaces, giving controllable and selectable functionality. The stirring plasma system provides uniform and effective treatment of nanomaterials. The plasma plus thermal system combines both plasma and thermal energy to achieve controllable nanofabrication as well as elemental doping of nanosemiconductors. The nanosecond pulsed atmospheric pressure plasma, especially in a liquid, opens up huge opportunities for applications. A specialised custom-designed facility which combines physical vapour deposition with plasma enhanced chemical vapour deposition in a dual chamber system will soon be operational. Its multi-functional capabilities will enable the dry fabrication of nanostructures (both top-down and bottom-up) and their surface treatment in one go, while avoiding surface contamination thus producing new and higher quality materials.

AUTHOR BIO

Xiujuan Jane Dai received her PhD degree in plasma physics from the Australian National University. She also has MSc and BSc degrees in plasma physics and semiconductor physics from China. Her research has focused on the development of novel plasma technologies and methodologies, and the development of materials with new functionality, for applications ranging from energy, biomedicine and nanotechology, to composites, transport and textiles. A persistent theme has been the improved understanding of underlying mechanisms through surface characterization, analysis and diagnostics. She was an invited speaker at the Gordon Research Conference (USA) on plasma science & technology in 2000, and joint recipient of the CSIRO Research Medal and a NanoVic Prize in 2006 for her work on carbon nanotubes. She has established a new plasma laboratory at IFM since joining Deakin University in 2009. She is committed to helping young scientists grow and to bringing different experts together in a harmonious working environment.

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Acknowledgments

I would like to express my sincere thanks to my plasma team, the technical officers, administration and management staff at IFM, and the research staff of other groups at Deakin. Without their hard work and strong support, it would have been impossible to establish this new plasma laboratory with such exciting capabilities and to develop/undertake more than thirty PhD projects and collaborative projects within three years. I would also like to thank RMIT for our long term and very productive collaboration, and thank Monash University and CSIRO for growing and extended collaboration.

The plasma team

We are based at the Institute for Frontier Materials, Deakin University, Geelong Waurn Ponds campus, from left to right, are Zhiqiang Chen (PhD student on nanocomposites), Haiying Chen (Masters student on wastewater treatment), Marion Wright (staff), Robert Lovett (staff), Ailan Wan (PhD student on anti-pilling), Xiujuan Jane Dai (team leader and the author), Tariq Mehmood (PhD student on electrical textiles), Gayathri Devi Rajmohan (PhD student on DSSCs), David Rubin de Celis Leal (PhD student on energy storage), Yang-Choon Lim (PhD student on microcantilever aptasensor), and Peter Lamb (staff). Three members are missing, Ling Li (PhD on BNNTs), Md Saiful Islam (PhD on biosensors), and Sri Balaji Ponraj (PhD on nanotuboids for biomedicine).

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Physics World's top 5 breakthroughs for 2012

In keeping with Summer holiday laziness, Samplings brings you Physics World's judgement of the top 5 breakthoughs for 2012. PW's assessment criteria included:

- Fundamental importance of research
- Significant advance in knowledge
- Strong connection between theory and experiment
- General interest to all physicists

1. CERN discovers Higgs-like boson

If for nothing else, 2012 will be remembered as the year that physics hit the mainstream – at least for one glorious week in July when physicists working on the ATLAS and CMS experiments at CERN announced that they have discovered a "Higgs-like particle". The July announcement was much anticipated because physicists have had the Higgs boson in their sights for nearly 50 years. Its discovery completes the Standard Model of particle physics – making it the most important physics breakthrough so far in the 21st century. And while care has been taken to call the discovery a "Higgs-like particle" – just as the collaborations themselves have done – evidence is now growing that the particle is a Higgs boson as described by the Standard Model of particle physics.

