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Australian Institute of Physics
Promoting the role of physics in research, education, industry and the community

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EDITORIAL

RESEARCH TRAINING IN AUSTRALIA

In May 2015 the Australian Council of Learned Academies (ACOLA - representing the four Learned Academies: the Australian Academy of the Humanities, the Australian Academy of Science, the Academy of the Social Sciences in Australia and the Australian Academy of Technology and Engineering) was commissioned by the Minister for Education and Training, the Hon Christopher Pyne MP, to conduct a comprehensive review of Higher Degree by Research (HDR) training in Australia.

While the report concludes that Australia’s HDR system currently performs well, it nevertheless finds aspects in need of improvement. High among these is industry-research collaboration, which the report finds is ‘amongst the lowest when measured against OECD competitor countries.’ The report also questions the adequacy of ‘Australia’s unique Honours year’ as a pathway to HDR training. Several universities have replaced this with a Masters degree; the report recommends this as the preferred pathway.

The first article Graduate education in physics: International standards by Peter Drummond (Swinburne University), discusses the issues raised by the ACOLA report with particular emphasis on current practice and proposed changes based on benchmarking with HDR programs in Europe, US and Asia.

Each year the AIP awards the Bragg Gold Medal for Excellence in Physics to the ‘student who is judged to have completed the most outstanding Ph.D. thesis under the auspices of an Australian university’. Each university in Australia is invited to submit a thesis for consideration. The Bragg Medal for 2016 has been awarded to Phiala Shanahan (University of Adelaide, now at MIT). Phiala described her PhD project in the second article Strangeness and Charge Symmetry Violation in the Nucleon.

The third article We’ve signed up to the Paris Agreement on climate change; what next? by Evan Gray (Griffith University) considers what Australia needs to do in order to achieve its commitments made at the 2015 UN Paris Climate Conference.

Brian James

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www.aip.org.au
The last two months have been particularly eventful on the scientific and political fronts, as well as for a number of members of our Physics community receiving significant recognition for their contributions in research.

At the beginning of May the Federal Budget was announced. Understandably, this did not have a lot of new spending announcements for science, given the many that were contained in the National Innovation and Science Agenda (NISA) announcement in early December last year (which included major long-term allocations of funding to the Australian Synchrotron Facility, NCRIS, and the Square Kilometer Array Project). In the areas of physics and astronomy, there were only two announcements of note: $39.4M over the next 3 years to ANSTO to assist with the cost of reprocessing its spent nuclear fuel, and $12.6M to my own organization, the Australian Astronomical Observatory, to extend its current terminating funding program by another year until 2019-2020. In terms of science spending more broadly, there was much welcome additional funding for Geoscience Australia, as well as the support of Australia's research infrastructure and presence in Antarctica. For the university sector, the rationalization of the research block grant scheme from the current six programs into two was confirmed, as also the additional funding of $40M over the financial years 2017-18 and 2018-19 to help universities adapt to changes in the block grant formula. Finally, it was very pleasing to learn that the ARC's Future Fellowship Program will now be on-going, with 100 Fellowships expected to be awarded each year from 2016 onwards.

In late May, the Australian Academy of Science announced its new Fellows who have been elected this year. Notably, 4 of the 21 new fellows are physicists or who work in a closely related area. They are: Ian Allison (UTas), for his research in glaciology, in particular advancing the understanding of the role of Antarctica and sea ice in climate variations; Ben Eggleton (USyd), for his research in nanophotonics and non-linear optical physics, in particular the development of optical communication technologies; Halina Rubinsztein-Dunlop (UQ, and a member of the AIP Executive), for her research in laser physics and linear & non-linear high resolution spectroscopy, in particular its use to demonstrate dynamical tunneling in quantum systems; and Susan Scott (ANU), for her research in general relativity and gravitational wave science, in particular the analysis of astrophysical signatures in gravitational wave experiments. I would like to warmly congratulate Ian, Ben, Halina and Susan on their election and this well deserved recognition of their research contributions and leadership, as indeed all the other new fellows elected to the Academy this year.

It also gives me great pleasure to mention the award of the Association of Asia Pacific Physical Societies' Division of Plasma Physics 2016 Subrahmanyan Chandrasekhar Prize of Plasma Physics to Prof Don Melrose from the University of Sydney. This prize is awarded to recognize outstanding contributions to experimental and/or theoretical research in fundamental plasma physics and plasma applications in all fields of physics. Don will receive his prize at the joint 13th Asia-Pacific Physics Conference and 22nd AIP Congress in Brisbane in early December, providing a great opportunity for all of us to congratulate Don on the receipt of this richly deserved award.

And while on the topic of our biennial AIP Congress, I have been deafened by the silence in response to the idea that I floated in my last column of an “AIP Congress Lite”. This would involve either replacing the current congresses with much more cheaply run and slimmed-down meetings that would be held annually or, alternatively, retaining the current biennial congress, and holding “Lite” congresses in the intervening years. It is important the AIP Executive hear your views on this proposal, which can be emailed to me at aip_president@aip.org.au.

To end on a scientific note, what exciting news to hear as I write this column that a second gravitational wave event has been detected by the LIGO team, following hot on the heels of the very first one that they announced back in early February. This second detection, which was made on Boxing Day last year, would appear to be due to another black hole merger, this time involving two less massive objects (each ~10 times the mass of the Sun rather than ~30), that were more than one billion light years from Earth. This would indicate there are many more black holes in the universe than originally thought, and we can expect tens to hundreds more gravitational wave detections associated with their merger over the next 2-3 years. The future of gravitational wave astrophysics, particularly in Australia, therefore looks very bright!
NEW AAS Fellows
In May the Australian Academy of Science announced 21 new Fellows, 6 women and 15 men who have made outstanding contributions to a range of scientific areas including agriculture, advanced communications and cancer research. Among these were four physicists.

Ian Allison, a geological physicist who, at the University of Tasmania and Australian Antarctic Division, has made many significant contributions to our understanding of the mechanisms of Antarctic sea ice change.

Ben Eggleton, ARC Laureate Fellow and Professor of Physics at the University of Sydney, Director of the ARC Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), and Director of the Institute of Photonics and Optical Science (IPOS) at the University of Sydney. Ben was the winner of the 2011 AIP Walter Boas medal.

Susan Scott, a general relativity and gravitational wave researcher at the Australian National University and a leading expert in the singularity structure of spacetime, including the singularities at the heart of black holes.

Halina Rubinsztein-Dunlop, Director of the Quantum Science Laboratory at the University of Queensland and internationally recognised for her work in laser physics, linear and nonlinear high resolution spectroscopy, laser micromanipulation, atom cooling and trapping and nanoptics. Halina is a Special Project Officer on the AIP Executive and was the AIP 2003 Women in Physics Lecturer.

Review of the Research Training System
The Australian Council of Learned Academies (ACOLA - representing the four Learned Academies: the Australian Academy of the Humanities, the Australian Academy of Science, the Academy of the Social Sciences in Australia and the Australian Academy of Technology and Engineering) has published a Review of Australia’s Research Training System. The review looks at the present variety of higher research degree programs currently operating in Australia and compares them with systems in other parts of the world. The main recommendation is that the Bologna model offers the best benefits for Australia. At the present time the University of Melbourne, University of Western Australia and Macquarie University have programs similar to the Bologna model, and the University of Sydney has announced its intention to also move to a similar model. The article by Peter Drummond on p125 reviews the various international systems for research training and graduate coursework and their relevance for Australia.

New CEO for Science & Technology Australia
Science & Technology Australia (STA) has appointed Kylie Walker as its CEO, to replace Catriona Jackson, who is moving to Universities Australia as deputy CEO.

Ms Walker was formerly Director of Communications and Outreach at the Australian Academy of Science. She has worked in senior communication and advocacy roles within the science and health sectors, including Catholic Health Australia and the Australian Medical Association. Prior to that she worked as a journalist for Australian Associated Press and the ABC.
'Its" is a strong and vital voice for Australian science, and I am delighted to be joining the organisation," Ms Walker said.

'Its" is the peak group for the nation's 68,000 scientists and those working in technology. Its mission is to bring together scientists, governments, industry and the broader community to advance the role, reputation and impact of science and technology in Australia.

**New microscope announced**

A breakthrough new microscope opens a new window into the scientific world. The scanning helium microscope (SHeM), developed by a team at the University of Newcastle (UON), led by Professor Paul Dastoor in collaboration with researchers from the University of Cambridge (UK), uses neutrally charged helium to allow delicate materials to be accurately imaged for the first time.

Scientists have worked for decades on developing helium microscopy. The challenge lay in generating the helium beam. In the SHeM, the gas passes through an aperture to a vacuum chamber thereby forming a beam that can be scanned across a surface.

Helium is able to image sensitive structures with zero damage as it is chemically, electrically and magnetically inert, allowing many surfaces to be studied for the very first time. The helium atom beam's energy is less than 0.1 eV, far lower than the roughly 1 eV energy of a typical chemical bond. As the sample is moved in front of the beam, the helium atoms bounce off the sample and the measured scattered intensity as a function of position can be used to generate an image.

**Vale Bill McFadden, founder, Warsash Scientific**

The founder of Warsash Scientific, Bill McFadden, passed away on the Saturday 11 June 2016, aged 96. He founded Warsash Pty Ltd in 1976 and pioneered the introduction of many emerging photonics technologies to Australian research and industry, including lasers and detectors, micro & nano positioning systems and piezo actuators, single photon counting modules, laser Doppler vibrometers, fibreoptic temperature sensing and high-efficiency Raman microscopes, to name a few.

Bill was a strong early supporter of Australian scientific communities building strong relationships with the CSIRO, AOS, ACOVS, Australian Institute of Physics, the Macquarie University Centre for Lasers and Applications and the UNSW photovoltaic research community.

**The French Ambassador to Australia Monsieur Christophe Lecourtier (left) presents Bill McFadden (right) with the French Legion of Honour on April 2015. (credit: Navy Daily, 21 April 2015)**

Bill was a former World War II wing commander, who during D-Day was stained in the coastal village of Warsash in the south of England, after which he named the company. He was one of a select few with knowledge of the then top secret development now known as radar. This interest in scientific developments led him to found the company.

As recently as 2015 Bill was awarded the by the French Ambassador to Australia the Legion of Honour for his services to France during the war, on a French Destroyer on Sydney Harbour in April 2015.

**New CSIRO Climate Science Centre**

In late April CSIRO Chief Executive Dr Larry Marshall announced the establishment of a national climate research centre to be based in Hobart. The CSIRO Climate Science Centre will focus on climate measurement and modelling, and will be staffed by 40 climate scientists.
This followed an earlier announcement of broad job cuts in CSIRO in February 2016. The later announcement reduced the total job losses from 350 to 275. This includes around 75 positions lost within the CSIRO’s Oceans and Atmosphere division, which is responsible for climate science, from around 420 full-time staff. The cuts were widely criticised by climate scientists in Australia and overseas.

“Our Strategy 2020 is focussed on collaboration, global connection, excellent science and innovation – all four of these pillars are at work in this Centre,” Dr Marshall said. “As I indicated at the start of CSIRO’s current broader change process, it is critical that we retain the capability that underpins our national climate research effort. The announcement is a culmination of the ongoing consultation and feedback we’ve had from our staff and stakeholders, and this new Centre is a reflection of the strong collaboration and support right across our system and the global community.”

