Australian Physics

Volume 50, Number 6, Nov–Dec 2013

HISTORY OF COSMIC RAY RESEARCH IN AUSTRALIA - PART 2

ALAN WALSH & ATOMIC ABSORPTION SPECTROSCOPY

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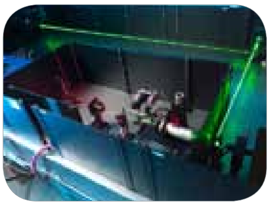

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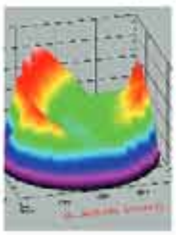

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Aurora Australis above the Cosmic Ray Laboratory at the Australian Antarctic Division's Mawson station (see article by John Humble and Marc Duldig on p195). Photo: Kym Newbery

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Articles for submission to *Australian Physics* should be sent by email to the Editor. The text should be sent as a Word file and authors are advised to consult a recent issue as a guide to style. Images should not be embedded in the document, but should be sent as high resolution attachments in JPG or PNG format. Authors should also send a short bio and a recent photo. The Editor reserves the right to edit articles based on space requirements and editorial content.

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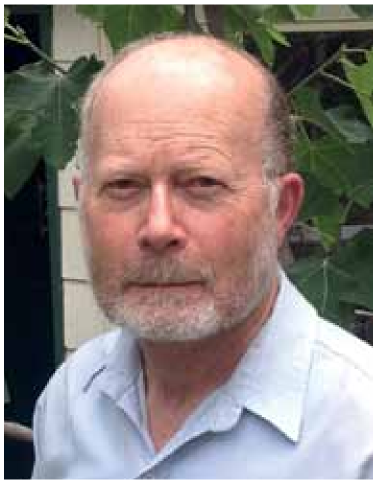
EDITORIAL

A little history



By coincidence, rather than contrivance, both articles in this issue are historical in nature. Peter Hannaford's Alan Walsh and the Atomic Absorption Story: Celebrating 60 Years describes how Alan Walsh, working at the CSIRO Division of Chemical Physics came to develop the technique of Atomic Absorption Spectroscopy (AAS) to overcome the deficiencies of analytical techniques using emission spectroscopy. After a slow acceptance AAS provided a simple, reliable technique for atomic analysis that became standard instrumentation for chemical analysis. The large market for the instrument contributed to the development of a scientific instrument industry in Australia. It is indeed a remarkable story. Members may know that in honour of Alan Walsh, the AIP named its award for service to industry the Alan Walsh Medal.

The second article, by John Humble and Marc Duldig, is part 2 of the history of cosmic ray research in Australia, and deals in particular with research based in Tasmania and Antarctica. Part 1 appeared last year (Duldig and Humble, Aust. Phys. 49, 170 (2012)), the year in which the centenary of the discovery of cosmic rays was celebrated. Part 3, the final article in this series will appear in a future issue.

It is important for Australian Physics, as a journal of record, to publish articles of this kind as they chronicle aspects of Physics in Australia the knowledge of which might otherwise be lost with the passage of time. I invite members to contact me if they have ideas for articles of this kind, even if you do not want to volunteer as author. Offers of authorship, or suggestions of potential authors, would, howver, be appreciated.

Have you looked at the AIP website since it was restructured about a year ago? I will be discussing with the executive ways in which the website can be used to provide archival access to past issues of Australian Physics. In the longer term we will need to consider optional electronic distribution, as is now happening for many periodicals via tablet applications.

I have included in this issue, on the inside back cover, a list of the articles that have appeared on the six issues of volume 50 (2013).

I wish members a happy and relaxing end to 2013 and start to 2014.

Brian James

This Year's Nobel Prize in Physics

I write the day after the announcement of this year's Nobel Prize in Physics to Francois Englert and Peter Higgs, for their prediction of the "Higg's boson" which reflects the field which give the elementary particles their mass, as all of our members will surely know. What a fantastic day for physics! As so often happens, there may yet be another prize, in the future, to recognise the achievements of those at CERN in building the apparatus and doing the experiments to show that this was really what nature is doing. Many of us have since been reflecting on the roles of theory and experiment (or observation) in science, and this was a case in which theory was decades ahead of the technology with which to test it, just like the predictions of black holes and neutron stars in astrophysics. But in other cases, experiments throw up something entirely new (think of superconductivity), and it may take decades until there is a proper theoretical explanation, or indeed any explanation. And then again, sometimes there is a particularly happy confluence when theory and experiment walk along at more or less the same pace.

Or think also of the contrast between the small numbers of theoretical physicists involved, though perhaps not quite as small as the Nobel committee would really have wanted, as opposed to the thousands of scientists and engineers involved in the experiments in Geneva. I once heard a lovely talk by Emilio Segre, back when I was a graduate student, reflecting on his time with Ernest Lawrence in Berkeley before the Second World War, and his introduction to "industrial-scale physics, American-style". Like it or not, "big science" is with us, has long dominated in particle physics and astronomy, and now plays an increasing role in other areas of physics, and even as far afield as biology.

Changing subjects, we should also congratulate our sister society, the Australian Optical Society (AOS) on its recent thirtieth birthday. The AOS was founded at a meeting at the National Measurement Laboratory in Sydney in May 1983 following discussions during an AIP Conference on Applied Physics in 1981. From the outset, the AOS has welcomed anyone interested in optics in the widest sense. Although many of its members are physicists, the society welcomes technicians and members of other professions involved in optics such as chemists, biologists and engineers. Thirty years after its establishment, the AOS continues to provide a forum for those involved in optics, seeks to strengthen the teaching of optics in Australia, promotes research and other activities in optics and fosters collaboration in optics both nationally and internationally. The society also runs an annual meeting which has been incorporated into recent AIP Congresses. This year's meeting will be the ANZ Conference on Optics and Photonics to be held in Fremantle in December. Happy Birthday AOS!

And now that the Federal election is over, things in Canberra are starting to settle down again. While "Science" no longer has its own named Cabinet seat, my own perception is that we may have a strong friend of science in Ian Macfarlane as the new Industry minister. Last year, I met with Mr. Macfarlane twice in quick succession, when he visited us at ANSTO and then again as part of Science Meets Parliament, and he showed a keen and educated interest in a wide variety of research issues. Of course, some responsibilities will remain with the Department of Industry, while others (including the Australian Research Council) will be in the Education Portfolio of Christopher Pyne. Things will obviously take some more time to settle down into some kind of equilibrium, but we should all continue to engage with the political process. For myself, I will continue to serve on the Board of Science and Technology Australia, which organises Science Meets Parliament – the next one is scheduled for 24-25 March 2014.

Thanks to my place on the Board of Science and Technology Australia, I was fortunate enough to attend the ceremony for awarding the Prime Minister's Science Prizes in Parliament House on 30th October. Heartiest congratulations to physicist Andrea Morello on winning the 2013 Malcolm McIntosh Prize for Physical Scientist of the Year— it's a fantastic dream to make qubits in silicon, and Morello and others at UNSW are making it a reality.

Rob Robinson

NEWS & COMMENT

New Federal Ministers

Following the federal election in September 2013, the minister with responsibility for science in the new government is Ian Macfarlane, the Minister for Industry. His responsibilities include CSIRO, ANSTO, NMI, CRCs, AAO, AAD and the Office of the Chief Scientist. The new Minister for Education, Christopher Pyne, has responsibility for higher education and the ARC. DSTO is the responsibility of the Minister of Defence, Senator David Johnston.

(L to R): Ian Macfarlane, Christopher Pyne, David Johnston

2013 Malcolm McIntosh Prize

UNSW electrical engineer and quantum physicist, Associate Professor Andrea Morello (Quantum Nanosystems in the School of Electrical Engineering and Telecommunications, and Program Manager in the ARC Centre of Excellence for Quantum Computation and Communication Technology) has been awarded the 2013 Malcolm McIntosh Prize for Physical Scientist of the Year for his intellectual leadership in developing the silicon components to make quantum computing possible. Andrea Morello and his colleagues expect to build a small working prototype quantum computer within a few years.

Associate Professor Andrea Morello
(credit: Dept. Industry, Aust. Govt.)

AOS 30th anniversary

The Australian Optical Society (a cognate society of the AIP) celebrates its 30th anniversary this year. The first office bearers were W.J. Steel (President), J.A. Piper (Vice-President), R.C. McPhedran (Secretary), J.L. Gardner (Treasurer), and M.D.Waterworth, I.J. Wilson, B.A. See, and P. Hariharan (members of the Council). An account of the founding of AOS is available at http://optics.org.au/about/history.

Fred Watson wins the 2013 Bragg Prize for Science Writing

Professor Fred Watson, Astronomer-in-Charge of the Australian Astronomical Observatory, has been awarded the 2013 Bragg Prize for Science Writing. This is an annual prize by New South Publishing for the best short non-fiction piece on science written for a general audience. Of the 7 short-listed pieces for the award, Professor Watson's *Here come the ubernerds: Planets, Pluto and Prague* (from *Star-Craving Mad: Tales from a travelling astronomer*) was selected as the winner. The award was made at New South Wales Government House by the Governor, Professor Marie Bashir on 29 October 2013.

Photo caption: Her Excellency Professor Marie Bashir, Governor of NSW; Professor Fred Watson, AAO; and Professor Merlin Crossley, Dean, UNSW Faculty of Science. (credit: UNSW Science)

Peter Quinn elected ATSE Fellow

Professor Peter Quinn
(credit: UWA)

Peter Quinn, Professor of Astronomy and Astrophysics at the University of WA and Director of the International Centre for Radio Astronomy Research, has been elected a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE). Professor Quinn's research focuses on the formation and evolution of galaxies using supercomputer computations and simulations. In particular, he is working on the nature of Dark Matter, the formation and evolution of Dark Matter around galaxies and its influence on the galaxy formation process.

Scientists in Residence

The Australian Science Media Centre has embarked on a national effort to embed scientists within newsrooms around the country, in a new program called *Scientists in Residence*. It would like to hear from well-established scientists who are keen to engage with the media about their research, and editors interested in hosting a scientist.