2. Majorana fermions

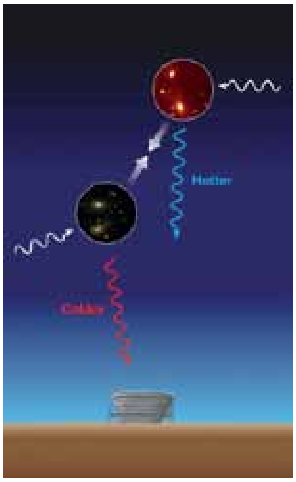
"Majorana fermions" are particles that are also their own antiparticles and were first proposed in 1937 by the Italian physicist Ettore Majorana. More recently, physicists have argued that Majorana-like quasiparticles could be lurking in materials with special topological properties. Now, Leo Kouwenhoven and colleagues at the Delft University of Technology and Eindhoven University of Technology have spotted the first hints of Majorana fermions at the interface between a topological superconductor and a semiconductor. Majorana fermions are expected to be impervious to environmental noise and therefore could prove useful in quantum computers. [*Science* 336 (6084) pp. 1003-7 (2012), see also *Science* 336 (6084) pp. 989-90(2012)].

3. Time-reversal violation

Physicists have been waiting for almost 50 years for a direct observation of time-reversal (T) violation. Now, researchers analysing data obtained at the BaBar detector at the PEP-II facility at the SLAC National Accelerator Laboratory in California have done just that. The collaboration focused on transitions between the quantum states of the B0 meson and found that the transition rates differed. While T-violation comes as no surprise, its direct experimental measurement is an important verification of quantum field theory. [*Phys. Rev. Lett.* 109, 211801 (2012), see also *Physics* 5, 129 (2012)].

4. Galaxy-cluster motion

The motions of distant galaxy clusters can tell us much about how the universe formed and also shed light on the mysterious dark matter and dark energy. Some 40 years ago, the Russian physicists Rashid Sunyaev and Yakov Zel'dovich calculated that this motion could be observed by measuring a slight temperature shift in the cosmic-microwave-background (CMB) radiation. Now, Nick Hand and colleagues at the Atacama Cosmology Telescope (ACT) and the Baryon Oscillation Spectroscopic Survey (BOSS) have done just that in another triumph of precision cosmology. [*Phys. Rev. Lett.* 109, 041101 (2012), see also *Physics* 5, 81 (2012)].

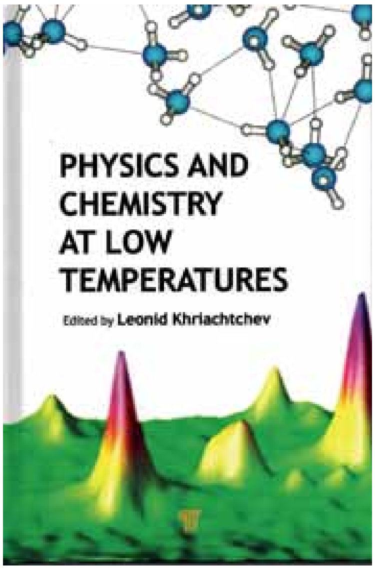


The Atacama Cosmology Telescope observes the motion of a large mass, such as a galaxy cluster, by detecting frequency shifts in the cosmic microwave background, which scatters inelastically from the moving mass. Light that scatters from a galaxy cluster moving away from the observer is shifted to longer wavelengths (cooler, or "redshifted" light). Galaxy clusters moving toward the observer scatter light to shorter wavelengths (warmer, or "blueshifted" light).

5. Peering through opaque materials

Much of modern medicine relies on the ability to peer inside the human body, with techniques ranging from X-rays to magnetic resonance imaging having been developed to do just that. However, as tissue is opaque to much of the electromagnetic spectrum – including visible light – doctors are limited in terms of what they can "see". Now, Allard Mosk and colleagues at the MESA+ institute at the University of Twente have used a common effect called laser speckle to see micrometre-sized fluorescent objects through several millimetres of opaque material. [*Nature* 491, 232-4 (2012), see also *Nature* 491, 197-8 (2012)].

BOOK REVIEWS

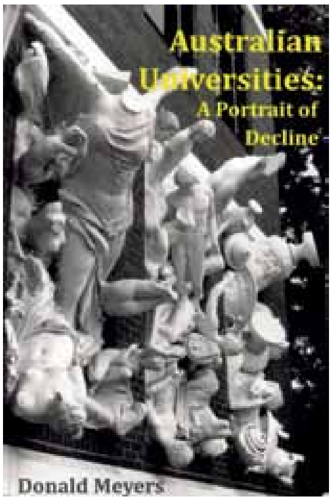


Physics and Chemistry at Low Temperatures, by Leonid Khriachtchev (ed).