The Cape Grim baseline air pollution station - a joint responsibility of the Bureau of Meteorology and CSIRO.

Operating as part of CSIRO Oceans and Atmosphere, the new CSIRO Climate Science Centre has a guaranteed research capability for 10 years. Collaboration and partnership will be a cornerstone of this decadal commitment. In recognition of this, the Minister for Industry, Innovation and Science has agreed that an independent National Climate Science Advisory Committee will be established. The Committee will have representation from CSIRO, the Bureau of Meteorology and other experts from Australia and overseas. It will report at Ministerial level to inform the future direction of Australia’s climate science capability and research priorities.

(source: CSIRO and The Conversation)

New solar cell efficiency record for UNSW

A new solar cell configuration developed by engineers at the University of New South Wales has pushed sunlight-to-electricity conversion efficiency to 34.5% – establishing a new world record for unfocused sunlight and nudging closer to the theoretical limits for such a device. The record was set by Dr Mark Keevers and Professor Martin Green, Senior Research Fellow and Director, respectively, of UNSW’s Australian Centre for Advanced Photovoltaics, using a 28 cm² four-junction mini-module – embedded in a prism – that extracts the maximum energy from sunlight. It does this by splitting the incoming rays into four bands, using a hybrid four-junction receiver to squeeze even more electricity from each beam of sunlight.

The triple-junction cell targets discrete bands of the incoming sunlight, using a combination of three layers: indium-gallium-phosphide; indium-gallium-arsenide; and germanium. As sunlight passes through each layer, energy is extracted by each junction at its most efficient wavelength, while the unused part of the light passes through to the next layer, and so on. Some of the infrared band of incoming sunlight, unused by the triple-junction cell, is filtered out and bounced onto the silicon cell, thereby extracting just about all of the energy from each beam of sunlight hitting the mini-module.

(schematic diagram of the spectrum-splitting, four-junction mini-module. (Credit: UNSW)
Multi-junction solar cells of this type are unlikely to find their way onto the rooftops of homes and offices soon, as they require more effort to manufacture and therefore cost more than standard crystalline silicon cells with a single junction. But the UNSW team is working on new techniques to reduce the manufacturing complexity, and create cheaper multi-junction cells.

However, the spectrum-splitting approach is perfect for solar towers, like those being developed by Australia’s RayGen Resources, which use mirrors to concentrate sunlight which is then converted directly into electricity. The research is supported by $1.4 million grant funding from the Australian Renewable Energy Agency (ARENA). (Source: UNSW)

Chandrasekhar Prize of Plasma Physics awarded to Don Melrose

The Division of Plasma Physics of the Association of Asia-Pacific Physical Societies has awarded Professor Donald Melrose of the University of Sydney the 2016 Subramanyan Chandrasekhar Prize of Plasma Physics for his sustained original contributions to the theory of coherent emission processes in astrophysical and space plasmas, and for his seminal contributions to the theory of quantum plasmas.

The Chandrasekhar Prize is awarded annually to a scientist who has made seminal/pioneering contributions in the field of plasma physics. The Prize will be presented at the joint meeting of the 13th Asia Pacific Physics Conference and the 22nd Australian Institute of Physics Congress in Brisbane, 4-8 December 2016.

NMI awards mark World Metrology Day 2016

The National Measurement Institute (NMI) marked World Metrology Day 2016 (20 May) by recognising the outstanding achievements in metrology of two Australian researchers.

Chandrasekhar Prize of Plasma Physics awarded to Don Melrose

In announcing the awards, NMI CEO Dr Peter Fisk said that ‘The awards acknowledge and celebrate the outstanding achievement in practical applications of measurement, something which affects our everyday lives.’

The 2016 Barry Inglis Medal was awarded to Professor Mike McLaughlin, on behalf of a CSIRO team and Ziltek Pty Ltd. They developed and commercialised a rapid, simple and relatively inexpensive method to detect and quantify total petroleum hydrocarbons (TPH) in soil. Sites contaminated by TPH, such as old petrol stations, pose a health risk to both humans and animals through soil and groundwater contamination.

L to R: Mr Les Janik, Prof. Mike McLaughlin and Dr Martin Soriano-Disla, all from CSIRO Land and Water.

Professor McLaughlin and his team developed a portable instrument that reflects an infrared beam off a soil sample to detect and measure TPH directly. This on-site technique allows industry to measure TPH levels in the field and means fewer samples have to be collected for laboratory analysis thereby saving time and money. ‘The refinement of this technique by CSIRO and its subsequent commercialisation by Ziltek is an excellent example of how small businesses and Australian scientists can work together to address global environmental problems,’ Dr Fisk said.

Dr Suelynn Choy from RMIT University won the 2016 NMI Prize for having demonstrated – in an Australian first – that data generated by local infrastructure and transmitted by a regional satellite navigation system can be used to provide accurate point positioning anywhere outdoors in Australia at any time.
Dr Chris Barty, the Chief Technologist of the world’s largest laser at the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory in California, spoke at a joint event of the NSW Branch, the UNSW School of Physics and the Royal Society of NSW on 28 April 2016. In his talk Dr Barty argued the case for laser-driven fusion as a contribution to ameliorating climate warming. Informed by his more than 20 years activity at the NIF-laser - with nearly 100 times larger pulse energy than any other laser in the world – Dr Barty described the prospects for laser driven fusion.

‘Dr Choy’s research is laying the foundations for significant improvements to our current global navigation systems which will in turn benefit many industries such as transportation, emergency services, engineering and mapping,’ Dr Fisk said.

(source: NMI)

BRANCH NEWS

New South Wales
Dr Chris Barty, the Chief Technologist of the world’s largest laser at the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory in California, spoke at a joint event of the NSW Branch, the UNSW School of Physics and the Royal Society of NSW on 28 April 2016. In his talk Dr Barty’s argued the case for laser-driven fusion as a contribution to ameliorating climate warming. Informed by his more than 20 years activity at the NIF-laser - with nearly 100 times larger pulse energy than any other laser in the world – Dr Barty described the prospects for laser driven fusion.

Free Undergraduate Student Membership

Nominations for the AIP Executive
Every two years the AIP President, Vice-President, Secretary, Treasurer and Registrar. The President and Vice-President may not seek re-election for the same position.

Any AIP member can nominate a candidate for these positions, and in accordance with our constitution the current executive has nominated the following:
• Andrew Peele (as President)
• Jodie Bradby (as Vice-President)
• Joe Hope (as Secretary)
• Ian McArthur (as Registrar)
• Judith Pollard (as Treasurer).

In Accordance with the constitution, if you’d like to submit a nomination for any of these positions, please send it with a named and signed nominator and seconder (all of whom must be financial AIP Members, Fellows or Honorary Fellows) along with a signed letter of consent from the nominee to aip@aip.org.au, or by mail to AIP, P O Box 546, East Melbourne Vic. 3127 Australia.

Nominations close 21 August 2016.
Graduate education in physics: International standards

Peter D Drummond, FAA
Swinburne University of Technology, GPO Box 5387, Melbourne, Australia, 3001

Universities in Australia are changing rapidly. With the release of the Australian Council of Learned Academies (ACOLA) report on graduate training in Australia, there is an increased impetus for improvements at the graduate level. What will happen to our graduate physics education? This article summarizes the international situation, focusing on the graduate training offered in the two major world systems: the US/East Asian integrated PhD, and the European Bologna model. It also covers how Australian universities are already modifying their degrees, and compares graduate coursework in physics around the world.

Introduction

In view of the recent Australian Council of Learned Academies (ACOLA) Report on graduate training, and to plan MSc and PhD degree requirements in Australia, we first must understand the relevant international education systems. This article will analyse the two main standards for graduate education in the world today, namely the US/East Asian and the European/West Asian systems.

As a result of shorter degrees in most Australian universities compared to these international standards, our student preparation has not been world class. This disadvantages our graduates, and makes them less attractive as employees. When they apply for jobs, they often have to compete with students educated elsewhere in the world. For many years, it was not uncommon for Australian students to plan to travel internationally for their graduate education. Fortunately, a number of major Australian universities are now offering internationally competitive graduate degree programs. It is likely that this will become a more attractive option for all prospective students.

The most well known example in Australia is the University of Melbourne, Australia’s top-ranked university. Despite many predictions that its Bologna-type MSc/PhD program would not attract students, it has proved very attractive to science students. Its MSc enrolment numbers appear larger than any traditional Honours program in Australia. In fact, they are now able to enrol all the top-ranked science students they can accommodate, despite a one year longer degree. The main problem at University of Melbourne is being able to supervise the large number of students that they recruit!

The other Australian universities that have switched to this type of program are the University of Western Australia and Macquarie University, with the University of Sydney recently announcing a similar plan. It is certain that every university in Australia is studying this trend. It would be very surprising if no more universities changed in future, especially as this is the recommended program of the recently released ACOLA Review of Australia’s Research Training System (see Table 1).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Undergraduate education</th>
<th>Initial HDR training component</th>
<th>Research training</th>
</tr>
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<td>Component</td>
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<td>Research training coursework</td>
<td>Research Doctorate</td>
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<td></td>
<td>Masters degree</td>
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<td>Length</td>
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<td>2 years</td>
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<td>CSP + HECS FEE-HELP</td>
<td>Research training block grant</td>
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<tr>
<td>Student support</td>
<td>Youth allowance, Austudy, ABSTUDY</td>
<td>Youth allowance, Austudy, ABSTUDY</td>
<td>Scholarship</td>
</tr>
</tbody>
</table>

Table 1: Preferred model emerging from consultations with stakeholders (Table 8 from the ACOLA Review of Australia’s Research Training System).
Once it becomes clear to every student that this type of degree is both the international and national ‘gold standard’, it will become impossible to recruit any but a few graduate students to older types of program. As a result of these dynamic changes, it is vitally important to understand the current environment and the relevant international norms.

This article will focus on individual, top-ranked universities, because these flag-bearers set the standards for entire regions. One finds that most universities in a given geographical area soon copy the standards of leading universities, or else they face losing their hard-won reputation and their high-quality student enrolments.

The analysis given here will focus in detail on graduate physics requirements for definiteness. Apart from some minor discipline-specific changes, these requirements do not change dramatically for different areas of science and technology. Even in economics, or humanities subjects like linguistics, one sees very similar patterns.

**American/East Asian system**

The USA has no official graduate education policy, yet its leading universities have a common standard that has only minor variations across the whole country. This is the most successful country in science and technology, with the most Nobel prizes, the world’s largest economy, and the world’s leading technology companies.

Even if one argues that technological leadership is passing to China and Japan, this is almost irrelevant to the education question. Both China and Japan have cloned the US education system. Thus, no matter which of these three has the largest GDP or the largest output of science and technology, the lessons to be learnt are the same.

In fact, the US system has been widely copied throughout North and South America, as well as in all of Asia’s leading economies, especially China, Taiwan, Korea and Japan. As a result, this system educates most of the world’s scientists. It is responsible for educating much of the competition that Australian students will face in their careers.