Funded with a grant from *Inspiring Australia*, the program aims to improve linkages between scientists and the media by encouraging them to generate collaborative content and build ongoing relationships. Unlike a trainee program, scientists are not there to learn how to be journalists but to provide independent, evidence-based scientific advice to newsmakers.

For more information, please contact Abbie Thomas, program manager, Scientists in Residence, Australian Science Media Centre, abbie@smc.org.au or +61 414 525 492.

BRANCH NEWS

ACT

The winners of the second ACT AIP *Frame Your Physics* competition were announced at a prize night on 18th September at Questacon in Canberra. Congratulations to all of the finalists and a thank you to all who entered the competition. Videos can be viewed at https://www.facebook.com/FrameYourPhysics

School Category:

1st: *Fire and the Colours of the Elements*
(Steph Comfort, Linden Muellner-Wong, Hania Syed and Michael Cooper from Gungahlin College)

2nd: *Project Thunderbird*
(Joshua Thomas, Luke Starkey and Jordan Haddrick from St. Francis Xavier College)

3rd: *The $18 billion dollar Doughnut*
(Jake Coppinger from Gungahlin College)

University Category:

1st: *Acoustics* (Chris Bentley, ANU)

2nd: *Strength of Air Pressure* (Andrew Jamieson, ANU)

3rd: *Non-newtonian fluids*
(Paul Wiggley and Ethan Barden, ANU)

The ACT AIP *Frame Your Physics* prize night.

NSW

The Einstein Lecture, a collaboration between the Australian Institute of Physics (NSW) and the Powerhouse Museum in Sydney, was a part of the Ultimo Science Festival 2013. Professor Benjamin Eggleton, an ARC Laureate Fellow at the University of Sydney and Director of the ARC Centre of Excellence for Ultrahigh-bandwidth Devices for Optical Systems, spoke on *Photonics in the new information age: faster, smaller and greener* to one of the largest audiences at the Powerhouse Museum in a lecture that included a number of simulations and experiments to demonstrate how information is transported by optical fibres.

Ben Eggleton

The 2013 Women in Physics (WIP) Lecturer, Professor Elizabetta Barberio, a member of the Experimental Particle Physics Group at the University of Melbourne since 2004 and previously a staff researcher at CERN, came to NSW in October as part of the national WIP tour. Her tour of NSW was an outstanding success, with packed audiences. Elizabetta spoke at high schools in Newcastle, Wollongong and Sydney as well as at a public lecture held at Sydney Observatory.

Elisabetta Barberio and Graeme Melville

On 23 October, the NSW Branch joined the Royal Society of NSW and the University of Sydney

to host the Pollock Lecture in the memory of Professor J.A. Pollock, Professor of Physics at the University of Sydney (1899-1922). Professor Michelle Simmons, Director of the ARC Centre of Excellence for Quantum Computation and Communication Technology, a Federation Fellow and Scientia Professor of Physics at the University of New South Wales, gave an overview of the different research approaches to realizing the first true quantum computer. She described the work at UNSW that involves burying single dopant atoms in silicon to form a qubit.

L to R: Simon Fleming, Scott Martin, Michelle Simmons and John Hardie (Royal Society of NSW)

Tasmania

The University of Tasmania's optical astronomy observatory, Mt Canopus near Hobart, is about to close. Its replacement, the Greenhill Observatory at Bisdee Tier about 60 km north of Hobart, was officially opened earlier this year. On 29 October John Greenhill gave an interesting talk to the Branch on the transition. As well as discussing some of the background that led to the construction of the Canopus observatory forty years ago, John brought us up-to-date on the present state of the exo-planet search by microlensing.

University of Tasmania's new Greenhill Observatory

Victoria

The particle now known as the Higgs boson continues to capture the imagination of the public. With the award of the 2013 Nobel Prize in Physics to Francois Englert and Peter Higgs, the Victorian Branch held a public forum with a panel of seasoned high-energy physicists. A tradition of the Victorian branch, the lecture commemorating the 2013 Nobel Prize in Physics was delivered by Raymond Volkas (Melbourne). In particular the lecture was a celebration of the particle's discovery and announcement on the 4th of July 2012 – on the eve of the *International Conference in High Energy Physics* (ICHEP) 2012, held in Melbourne. This lecture set the stage for a lively panel of physicists from across high-energy physics: Raymond Volkas (Melbourne), Martin White (Adelaide), Csaba Balazs (Monash), Lucien Boland (Melbourne), Bruce Yabsley (Sydney)

To paraphrase Raman Sundrum's observation at ICHEP last year: it is one thing to see a packed lecture theatre at CERN to hear about discoveries, and infinitely more pleasing to see the public of Melbourne turn out in droves with their own questions.

L to R: Raymond Volkas, Martin White, Csaba Balazs, Lucien Boland and Bruce Yabsley

Copies of AIP Congress proceedings for 1974 & 1984?

Copies of proceedings for the 1st AIP Congress (Adelaide, May 1974) and the 6th Congress (Brisbane, August 1984) are needed to complete a national library collection of AIP Congress proceedings. If you have a copy please contact Prof Stephen Collins: Stephen.Collins@vu.edu.au

AIP Women in Physics Lecture Tour

CALL FOR NOMINATIONS - 2014

The Australian Institute of Physics Women in Physics Lecture Tour celebrates the contribution of women to advances in physics. Under this scheme, a woman who has made a significant contribution in a field of physics will be selected to present lectures in venues arranged by each participating state branch of the AIP. Nominations are currently sought for the AIP WIP Lecturer for 2014.We are seeking a woman working in Australia or overseas who:

- has made a significant contribution in a field of physics research
- has demonstrated public speaking ability
- is available in 2014 to visit Canberra and each of the six Australian State capital cities and surrounding regions.

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

Nominations should be sent via email to the AIP Special Projects Officer (see details below). Self-nomination is welcomed, as are nominations from branches or employers/colleagues.

NOMINATION REQUIREMENTS
Submissions must include the following:

- Fully completed 2014 nomination form
  (see **http://www.aip.org.au/info/?q=content/women-physics-lecturer**).
- Nominee's CV, including a detailed record of presentations given to the general public, schools and media.
- A 300-500 word nomination containing:
  - a brief statement of the research area of interest to the nominee,
  - an outline of her significant contributions to physics,
  - references to key publications in which these contributions were presented (via curriculum vitae)
  - evidence of her ability to give a lecture which will excite an enthusiastic response in senior secondary and undergraduate students. (NOTE: this requirement must be adequately addressed in order for the nominee to be considered for selection)

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

Closing Date: 10th January 2014

Applications and nominations should be sent by email to:
Dr Olivia Samardzic
AIP Special Projects Officer
Email: olivia.samardzic@dsto.defence.gov.au

Alan Walsh and the Atomic Absorption Story: Celebrating 60 Years. [1]

Peter Hannaford

Centre for Atom Optics and Ultrafast Spectroscopy
Swinburne University of Technology, Hawthorn, Victoria 3122, Australia

Alan Walsh originated and developed the atomic absorption method of chemical analysis, which revolutionized quantitative analysis in the 1960s. Atomic absorption provided a rapid, accurate and highly sensitive method of determining the concentrations of nearly all the elements, rendering traditional wet-chemical methods obsolete.

1. Background

Alan Walsh grew up in Hoddlesden, a small moorland village in Lancashire, about twenty miles from Manchester. In 1935 he entered the honours school of physics at the University of Manchester: "It was only after I went to university that I experienced the real joys of learning and research. I had been at university only two weeks when I attended a lecture to the University Physical Society by Professor Lawrence Bragg, in which he told, in extremely simple language, the story of the pioneering work he and his father had done in their development of X-ray methods for determining the structure of crystals. The basic simplicity and beauty of their contribution greatly impressed us freshers..." Alan later undertook postgraduate research in X-ray crystallography in the Physics Department at the Manchester College of Technology (later UMIST). During this period his research was influenced by Henry Lipson, who suggested that he study the structure of β-carotene, which presented a considerable challenge to X-ray structure analysis at that time.

In September 1939 Alan commenced work at the British Non-Ferrous Metals Research Association (the BNF) in London, under the direction of the British spectrographer, D. M. Smith: "In the first place I was to work on the development and application of spectroscopic [emission] methods of metallurgical analysis, about which I virtually knew nothing, but with the intention also, in due course, working on X-ray studies of metals. With the outbreak of war [on the day he was due to start], these plans were abandoned and for the duration I worked only on spectroscopy". Alan was given the task of determining which metals were being used in enemy aircraft that had been shot down. This information was passed on to the war economists, who could then infer how the German war effort was progressing. During this time Alan developed a 'General-Purpose Source Unit' for the spectrographic emission analysis of metals and alloys [2], which was later commercialized by the British company Hilger and Watts.

During the spring of 1945 the BNF was asked to explore the possibilities of developing a spectrographic technique for determining impurities in uranium metal, and Alan devised a method for doing this that was released for publication some years later [3]. Around this period the BNF was involved in the *'Tube Alloys Project'*, which was a cover for the development of the British atom bomb. Former staff from the BNF were astonished to read in a September 1999 issue of *The Times* that the personal secretary to the Director of the BNF, Melita Sirnis (later Melita Norwood), had been passing on 'highly sensitive' material to the Soviet Union for forty years under the code name 'Hola'. A detailed account of Hola's activities are given in David Burke's book *The Spy Who Came in from the Co-op* [4].

"…regarding the development of spectrochemistry…further progress would require a completely new line of attack."

Of his time at the BNF, Alan wrote: "By the end of the war I think there was a general feeling of satisfaction, and perhaps even a state of euphoria, regarding the development of spectrochemistry. I believe few workers shared my strong conviction, which I frequently expressed, that further progress would require a completely new line of attack... I was particularly conscious of the fact that accurate analysis [by atomic emission] required standards of similar composition to the sample for analysis. If one

[1] Based on a lecture presented by the author at CSIRO in Clayton on 19 November, 2012 to celebrate the 60th anniversary of Walsh's conception of the atomic absorption method of chemical analysis, and on material in a biographical memoir by the author [1].

wanted to be cynical about this then one could claim that accurate spectrochemical analysis consisted in confirming that the composition of a sample was what it was supposed to be... It was with a sigh of relief that I left these problems of spectrochemical analysis in 1946".