Pan Stanford Publishing, Singapore 2011
ISBN 978-981-4267-51-9 (hardcover), 503pp.

Reviewed by John Macfarlane, Trevallyn, TAS 7250.

Several quite diverse but nevertheless complementary topics, having in common the use of cryogenic techniques, are covered in the 15 Chapters of this multi-author volume. Highlights which demonstrate my limited experience of the field would include: Matrix isolation in helium droplets , Photolysis and Radiolysis of water ice, and Cool interstellar physics and chemistry. The outstanding value of these, and other, chapters is in the high level of experimental cryogenic techniques described, with excellent diagrams and sketches. I had never before imagined, for instance (Ch.7), how micron-sized superfluid helium droplets at sub-1K temperatures could be produced in the laboratory, and induced to contain small populations of solute organic molecules such as methane from which meaningful infra-red spectra can be routinely recorded by absorption of laser light. Because the helium is a superfluid, the embedded molecules in each droplet are effectively contained within a zero-viscosity, non-interacting medium and are free to undergo their unperturbed rotational and vibrational spectra. The experimental design criteria involving all the familiar vacuum, materials and cryogenic techniques are clearly detailed. Control experiments with other non-superfluid liquids such as argon, which fail to reproduce the high-definition spectral data, are convincing proof that the superfluid-helium technique is truly unique. Then in Ch. 11, we are transported to the conditions of inter-stellar Space, where the photochemistry of interstellar ice, containing a variety of adsorbed organic radicals, can be deduced from cryogenic laboratory experiments, leading to information about star and planet formation. The development of airborne and orbiting spectroscopic telescopes "has opened a new window into the Cosmos", enabling hostile and unreachable environments to be accurately reproduced and studied in the laboratory. If this impressive volume did nothing else, it certainly convinced me that my long-standing obsession with superconductivity and its undoubtedly fascinating electrical and magnetic phenomena, covered only a fragment of the vast and growing field encompassed by physics and chemistry at low temperatures.



Australian Universities: A Portrait of Decline

by Donald Meyers
(Published by AUPOD - ISBN 978-0-646-57774-6)

Reviewed by Anthony Thomas,
University of Adelaide.

This is not a feel good book and readers looking for a volume to lift their spirits will be sadly disappointed. Meyers clearly feels enormous frustration with the evolution of tertiary education post-Dawkins, particularly through his first hand experience of it at the University of the Sunshine Coast. Although the process of writing it must have been cathartic, his level of frustration may have been lifted again by the refusal of mainstream publishers to publish this volume.

Should it have been written and is it worth reading? In my view the answers to these key questions are a qualified "yes". The qualifications relate to the lack of a broader perspective and documentation to back up much of what is stated and clearly strongly felt. They also stem from the rather too personal chapters describing the period around

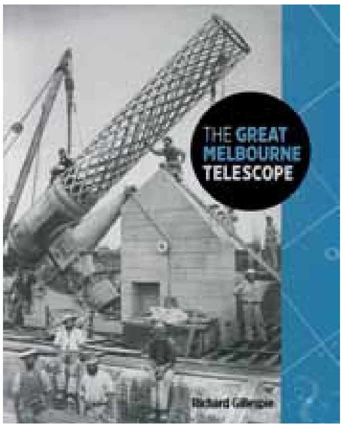
the experience of being made redundant at USC. However, much of what is said will ring true to those working within the tertiary system. One person's reforms are often another's betrayal and Meyers makes a very strong case that in the case of Dawkins it was much more the latter.

At the time of the Dawkins changes the government faced a tremendously noisy lobby from the teachers' colleges and institutes of technology whose jealously over perceived inequities in funding led to harsh and very public criticism of the government. From the political point of view Dawkins's response was brilliant: Call them all universities and let them fight each other over limited resources rather than attacking the government and all in the name of improved access. As Meyers observes the "Dawkins merger plan must score full points for sheer ruthlessness and reptilian cunning" and "during the Dawkins era, government funding per student dropped to the lowest level seen since the Australian Bureau of Statistics started keeping the relevant figures in the early 1960s".