The analysis given here will focus in detail on graduate physics requirements at one major public and one private US university, to have well-documented and traceable evidence available. Yet if it were repeated with a different choice of university or discipline, almost exactly the same results would be obtained.

**Graduate school requirements do not change very much according to discipline or even from university to university across the USA.**

**Summary of typical US graduate systems**

**USA private: Harvard University**

Entering PhD students are expected to have a four-year B.Sc. degree. Eight to sixteen additional postgraduate courses are required in the first two years of the PhD degree, which lasts for 5-6 years. These are one semester, 36 lecture hour courses, with at least four core and four advanced courses. The courses can also be used to obtain a Masters degree. This is a 4+5 or 4+6 system.

**USA public: University of California at Berkeley**

Entering PhD students are expected to have a four-year B.Sc. degree. Ten additional postgraduate courses are required in the first two years of the PhD, which lasts for 6 years. These are one semester, 32 lecture hour courses, with at least five core and five advanced courses. Students commence research while taking courses. This is a 4+6 system.

The pattern at both universities is therefore a 4+5 or a 4+6 year system. All students would be expected to have taken at least four years of undergraduate studies before commencing, with Berkeley stating very clearly that it regards a six-year PhD as the norm. The minimum number of advanced graduate school courses taken is eight, but this is not typical of most students.

Although the average number is not documented, one can estimate from the Harvard University range of 8-16 graduate courses that about 12 graduate courses or 18 months study is typical, depending on an individual’s research program and study requirements of their supervisor. Each one-semester course is about 12 weeks, with 30-36 lectures.

The graduate course details are outlined in the relevant university webpages. It is notable that they are all advanced, discipline specific graduate courses. They cover topics in the science field being researched – for example, classical mechanics, fluid dynamics, quantum physics, and relativity. They do not include generic studies or research management.
The American Physical Society reports the current median time to completion in physics as seven years. This is a total of eleven years of tertiary studies, which is possibly too long. This is something of a weakness of the USA system: there are incentives for supervisors to extend PhDs, sometimes for too long an overall period.

One notable feature of this program is that there is a clear philosophy that undergraduate studies do not fulfil the coursework requirements. Instead, one must re-educate students with a more detailed and rigorous understanding of every aspect of their subject. The graduate requirements are not just specific to one given research topic. Graduate studies in this system prepare students for a full career in their chosen scientific field, by giving them a background that is both broad and advanced. This aspect is a very positive one, and does result in exceptionally well-prepared scientists.

In summary, the American-East Asian system provides an average of 18 months of full-time, advanced, discipline-specific graduate courses at the 5th and 6th years of an overall program.

**European/West Asian system**

Europe, via the European Union, has an increasingly integrated economic and education system. The combined EU economies have a GDP of US$18 trillion, exceeding any individual nation and larger than the USA or China. This is also one of the greatest science and technology groupings in the world, manufacturing every kind of high technology.

One of the major educational achievements in the EU was the Bologna agreement, to harmonize graduate studies in the EU. The purpose of the Bologna agreement is to introduce qualifications at three levels to allow for portability across Europe, at all stages in any student’s educational career. This goal has largely been achieved.

The main difference with the USA/East Asian system is the emphasis on portability. To allow this, an MSc degree is taken between the bachelors and the doctoral degree, to permit easier exchange.

The Bologna agreement is not prescriptive, as some variations are permitted. Nor is it entirely restricted to the EU only. Non-EU members include Turkey, Georgia, Russia, Ukraine, Switzerland, Belarus and former Soviet bloc Asian countries. It is clearly possible for other countries to join from outside the EU, and it may be feasible for Australia to join, if degrees were harmonized. As this system is now spreading east to Russia and Kazakhstan, it is no longer purely European. Therefore it is best characterized as the European-West Asian system, rather than a European system only.

The most typical Bologna course is a 3+2+3 course at bachelors, masters and doctoral levels. However, in Russia a 4+2+3 approach is more common, and this is permitted. The longer Russian education system is closer to the US model. It is possible that the wide range of student backgrounds in Russia has meant that an extra year is needed.

Unlike the USA, almost all European universities and graduate schools are publicly funded. There are very few private universities, and tuition is often free. In many European graduate schools there is an English language lecture course system for students at MSc level or above. This makes it very competitive for international students.

The largest economy in the EU is Germany, with a GDP of US $4 trillion, nearly 25% of the entire EU economy. It is also the largest exporter, and the most highly technological economy in the EU. It has an aerospace industry, an automotive industry, electronics and medical instrumentation industry, as well as many other fields.

This analysis will choose a large German university for comparisons, namely Heidelberg, which also has the largest physics enrolments of any German university, and a high ranking. Heidelberg is a typical large German university, and it is very similar to a large number of other German universities of similar ranking. A top university in Sweden is included as well. The reason for this is that Sweden is an example of a relatively low population and even rather agricultural country, indeed somewhat like Australia. Despite this, it has built a high-technology scientific base within the EU and Bologna system.

Stockholm is the highest ranked Swedish University.

**Summary of typical EU graduate systems**

**German public: Heidelberg University**

Entering PhD students have an MSc degree. The two-year MSc consists of 18 months of graduate courses, and a six-month research thesis. Around 7-8 half-year courses are required in the first year, each with a 240-hour workload and 4 lecture hours/week. The second year includes a thesis, a specialized course, and a course on scientific methods. This is a typical 3+2+3 system.
**Swedish public: Stockholm University**

Entering PhD students have either a four-year B.Sc. or MSc degree. The PhD lasts four to five years, and includes 25% course work and 75% thesis. The MSc lasts two years, and includes at least six full-semester physics courses and a one-year thesis. There is a requirement for computational physics in all physics MSc programs. This is a 3+2+4 OR 4+5 system.

The pattern at both is similar, except that at Heidelberg the two-year masters degree program includes 18 months of graduate courses. This is compulsory for entry to the PhD at Heidelberg, which then lasts another three years. This includes one course on research planning or scientific methods, as well as specialized courses.

By comparison, the MSc course work requirement at Stockholm is shorter – only one year – but there is an additional year of coursework required during the PhD. The total course work required appears to be two years, which is slightly longer than the usual 18-month requirement at either Heidelberg or most US universities.

Apart from the shorter three year B.Sc. found in most European countries – except for Russia – the graduate program as a whole is nearly identical in either the USA or the EU/Bologna type system. It involves at least 18 months – in some cases 24 months - of full-time graduate course work, equivalent to 12-16 one-semester course units.

There is some evidence of generic skills being required, but no more than a single course, or about 10% of the overall graduate school course-work requirement. In Stockholm University, with an economy very similar to Australia, the generic skills course required in physics is in computational physics, and no course in management is required.

In summary, the total graduate coursework required in the EU-West Asia or Bologna system is at least 18 months of full-time graduate studies in a general discipline area.

**Australian system**

The Australian system is relatively deregulated and unstandardized, apart from funding limits. There was a UK-style, 3+1+3 system prevalent throughout Australia in the twentieth century.

A typical Australian science course in the twentieth century included only 3½ years of course work followed by a ½ year Honours thesis, then enrolment in the PhD with no further courses. The course work requirement was two years shorter than in the US/East Asian system, and at least one year shorter than the EU/West Asian system.

Even at the present time, while all undergraduate enrolments are fully funded and uncapped, there are very restrictive quotas on Commonwealth funded enrolments in MSc level degrees. This limitation has meant that Australian universities were largely prevented from offering either US or European style courses, due to funding caps.

This deadlock was broken by the efforts of Australia’s leading public university, the University of Melbourne, which negotiated a government funded masters program that is essentially a clone of the Bologna system in the EU. This allowed Melbourne to offer a two-year MSc, increasing the graduate coursework to a full year.

Some universities in Australia require graduate courses, taught internally, as part of a PhD program. As one example, this has proved successful in the Swinburne University of Technology’s Centre for Quantum and Optical Science, and helps students complete.

**Australian old system: Australian National University**

Entering PhD students have a four-year BSc (Hons) degree. The PhD lasts three years or more. The B.Sc. (Hons) includes a half year course in prescribed physics subjects past the usual three-year bachelors level, together with a six month Honours thesis. This is a 3+1+3 or 4+3 system.

**Australian new system: University of Melbourne**

Entering PhD students have an MSc degree. The PhD lasts three years or more, the MSc two years. The MSc requires seven full semester courses, each typically 30-35 lectures, in prescribed physics areas. In addition, students are required to take a ‘Professional Tools’ course, e.g. Ethics or e-Science. There is a one-year MSc research project with thesis. This is a 3+2+3 system.
Even under the new Australian system, pioneered at Melbourne and also offered at UWA and Macquarie, there is only a single year of graduate course work. The total course length is still 18 months less than in the US-East Asian system. Some Melbourne students now take an additional undergraduate year, obtaining an extra undergraduate diploma, to compensate for this shortfall.

These universities may also provide the older Honours programs in parallel, in some Faculties.

The new Australian graduate system has doubled the average coursework required compared the Honours program, but still has lower coursework content than either the EU or the USA.

Figure 1 shows the number of years of courses required for degrees past the third year. This does not usually include topics like research management, although this is only offered as a one-semester course at Heidelberg University in Germany.

The notable point is that the typical international standard for specialized postgraduate coursework after the bachelors is now around 1.5 years, or about 12 full semester courses of 3 lectures per week for 12 weeks. This is three times higher than in the ANU Honours degree, and 50% higher than the Melbourne-style Bologna model. These longer postgraduate courses are accompanied by long PhD theses, of around 3.5-4.5 years. Funding a Masters either partially or fully using the Research Training Scheme (RTS) in Australia is questionable. This reduces the fundable time of the research PhD down to 2-3 years, which is shorter than current averages at most Australian universities.

The Melbourne-UWA model of two years of Commonwealth Supported Places (CSP) seems better, if it can be negotiated federally. This is different to the Macquarie model of one year of CSP and one year RTS.

In summary:
- The longer postgraduate courses offered in an MSc are internationally almost universal.
- It is standard to have 1-2 years or 8-16 units of discipline specific postgraduate courses.
- The two-year CSP model at Melbourne seems preferable to the CSP+RTS model.

Finally, the conclusions drawn here are identical to the preferred model in Table 8, p26 of the recent ACOLA Review of Australia's Research Training System, published in April 2016.
References

    https://www.physics.harvard.edu/academics/grad/requir

Author biography

Peter Drummond is Science Director of the Center for Quantum and Optical Science at Swinburne University of Technology, researching ultra cold atomic physics and quantum information. He has a Masters from Harvard University and a PhD from Waikato University, supervised by New Zealand’s Dirac Medallist, Dan Walls. He has worked at Rochester, Auckland, Erlangen and Queensland Universities, at IBM Laboratories in San Jose, and NTT Laboratories in Tokyo. He has won the AIP Boas and Massey medals for research, the German Humboldt award, and is a Fellow of the Australian Academy of Science, the AIP and the American Physical Society.