2. Early Days at CSIR/CSIRO

In 1945 Alan applied for the position of Research Officer for Spectroscopic Investigations in the Division of Industrial Chemistry of the Council for Scientific and Industrial Research (CSIR)[2] in Melbourne. The Chief of the Division, Ian Wark, had established a new Chemical Physics Section (later to become the Division of Chemical Physics), headed by Lloyd Rees, to apply modern physical techniques to the solution of chemical problems.

Upon commencing at CSIR, Alan set about installing a new Perkin-Elmer Model 12B infrared spectrometer, the first infrared spectrometer in the country. He soon realised that the resolution of the spectrometer was inadequate for resolving the rotational lines of any but the lightest molecules. To improve the resolution he devised a simple and elegant modification of the infrared prism monochromator in which radiation was passed two or more times through the same optical system. To do this he placed a pair of right-angle mirrors at the exit slit of the spectrometer to reflect the light back through the prism and in order to isolate the desired multiple-pass beam from the other beams he placed a rotating 'chopper' in front of the additional mirrors to modulate only the multiple-pass light and fed the output of the detector to an amplifier tuned to the frequency of the chopper. Alan's 'double-pass monochromator' was patented in 1950, and Perkin-Elmer began manufacturing a kit of 'Walsh Mirrors' to allow the conversion of their standard infrared spectrometer to a double-pass monochromator system. This experience with patenting and licensing and the interaction with Perkin-Elmer proved to be important for future events in that it involved Alan personally with the commercial aspects of his research.

Shortly after his arrival at CSIR Alan initiated a project to investigate the electrical spark processes occurring in spectroscopic atomic emission sources similar to the BNF design [2]. However, the CSIR unit proved rather to be unreliable and was not sufficiently stable for the research Alan was proposing.

[2] In 1949 the CSIR became the Commonwealth Scientific and Industrial Research Organization (CSIRO).

3. Conception and Establishment of the Atomic Absorption Method

In an address to the Silver Anniversary Symposium on *Great Moments in Analytical Chemistry* at the Pittsburgh Conference on Analytical Chemistry in 1974, Alan recalled [5]: "My initial interest in atomic absorption was a result of two interacting experiences, one of the spectrochemical analysis of metals over the period 1939-46, the other of [infrared] molecular spectroscopy over the period from 1946-52. The interaction occurred in early 1952 when I began to wonder why, as in my experience, molecular spectra were usually obtained in absorption and atomic spectra in emission. The result of this musing was quite astonishing: there appeared to be no good reasons for neglecting [atomic] absorption spectra; on the contrary, they appeared to offer many vital advantages over atomic emission spectra as far as spectrochemical analysis was concerned. There was the added attraction that absorption is, at least for atomic vapours, produced thermally, virtually independent of the temperature of the atomic vapour and of excitation potential".

Alan's flash of inspiration came one Sunday morning in March, 1952 while he was working in the vegetable patch at his home [1]. The next morning he set up a simple experiment, using the element sodium. By morning tea he had a successful result: "I was very excited and called in my colleague: 'Look', I shouted 'That's atomic absorption'. His reply, which I have never let him forget, was 'So what?' This was typical of the general reaction to my early work on atomic absorption". In this initial demonstration, Alan used a simple sodium vapour lamp operated from a

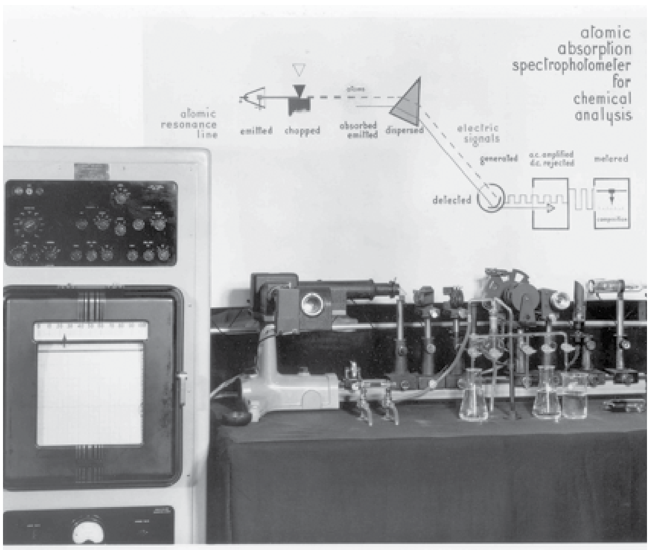


Figure 1: The first atomic absorption spectrophotometer, exhibited at an exhibition of scientific instruments at the Victorian Branch of the (then British) Institute of Physics, Melbourne, in March 1954

50 Hz mains supply and thus had an alternating output, so that it was not necessary to use a 'chopper'. The sodium D lines from this source were isolated by means of a simple direct-vision spectrometer and their combined intensity was measured by means of a photomultiplier tube, the output of which was recorded on a cathode ray oscilloscope. Amplification of the signal was by the AC amplifier in the oscilloscope. A simple air-coal gas flame 'atomizer' was interposed between the sodium lamp and the entrance slit of the spectrometer. When a water solution containing a few milligrams of sodium chloride was sprayed into the air supply of the flame the cathode spot on the oscilloscope deflected to zero, thus establishing the principle of the atomic absorption method.

Apparently, while reading Tolansky's book *High Resolution Spectroscopy*, Alan learned that a hollow-cathode discharge can provide a source of very sharp lines for a large number of the elements. In 1953 he, together with colleagues John Shelton, George Jones and Frank Williams, set out to construct hollow-cathode lamps which used a closed gas-circulating system, of the type described by Tolansky, in which the rare gas was pumped continuously through traps to remove molecular impurities liberated by the discharge from the cathode and from the walls of the tube. This system involved a rack of elaborate gas handling and pumping gear and was not convenient. During a visit to the USA in mid-1953, Alan reported back on the work of Dieke and Crosswhite [6] who were using compact sealed-off hollow-cathode lamps in which the gaseous impurities were removed by a 'getter' of activated uranium. Alan and John Shelton then began the development of sealed-off hollow-cathode lamps for a wide range of the elements, using zirconium getters.

Figure 2: Alan Walsh and the Techtron AA-3 atomic absorption spectrophometer, the first all-Australian atomic absorption instrument.

At this stage Alan had arrived at a satisfactory method for making the atomic absorption measurements and an experimental arrangement: a sealed-off modulated hollow-cathode lamp as source, a flame atomizer as absorber, and a 'chopper' and synchronously tuned amplifier to discriminate between the emission of the source and that of the luminous flame absorber. A provisional patent application was lodged in November 1953 and the final patent specification was filed in October 1954. Soon afterwards, in November 1954, Alan submitted his landmark paper *The application of atomic absorption spectra to chemical analysis* [7].

The first public demonstration of a working atomic absorption instrument was in March, 1954 at an exhibition of scientific instruments held by the Victorian Division of the (then British) Institute of Physics at the University of Melbourne. The exhibited instrument (Fig. 1) had all the essential components of a modern commercial atomic absorption instrument. The source was a copper hollow-cathode lamp, but there was also provision for a sodium vapour lamp and viewers were invited to 'dip their (salty) finger' into a beaker of water and this would register as a deflection on the strip chart recorder. Alan recalls: "The apparent complexity of the instrument was due largely to its being of the double-beam type, which in our early experiments we regarded as essential because of the poor stability of many of our hollow-cathode lamps. The viewer was possibly further confused by the optical path being in opposite directions on the instrument and on the explanatory diagram (Fig. 1). Whatever the reason, the instrument aroused no interest whatsoever during the three days it was on exhibition".

"...the first analytical atomic absorption results...the determination of trace amounts of magnesium in various agricultural samples."

In 1958 Eric Allan of the Ruakura Soil Research Station in Hamilton, New Zealand, who had assembled his own atomic absorption equipment following discussions with Alan, reported the first analytical atomic absorption results, on the determination of trace amounts of magnesium in various agricultural samples. Shortly afterwards, John David of the CSIRO Division of Plant Industry in

Canberra, using improvised equipment made with Alan's assistance, reported the determination of zinc and other elements in plant-digest solutions. This was followed by analytical applications in clinical chemistry by John Willis from the CSIRO Division of Chemical Physics and in the mineral processing industry by Max Amos and coworkers from Conzinc Rio Tinto Australia. These initial analytical results on the applications of atomic absorption stimulated a steady flow of requests to Alan for help in getting atomic absorption into wider use in Australia.

By 1958 there was no sign of any instrument manufacturer prepared to produce the type of instrument Alan considered necessary. He then decided to embark on *'Operation Backyard'* and gave instructions on how to put together a 'do-it-yourself' kit [8]. Fred Box of CSIRO designed and built the electronics, George Jones and later Jack Sullivan of CSIRO developed and provided the expertise and 'hands-on' skills for producing the hollow-cathode lamps, while John Willis worked on the analytical methods for specific analyses. A simple commercial monochromator, such as a small Zeiss quartz-prism monochromator, was recommended for isolating the atomic absorption lines.

"By mid-1962…in excess of thirty of these 'do-it-yourself' kits had been supplied to Australian laboratories and about ten to other parts of the world."

Alan then had to find businesses that were prepared to co-operate in manufacturiung components that were not available commercially: "The electronic part of our equipment was perfectly conventional electronics, nothing fancy, so we put out a tender for manufacturing six of our amplfiers and power packs, and a little firm called Techtron put in the lowest bid....Then I toured the backyards of Melbourne to find a little machine shop [Stuart R. Skinner] with a staff of eight. Then we tried various glass-blowing people for the lamps, and we found a little firm [Ransley Glass Instruments, later to become Atomic Spectral Lamps] that was willing to try. This was a pure glass-blowing firm, who knew nothing about vacuum technique or electrical discharge in gases, and they had no technical people on their staff at all". By mid-1962, it was estimated that in excess of thirty of these 'do-it-yourself' kits had been supplied to Australian laboratories and about ten to other parts of the world.

4. Commercialisation of Atomic Absorption

From 1958 Alan made regular visits to the USA, conducting lecture tours and reporting recent atomic absorption results from Australia and New Zealand. The analytical spectroscopists and major American instrument manufacturers remained sceptical of the value of the method. During his 1958 visit, Alan visited the Perkin-Elmer Corporation and a representative indicated that the company would be seriously interested in becoming a licensed manufacturer of atomic absorption equipment if it could be shown capable of determining calcium in blood serum.