Meyers dwells at great length on the more insidious problems within the institutions where "those, at any level, who were prepared to implement the reforms in return for power or security of employment would be much more likely to win out over anyone trying to hold true to academic principles". He gives many examples of the drop in academic standards required by an extremely top-down managerial system in order to keep pass rates high when "something like 50% of students entering the system do not have the basic academic ability (English and mathematics) to successfully negotiate an undergraduate university science degree".

Readers working in the system will be familiar with Meyers' outline of the regime of top-down management fed by KPIs (Key Performance Indicators) and consultant-produced management plans that purport to successfully ensure quality in a system where student-staff ratios have doubled since Dawkins. He correctly describes the bloating of the administrative side of the University, partially driven by Canberra's unrelenting appetite for data, both concepts which were just recently highlighted by Ernst and Young. The book may be uncompromising in its description of the system but the author seems to keep good company.

Hopefully by now I have provided enough of a taste that your curiosity will lead you to read the book. It is never fair or balanced but it does make many important observations and anyone truly concerned about the quality of tertiary education in this country would do well to reflect on what the author has to say.



The Great Melbourne Telescope. By Richard Gillespie (2011)

Melbourne: Museum Victoria.ISBN 9781921833052.

Reviewed by Barry Clark,
Volunteer, GMT Reconstruction Project, Astronomical Society of Victoria Inc ,

The 48-inch (1.2 m) Great Melbourne Telescope (GMT) of 1869 failed to produce the spectacular results expected, but an international imbroglio about real and imagined faults of it and its builders, managers and observers soon filled this gap in newspapers. Regardless, the GMT was used diligently over the next fifteen years on the major task set for it by the Royal Society, visual re-examination of the southern hemisphere nebulae discovered by Sir John Herschel in the 1830s. It was starved of resources and little used for scientific work after the 1890s global financial crisis. Most of its observations remain unpublished. In 1904,master telescope maker George Ritchey lambasted the GMT as a "lamentable failure"and "greatest calamity" attributed to errors in optical figure, tube flexure and collimation slack. Although he was wrong on all counts, many others who should also have known better perpetuated and extended its mythical faults in book chapters and journal papers.

Science and technology historian Richard Gillespie has now done much to put the record straight with the first full-length book on the GMT. Not only is the work meticulously researched, but also beautifully written and illustrated. The narrative sails along compellingly, avoiding 'dry as dust' and throwing in the occasional surprise. Nowadays the GMT's skeleton tube and its open air observing mode are no longer heavily criticised, but who was aware of the strange connection between its building's roll-off roof and a king of England?

In 1946 the Victorian government was glad to see the GMT off its hands for scrap value. The GMT went to the

Commonwealth Solar Observatory at Mt Stromlo as part of that facility's transformation to a modern astrophysical observatory. The GMT came close to being scrapped at least once more during its three lives there, but it did better each time, culminating in the first observations of dark matter. Then in a truly calamitous firestorm in 2003, it was destroyed beyond further professional use along with all the other major facilities at Mt Stromlo. The large iron castings of the GMT and remnants of its modern parts were left corroding away in the open as a sad memorial.

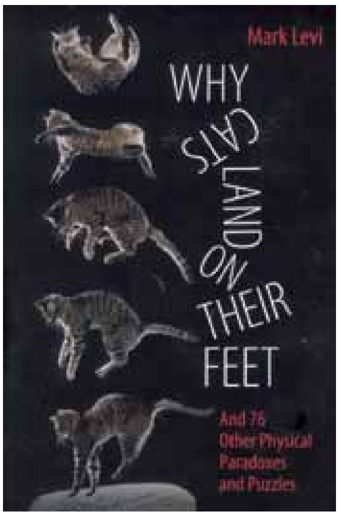
After extended negotiations, the original parts were transferred to Museum Victoria in 2008. Fortunately, the Museum had taken the trouble in the 1980s of collecting GMT pieces discarded in rebuilds. With about 90% of the original parts in the Museum's collection and the original GMT House still extant at Melbourne Observatory, heritage reconstruction of the GMT for public use is under way with volunteers from the Astronomical Society of Victoria in the Museum department headed by Dr Gillespie.