Women in Physics tour: August dates announced

The lecture dates have been announced for the 2016 Women in Physics lecture tour with lecturer Dr Catalina Curceanu, Head Researcher at Italy’s National Institute of Nuclear Physics:

Dr Catalina Curceanu

- Tasmania 8-9 August
- NSW 10–12 August
- Queensland 15–16 August
- South Australia 17–18 August
- Western Australia 19 August (TBC)
- ACT 22 August
- Victoria 23–25 August

ODE TO STRING THEORY

Modern Physics based on strings
Can model all existing things
And put each one into its place
In twenty-four dimensioned space.

But does this any insight give
About the world in which we live?
Or does it simply give a reason
For theorists’ annual travel season?

How nice it is to have a theory
Whose outputs do not make you weary
For if predictions don’t fit data
You just add more dimensions later.

Perhaps I’ll give up condensed matter
And all our present Physics chatter
And look for strings up in the sky –
If they can see them, why not I?

Neville Fletcher
Strangeness and Charge Symmetry Violation in the Nucleon

Phiala Elisabeth Shanahan*
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To test the Standard Model of nuclear and particle physics it is essential to understand the predictions of this theory for properties of particles such as the proton and neutron. Particularly interesting are observables related to ‘strangeness’ and ‘charge symmetry violation’, which are important in contexts ranging from dark matter direct detection to neutrino-nucleus scattering experiments. These key quantities can be studied using supercomputer simulations of the strong-force part of the Standard Model, Quantum Chromodynamics, on a space-time lattice.

Protons and neutrons, collectively called nucleons, are the building blocks of atomic nuclei and constitute more than 99% of the visible mass in our universe. Quantitatively describing the structure of these particles in terms of the quark and gluon constituents encoded in Quantum Chromodynamics (QCD), our theory of the strong force, remains a defining challenge for hadronic physics research. The ultimate goal is to ‘map out’ the complete spatial, momentum, spin, flavour, and gluon structure of the nucleon; to understand (and be able to predict) its interactions and resonances precisely. Such a map is not only the key to interpreting our observations of Nature in terms of the currently-accepted fundamental theory, but is essential to inform searches for physics beyond the Standard Model (SM). For example, QCD calculations of the SM background are necessary to constrain direct searches for new physics at the high-energy frontier at the Large Hadron Collider. In the low energy-regime – at the so-called intensity frontier – QCD is typically the limiting factor in indirect searches for non-SM physics, from charge-parity violation in $b$-quark decays to permanent electric dipole moments in hadrons and nuclei.

Over several decades of experimental investigation and theoretical analysis based on QCD, a complicated picture of the nucleon has emerged – see Figure 1. The modern understanding is that its structure is generated not only by three ‘valence’ quarks – the simplest configuration needed to carry the observed quantum numbers – but additionally any number of ‘sea’ quark-antiquark ($q\bar{q}$) pairs and gluons. Deep inelastic scattering of electrons and neutrinos off nuclear targets has demonstrated that, at low values of the probing momentum-scale $Q^2$, valence-quark effects dominate. For the proton and neutron, with valence - quark content $(uud)$ and $(udd)$ respectively, the $u$ and $d$ quarks are thus of primary importance. However, with larger values of $Q^2$ the resolving power of scattering probes increases, and the increasingly-significant role of the vacuum-generated ($q\bar{q}$) pairs and gluons is exposed. Because the large masses of the heavy quarks ($Q = c, b$ or $t$) prohibit any significant admixtures of $Q\bar{Q}$ pairs in the nucleon wavefunction, strange quarks – the lightest of the sea-only quark flavours – play a unique role. Providing tremendous insight into the nature of the quantum vacuum, strange nucleon observables occupy a position in QCD comparable in significance to that of the Lamb shift in the history of QED. The calculation of these quantities within QCD, and their verification by experiment, is thus of fundamental importance.

Figure 1: This artistic rendition shows the modern picture of a proton and how experimentalists probe its structure through electron scattering. The blue and green blobs illustrate the typical structure of the gluon-field configurations which are averaged over in describing the vacuum properties of QCD. This part of the image was created using supercomputer simulations of the QCD action density (similar to an energy density). The spheres represent the proton’s uud valence quarks and an $SS$ vacuum quark pair. The volume of the box shown is on the scale of a few protons. (Image courtesy of Derek Leinweber, CSSM, University of Adelaide.)
As well as providing a key test of our understanding of QCD, strange observables are relevant to searches for physics beyond the SM. The role of the strange quark in generating the nucleon mass – encoded in a quantity named the strange sigma term – is particularly topical as the uncertainty on this much-debated quantity is the limiting theoretical factor in the interpretation of experimental searches for particle dark matter. The spatial distribution of the nucleon’s strange quark content has also received considerable attention in recent decades. Despite significant accelerator facility programs at Jefferson National Laboratory and at Mainz, the best experimental values of the proton’s strange electromagnetic form factors, which describe the strange quark contribution to the spatial distribution of the proton as seen by an electromagnetic probe, are indistinguishable from zero. The limiting uncertainty in future determinations of these quantities is theoretical, arising from the assumption of good charge symmetry – see Figure 2.

Figure 2: This image illustrates the concept of ‘charge symmetry’: the symmetry relating up quarks in the proton (which has valence quark structure uud) and down quarks in the neutron (which has valence uud quarks), and vice-versa.

Charge symmetry violating (CSV) effects quantify the breaking of the approximate flavour symmetry of the u and d quarks which have almost equal masses. Beyond their relevance to the experimental investigation of strangeness in the nucleon, the precise determination of CSV observables has, with increasing experimental precision, become essential theoretical input for searches for physics beyond the SM. In particular, the long-neglected CSV effects in the parton distribution functions, which describe how momentum is distributed among the proton’s quark and gluon constituents, are important to the interpretation of neutrino-nucleus deep inelastic scattering experiments. Clearly it has become imperative to determine both strange and CSV observables precisely from QCD.

The only known way to directly probe QCD in the low-energy regime is using a numerical technique named lattice QCD. This method involves explicitly calculating observables within a discretised formulation of QCD using the supercomputers such as ‘Isaac’ at the University of Adelaide – see Figure 3. First proposed in the mid-1970s, lattice methods, computer infrastructure, and the theoretical techniques used to interpret lattice simulation results, have now reached a level of sophistication that allows truly quantitative predictions to be made from QCD. My PhD explored nucleon structure using lattice QCD, with a particular focus on both strangeness and CSV.

Figure 3: The Isaac supercomputer at the University of Adelaide, used for numerical simulations of Quantum Chromodynamics. (Image courtesy of James Zanotti, CSSM, University of Adelaide.)

A key result from my work is a precise new value for the strange sigma term. As many dark matter candidates (e.g., the supersymmetric neutralino) have interactions with nuclei which depend quadratically on the sigma terms, the uncertainty of theoretical dark matter scattering cross-sections (and thus our expectations for dark matter detection experiments) is largely driven by the poor knowledge of the strange sigma term. My PhD work supports modern revisions of this quantity with the result that predicted dark matter cross-sections have been reduced by an order of magnitude, with significant
increases in precision. Another important aspect was a study of the long-neglected CSV effects in the nucleon’s parton distribution functions, which describe how momentum is distributed among the proton’s quark and gluon constituents. The results confirm that the omission of these effects led to an over-inflated view of the importance of the deviation from SM expectations observed in neutrino-nucleus deep inelastic scattering experiments.

My PhD work also included a comprehensive lattice-based study of the electric and magnetic factors which describe the spatial distribution of the proton as seen by an electromagnetic probe. By combining experimental and lattice input, we deduced the strange nucleon form factors over a far larger range of momentum-scales than is accessible experimentally. Our calculation of the strange magnetic moment is an order of magnitude more precise than the closest experimental result. Until now, the dominant uncertainty in experimental determinations of the strange proton form factors has come from a lack of knowledge about the size of CSV in these quantities. By revealing that the CSV form factors are an order of magnitude smaller than suggested by previous work, our calculations also open the door for a new generation of experimental tests of QCD through the proton’s strange form factors.

**Author Biography**

Phiala completed her PhD at the Center for the Subatomic Structure of Matter (CSSM) and Center of Excellence for Particle Physics at the Terascale (CoEPP) at the University of Adelaide. Phiala is now a postdoctoral researcher at the Center for Theoretical Physics at the Massachusetts Institute of Technology in the United States. She is currently using supercomputer simulations of QCD to study the gluon structure of particles like the proton and to explore how nuclei emerge from their constituents.

* Winner of the 2016 Bragg Gold Medal for her PhD thesis *Strangeness and Charge Symmetry Violation in Nucleon Structure.*
We've signed up to the Paris Agreement on climate change; what next?
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The case for powering our global society using the ultimate renewable – because unstoppable – energy is made. The solar energy resource (including wind) available at the earth’s surface is of order 10⁴ times our average global energy consumption. But how can we get from here – with some 81% of global primary energy demand coming from fossil fuels – to the there of renewables?

Paris and the INDCs
The dust is settling after the UN Paris Climate Conference (COP21) [1]. Agreement has been reached to limit the global average temperature rise to 2°C, with an aspirational goal of 1.5°C. As always, one should scrutinise the fine print, in this case the ‘Intended Nationally Determined Contributions’ (INDCs) [1], which are climate action plans submitted by each country. They outline how, and by how much, countries will reduce their emissions, and the actions they will undertake to strengthen climate resilience. At the time of writing (May 2016), 162 INDCs had been submitted, representing 189 countries (1 combined INDC for the 28 member countries of the European Union), covering 98.8% of global emissions [2]. As widely reported in news media, 175 parties (174 countries and the EU) signed the Paris Agreement on 22 April, with a further two signing since. Global agreement on this scale is unprecedented, and necessary, but there is a yawning gulf between aspiration and the reality to be grappled with as the post-Paris euphoria wanes.

The International Energy Agency 2°C scenario (2DS)
“The 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C.” The 2DS sets the target of cutting CO₂ emissions (including emissions from fuel combustion and process and feedstock emissions in industry) by almost 60% by 2050 (compared with 2013), reaching a cumulative emissions level of about 1000 Gt CO₂ from 2013 to 2050. Carbon emissions are projected to decline after 2050 until carbon neutrality is reached.”

Estimates based on the 155 INDCs submitted by October 2015 indicate that even if countries implement INDCs, the planet will still experience an increase in average global temperature of 2.7–3.5°C, depending on the assumptions used in the modelling [1]. Movement towards stronger commitments to CO₂ emissions reduction were already underway at COP21, allowing hope that the political climate will be conducive to meeting or exceeding the 2°C target, but what about the technical possibilities for the required revolution in energy production and supply?

Can the 2DS be realised?
Making even the 2°C temperature-rise scenario reality requires first that emissions of CO₂, the principal culprit in anthropogenic warming, fall very swiftly. This implies rapid replacement of CO₂-emitting energy generators because they do not generate any during operation and not too much during building, or because their CO₂ emissions are captured and sequestered before entering the atmosphere.

Figure 1 shows the modelled contributions of energy technologies to reductions of CO₂ emissions assumed in the 2DS. In the words of the IEA "A portfolio of low-carbon technologies is needed to reach the 2DS; some solutions will be broadly applicable, while others will need to target specific sectors" [3]. The reasons for projecting a mix of technologies are practical. Firstly, we need to incorporate currently available benign technologies. Secondly, as we will see, at least in the crucially important next few decades, no single technology could be developed fast enough to directly displace all fossil-fuel use or ameliorate its consequences...or could it?
And what about the "aspirational goal" of 1.5°C urged by vulnerable nations? We have reached a global average temperature rise of about 0.85°C over the period 1880–2012 [4]; how will 2°C feel?