In March 1959 Alan's colleague, John Willis, submitted an interim report of his work on calcium and magnesium in blood serum to Perkin-Elmer and later that year the company was granted a license from CSIRO to manufacture atomic absorption equipment. The following year Perkin-Elmer established a group, headed by Walter Slavin, to develop an atomic absorption instrument. In 1961 Walter Slavin and a colleague, Herbert Kahn, submitted a detailed report to Perkin-Elmer management that included the design of a completely new atomic absorption instrument, the Model 303. The report met with massive management resistance and in early 1962 it was clear that management would block, or at least continue to delay, the start of the Model 303. So Walter Slavin phoned Alan, who agreed to go to Perkin-Elmer in Norwalk to meet with senior management. Alan recalls: "After I had described the widespread use of atomic absorption methods in Australia the chairman of the meeting, Chester Nimitz Jr (a former submarine commander and son of Chester Nimitz, who commanded the US Pacific Fleet in World War 2) asked rather tersely: 'If this goddam technique is as good as you say it is, why isn't it being used right here in the United States of America?" My reply, which my friends at Perkin-Elmer love to recall, was 'You'll have to face up to it, Chester, the United States is just an underdeveloped country'".

In March 1962 Perkin-Elmer began building the Model 303. It was released on the market in April, 1963 and by 1965 it had already overtaken infrared spectroscopy as Perkin-Elmer's largest product line and had captured the bulk of the atomic absorption market.

In July 1962 Alan and Lloyd Rees arranged a symposium on atomic absorption spectroscopy through the Victorian State Committee of CSIRO. The meeting was attended by about eighty potential users and CSIRO staff. At the end of the symposium, Geoffrey Frew, Chairman of Techtron Appliances Pty Ltd, declared his intention to manufacture a 'complete' atomic absorption spectro-

photometer. Alan recalled how all the main players were present at the symposium and the whole deal was virtually signed and sealed that evening. This announcement by Frew was 'tantamount to announcing the impending birth of an Australian spectroscopic instrument industry'.

"In early 1964, Techtron produced the first all-Australian atomic absorption instrument…"

In early 1964, Techtron produced the first all-Australian atomic absorption instrument, the Model AA-3 (Figs. 2 and 3), which incorporated a 'Sirospec' grating monochromator designed by John McNeill at CSIRO, diffraction gratings ruled on a ruling engine designed and constructed by Dai Davies and Geoffrey Stiff at CSIRO, and a 'working man's amplifier' unit designed by Fred Box at CSIRO. The AA-3 was exhibited publicly for the first time at the Pittsburgh Conference on Analytical Chemistry in March 1964.

In 1965 Max Amos from Sulphide Corporation and John Willis reported the use of the high-temperature nitrous oxide-acetylene flame atomizer [9] to extend the applicability of the atomic absorption method to more than sixty-five elements, including previously recalcitrant refractory elements such as aluminium, vanadium, zirconium and beryllium. From that stage onwards there was a dramatic increase in interest in the atomic absorption method and it rapidly gained wide acceptance. Alan recalled: "The real winner in Australia, of course, was the mining boom and its timing was a real fluke. At the very time when we suddenly wanted tens of millions of analyses there was a technique waiting to do it....".

In August 1965, Techtron Appliances Pty Ltd merged with Atomic Spectral Lamps Pty Ltd to form Techtron Pty Ltd, with Geoffrey Frew as its Chairman. Techtron manufactured the Model AA-4 with a synchronously tuned amplifier and a nitrous oxide-acetylene burner. This was followed by a period of rapid growth, with staff increasing to around 200 in 1966, In 1967 the company moved to a new factory, in Mulgrave in the outskirts of Melbourne. In October 1967, Techtron Pty Ltd was approached by Varian Associates, a successful instrument manufacturing company in Palo Alto, California, with an offer of acquisition, first a 50.5% holding and progressing to 100% over five years. The merger, to form Varian-Techtron Pty Ltd, brought 'great strengths to the company in the way of manufacturing techniques, financial support, and perhaps most importantly, a world-wide distribution network for its products'. This was followed by further rapid growth, with sales increasing at around 30% a year for the next six years and staff growing to 630 by 1972. The company became Varian Australia in 1972 and was acquired by Agilent Technologies in 2010.

5. Benefits of the Atomic Absorption Method

The atomic absorption method provided, for the first time, a rapid, accurate and highly sensitive method of chemical analysis that was applicable to almost any element, with applications as diverse as medicine, agriculture, geochemistry, metallurgy, food analysis, biochemistry, environmental control… It revolutionized trace element analysis and has been described as the 'most significant advance in chemical analysis this [the twentieth] century' [10].

In 1968 Albert Brown, a scientist with postgraduate qualifications in business administration, was commissioned by CSIRO to conduct a cost-benefit analysis of the atomic absorption project [11]. This study conservatively assessed the value of the net benefits to the Australian economy at around $22 million (in 1968 Australian dollars), compared with $1.3 million spent on the research. Much to the surprise of many, Brown found that the major benefits to the economy were not through the manufacture of atomic absorption equipment in Australia, but rather through benefits to the user associated with productivity gains, especially the ability to perform large numbers of assays very rapidly and with a high order of accuracy. This component far outweighed the benefits of the manufacture. Royalty income was miniscule by comparison.

In 2003 the world market for atomic absorption instruments was around $500 million per year. Varian Australia in Mulgrave, which had a staff of around 400 and a similar number outside engaged in contract work, had the second largest share of the atomic absorption market, after Perkin-Elmer. GBC Scientific Equipment in Melbourne, which had a staff of around 180, had the third largest share of the market. Photron Pty Ltd in Narre Warren manufactured hollow-cathose lamps for atomic absorption. By 2012 it was estimated that there had been over $3 billion in exports from Australia [12].

When asked about the appropriateness of the development of atomic absorption in Australia, Alan replied: "Well, it was fortunate. We say it was good planning! I think it's a good example of how uncommitted research can finally be more significant than directly applied work. If somebody had said in 1950 that there was going to be a mineral boom in ten years' time which would need new

methods of analysis I'm sure we would have tried to elaborate existing methods, rather than follow a completely new line".

In his final scientific paper, Alan concludes: "There are two important lessons to be learned from this account of the development of atomic absorption methods and the difficulties encountered in convincing analysts and scientific instrument manufacturers of their potential. First, it should be noted that this work originated in a laboratory where scientists were encouraged to study a subject at a basic level and were not expected to have a specific goal for every set of investigations. I think this is a tremendously important point.... The second lesson is that it is a mistake for the scientist or the inventor to try to sell an invention by scientific and technical arguments rather than by a demonstration of how well it can fulfil the functions it claims to fulfill. The licensee is not interested in how clever the invention is; he or she merely wants to know what benefits the invention affords the designer, manufacturer, and user of the equipment in which it is incorporated".

Shortly after Alan's death, in 1998, Barry Jones, a former Minister for Science in the Australian government, remarked on the ABC Science Show: "I don't know there is a single significant laboratory anywhere in the world that doesn't have an atomic absorption spectrophotometer. The tragedy is, of course, as with so many other of our ideas with something that really began here, licensing rights were sold off to other countries and the result is that only a small proportion of the actual machines were manufactured in Australia after a while." During the period 1954-62, Australia did not have the scientific instrument manufacturing capability to handle the massive expansion that resulted first from the Australian mineral boom of the 1960s and later from the 'environmental boom' and the enormous demand from around the world. There was no company in Australia geared up to cope with such a demand.

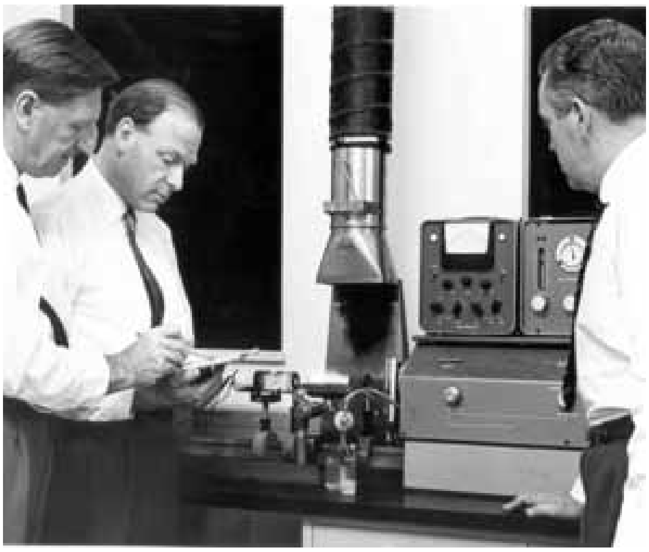


Figure 3: Alan and colleagues, John Willis and Jack Sullivan, with the AA-3 atomic absorption spectrophotometer at the CSIRO Division of Chemical Physics in Clayton.

"...it should be noted that this work originated in a laboratory where scientists were encouraged to study a subject at a basic level..."

In 1970, the Chairman of Varian-Techtron Pty Ltd, Geoffrey Frew, donated a substantial sum to the Australian Academy of Science 'in recognition of the successful commercial development of atomic absorption spectrochemical analysis, which had been originated by Dr A. Walsh of the CSIRO Division of Chemical Physics in 1954'. The Frew Fellowships enable distinguished scientists to travel to Australia to participate in Australian Spectroscopy Conferences and to visit scientific centres around the country. Recipients include Nobel laureates Arthur Schawlow, George Porter, Gerhardt Herzberg, John Hall, Claude Cohen-Tannoudji, John Polanyi, Carl Wieman and David Wineland.

Alan was involved in the break-away of the Australian Institute of Physics from the British Institute of Physics in 1963, for which we are currently celebrating the 50th anniversary. He then served as President from 1967 to 1968. In 2002, The AIP established the Alan Walsh Medal for significant contributions by a practising physicist to industry in Australia.