The GMT's role in Marvellous Melbourne and its survival through adversity are well captured by this book. Technicalities are kept within the grasp of lay readers. It is well worthwhile to have your own copy, but others would make really nice presents.

Why Cats Land on their feet and 76 other physical paradoxes

By Mark Levi
Princeton University Press, 2012, pp 190 (softcover)
ISBN 978-0-691-13018-7

Reviewed by Lee Weissel
Trinity Anglican College, Albury



Several strengths are immediately apparent in this book. The first of its strengths are the works' easy accessibility into a wide range of physical phenomena through clear and discrete problems. The author, Mark Levi is currently the professor of Mathematics at Pennsylvania State University, and this book is not just a collection of problems about physics and applied mathematics, but rather lessons in dealing with physical paradoxes. To get the most out of this book, reader should at least know some elementary physical principles. However, Levi does provide revision of some of the general mathematical principles in order to assist the reader further. Issues examined in the book are varied and are collected under topics or themes to assist in understanding the connection with many principles. Topics include such areas as Newton's laws, energy, center of mass, angular momentum, etc. Levi does use simple formulas in his discussion of attempting to understand problems, and also uses some mathematics, but secondary school knowledge of Physics will suffice.

Another strength of this work is how the author tests the reader's critical thinking skills by showing how many puzzles and indeed some seeming paradoxes can be solved by physical intuition. It enables both a theoretical and a physical understanding of the concept being discussed. For someone who teaches Physics regularly, this is immensely helpful in giving an educator further connections for the student to understand. These puzzles involve floating and diving, sailing and gliding, gymnastics, bike riding, outer space, throwing a ball from a moving car, centrifugal force, gyroscopic motion, and, of course, falling cats.

A third strength of the work is the shear variety of problems presented. All of them are really surprising and keep you reading on. It is almost standard that the correct answer is opposite to what intuition predicts. Sometimes the wrong answer is explained according to apparently correct arguments and the reader is asked to find the flaw. In any case, the right arguments with the right answer are always given. Each chapter is short enough and engaging enough that it can be read in a few minutes time, say while you are drinking a cup of tea or coffee. It will give the reader a lot of inspiration to challenge or entertain their friends during a reception or another get-together with some different kind of beverages. Of course you will impress them only when they haven't read the book themselves already. Hence make sure that you are the first.

PRODUCT NEWS

LASTEK
Picoquant Solea Supercontinuum

Introducing the the latest innovation from Picoquant, the Solea picosecond supercontinuum laser. The Solea has a broadband output ranging from 480 to 700 nm with a total output power of 350 mW across the output spectrum. A major advantage of the Solea is the ability that allows the user to program the internal oscillator, allowing selectable repetition rates of 1.25 MHz - 40 MHz. Additionally, the Solea is externally triggerable from 1 - 40 MHz. These features remove the need for classic, external pulse pickers.

Features:

- Spectral range: 480 to 700 nm
- Visible power: 350 mW
- Average spectral density: > 1 mW/nm
- Pulse width: < 150 ps
- Externally triggerable: 1 to 40 MHz
- Internal oscillator: 1.25 to 40 MHz,
- user selectable
- Synchronization output

The Solea is due for release after Photonics West 2013

Quantum Composers Sapphire Series Digital Delay Pulse Generator

The newest release from Quantum Composers is the Sapphire Series pulse generators, a revolutionary package that offers an economical solution without a trade-off in performance. Coming in a 181 x 130 x 38 mm package, the Sapphire is one of the smallest units available with many features and programmability, such as wireless connectivity via Bluetooth and USB power. The Sapphire is ideal for moderate precision applications requiring multi-channel capabilities and offers a range of operating modes, such as continuous, single-shot, burst and duty cycle. Combine these with external trigger/gate inputs and the Sapphire allows for a full set of complex waveforms. Additional features include;

- 2 or 4 Fully Independent Output Channels
- 10 ns Resolution
- < 500 ps RMS jitter
- Output Multiplexer
- Fast Rise Time, < 2 ns
- Small Form Factor
- Quick Recall of up to 6 System Configurations
- DC Wall Mount or USB Powered
- Wireless Option via Bluetooth
- 2 Year Warranty
- Intuitive GUI
- Dependent and Independent Timing Events