According to The World Bank [5], even the lowest published emissions scenarios in recent literature lead to warming projected to peak at around 1.6°C and decline to an eventual median level of 1.3°C above pre-industrial by 2100 (Figure 2). A second necessity, in addition to drastically reducing CO₂ emissions, probably will be active recapture of atmospheric CO₂, which is feasible in principle using "artificial trees", for instance [6], in addition to natural photosynthesis. There is no available grand-scale technology right now, although recapture might be important in achieving a lower ultimate temperature rise.

For the moment, the urgent question is how can we bring new CO₂ emissions to zero? This question cannot (at least, should not) be answered before understanding the scale of the problem. A big related question is whether the global economic system be maintained in something like its present form, with its reliance on growth for stability, or must we in the rich countries retreat to a more parsimonious lifestyle and try to force developing nations to limit their development aspirations? The availability of energy underpins the modern world absolutely, and so a really fundamental question to address first is whether we can in fact sustain our present or projected global energy use while staving off climate change. The ultimate problem is ourselves and our teeming numbers, of course, but my aim here is to stick to technical matters and proceed based on evidence.

**Fossil fuels**

According to the International Energy Agency [7], in 2013 (latest available data) 81.4% of world primary energy supply was from fossil fuels – coal, oil and natural gas. Fossil fuels contain carbon and hydrogen atoms that are strongly bonded together, thus storing chemical energy. Burning (oxidation) breaks those bonds and liberates heat, that is, kinetic energy of the combustion products, of which CO₂ is of prime concern. In a typical coal-fired electricity generating station, the hot combustion products are used to generate superheated steam at around 600°C and this steam drives a turbine which rotates an electricity generator. The chemical energy has become kinetic energy of various kinds and, ultimately, electrical energy. An obvious but key point here is that from the final use of energy there is an audit trail back to its source. To use the energy, we had to have it in the first place in some accessible form, and therein lies the origin of the atmospheric CO₂ problem.

Fossil fuels are ancient stores of chemical energy that are accessible and easy to use, making the liberated kinetic energy relatively cheap – hence their overwhelming dominance of the energy market since the Industrial Revolution. The process of forming fossil fuels from dead plants is on the other hand geologically slow and we are burning fossil fuels much faster than they are replenished through natural capture of CO₂ from the atmosphere – hence the build-up of CO₂.

Coal is the worst offender, liberating about 90 kg CO₂ per GJ of thermal energy released from black coal or about 0.9 kg of CO₂ per kWh of electricity produced.
in a typical coal-fired power station with 37% thermal efficiency. The figures for oil (about 70 kg CO₂/GJ) and natural gas (about 51 kg CO₂/GJ) are somewhat better [8]. This difference comes about because natural gas contains more hydrogen atoms per carbon atom than oil, which contains more hydrogen per carbon than coal.

**What to do?**

Does all this mean that we have to use less energy on a global scale? Can we instead use energy from a different source? Is there enough to support our current global economy in the long term, especially as poorer countries become industrialised? These are complex questions, so we should tread carefully. As H.L. Mencken famously said, “There is always a well-known solution to every human problem – neat, plausible, and wrong” [9].

So can we use energy from a different source? For instance, if we all drove battery- or fuel-cell- electric cars, wouldn’t that help? It certainly wouldn’t help if the electricity came from burning coal. It would preserve valuable oil, lessen pollution in cities and make them cooler because of higher vehicle efficiency, but the most concerning by-product of using the energy – CO₂ – would be displaced to the surroundings of the power stations, not avoided. This is an example both of what Mencken meant and of the energy audit-trail concept.

Electrical energy accessed without generating CO₂, not just during the electricity generation but in the building of the power station and manufacture of all the materials involved, would solve this problem in principle. We should be suspicious of such simple-sounding solutions and ask hard questions about the demand on commodities to establish this technology and the capacity to diffuse it on the global scale within the required time.

**The scale of the energy problem**

The first necessary information is how much energy we need, or at least use. According to the International Energy Agency [7], the amount of energy used on earth in its final useful form is presently about 108,000 TWh per year, equivalent to a continuous average power consumption of about 12 TW, and growing slowly. In reality about 21% of final energy used (about 23,000 TWh per year, equivalent to roughly 2.5 TW continuous average power) is provided as electricity. Now for another key point. Electricity generation accounts for much more of the total energy used than 21%. If all electricity were generated in coal-fired power stations with their typical efficiency of about 37%, some 62,000 TWh of thermal energy would be required. The fraction of total energy demanded as electricity will increase as the transport sector moves away from oil-derived fuels. Natural gas shows no sign of taking over the transport sector, whereas electric vehicles are on the market, primarily relying on battery storage at the moment, but with fuel-cell electric cars now commercially available in small numbers (Table 1). Whether the vehicle stores electricity directly in a battery or indirectly as hydrogen, the origin of the energy is electricity. In the case of hydrogen-fuelled vehicles, water electrolysis is presently the only large-scale route for generating hydrogen
Reducing fossil-energy use is an immediately effective way of reducing CO₂ emissions, but that relates to our present post-Industrial Revolution problem, not necessarily to the longer-term view. The reasons we mustn’t continue to use fossil fuels in the present way and ever faster are that they will run out and, more importantly right now, that their use is altering the global climate in an extremely dangerous way. We must certainly use less fossil-fuel energy – much, much less – or succeed in sequestering the CO₂ on a grand scale.

Carbon sequestration

Carbon capture and storage (CCS) is technically feasible in principle and has been demonstrated in practice. According to the Global CCS Institute [11], 15 projects are currently in operation with a combined storage capacity of 28 Mt of CO₂ per year. Seven projects are under construction and another 23 projects are in early or advanced stages of planning, taking the total present and immediately projected capacity to about 80 Mt per annum. At 0.9 kg CO₂ per kWh of electricity produced, 80 Mt annual storage capacity corresponds to approximately 90 TWh of electricity from coal. Yet our annual electricity use is about 23,000 TWh, or about 250 times more. Thus we would have to hope for an enormous expansion in carbon sequestration capacity within just several decades for this technology on its own to allow us to continue to burn coal to generate electricity while generating much less CO₂. This can hardly be feasible, although CCS will unquestionably be implemented at larger than present scales in some locations. Even the 2DS implies a cumulative total of nearly 50 Gt emissions reduction from 2016 to 2050 (Figure 1), or about 1.5 Gt average per annum, nearly 20 times the currently planned capacity. This is an example of the gulf between what has been signed-up to after COP21 and present reality.

Nuclear energy

Nuclear energy passes the low-carbon test, as long as the materials required are produced with acceptable CO₂ emissions. A present-day nuclear electricity generating station works just like a coal-fired station once heat is obtained from the fuel, but in this case primordial nuclear binding energy is liberated. According to the International Energy Agency, nuclear power contributes around 11% of global electricity provision [7]. According to the World Nuclear Association [12], and depending strongly on how we define "reasonably assured resources" of uranium, at least 200 years at the present consumption rate are possible with current reactor technology. Using fast breeder reactor technology would extend this time to many thousands of years. There are three practical problems with contemplating nuclear power for supplying the majority of the current global electricity demand, not just the current 11% or so, and ignoring the escalating demand. First, the "reasonably assured reserves" would only last a few decades at this higher rate of consumption if used in conventional reactors. Second, the lead time for nuclear power stations presently averages around ten years. Third, breeder reactor technology is not commercial at any significant scale, with only a handful of reactors operating or in commissioning [12]. Even setting aside the challenge of safely sequestering nuclear waste essentially for eternity, a rapid scale-up to provide most of the world’s electricity seems no more technically feasible than grand-scale carbon sequestration. Nuclear energy is certainly important, and will become more important in some countries. Ultimately, however, the most telling factor might not be technical feasibility but political will, which depends on the sensitivity of governments to public distrust of the safety of nuclear energy.
Nuclear fusion has for decades been said to be decades away, and appears still to be so as a commercial proposition, despite amazing feats of technology in achieving ever higher plasma temperatures and longer fusion times [13].

**Sustainable energy sources**

Here is a thought experiment with associated calculations that can literally be written on the back of an envelope. Instead of assuming that we irreversibly consume resources found on earth, suppose we tap into energy that arrives anyway. The surface of the earth receives energy from two main sources. These are the sun, which radiates owing to heating by fusion reactions, and geothermal energy, which keeps the interior of the earth hot, owing to nuclear decay which releases energetic particles whose kinetic energy ends up as heat. These are true sources, in the sense that they can’t be switched on or off. Geothermal heating of the earth corresponds to a power of about 44 TW [14], approaching four times the average continuous global power consumption in 2012. This is a big resource, with a contribution to electricity production expected to grow to 10^4 TWh (electric) by 2020 [15], but it is dwarfed by the solar power earth receives.

![Figure 3. Annual energy flows across the surface of the Earth and within the atmosphere and oceans. Based on Ref 16.](image)

Just outside the earth’s atmosphere, the power received from the sun is easily calculated with the Stefan-Boltzmann law, knowing the surface temperature of the sun and our distance from it, to be on average 1366 W/m² of area perpendicular to the line between the earth and the sun. Multiplying by the area of the disc of the earth seen from the sun gives a total intercepted power of 174,000 TW, or 1,520,000,000 TWh per annum (see Figure 3). This is 14,500 times our average global energy consumption! About 1000 W/m² reaches the surface of the earth near the equator at midday in clear conditions. Around 5% of the incoming annual solar radiation ends up as atmospheric wind and around one-tenth of that ends up as waves. Even these relatively minor resources are very large compared to the final global power consumption. Not all of the available solar radiation or wind or wave energy could be intercepted, of course, but it is clear that our present energy usage is tiny compared to the resource. So tiny is it that if we were to set aside an area about 600 km × 600 km near the equator, with a dry climate, and cover it with commonly available solar photovoltaic panels, the entire present final energy requirement of humankind could be supplied, as electricity moreover. To supply the present global demand for electricity, less than 300 km × 300 km and around 2.5 TW average would suffice. This thought experiment should not be taken literally as a proposal to build such a generator, and numerous factors comparable to one are ignored, but it establishes the principle that our energy consumption is able to be satisfied by an area of collection that is tiny compared to the size of any of the continents.