References:

[1] P. Hannaford, "Sir Alan Walsh", *Biographical Memoirs of the Fellows of the Royal Society of London* 46, 533 (2000); Historical Records of Australian Science **13**, 179 (2000)

[2] A. Walsh, " A general-purpose source unit for the spectrographic analysis of metals and alloys", *Bulletin of the British Non-Ferrous Metals Society* No. 201, 60 (1946)

[3] A. Walsh, "Spectrographic analysis of uranium", *Spectrochimica Acta* **4**, 47 (1950)

[4] David Burke, *The Spy Who Came in from the Co-op: Melita Norwood and the Ending of Cold War Espionage,* Boydell Press, Rochester, NY, 2008.

[5] A. Walsh, "Atomic absorption – stagnant or pregnant", *Analytical Chemistry* **46**, 689A (1974)

[6] G. Dicke and H. M. Crosswhite, "Purification of rare gases by activated uranium", *Journal of the Optical Society of America* **42**, 433 (1952)

[7] A. Walsh, "The application of atomic absorption spectra to chemical analysis", *Spectrochimica Acta* **7**, 108 (1955)

[8] J. B. Willis, "Three little companies – the birth of the Australian instrument scientific industry", *Historical Records of Australian Science* **14**, 403 (2003)

[9] I. W. Wark, *Why Research? A Research Scientist Writes of his Work*, Reading, UK, 1968: Educational Employers Ltd

[10] M. D. Amos and J. B. Willis, "Use of high-temperature pre-mixed flames in atomic absorption spectrocopy", *Spectrochimica Acta* **22**, 1325 (1966)

[11] A. W. Brown, "The economic benefits to Australia from atomic absorption", *Economic Record* **45**, 158 (1969)

[12] Philip Binns, Agilent Technologies Australia

[13] A. Walsh, "The development of the atomic absorption spectrophotometer", *Spectrochimica Acta* **54**, 1943 (1999)

AUTHOR BIO

Peter Hannaford is currently Professor Emeritus at Swinburne University of Technology in Melbourne. He worked in Alan Walsh's group at the CSIRO Division of Chemical Physics in Clayton in the 1960s and 70s and is the author of Walsh's biographical memoir [1]. He served as Chair of the Victorian Branch of the AIP from 1989-90 and was the recipient of the AIP's Walter Boas Medal in 1986. He is a Fellow of the Australian Academy of Science.

ANU
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The 21st biennial Australian Institute of Physics Congress ,The Art of Physics, which will be held at the ANU in Canberra in the week December 7-12 in 2014. The Congress also incorporates the annual meeting of the Australian Optical Society as well as meetings of the many technical groups and discipline areas associated with the AIP. The AIP Congress will be preceded by the OSA Renewable Energy and Environment Congress, which will also be help at the ANU on December 2-5.

The AIP event will be held over five days with plans for seven concurrent sessions, daily plenaries, an Industry Forum and a packed and lively social calendar. The The Art of Physics theme was chosen to explore the links between, and the beauty of physics and art. To generate a creative and stimulating atmosphere at the Congress, a wide range of theme-related activities and events are planned. Congress delegates, sponsors and exhibitors are also encouraged to be adventurous in working the theme into their presentations, posters and exhibits.

Current plenary acceptances:

- Dr Steven Chu, co-recipient of the Nobel Prize for Physics (1997)
- Prof Paul Corkum, Director of the Attosecond Science Program at NRC and University of Ottawa.
- Prof Steven Cowley, CEO, United Kingdom Atomic Energy Authority
- Dr Lisa Harvey-Smith, project scientist for the Australian SKA Pathfinder (ASKAP)
- Prof Lawrence M. Krauss, Arizona State University & ANU
- Prof Steven Sherwood, Climate Change Research Centre, UNSW

Registration opens Friday 7 March 2014 **website: www.aip2014.org.au**

100 Years of Cosmic Rays – An Australian Perspective: Part 2, Tasmania

John Humble and Marc Duldig

Part 1 of this paper (Duldig and Humble, 2012) covered cosmic ray research in Australia up to the 1940s. After World War 2 ended research in the field resumed at the University of Melbourne, under the leadership of Professor L Martin and Dr H Rathgeber, and at the University of Tasmania under Professor A L (Lester) McAulay and Dr A G (Geoff) Fenton. Both groups studied what became known as cosmic ray modulation. Their initially separate aims coalesced into a program based in Hobart which mainly sought to study modulation in the heliosphere. Later, other long-running cosmic ray programs were established at the Universities of Sydney and Adelaide.

Instrumental History, Tasmanian Group

The Tasmanian group expanded rapidly when Dr Phil Law moved the base of the ANARE (Australian National Antarctic Research Expeditions) cosmic ray program from the University of Melbourne to the University of Tasmania in Hobart nearly thirty years before the rest of ANARE, by then renamed the Australian Antarctic Division, moved to Tasmania. Meson detectors were installed at Hobart, Heard Island (1948), Macquarie Island (1948), Mawson (1955) and Lae, New Guinea (1957). Detailed descriptions of these instruments, and the problems encountered when commissioning them at the non-Tasmanian stations, have been published (Duldig, 2000). Figure 1 shows one of the early muon telescopes. The vacuum tube scalars are clearly visible, as are the high voltage power supplies located at the base of the telescope.

The IGY (International Geophysical Year, actually 18 months from July 1957 to December 1958), led to the widespread introduction of neutron monitors (NMs) mostly using the IGY design pioneered by Professor John Simpson and his co-workers at the University of Chicago.

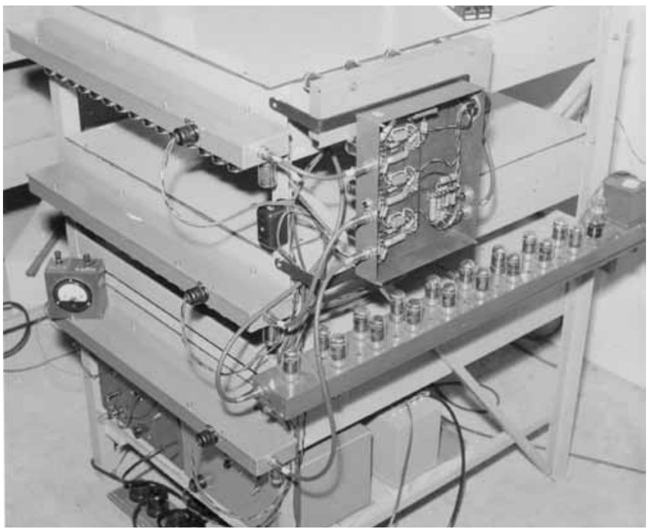


Fig 1. One of the early 1 m2 muon telescopes

Seeking high count rates, the first such monitor was installed at an altitude of 3400 m at Climax, Colorado, in September 1951. International development was initially slow, the first Australian NM being installed at a site partway[1] up Mt Wellington, near Hobart, in July 1956. A second was installed at Mawson, Antarctica in March 1957 and a third went to Lae, New Guinea, for the start of the IGY. These NMs were long lasting but one installed by the University of Sydney in the Sydney area at the start of the IGY was closed after the IGY, transferred to the University of Tasmania and installed at Brisbane in November 1960. A similar instrument was installed by the University of Tasmania at Wilkes, Antarctica, in March, 1962. Data recording at Hobart, Mawson and Wilkes was by hourly accumulation of scaled counts in banks of 48 post-office telephone registers (simple electro-mechanical counters), one bank for each of the three channels in an NM. Use of 48 registers meant that one set was available for human reading every day. This seven-day a week process required rosters at Hobart. Figure 2 shows an early version of a register bank, designed for the two section neutron monitor in use at Mawson pre-1960[2].

The two Antarctic stations each had a dedicated cosmic-ray physicist/engineer, full-time through 1988. Each new expeditioner spent some months at Hobart for training prior to going south and, at least initially, a month or two after they returned working up data. One of their tasks on station was to read the registers each day. The tabulated results were then returned to Hobart initially by telegram, later by telex. The register recording systems were supported by multi-channel Evershed, and later Esterline Angus, chart event recorders designed to cope

[1] The site was chosen as the then upper limit of available electrical power on Mt Wellington.

[2] In 1959 and 1960 the group's NMs were changed from two sections of six counters each to three sections of four counters, to provide more information on efficiency changes.

Fig 2. An early two-section register bank.

with both normal count rates and with possible "flare" increases. At Brisbane and Lae charts were later replaced by accumulating printers. Although the best affordable technology at the time these were not all that reliable. Their tapes, and the charts, were posted back to Hobart to be read out by a team of dedicated data assistants. Looking back it all seems dreadfully primitive and time consuming.

"The two Antarctic stations each had a dedicated cosmic-ray physicist/ engineer, full-time through 1988."

The NM was the dominant instrument for medium energy studies for several decades. Surface level muon telescopes suffer from two significant atmospheric temperature effects, one positive and one negative, which are difficult to eliminate. In contrast, the major atmospheric contribution to neutron monitor observations is simply due to the amount of matter traversed by the neutron cascade. To first order this can be represented by a pressure correction coefficient, larger than investigators would like but manageable. The only requirement is accurate knowledge of the surface pressure, preferably to 0.1 mb.

Cosmic rays contain a significant high energy component. (Note that "high-energy" is a relative term, often closely linked to the observations under discussion. Here we mean particle energies in excess of 10-15 GeV). Such particles can penetrate significant quantities of rock. In 1957 two 1 m^2 vertical muon telescopes were installed in a long-abandoned railway tunnel quite close to Hobart, to observe cosmic rays with a median primary energy around 25 GeV. At that time the positive and negative temperature effects involved with particles of this energy were believed to be more-or-less equal in magnitude. Being opposite in sign they would cancel and therefore the only significant correction required would be for pressure changes, the coefficient being significantly less than it is for surface neutron monitors[3]. It was later realised that the energy at which the effects cancel is rather higher, of order 150 GeV. Advantage of this was taken at Mawson in the early 1970s.

A third 1 m^2 vertical telescope was added in the tunnel and an apparent diurnal variation in sidereal time was observed (Jacklyn 1966). To lasting confusion, the location of this instrument has at various times been described as Cambridge (about 3 kilometres to the east of the site) or Hobart (about 10 km to the west). At a later stage two inclined telescopes were added. Operation continued until the mid- 2000s.