Continuum Horizon High Efficiency Mid-band OPO

The new Horizon mid-band OPO system from Continuum offers unmatched performance. Its intelligently integrated optical design delivers the highest output powers available over an extensive tuning range (192-2750nm). Fully automated with precision scanning for true hands-free operation, the Horizon is a robust system delivering optimal performance – all day, every day. With the highest conversion efficiency available from any mid-band OPO, the Horizon gives you unprecedented advantages: outstanding beam quality, excellent beam pointing stability and the option for wavelength access extended into the vacuum ultraviolet. With crystals and Pellin Broca prisms mounted directly to ultra-high resolution stepper motors, the Horizon has been engineered or optimal stability and reproducable tuning at all wavelengths.

- Extended tunability from vacuum UV to IR
- High energy output (up to 110 mJ at 425 nm)
- Linewidth down to 3 wavenumbers
- Excellent beam quality and low divergence
- Automated precision scanning
- Full optical design integrated into a monolithic platform

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

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COHERENT SCIENTIFIC NEW SEMROCK CATALOGUE

Semrock has released their 2012-2013 catalogue. New products include the improved ultra broadband MaxMirror (350-1100nm with >99% average reflectance) , high laser damage threshold PulseLine femtosecond mirrors and ten new key laser wavelength EdgeBasic long pass-edge filters.

The catalogue can be downloaded via .pdf (see our home page for the link) or contact us for a paper copy (sales@coherent.com.au).

IMAGING SPECTROGRAPH WITH ABERRATION-FREE PERFORMANCE

Princeton Instruments has released IsoPlane, a next-generation imaging spectrograph which produces sharply focused images or spectra across the entire 27mm x 8mm focal plane. Isoplane improves on traditional Czerny-Turner spectrographs by eliminating astigmatism and greatly reducing coma. The result is sharper images and sharper spectral lines with constant width across the focal plane. For spectroscopy, this means that more photons end up at the peak, thus improving signal to noise ratio.

The results have to be seen to be appreciated so please visit Princeton Instruments website (**www.princetoninstruments.com**) to see sample images and videos illustrating the performance of this unique new instrument.

Princeton Instruments

FIBRE LASER FOR ATOM COOLING

Quantel has released the EYLSA 780 fibre laser designed specifically for rubidium atom cooling.

EYLSA is a single-frequency laser delivering 1W at 780nm with linewidth less than 2.5MHz (200kHz option is also available). The wavelength is tunable over a 100GHz range covering both the Rb85 and Rb87 D2 lines. A wavelength locking control loop is included and may be connected to a commercially available PID device.

The EYLSA laser comes in a compact package with 19" rackmount and touchscreen control.

FLUORESCENCE LIFETIME INSTRUMENTATION FROM EDINBURGH INSTRUMENTS

Edinburgh designs and manufactures steady state fluorescence spectrometers, dedicated fluorescence lifetime spectrometers and laser flash photolysis spectrometers covering the vacuum UV to the near infrared with outstanding sensitivity. They have pioneered the technique of Time Correlated Single Photon Counting (TCSPC), permitting lifetime measurements down to 5ps to be made quickly and easily. Edinburgh's spectrometers are highly modular, allowing systems to be configured for a wide variety of applications or to be upgraded as research priorities change.

Edinburgh's products are used across a wide range of applications including photophysics, photochemistry, semiconductor physics and biophysics.

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

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116 Sir Donald Bradman Drive
Hilton SA 5033
Ph: (08) 8150 5200 Fax: (08) 8352 2020
www.coherent.com.

WARSASH SCIENTIFIC

Single Frequency DPSS Lasers with Even Higher Power

Recently, the Swedish manufacturer of high performance lasers, Cobolt, has released four higher power lasers on the single frequency DPSS laser platform, 05-01.

No diode light leakage during high speed modulation for applications using laser induced fluorescence is essential. In the new MLD series of CW diode lasers, available from Warsash Scientific, these diodes and their accompanying electronics have been especially designed to be truly off when there is 0 current through the diode. As a result, the measured extinction rations during both analogue and digital modulation are currently the highest available on the market. During digital modulation, extinction rations of >10,000,000:1 (70dB) have been measured on multiple wavelength units at 10MHz and for analogue modulation >1,000,000:1 (60dB) at 1mHz.