Remembering Mencken, and getting closer to the heart of the matter, it’s not that simple, since the captured energy would have to be stored for use when our generator was in darkness, and transmission around the globe would be needed, both involving energy loss. We should also ask about the demand for raw materials – the silicon, aluminium, glass, steel, concrete and so on. And what about cost? The installed cost of photovoltaic systems is crashing faster than projected. Even small residential systems are approaching USD0.50 per peak watt (meaning perpendicular to the solar radiation at 1000 W/m², at 25°C cell temperature). A further fall in cost by a factor two for large systems is to be reasonably expected in the near future. At USD0.25 per peak watt, our 2.5 TW average generator of all the world’s present electricity demand would require a peak power capacity of about 8 TW (assuming we build it in a dry climate zone at the equator) and therefore cost about USD2 Trillion. Put in context, this enormous-sounding sum is in fact is about three times the annual military spending by the USA and a small-ish fraction of its gross debt of about USD18 Trillion. Once again, this calculation is simplistic, because it ignores the costs of capital and replacement, but a USD2
Trillion investment in our hypothetical solar photovoltaic generator earning even 5 cents per kWh would have a payback time of just a couple of years. Is there capacity in global industry to undertake this mighty feat? A 2015 study by the Fraunhofer Institute for Solar Energy Systems [17] concluded that global installed photovoltaic capacity could exceed 30 TW peak power by 2050, well above the IEA’s prediction. Applying the availability factor, this is equivalent to about 10 TW available peak power, which is enough to supply our current electricity requirement several times over. This would be a truly disruptive development in energy supply. In the Australian context, the distributed PV resource in Queensland already represents the second-largest power station in the state, with a peak capacity of some 1.5 GW [18], and in South Australia the installed wind-power capacity is similar, supplying around 40% of the electricity used in 2014 [19].

The take-away message is this: solar power can supply our conceivable energy needs many, many times over. In response to the obvious retort from sceptics – "if it’s so good, why aren’t we doing it?" – we have to acknowledge that solar power is inconveniently low in energy density compared to coal or uranium mines and conventional or nuclear power stations, and its availability is not constant. On the other hand, we can now generate solar electricity more cheaply than we can buy coal-fired electricity, and that’s before the societal costs in health care associated with burning fossil fuels in power stations and cities are factored-in.

The biggest problem with solar power (and solar energy generally, including wind power) is its intermittency, which has a stochastic character owing to weather in addition to the systematic diurnal and seasonal variations. A truly global electricity grid, perhaps an analogue of the internet, might overcome the intermittency problem entirely, as long as generators able to supply the instantaneous global demand were illuminated at all times. Given the present limitation to grid extent owing to $\gamma R$ losses, which range from about 5% for distribution within economically advanced nations (including Australia) to about 15% in poorer nations [20], this seems infeasible without global-scale superconducting transmission cables of enormous capacity, a technical feat that is not on the horizon, although the first 1-km cable with 40 MW capacity has been put into service in Essen, Germany [21]. National or continental grids extending further than the dimensions of a weather system could ameliorate both the diurnal and stochastic intermittency factors. On balance, though, it appears necessary to solve the puzzle of storing solar energy before congratulating ourselves on finding a globally viable alternative to fossil fuels.

In addition to tapping into a small fraction of the incident solar energy, then, we need to delay its ultimate degradation to low-grade heat radiated back to space, by storing enough to bridge the gaps in availability owing to night and non-sunny (or non-windy) weather. For this reason a vast increase in the capacity to store energy in real time (as distinct from ancient times) in a form compatible with electricity supply must go hand-in-hand with the accelerated roll-out of solar electricity capacity (Figure 4). The beginning of this transformation is already apparent in the demand for residential battery storage systems to go with solar photovoltaics, which is happening without incentives and despite the reluctance (in Australia) of electricity supply authorities. Once again, the required feat at the grand scale seems mighty, but in contrast to gigawatt-scale centralised CCS schemes or nuclear power plants, technologies for distributed storage of sustainably captured energy in homes, businesses, vehicles etc. are with us now and being adopted. Nevertheless, questions about the demand for commodities and the capacity of industry to supply these technologies need to be asked.

The take-away message is this: solar power can supply our conceivable energy needs many, many times over. In response to the obvious retort from sceptics – "if it’s so good, why aren’t we doing it?"
Conclusion
In deciding how to access and use energy we have to choose a strategy somewhere between two extremes. At one extreme is obtaining energy from convenient and cheap resources that are themselves repositories of anciently stored energy, such as coal and uranium. The ancient resources are irreversibly consumed and their stored energy is added to the total current energy budget of the earth. This is pretty much the status quo and how we got to where we are with climate change. The alternative extreme is to intercept just a little of the vast amount of energy that arrives at the earth’s surface anyway from solar radiation (including wind) and geothermal heating. We can extract what we need as electricity, heat or motive power and send the rest on its way down the natural chain of transformation to heat, which is how it would end up if we did not tap into it. Reality will be somewhere in-between, depending on the tolerable rise in global temperature. It really does seem that we can choose to sustainably power our society and meet the inevitable increase in demand for energy as poor nations industrialise, as long as the roll-out of energy storage keeps pace with the displacement of fossil-fuel technologies by renewables.

References
[2] Climate Data Explorer, World Resources Institute, cait.wri.org/indc.

AUTHOR BIOGRAPHY
Evan Gray is a Professor of Physics at Griffith University, with research interests focused on the physics of energy-related materials and modelling energy systems. Evan completed his PhD in solid-state physics at Monash University in 1979. He has worked on materials for solid-state hydrogen storage for 30 years, using national and international neutron and synchrotron beam facilities to study structure-function relationships. Evan manages the National Hydrogen Materials Reference Facility at Griffith University and has a strong interest in the deployment of hydrogen-energy technologies in Australia.
Lecture Notes on Field Theory in Condensed Matter Physics

by Christopher Mudry
World Scientific (2015)
Paperback, 724 pages
ISBN 9789814449106
Online ISBN: 9780750311038
Reviewed by Rev Dr Lee Weisel, The Hutchins School, Sandy Bay, Tasmania

Broad in its scope and technical in nature, Christopher Mundry’s book, Lecture Notes on Field Theory in Condensed Matter Physics, is a very welcome addition to graduate study literature in this field. Well written and easy to follow, it does require an understanding of undergraduate physics.

Condensed Matter Physics is currently one of the most active fields in physics research, with often a great need for specialists in this area in industry and in research. Designed for Graduate students, the aim of the book is to introduce the reader into selected concepts of condensed matter physics by using the language and the design of field theory.

The book is divided into two major overarching sections, Bosons and Fermions, and each section scaffolds the subject’s understanding from classical to quantum mechanical approaches. There are many topics which cover themes such as harmonic crystals, Bogoliubov theory, non-linear sigma models to superconductivity, and random phase approximations. The range and breadth of topics that are covered by Mudry is impressive but it also shows that the difficulty with any work written on postgraduate themes is that by choice some areas simply cannot not be covered. The work at 724 pages already stamps its in-depth approach in the areas that it seeks to illuminate.

Under the first section on Bosons, Mundry develops his approach by working from the classical to the quantum mechanical model of harmonic oscillations. He further assists the reader by also moving from a one-body to a multi-body model, explaining his process and his rationale for doing so. In this first section, the third chapter on non-linear sigma models is the most comprehensive as it develops important frameworks and understanding in proceeding with more advanced ideas and concepts in condensed matter physics. Mudry effectively introduces this model and works thoroughly through the equations for the reader to follow his argument.

His persuasiveness in the model’s application opens up a broader understanding of the applications of condensed matter. As is the case for all chapters, these chapters have helpful problems that are worked through to further the understanding of the concepts presented.

The second section of the book focuses on the discussion of Fermions and understanding their properties. The author takes the same intensity and elaboration in the explanation as he has done in previous chapters. Mundry commences with a review of non-interacting Fermions and introduces the reader to the non-interacting jellium model. The jellium model is very helpful and enables the reader to develop a strong working representation of the behavior and interactions of the particles. This becomes important in working through each behavior and condition under which the particles are examined. The understanding of superconductivity is a helpful example of this approach, supported by the exploration of the repulsive interaction as it is decoupled through the pairing order parameter.

The abundance of appendices add to this work, by engaging some of the presented ideas further as well as extending the reader’s thinking into related areas. Each topic in the appendices is methodically treated and set out so the equations can be meticulously followed. This is extremely helpful as some of the areas of investigation may be unfamiliar to the reader. An excellent book for those wishing to extend their knowledge and understanding in this area.

Transport in Semiconductor Mesoscopic Devices

by David K. Ferry
Hardback, 316 pages
Print ISBN: 9780750311021
Online ISBN: 9780750311038
Reviewed by Prof Mukunda Das, The Australian National University, Canberra

Because of the unconventional behavior exhibited by many meso/nanoscale systems, and their in many ways unusual properties compared with conventional materials, this area has emerged as a very active interdisciplinary field. David Ferry is an accomplished researcher as well as a prolific author of books. This book appeared after the second edition of “Transport in
Nanostructures” by the author, with Stephen Goodnick and Jon Bird as co-authors. Many of the topics in latter are included in addition to some new ones. Neither of these books, however, contains any clear operational distinction between what constitutes a “nano-” over against a “meso-” system.

Quantum mesoscopic science, commonly understood, covers a whole class in interference effects related to the coherent propagation of waves in complex and random media. It refers to the physics of structures in the submicron dimension, demanding a profound understanding of fundamental phenomena on meso-scales (nominally from microns down to tens of nanometres). There are certain universal features such as conductance quantisation, conductance fluctuations etc. These are usually not observed in nanosystems with active regions (nominally on the scale of nanometres and down almost to atomic dimensions).

In view of space limitations, I shall describe the contents of the book in brief and focus on a couple of issues in more detail. After an introduction including metal-oxide-semiconductor field effect transistor (MOSFET) and hetero-structure devices, in chapter 2 Ferry presents the basics of quantum wires and device channels highlighting the magic Landauer formula and its related scattering (mainly elastic) formalism. Chapter 3 treats the Aharonov-Bohm effect in a ring and other multiply connected structures; the effects of phase interference are presented within a simple gauge theory. Here the role of magnetic fields and localisation of electron waves are highlighted. Chapter 4 deals briefly with graphene (a planar carbon sheet) and carbon nanotubes. Two other items, topological insulators and chalcogenides, are also mentioned with little detail.

Localisation and fluctuations are two important items covered in Chapter 5, a bird’s eye view of theory and experiments. Chapter 6 covers mainly the integral quantum Hall effect (IQHE) with a cursory mention of the fractional quantum Hall effect. Landauer-Büttiker’s multi-terminal method is used to explain IQHE, and the following Chapter 7 discusses the spin Hall effect. Chapter 8 presents tunnel devices, already previewed in Chapter 2 in relation to quantum-point contact and quantum-wire devices. Particular issues like Coulomb blockade, single-electron quantum dot structures and resonant tunnelling diodes are treated in detail. Chapter 9 covers open quantum dots; conductance fluctuations and magneto-transport etc. are discussed elaborately. The last chapter gives a short account of hot carriers in meso-devices.

As per the title of the book, one of the main themes is electronic transport in mesoscopic devices. Over almost four decades, people have popularly invoked a kind of ready mantra for all seasons, the Landauer formula, which assumes that (unitary) quantum transmission is the exclusive origin of finite conductance for one-dimensional conductors. This model limits itself to a relatively naive single-particle (noninteracting) form of quantum scattering. It has a conceptual difficulty: the scattering is perforce elastic, thus it cannot describe dissipation. It follows that active inelastic processes ought to be brought into the theory. There exist more sophisticated formalisms such as the Kubo formula or, equivalently, nonequilibrium Green function approaches. Although these topics are discussed in the author’s earlier book, a serious student will risk being misguided by the claimed universality of the simple Landauer formula as championed in this book. A crucial point of concern is the problematic use of multiple chemical potentials for one system, when its circuit is electrically closed. This was already remedied by Kamenev and Kohn in Phys. Rev. 63 155304 (2001) – a significant omission from the bibliography.