The gyro-radius of a charged particle in a magnetic field is given by $r = mv_p/qB$, where v_p is the velocity component perpendicular to B. The "rigidity" P of such particles is defined as momentum per unit charge; thus particles of the same rigidity have the same gyro-radius for a given B. Cosmic ray primary particles sufficiently energetic to allow their secondaries to reach ground level are about 90% protons, with most of the remainder being alpha particles. Analysis in terms of rigidity allows the charge differentiation to be ignored.

Should the gyro radius become large relative to typical solar system dimensions it could be assumed that such particles are largely unaffected by solar system phenomena. In trying to distinguish between cosmic-ray modulation due to solar effects and modulation that reflect effects outside the solar system the concept of Upper Limiting Rigidity arose. An early paper comparing results from the Cambridge underground installation and from the Mt Wellington NM concluded that the Upper Limiting Rigidity was around 100 GV (Jacklyn and Humble, 1965). This was considerably less than the 500 GV, effectively infinite for neutron monitors, that had been assumed by previous investigators.

Intriguing results from the Hobart/Cambridge railway tunnel led to a wish to install detectors which would only observe cosmic rays whose energies would be large enough that it would be reasonably certain that they would be unaffected by solar modulation. Thus in 1972 a deep underground facility was established in a Hydro-Electric Commission underground power station at Poatina, in northern Tasmania, at a depth of 365 metres water equivalent. For secondary particles to reach this depth the primaries require energies of order 1 TeV or more. It was considered that such particles could not be

[3] Underground observations are, however, potentially subject to a different environmental problem, for example varying water content in the overburden.

modulated by solar system effects and therefore the installation might confirm any true diurnal variation in sidereal time. In practice, the initial count rates were too small for unambiguous results to be obtained. The space was severely constrained and although two larger proportional counter telescopes, each 4 m^2, were installed later, instrumental and environmental issues prevented the station from reaching its full potential. It was decommissioned in November 2008.

"…to clarify the solar vs sidereal explanation of the early muon measurements an underground observatory was excavated at Mawson during winter 1971."

In a parallel attempt to clarify the solar vs sidereal explanation of the early muon measurements an underground observatory (the vault) was excavated at Mawson during winter 1971. It was commissioned in 1972, along with high zenith angle surface muon telescopes. Until the construction of the Ice Cube experiment at the South Pole in recent years this was the only polar underground observatory. There will be further mention of the underground Mawson installation in part 3 of this series.

The neutron program was significantly disrupted when the Mt Wellington NM was destroyed in the February 1967 bushfires, which did so much damage in the Hobart area. It wasn't until June 1970 that it could be replaced on the same site by an IQSY type monitor with a much higher count rate. A few years later the University was gifted an eighteen counter IQSY type NM from the University of Texas at Dallas (UTD). This was split into two nine-counter monitors that were installed at Brisbane and Darwin airports, chosen because local Bureau of Meteorology staff could readily undertake the weekly chart changing as well as easily provide the vital surface-level pressure data. The aim was to obtain good latitudinal coverage, when combined with observations from the Antarctic and from Tasmania, for observations of short-term CR intensity fluctuations.

Towards the end of the 20th century it became increasingly difficult to obtain operational funding to continue the neutron observations. Consolidation began and in January 2000 the Brisbane NM was returned to Tasmania, followed nine months later by the Darwin instrument. Their components were used to create a new 18-counter NM at the Australian Antarctic Division headquarters site at Kingston, south of Hobart[4]. The Mt Wellington NM was closed in December 2001, with its components being used as part of the enlargement of the NM at Mawson.

A series of international collaborations began in the early 1980s. The first was instigated by Professor K Nagashima and others from Nagoya University who wished to run an air-shower experiment in the southern hemisphere on a similar longitude to their observatory in Japan. The new station was established at the Inland Fisheries research site at Liawenee, on the shores of Great Lake in Tasmania's central highlands. Later, Shinshu University, Matsumoto, Japan, also became involved and instigated a multi-direction underground telescope in a disused Hydro-Electric Commission adit tunnel at Liapootah, also in the central highlands. Shinshu also introduced a similar set of telescopes at surface level on the University campus at Hobart. This was moved to Kingston in early 2002 and enlarged about a decade later. It is still in operation as part of the GMDN (Global Muon Detector Network).

In the early days of cosmic ray modulation research there was considerable interest in the latitude distribution of cosmic ray intensity. Dr J R (Jack) Storey, at the time a post-doc in Hobart, conducted observations with a two-counter portable IGY type NM, suitably modified for air carriage, in flights in an RAAF Lincoln Bomber flying at 20,000 ft pressure altitude (475 g cm^{-2}). The flights ranged between 34°N (Tokyo) and 52°S (near Macquarie Island) and observations were conducted throughout the northbound and southbound flights (Storey, 1959).

Fig 3. Nod Parsons (left) and Geoff Fenton, sometime in the 1950s.

The People, Tasmanian Groups

Led by Geoff Fenton (University) and Nod Parsons (ANARE) (Figure 3), the groups were joined by Bob Jacklyn, Ken McCracken, Peter Ford, David Johns, John Greenhill, Paul Edwards, John Phillips, John Humble,

[4] Thus the original UTD NM was reformed to its original configuration 25 years after it had been split.

David Cooke, Attilla Vrana, Roger Francey, Gary Webb, Marc Duldig, Peter Lyons, Chris Baker, Damian Hall, Jenny Lovell (nee Cramp) and Daniel Bombardieiri, who all made major contributions to the programme over a period of almost sixty years. They were supported by ANARE, later AAD, expeditioners who maintained the equipment at Mawson and Wilkes/Casey.

"At that time…the physicists in charge of the various experiments were expected to handle most of their electronic problems themselves."

The expeditioner positions were interesting. Until well into the 1960s all the NM and muon telescope electronics were vacuum tube based. At that time Mawson had a single electronics engineer and the physicists in charge of the various experiments were expected to handle most of their electronic problems themselves. Discrete components made this relatively straightforward. The advent of transistors about 1961 required another new skill set. The cosmic ray expeditioner also had to run regular efficiency tests of the Geiger counter tubes in the muon telescopes, to ensure the high voltage supply remained at an appropriate level for the tubes, which deteriorated with time due to deposition on the anode.

The neutron detector tubes contained BF_3 with the Boron enriched to 95% ^{10}B. A couple of times a year the expeditioner was required to test the tubes' operating plateaus using a 1mCi (37 MBq) Radium - Beryllium neutron source. The OH&S instructions simply said keep the source, when not in use, in a shielded box outside the laboratory as far as possible from the NM!

Studies and outcomes, Tasmanian Group

When one of us (JEH) arrived in Tasmania in 1959 studies were still focussed on trying to understand why detectors at similar magnetic latitudes in different parts of the world recorded such different temporal responses to what were clearly world-wide changes in the cosmic ray flux. Four main problems were under consideration.

1. In Forbush Decreases[5] (FDs), the count-rate of an NM can drop by up to a few, often less than five but occasionally up to ~twenty percent over a few hours, and remain low, with a gradual recovery, for days. The time signature is usually very recognisable. By the end of the IGY it was clear that individual FD's were world-wide events, even though the time-signatures at different stations could be quite different.
2. Occasional cosmic ray "Flares", now referred to as Ground Level Enhancements (GLEs) were observed. In the large event on 23 February 1956 the then recently installed NM at Leeds, UK, had recorded a flux increase of ~4500% over background whereas the increase at other stations had been less. Given that several other large events were known to have occurred in 1942, 1946 and 1949 it was assumed that large events were relatively common. The chart recorder systems were designed to cope with events of this magnitude. Experience over the following 50 years revealed an average occurrence rate of about one event per year, normally with increases on only a few percent.
3. The diurnal variation in cosmic ray flux. Was this of terrestrial or extra-terrestrial origin?
4. The "East-West" effect. Rotating muon telescopes had revealed that there was a slight excess of particles arriving from westerly directions compared with those arriving from the east.

Comparing the Tasmanian group NM's records with simultaneous data obtained elsewhere, particularly from the Canadian NM's at Deep River (near Ottawa), Churchill (on Hudson Bay) and Sulphur Mountain (near Banff, Alberta) helped to understand why different observatories had different responses to what was ostensibly the same event. K G (Ken) McCracken, then a PhD student at Hobart, developed the idea of Impact Zones, particularly for GLE's. The work led to three papers Ken published in the Journal of Geophysical Research early in 1962 which used the Mawaon data, amongst other, to confirm the existence of the Parker spiral interplanetary magnetic field (McCracken 1962).

As so often happens the observations led the explanations. There were at least two complications. The quantitative relationship between the primary fluxes and the fluxes observed at Ground Level was uncertain. W R (Bill) Webber and J A (Jack) Lockwood's definitive paper on the topic didn't appear until 1967. Previously the group had relied on earlier work by Webber and Quenby 1959.

The other complication was the then limited knowledge of the trajectories of cosmic rays in the magnetosphere. Until the early 1960s the best that could be done was to assume the terrestrial magnetic field could be represented by an off-set dipole. Sets of sixth-order expansions of the field, derived from surface measurements, first became available in 1957 but were of limited value until

[5] **Named after Scott Ellsworth Forbush (1904 – 1984), who first described them.**

sufficient computing power appeared. McCracken et al (1962) were the first to publish FORTRAN code that could be used to calculate individual trajectories. Its use in Hobart was delayed until 1964, when an Elliott 503 became the first digital computer available in the university. It only had an Algol compiler so the McCracken et al code had to be translated. Difficulties were compounded by the limited available storage, 16 k of 39-bit "words". The computer was also slow, by modern standards, running at about 300 integration steps per minute. This was improved upon somewhat when the innermost loops of the trajectory program were re-written in machine code.

"The computer was also slow, by modern standards, running at about 300 integration steps per minute."

There were other interesting sidelines. In the mid-1970s suggestions were made that tachyons might explain a surprising result in an air-shower experiment at Adelaide. Accordingly the Fentons set up a scratch experiment on the roof the of the Physics building at the University of Tasmania. While presenting a paper at the 16th International Cosmic Ray Conference at Kyoto in 1979 one of us (JEH) mentioned this experiment, saying that the results were inconclusive. Naughtily, I thought, Professor Harry Elliot picked this up while presenting his rapporteur review of the field, to my horror saying that the Tasmanian group thought they may have detected tachyons. I'd made no such claim. Fortunately there's no mention of the topic in the printed version of Harry's paper (Elliot, 1979).