ZOUK™ 355NM 20MW

Perfect for fluorescence analysis with Hoecht Blue Indo-1 or DAPI, for example, for DNA content analysis or calcium imaging in flow Cytometry and confocal TIRF microscopy, as well as Raman spectroscopy on semiconductors.

COBOLT SAMBA™ 532NM 1,5W

Great for Raman spectroscopy, Interferometry, Ti:Sapphire pumping and Nonlinear optics.

COBOLT FLAMENCO™ 660NM 500MW

Excellent for Raman spectroscopy, super-resolution STED nanoscopy, Interferometry, DNA sequencing and Particle analysis, eg, DLS/PCS.

COBOLT RUMBA™ 1064NM 3W

Perfect for Light scatter analysis and optical tweezers.

Polytec Portable Laser Doppler Vibrometer Educational Kit

Polytec of Germany is the world leader in laser Doppler vibrometry solutions and has released the PDV-100 vibrometer education kit designed for technical education of the principles of vibration and structural dynamics using innovative laser technologies.

The Portable Digital Vibrometer PDV-100 Vibrometer Education Kit, available from Warsash Scientific, is designed to introduce the fundamentals of structural dynamics through direct experimental measurements using laser Doppler vibrometry. The PDV-100 Vibrometer measures the vibration velocity of the sample using Doppler-shifted, retroreflected laser light. This non-contact measurement technique monitors an object's natural dynamic behaviour with high precision.

MEASUREMENT SYSTEM

- PDV-100 Portable Digital Vibrometer (0-22kHz) 0-30m range
- VIB-E-220 USB Junction Box for interfacing the Vibrometer to a PC
- VibSoft-20 data acquisition and FFT analysis software
- Vibsoft-Desk data analysis software for 3 floating users

VIBRATION EXPERIMENTS

- Euler Disk Experiment including test structures/fixtures and tutorial
- Loudspeaker Characterisation Experiment including test structures/fixtures and tutorial

The PDV-100 Vibrometer Education Kit includes two fascinating educational experiments built to demonstrate the unique properties of the laser measurement system. The first experiment introduces very basic principles with an exciting characterisation of a loudspeaker cone including the visualisation of the deflection shapes from the speaker membrane when excited at specific frequencies.

The second experiment is for the more advanced student. The measurement is more complex and examines the fascinating and detailed motion of the spinning Euler-Disk. This movement is well known from the wobbling and spinning motion exhibited by a coin spun about its axis on the table. The dynamic frequency shift during the movement reveals an astonishingly intricate behaviour and can only be measured meaningfully by non-contact measuring methods.

When not used for teaching, the PDV-100 Vibrometer can be used for research measurement tasks. The PDV-100 in conjunction with VibSoft-20 is a precision, lab-qualified measurement system for single-point frequency analysis up to 22kHz. Critical experimental setups such as vibration measurement on macro and micro-structures are quickly configured and easy to perform.

Warsash Scientific now representing M Squared Lasers

Warsash Scientific are pleased to announce that we now exclusive distributors for M Squared Lasers in Australia and New Zealand.

M Squared Lasers develops and manufactures next-generation lasers and photonic instruments that bring new capabilities, higher reliability and greater ease of use to a diverse range of industrial and scientific applications. With a core team that has more than twenty years of experience, and a track record of supplying award-winning products to worldwide markets, M Squared is ideally placed to help solve problems, de-risk your projects and accelerate your applications.