A curious topic addressed in the book is the so-called “0.7” conductance anomaly observed below the first plateau. This conductance feature has been observed in many systems, at very many places, and over a range of values, a nonuniversal effect: namely from 0.2 to 0.9 (Landauer unit). No clear explanation is given why this anomaly should focus on just 0.7. The explanations highlighted, be it spin polarisation or a Kondo-like effect, remain entirely speculative and unconfirmed.

On a positive note the book adopts more modern quantum mechanical concepts for practical device applications. It includes numerous illustrations and deals with several experimental results. The book will be very useful for professional engineers working on semiconductor devices and electronic materials. It provides numerous exercises, suitable for early career graduate students in electrical and electronic engineering and nanoscience. Although it is recommended by the author as a study text, the book lacks any subject or author index; a serious shortcoming in my opinion.

I am informed that this title is available in eBook format and there are some embedded videos available in some chapters.
Artificial optical nanostructure outperforms butterfly wings

An artificial material with the eye-catching optical properties of the Callophrys rubi butterfly has been created by researchers in Australia. Using a special lithography technique, the team was able to make photonic "gyroid" nanostructures similar to those found in the butterfly’s wings. The artificial structures, which outperform their natural counterpart in many ways, could find use in a variety of photonics and optics technologies.

Gyroids are 3D periodic structures made up of intertwining, curved surfaces. They have lattice constants that are comparable to the wavelength of visible light, which means that they have a range of optical properties, such as structural colour. This is what gives the Callophrys rubi butterfly a beautiful blue-green sheen on its wings. Thanks to their cubic symmetry and the fact that they are mechanically strong, gyroids could also be ideal for making photonic crystals and other optical metamaterials. These are artificial structures that have a number of desirable optical properties that make them ideal for controlling light in technologies such as optical communications and displays.

Better than a butterfly: a new optical metamaterial.

However, the techniques employed to make optical metamaterials have been unable to produce artificial gyroid structures with lattice constants comparable to those found in butterfly wings. Now, a team led by Min Gu of RMIT in Melbourne has used a technique called optical two-beam super-resolution lithography to create 3D gyroid structures with lattice constants of 360 nm. This gives the artificial gyroids a similar blue-green colour to the butterfly’s wing. However, the artificial structures are mechanically stronger than natural gyroids, and have long-range periodicities and well-defined crystalline boundaries. The latter two properties are lacking in natural materials, which suffer from uncontrolled structural disorders.

Another unique feature of the artificial gyroids is that they have chiral properties that are lacking in the imperfect natural structures. An artificial structure, for example, will contain only left- or right-handed single gyroid enantiomers, while the natural version contains a mixture of both. This means that the artificial gyroids are much more suitable for applications such as photonic crystals with optical band gaps and miniature chiral beam splitters. Metamaterials made from the artificial gyroids are expected to have tuneable nonlinear optical properties and respond to light at ultrafast speeds, so making them ideal for high-speed optical switches.

Apart from applications in photonics, the new gyroid structures could help make more compact optoelectronics because, thanks to their smaller size, larger numbers of devices can be integrated onto a single chip. According to Gu, the superior mechanical strength of the artificial material makes it well-suited for high levels of integration.

[Z. Gan et al., Scientific Advances, 2 (2016) e1600084; DOI: 10.1126/sciadv.1600084]

Extracted with permission from an item by Belle Dumé at physicsworld.com.

Consortium sets out to build European laser plasma accelerator

Accelerator physicists in five European countries are developing plans for the world’s first high-energy laser plasma accelerator facility for use by science and industry. If built, the facility will deliver high-quality beams of electrons with energies up to 5 GeV. The EuPRAXIA consortium includes researchers at 16 institutes in the European Union (EU), including the DESY lab in Germany, the Italian National Institute for Nuclear Physics, the French national research council and the Science and Technology Facilities Council in the UK. EuPRAXIA also has 18 associate partners worldwide, including the Lawrence Berkeley National Laboratory (LBNL) in the US, RIKEN in Japan and CERN in Switzerland.
Riding the wave: electrons being accelerated by a laser pulse

The idea of laser plasma acceleration has been around for more than 30 years, and in 2014 physicists using the LBNL’s Berkeley Lab Laser Accelerator managed to accelerate electrons to energies as high as 4.2 GeV. The process involves firing very intense laser pulses into a gas to create a plasma. As a pulse travels through the gas, it rips electrons away from the positive nuclei, therefore creating a huge electric-field gradient in its wake. This gradient can be thousands of times greater than that found in conventional particle accelerators – and therefore can accelerate electrons to high energies over much shorter distances than conventional facilities.

The result is a compact accelerator that is not much larger than the laser used to create the plasma. That means that a laser plasma accelerator can be housed in a small building, rather than stretching over hundreds of metres or even several kilometres.

While laser plasma accelerators exist at several laboratories around the world, EuPRAXIA steering-committee member Carsten Welsch says that “no infrastructure exists where the quality of the accelerated beam satisfies the requirements of industry”. Welsch, who is at the UK’s Cockcroft Institute of Accelerator Science and Technology, adds that “creating such a facility would be a major breakthrough and would attract users from many different sectors”.

According to Welsch, one important early use of a European laser plasma accelerator would be to create a compact free-electron laser (FEL). FELs use high-energy electrons to produce coherent X-rays, which have a wide range of applications in physics, chemistry, biology and materials science. The European XFEL at DESY in Hamburg, which is currently under construction, has a 3.4 km-long electron accelerator, and the possibility of having much smaller laser-based facilities would be very attractive to science and industry.

Extracted with permission from an item by Hamish Johnston at physicsworld.com.

IceCube's search for sterile neutrinos draws a blank

Researchers have found no evidence of sterile neutrinos in two years’ worth of data from the IceCube Neutrino Observatory at the South Pole. The international scientific collaboration that runs the detector says that the results cast serious doubt on the existence of these hypothetical particles.

Buried beneath the ice at the Amundsen–Scott South Pole Station, IceCube is designed to search for high-energy particles from space, including cosmic rays and neutrinos. It consists of 5160 light sensors suspended on 86 strings in 1 km³ of ice. When a particle interacts with the ultra-clear ice, it can create flashes of light that are then detected. In 2013 the IceCube collaboration announced the first ever detection of cosmic neutrinos.

IceCube has found no evidence for sterile neutrinos

Neutrinos are particles with no electrical charge and are known to come in three "flavours": electron, muon and tau. They were originally thought to be massless, but the discovery that they can change, or "oscillate", between different flavours suggests that they do have mass. There is much that physicists do not understand about neutrinos, and some experimental results are difficult to rec-
oncile with the three-neutrino model. But the existence of a fourth type of neutrino, a sterile neutrino, could provide an explanation.

Sterile neutrinos would only interact with other matter via gravity – making them even harder to detect than other neutrinos. If they do exist, they would be able to help answer important questions about neutrinos, such as why they have mass and whether they are dark-matter particles. Several experiments are probing the existence of sterile neutrinos, but so far none of the particles have been detected.

In the latest research, the IceCube collaboration performed independent analysis on two sets of data from the observatory, looking for sterile neutrinos in the energy range between approximately 320 GeV and 20 TeV. If present, light sterile neutrinos with a mass of around 1 eV/c² would cause a significant disappearance in the total number of muon neutrinos that are produced by cosmic-ray showers in the atmosphere above the northern hemisphere and then travel through the Earth to reach IceCube. The first set of data included more than 20,000 muon-neutrino events detected between 2011 and 2012, while the second covered almost 22,000 events observed between 2009 and 2010.

As neutrinos travel through space, they oscillate from one flavour to another. Physicists know that this oscillation is modified when neutrinos travel through dense matter because the neutrinos interact slightly with surrounding electrons and nucleons. Sterile neutrinos, however, would not interact with matter, and this would result in a resonance effect on the oscillations of neutrinos at energies around a few TeV. Francis Halzen, IceCube’s principal investigator and a particle physicist at the University of Wisconsin–Madison in the US, says that this ”should be clearly seen as a sharp depletion in our measured muon-neutrino spectrum”, and should also produce ”a characteristic structure in the zenith-angle distribution of these neutrinos”. ”Neither one is seen,” he adds. ”The absence of this resonance is pretty striking and cannot be missed.”

[arXiv:1605.01990 [hep-ex]]

Extracted with permission from an article by Michael Allen at physicsworld.com.

Patterned liquid crystals guide light through planar lens

A new way to control light using liquid crystals has been developed by researchers in Japan, who believe that their method offers many of the advantages of an artificial ”metasurface” while being much easier to fabricate on an industrial scale. Among other applications, the researchers believe the work could be useful for the production of ”smart” glass.

Traditional refractive lenses have numerous uses, but also several problems. Most notably, the phase of a wave has to be continuous at both surfaces, with phase accumulating continuously as the wave propagates through the lens. This means that, to create a macroscopic deflection of light, a macroscopic thickness of lens is required, which often makes the lenses undesirably heavy or bulky. They are also insensitive to polarization – which is sometimes an advantage but does limit the possibilities that can be realized.

Liquid lensing: the lens created by the Osaka University researchers

In 2011 researchers at Harvard University unveiled an alternative type of lens called a metasurface, which uses dielectric or metallic resonators to interfere directly with the electromagnetic field of the wave. This changes the phase discontinuously at a single point in space, allowing for flat lenses. Unfortunately, the resonators have to be smaller than the wavelength of the radiation. This is relatively easy in the case of infrared radiation, but becomes increasingly difficult for shorter wavelengths such as visible light, for which nanometre-scale resonators are required, thus limiting the prospects for mass production.
Hiroyuki Yoshida, Masanori Ozaki and Junji Kobashi at Osaka University in Japan have taken a different approach, using two surfaces with a layer of cholesteric liquid crystals – liquid crystals with a helical structure that are chiral – between them. The rod-shaped molecules can form themselves into helical structures that interact with light waves, reflecting light with the same circular polarization as the helix, while transmitting light with the opposite polarization unperturbed. The researchers realized that they could control the phase imprinted on the reflected light (and thereby shape the reflected wavefront) by controlling the phase of the helices at every point around the surface of the lens.

This required controlling the orientation of every liquid crystal on one surface, and the rest of each helical structure would self-assemble from that starting orientation, almost like a spiral staircase building itself from the bottom step. The researchers achieved this using a process called photo-alignment, which required just a commercial LCD projector and a rotatable waveplate. "You don’t need to make tiny structures," says Yoshida, "so we didn’t need any nanofabrication techniques."

The researchers fabricated two optical devices from liquid crystals: a deflector to focus reflected light and a special type of lens called a Fresnel lens, which is used for theatrical lights and some camera lenses. Both devices achieved almost total circular-polarization selectivity.