Elsewhere in Australia

Other cosmic ray research has also been conducted in Australia since World War II. A group at the University of Sydney, under Professor Harry Messel, ran a Simpson type NM during the IGY. The observations were discontinued soon after the end of the IGY and the monitor was moved to Brisbane under the control of the Tasmania group. Later work was continued by Laurie Peak and Murray Winn with air-shower obervations at higher energies than studied by the Tasmanian groups.

Meanwhile the University of Adelaide, under Professor John Prescott, later supported by Roger Clay and Bruce Dawson, ran air shower observations for many years at Buckland Park. Eventually this led to participation, still on-going, in the Auger project in Argentina. At the same time, other projects such as Cangaroo, led by John Patterson, were also in progress.

Part 3 of this paper will discuss more recent developments in the field, again concentrating on the Australian contribution.

Addendum

After part 1 of this paper had closed for press, Ken McCracken showed us photographs of A.H.Compton conducting cosmic ray measurements on the slopes of Mt Kosciusko[6,7] in 1929, apparently as part of an altitude survey. We had previously been unaware of this work and know of no references to its outcome.

References

Duldig, M L (Ed) (2000), 50 Years of cosmic ray Research in Tasmania, *ANARE Research Notes 102,* Australian Antarctic Division.

Elliot, H (1979), Rapporteur paper for Sessions MG 6, 7, 8 and 9, Conference Papers, *16th International Cosmic Ray Conference,* Kyoto, **14**, 200-217

Jacklyn, R M (1966), Evidence for a Two-Way Sidereal Anisotropy in the Charged Primary Cosmic Radiation, *Nature*, **211**, 690-693

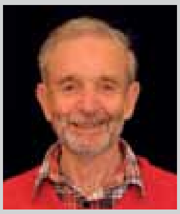
Jacklyn, R M and Humble, J E (1965), The upper limiting primary rigidity of the cosmic ray solar anisotropy, *Australian Journal of Physics,* **18**, 451-471

McCracken, K G (1962), The Cosmic-Ray Flare Effect, 3. Deductions regarding the Interplanetary Magnetic Field, J *Geophys Res*, **67**, 447-458

Storey, J R (1959), Cosmic-Ray Latitude Survey along 145° East Longitude Using an Airborne Neutron Monitor Phys. Rev. **113**, 297–301

McCracken, K G, Rao, U R and Shea M A (1962), The trajectories of cosmic rays in a high degree simulation of the Geomagnetic Field, *Technical Report No. 77*, Laboratory for Nuclear Science, Massachusetts Institute of Technology .

AUTHOR BIOS



John Humble has been a member of the cosmic ray group at the University of Tasmania since 1959. He wintered at Mawson in 1960 as the cosmic ray physicist, returning to Hobart to undertake a PhD. He subsequently became a lecturer in the Physics Department, rising to become Head of Department in 1991 and remaining in that role until retirement in 2000. He is currently an Honorary Research Associate in the School of Mathematics and Physics at the University of Tasmania, was a member of the AIP's National Executive 2007-13.

Marc Duldig joined the Australian Antarctic Division's (AAD) Cosmic Ray research group in 1980 becoming Head of the group in 1984. He led the group until his retirement in June 2011. He was Senior Principal Research Scientist and Program Leader of Space and Atmospheric Sciences at the AAD prior to his retirement. He is now an Honorary Research Associate in the School of Mathematics and Physics at the University of Tasmania. He has held numerous national and international committee and editorial positions and is the current Immediate Past President of the AIP.

[6] The spelling in use at the time. It was changed to "Kosciuszko" in 1997.
[7] At 2,229 m, the highest mountain in mainland Australia, including Tasmania. (Big Ben, on Heard Island which is politically part of Australia, is higher.)

Comprehensive study shows cosmic rays are not causing global warming

An analysis of more than 50 years' worth of climate data has found scant evidence for a controversial theory that attempts to link cosmic rays and global warming. The theory suggests that solar variations can affect the number of cosmic rays reaching the Earth, which in turn influences climate by impacting on cloud formation. The latest study was done by Rasmus Benestad of the Norwegian Meteorological Institute and he concludes that changes to the Sun cannot explain global warming.

Benestad compared variations in the 1951–2006 annual mean galactic cosmic-ray-flux data with annual variations in temperature, mean sea-level barometric pressure and precipitation. The cosmic-ray data were obtained using a high-altitude neutron monitor located in Climax, Colorado. He looked for meteorological responses to cosmic rays over timescales of more than a year, and for "fingerprint" patterns in both time and space. He also checked for responses to greenhouse-gas concentrations and the El Niño Southern Oscillation.

"The significance of the findings was that the results were negative – I found little evidence of the cosmic rays having a discernible affect on a range of common meteorological elements: temperature, the barometric pressure or precipitation," says Benestad. "Not for the global mean at least. One possible exception may have been for parts of Europe, however."

The galactic cosmic-ray flux was associated with lower temperatures in parts of Eastern Europe. Benestad is intrigued whether these results were a coincidence or do indeed show a connection between cosmic rays and both temperature and sea-level pressure. He plans to investigate further. "Why would a solar effect be seen only in a limited region?" he wonders. "This region is affected by the North Atlantic Oscillation, and this phenomenon is a bit special – a variation in the sea-level pressure over timescales of up to several years. The persistence in these variations may match the variations in the Sun by accident, but it could also be sensitive to variations in the Sun." If there is a real connection between changes to the Sun and the North Atlantic Oscillation, Benestad believes that this knowledge could benefit decadal predictions.

Cosmic rays cause clouds?

On a larger scale, the analysis indicated that the weak global mean-temperature response associated with cosmic-ray flux could easily be down to chance. What is more, there has been no long-term trend in cosmic-ray flux. "Hence, there is little empirical evidence that links galactic cosmic-ray flux to recent global warming," wrote Benestad. [Rasmus E Benestad *Environ. Res. Lett.* **8** 035049 (2013)]

Extracted with permission from *physicsworld.com*

How to store electrical energy as heat

An idealized model for a system that would store large amounts of electrical energy by heating a tank of fluid has been developed by German physicist, André Thess. The model is based on the concept of pumped heat electricity storage (PHES). Renewable energy sources such as wind and solar do not produce energy at a constant rate and as a result engineers are developing large-scale energy-storage methods that can hold excess energy for use when the wind is not blowing or when the Sun is not shining. However, creating efficient storage systems is proving difficult. Today, two techniques are used: pumped hydro storage (PHS) and compressed-air energy storage (CAES). Both, however, can be very difficult to implement. PHS needs kilometre-sized, elevated water reservoirs containing nearly 10 million cubic metres of water, while the CAES method involves finding or creating huge underground caverns.

PHES, on the other hand, is much simpler – electricity from a source such as a solar or wind farm is used to run a heat pump. The pump heats water stored in a large tank (normally about 100,000 cubic metres in volume) and then, when needed, the heated water is sent to a heat engine and electricity is produced. A heat pump, rather than an electric heater, is used to heat the water because it makes the whole process much more efficient.

Thess points out that no large PHES system exists today and therefore the actual efficiency of such systems is still unknown. To overcome this, Thess has developed a simple thermodynamic model that can predict the efficiency of a PHES system as a function of the temperature

of the thermal energy storage at maximum output power. For example, a PHES system that heats water at 20°C to 60°C would have an efficiency of about 38%. Thess says that the efficiency could be increased by increasing the storage temperature – which would involve using storage fluids other than water. Thess's analysis suggests that for storage temperatures above 400°C, PHES would be more efficient than CAES. [André Thess, *Phys. Rev. Lett.* **111**, 110602 (2013)]

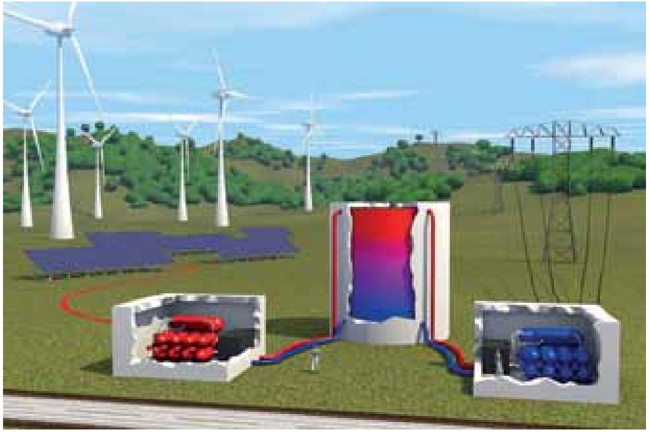


Illustration showing the PHES method in use

Extracted with permission from *physicsworld.com*

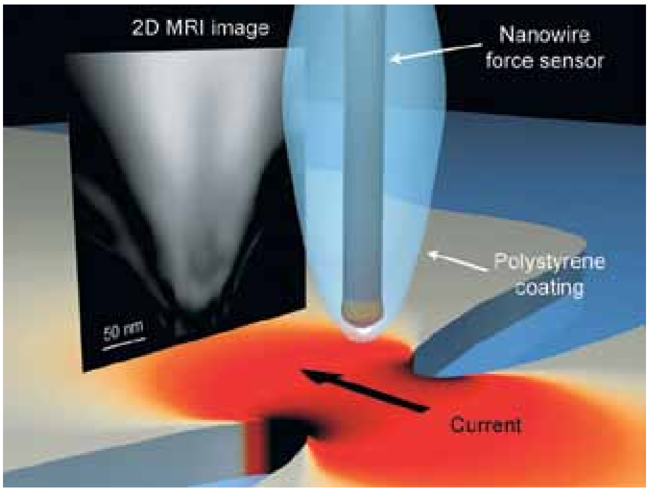
Magnetic resonance imaging done at the nanoscale

Magnetic resonance imaging (MRI) at spatial resolutions of just 10 nm has been achieved for the first time. Developed by researchers at the University of Illinois at Urbana-Champaign in the US, the technique could be particularly useful for imaging biological samples. If further improved, it could even be used to image viruses and protein macromolecules.