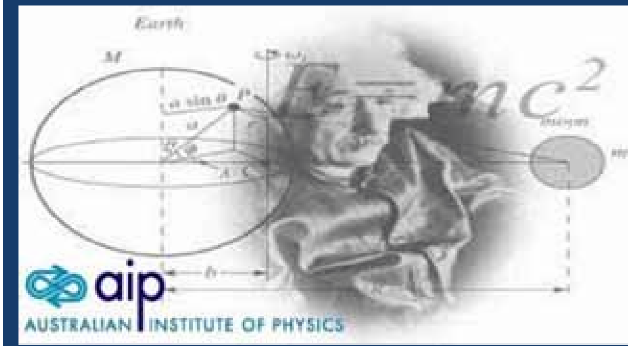
PRODUCTS INCLUDE

- Ti:Sapphire Lasers
- Optical Parametric Oscillators (OPOs)
- Laser Diode Drivers
- Temperature Controllers

For images and more information, contact Warsash Scientific on +61 2 9319 0122 or sales@warsash.com.au.

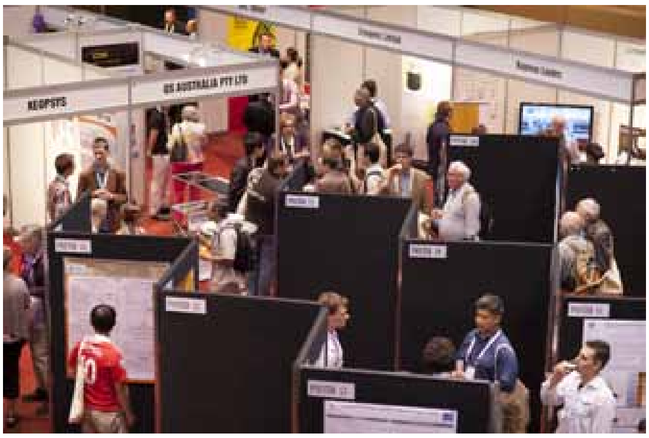
The AIP website has recently been upgraded and provides a user-friendly source of Physics information relevant to the AIP community. Find out who are the Office Bearers, who is on your State Committee, what Physics Groups relate to your field of interest, what Societies are linked to the AIP, what events/activities are planned for the coming year and much more.

Please visit the site at **www.aip.org.au**



December AIP Congress

Photography by **Jayne Ion, B-Side Design**



2013 WOMEN IN PHYSICS LECTURE TOUR

CALL FOR NOMINATIONS

The Australian Institute of Physics Women in Physics Lecture Tour celebrates the contribution of women to advances in physics. Under this scheme, a woman who has made a significant contribution in a field of physics will be selected to present lectures in venues arranged by each participating state branch of the AIP. Nominations are currently sought for the AIP WIP Lecturer for 2013. We are seeking a woman working in Australia who

- has made a significant contribution in a field of physics research
- has demonstrated public speaking ability
- is available in 2013 to visit Canberra and each of the six Australian State capital cities and surrounding regions.

Presentations will include school lectures, public lectures and research colloquia, subject to negotiation with the various AIP state branches and their contacts. School and public lectures are expected to be of interest to non-specialist physics audiences, and to increase awareness among students and their families of the possibilities offered by continuing to study physics. University lectures will be presented at a level suitable for the individual audience (professional or graduate). Air travel and accommodation will be provided.

Nominations should be sent via mail or email to the AIP Special Projects Officer (see information below) via the nomination form available from the Women in Physics Lecturer page of the AIP website, **http://www.physics.usyd.edu.au/wip/Main/Wiplecturer**. Self-nomination is welcomed, as are nominations from branches or employers/colleagues.

NOMINATION REQUIREMENTS

1. Nominee's details (via the 2013 WIP Lecture Tour nomination form)
2. Nominee's CV, including a detailed record of presentations to the general public, schools and media
3. A 300-500 word nomination which should include:

- a brief statement of the research area of interest to the nominee,
- an outline of her significant contributions to physics,
- references to key publications in which these contributions were presented (via *curriculum vitae*)
- evidence of her ability to give a lecture which will excite an enthusiastic response in senior secondary and undergraduate students. (NOTE: this requirement must be adequately addressed in order for the nominee to be considered for selection)

Self-nominations should include names of two referees who can attest to the ability of the nominee to give lectures appropriate for the target audience.

Closing Date: 28th March 2013

Applications and nominations should be sent by email or mail to:
AIP Special Projects Officer,
Dr Olivia Samardzic,
205 Labs, EWRD, DSTO,
P.O. Box 1500,
Edinburgh, SA 5111.

Email: olivia.samardzic@dsto.defence.gov.au

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