Yoshida believes this could be useful in smart glasses, because it could enable all of the light from a projector to be reflected into the wearer’s eye, whereas current designs transmit half of this light out through the lens. [J. Kobashi et al, Nature Photonics, 10, 289-392 (2016), DOI: 10.1038/NPHOTON.2016.66]

Gravitational waves ripple out from merging black holes

Gravitational waves are ripples in the fabric of space-time, and like the first detection, this latest signal was generated by the collision of two black holes. This time the black holes weighed in at 14 and 8 solar masses and merged to form a single, spinning 21-solar-mass black hole, some 1.4 billion light-years (440 Mpc) away. The collision and subsequent merger released approximately one solar mass of energy, which was radiated away as gravitational waves.

The so-called "Boxing Day event" is officially dubbed GW151226. In October 2015, LIGO recorded another possible event, dubbed LVT151012, which was below the threshold for an official detection. LIGO has therefore detected three events in the four months of observation since it was upgraded to aLIGO. This kicks off the era of gravitational-wave astronomy, and researchers can now begin to constrain predictions about the population of black holes in the universe.

Indeed, LIGO changed our view of the universe from its first observation in September. LIGO scientists had expected that binary neutron-star mergers would be one of the first systems that they would detect gravitational waves from. To date, these mergers have not been seen, while black-hole mergers – which were thought to be rare – have instead been detected.

Furthermore, the observed mergers have all involved stellar-mass binary black holes. This is surprising because theories previously suggested that such stellar-mass binaries would either not form at all or, if they did, would be too far apart to merge within the age of the universe. LIGO’s detections have now shown that the opposite is true, and that the rate of binary-black-hole mergers is...
higher than expected – between six and 400 per cubic
gigaparsec per year.

Since the first event in September, theorists have been
looking into how such binaries may merge – possibili-
ties include massive binary-stars that both evolve into
black holes that eventually merge or black holes in dense
stellar environments like globular clusters, where the
black holes would "sink" towards the cluster’s centre and
merge with others.

The latest signal was picked up within 70 s of it hitting
LIGO’s detectors in December, and was instantly recog-
nized as a good candidate. The signal itself was composed
of 55 gravitational-wave cycles that were produced as the
two black holes spiralled towards one another. Because
the orbital frequency of a system is half the frequency of
the wave, the LIGO scientists know they observed about
the last 27 orbits before merger.)

June 2016)]

Extracted with permission from an item by Tushna
Commissariat at physicsworld.com.

ITER fusion-reactor schedule slips by five years

The ITER fusion reactor currently being built in France
will achieve its "first plasma" in 2025, five years later than
previously planned. The decision has been announced by
the ITER Council, which also said that the project has
so far successfully achieved all of its milestones on time
or ahead of schedule. The decision to delay the project
comes after French nuclear-physicist Bernard Bigot, for-
mer head of France’s Alternative Energies and Atomic
Energy Commission, was brought in as ITER director-
general in 2015 to shake up the organization and draft
a credible schedule. Independent assessments of ITER,
however, question whether the 2025 target can be met.

Expected to cost tens of billions of euros, the ITER fu-
"ntion reactor is under construction in Cadarache, which
is about 70 km north-west of Marseille. The project
aims to show that it is technically feasible to get usable
amounts of energy from a controlled fusion reaction.
With the first plasma now expected in 2025, the first
experiments using "burning" fusion fuel – a mixture of
deuterium and tritium (D–T) – will have to wait until
2032.

Earlier this year, it was revealed that ITER managers
were pushing for the five-year delay and had asked for
an additional cash injection of €4.6bn. While the delay
has been granted, the project’s seven partners – China,
the EU, India, Japan, Russia, South Korea and the US
– have announced they are unlikely to raise the addi-
tional finances. This means that completion of the pro-
ject could slip even further beyond 2025, a worry that
was expressed earlier this year in a report from the US
Department of Energy (DOE) entitled "US Participa-
tion in the ITER Project".

The DOE report and an independent assessment of
ITER led by Albrecht Wagner, former head of the DESY
particle-physics lab in Germany, have both pointed out
that the new ITER schedule contains no contingency
for unexpected complications. The DOE report says
that 2025 for the first plasma and 2032 for D–T op-
erations "are not realistically achievable". To achieve
the 2025 date, the DOE estimates that the US would need
to spend $4.65bn, with annual contributions rising to
$275m. More realistic, the DOE states, is for ITER to
have its first plasma in 2028, at a cost for the US of
$4.76bn and a maximum annual payment of $250m.

Despite identifying "significant technical and manage-
ment risks" with ITER, the DOE has recommended
that the US should remain a partner in ITER until at
least 2018 – at which point it will reassess its involve-
ment. The report also states that ITER is the best way of
demonstrating a sustained burning plasma and that the
project is technically feasible.

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Banks at physicsworld.com.
PRODUCT NEWS

Coherent Scientific

Compact Spectrometer with Automated Focus

Andor has released the Shamrock 193i compact spectrograph with Adaptive Focus Technology. This latest addition to Andor’s portfolio of modular spectrographs complements their existing range of longer focal length Czerny-Turner, broadband Echelle and high throughput transmission spectrographs.

The new adaptive focusing automatically provides the best spectral resolution for any combination of grating, camera or wavelength range, with unmatched repeatability. The F/3.6 aperture, combined with Andor’s range of ultra-sensitive CCD, ICCD, EMCCD and InGaAs detectors offers a “workhorse” spectroscopy platform with superb photon collection efficiency, ideal for challenging low-light applications or routine spectroscopy. A wide range of accessories is available integrating the spectrograph with microscopes, optical fibre setups or other experiments.

We currently have a demonstration system available (with iDUS CCD detector) for trial in your lab. Please contact us to arrange a demo of this versatile and affordable system!

Scientific CMOS Cameras

Scientific CMOS (sCMOS) is a breakthrough technology has offers an advanced set of features making it ideal for high fidelity, quantitative scientific measurement. The multi-megapixel sensors offer a large field of view and high resolution, without compromising read noise, dynamic range or frame rate. Andor’s Zyla and Neo cameras offer 4.2 and 5.5 megapixel formats with the following impressive specifications:

- Peak QE : 82% (Zyla)
- Read noise : 1e^- (Neo)
- Frame rate: 100 fps at full resolution

These capabilities make sCMOS a compelling alternative to CCD cameras in many applications, especially as prices start below A$20,000.

We currently have a demonstration Zyla 4.2P camera available for trial in you lab. Please contact us to arrange a demo.

Energetiq – The Innovators in Light

Coherent Scientific is pleased to announce it is now distributing Energetiq’s products throughout Australia and New Zealand. Energetiq is a developer and manufacturer of advanced light sources that enable the manufacture and analysis of nano-scale structures and products. Used in complex scientific and engineering applications, Energetiq’s light products are based on new technology that generates high brightness and high power light in the 170 nm to 2100 nm range with high reliability, high stability and long life, all in a compact package.

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

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The newest addition to the Eagle family, the Eagle XO, uses a cooled 1 or 4MP CCD for direct detection of soft X-ray up to 20 keV. The open front end interfaces directly to vacuum chambers, making it ideal for synchrotrons and for plasma physics research. The deep cooled, back-illuminated CCD allows for ultimate sensitivity and noise performance.

Key features:
• CF152 (6”) flange for direct interfacing to vacuum chambers
• 2048 x 2048 back-illuminated CCD
• 1.2 eV to 20 keV direct detection
• Extremely low dark current < 0.005 e/p/s
• 16 bit CameraLink output
• Very high QE: >90% peak

Applications:
• Synchrotron and beamlines
• X-ray diffraction
• X-ray spectroscopy
• Plasma physics
• Holography and lithography

Gentec-EO has launched a laser beam profiling camera with an extra-large aperture of 20.5 x 20.5 mm². This incredible aperture is achieved with the use of an optical fibre taper that is fixed on the optical sensor. The fibre taper concentrates the beam onto an 11.3 x 11.3 mm² sensor, thus resulting in a multiplication factor of 1.8. All the necessary corrections are done by the software so the user doesn’t have to calculate the corresponding beam size. The Beamage-4M-FOCUS is perfect for the larger beams and eliminates the need to use complex re-imaging setups.
Warsash Scientific
Compact and robust linear stages at an affordable price
Warsash Scientific is pleased to announce the new linear stages in the L-406 series from PI (Physik Instrumente) which offer very good performance on compact installation space. Despite the narrow width of only 65 mm, travel accuracies up to only 0.5 µm are possible over a travel range of 25 mm.

The linear stages are equipped with recirculating ball bearings and leadscrews, and were conceived for loads up to 10 kg. The stress-relieved aluminium base ensures high stability.

The L-406 is available for strokes of 26 mm, 52 mm, and 102 mm. In addition, they can be easily mounted to XY set-ups without using an adapter or operated vertically using a bracket.

A high-resolution, integrated rotary encoder takes care of the position metrology in the versions with DC gear motor. The noncontact, optical limit switches and reference point switches with direction sensing in the middle of the travel range simplify use in automation tasks.

For single-axis control, PI offers the easy-to-operate C-863 digital Mercury motion controller for DC servo motors and the C-663 for stepper motors. DC motor control of up to four axes is possible with the C-884. Using the PI MotionMaster, it is possible to use the L-406 in a networked group to control up to 40 axes with different drive technology.

Spherical piezo elements enable use in 360° ultrasonic applications
PI Ceramic now manufactures piezo components as hemispheres and hollow spheres. These types of components are particularly suitable for use as 360° transmitters such as those used in sonar technology. The outside diameter is between 10 and 60 mm. Larger diameters are available on request. The minimum wall thickness is 1 mm and other dimensions are also possible on customer request.

Thanks to their design, the components are generally suitable for applications which function as 360° sound transducers with a high bandwidth. Therefore, these spherical piezo components can be used in many different sonar application areas such as underwater communication, underwater monitoring, depth and underground relief measuring or for locating swarms of fish.

The components are manufactured from ferroelectric soft or hard piezo materials according to the application range. This enables optimum setting with respect to the coupling factor and acoustic impedance. The spheres can be made with a hole or groove for easy mechanical integration.

NIR and timing resolution optimised SPCM
Warsash Scientific is pleased to announce the release of the all new high performance NIR and TR enhanced single photon counting modules (SPCM) from Excelitas Technologies.
Excelitas Technologies have extended its portfolio of low-light-level detection modules with enhanced versions of the well-known SPCM single photon counting module that is based on a unique silicon avalanche photodiode with a circular active area, achieving extremely high photon detection efficiency over a 180 µm diameter with unmatched uniformity over the photodiode. In addition to the standard AQRH series of modules offering 6 output signal options, the SPCM-AQ4C 4-channel photon counting array module, there are now more choices for various single photon counting applications.

The new SPCM-AQRH-TR is a fast timing enhanced version with timing resolution of less than 250 ps, designed to support applications such as time correlated single photon counting (TCSPC), fluorescence lifetime measurements and fluorescence lifetime imaging microscopy (FLIM).

The new SPCM-NIR is a high Photon Detection Efficiency enhanced version with optimized sensitivity in near infrared wavelengths, designed to support long range LIDAR, quantum communication, photon entanglement, and other photon counting applications in the NIR (700-1060 nm).

For more information contact Warsash Scientific at sales@warsash.com.au

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