MRI, based on nuclear magnetic resonance (NMR), is a powerful tool that allows scientists to study the chemical composition of many different materials. This includes living tissue and as a result MRI has become a powerful diagnostic tool in medicine. The technique works by measuring the response of the nuclear magnetic moments of a sample to external magnetic fields and electromagnetic radiation. But because the individual nuclear moments are tiny, MRI signals from small samples are weak and can be easily swamped by noise. As a result it has proven to be difficult to do MRI at spatial resolutions of less than about 1 mm, except under special circumstances.

This latest work was done by Raffi Budakian and colleagues, who attached the sample to be analysed – a tiny piece of polystyrene – to the tip of a silicon nanowire mechanical resonator. This is a small plank of silicon roughly 15 μm long and 50 nm wide. They then place this nanowire over a metal constriction 240 nm wide and 100 nm thick. By passing high-frequency electric currents through the constriction, they are able to generate the intense magnetic fields needed to do MRI.

"Our near-term goal is to achieve even higher spatial resolution and begin imaging virus particles," adds Budakian. "We would ideally like to tomographically image virus particles in 3D and, with sufficient improvement, might even be able to image macromolecules such as proteins in the future." [J.M. Nichol, *Phys. Rev. X* **3**, 031016 (2013)]



How to do nanoscale MRI

Extracted with permission from *physicsworld.com*

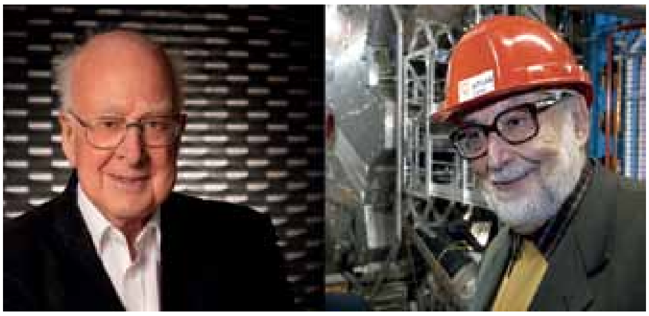
Nobel Prize for Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider.

In 1964, they proposed the theory independently of each other (Englert together with his now deceased colleague Robert Brout). The theory is a central part of the Standard Model of particle physics that describes how the world is constructed. According to the Standard Model, everything consists of just a few building blocks: matter particles. These particles are governed by forces mediated by force particles that make sure everything works as it should. The Standard Model also rests on the existence of a special kind of particle: the Higgs particle. This particle originates from an invisible field that fills up all space. It is from contact with this field that particles acquire mass. The theory proposed by Englert and Higgs describes this

process. On 4 July 2012, at the CERN laboratory for particle physics, the theory was confirmed by the discovery of a Higgs particle.

Even though it is a great achievement to have found the Higgs particle the Standard Model is not the final piece in the cosmic puzzle. One of the reasons for this is that the Standard Model treats neutrinos as being virtually massless, whereas recent studies show that they actually do have mass. Another reason is that the model only describes visible matter, which only accounts for one fifth of all matter in the cosmos. To find the mysterious dark matter is one of the objectives as scientists continue the chase of unknown particles at CERN.



Peter Higgs (left) and François Englert (right)

Extracted from *Nobelprize.org*

Quantum state endures for 39 minutes at room temperature

Quantum states have been shown to endure in a room-temperature solid-state device for a whopping 39 minutes, shattering the previous record of 2 s. The feat was achieved by physicists in Canada, the UK and Germany, who used phosphorus atoms in silicon as their quantum bits – or qubits. The breakthrough offers hope that normally fragile quantum states could be made robust enough to be used in practical quantum computers or even in "quantum money".

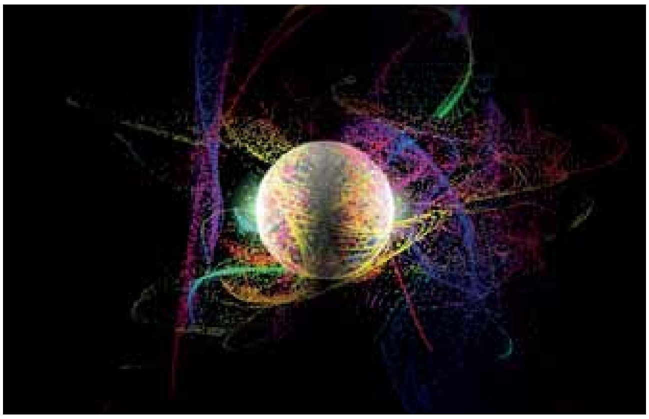
Quantum computers are designed to exploit the counterintuitive idea that tiny objects can exist in more than one state at the same time. Rather than processing bits – which are either 0 or 1 – such devices instead manipulate qubits, which can be 0 and 1 simultaneously. Vast numbers of operations could therefore, in principle, be carried out in parallel and rendering these devices far quicker than classical computers.

But anyone trying to build a working quantum computer has to deal with the fact that qubits tend to be incredibly fragile, which means the quantum information they hold is rapidly destroyed by external noise. One way of getting around this problem is to cool the qubit to near absolute zero to minimize its exposure to thermal noise. But working at such low temperatures is not particularly practical, which is why researchers are keen on find qubits that can operate at room temperature.

The new record-breaking system has been created by Mike Thewalt of Simon Fraser University and colleagues, by storing quantum information in the nuclear spins of phosphorous atoms in a silicon crystal. The idea of using these nuclear spins is not new and the system has already been shown to retain quantum information for long times at extremely low temperatures. But even at 10 K, this "coherence time" drops precipitously to just a few milliseconds.

To get around this problem, Thewalt and colleagues took advantage of the fact that phosphorous atoms in silicon at room temperature tend to give up their electrons and become positive ions. Removing the electrons eliminates an important link between the nuclear spins and surrounding electrical noise. Nuclear spins can therefore retain quantum information for much longer than those in neutral phosphorous. The downside is that removing the electrons makes the nuclear spins so well isolated that they cannot be "read" or "written" to. So to get around this problem, the team first cooled its crystal to 4.2 K and used laser and radio frequency (RF) pulses to put neutral phosphorous atoms into specific quantum states. A laser pulse then ionized the atoms before the crystal was warmed up to room temperature (298 K).

Under these conditions, RF pulses were used to perform a "spin echo" measurement of the coherence time, which was found to be 39 minutes. The crystal was then cooled back down to 4.2 K and another laser pulse was used to neutralize the phosphorus ions before the quantum information was read out using a sequence of laser and RF pulses. [K. Saeedi et al, Science, **342** 830-833 (2013); DOI: 10.1126/science.1239584]



Quantum state endures for 39 min.

Extracted with permission from *physicsworld.com*

Unpaired spins make graphene magnetic

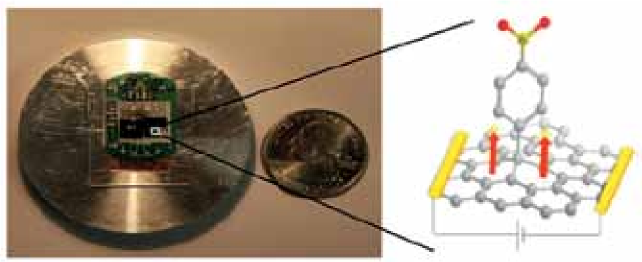
Researchers in the US have observed room-temperature ferromagnetism in a graphene nanostructure for the first time. The result, until now only predicted by theory, suggests that graphene could be used to create spintronics devices, which are circuits that use the spin of the electron to process and store information.

Graphene, a sheet of carbon just one atom thick, is a promising material for making molecular electronic devices of the future thanks to its unique electronic and mechanical properties. These include extremely high electrical and thermal conductivity plus exceptional mechanical strength. Room-temperature ferromagnetism can now be added to this already impressive list.

Sakhrat Khizroev at Florida International University and colleagues made their discovery by making a number of different measurements of the magnetic properties of graphene samples that had been functionalized with nitrophenyl (NP) groups. This involves the attachment of NP groups to the surface of grapheme (see figure). The resulting graphene-based material appears to become an organic molecular magnet with ferromagnetic and anti-ferromagnetic ordering that persists at temperatures above 400 K.

The researchers believe that the NP groups act to unpair electron spins at periodically spaced carbon sites along certain graphene orientations, known as 'armchair' and 'zigzag'. "It is the interactions between these unpaired spins that lead to the magnetic order observed. Graphene functionalized with hydrogen also appears to have similar magnetic properties.

According to the researchers, the NP-functionalized graphene could be used as a new type of single-layer magnet. It might also be used to make new types of spintronics devices based entirely on carbon that exploit the unpaired spins that are present. Spintronics is a relatively new technology that exploits the spin of an electron as well as its charge. [J.Hong et al, *ACS Nano* (2013), DOI: 10.1021/nn403939r]



Graphene-based molecular magnet

Extracted with permission from *physicsworld.com*

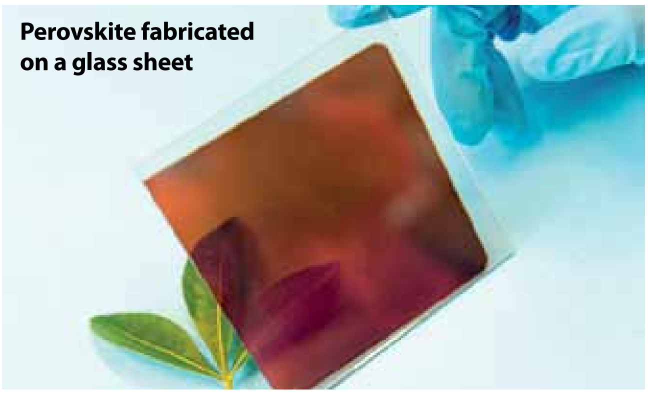
Ultrathin solar cell is efficient and easy to make

Researchers at the University of Oxford in the UK have made a thin-film solar cell with better than 15% light-conversion efficiency from an emergent class of semiconductors known as perovskites. The devices have a simple architecture and could easily be produced in large quantities because the vapour-deposition process used to make them is compatible with conventional processing methods for fabricating such solar cells.

Organometal trihalide perovskite semiconductors, which have the formula $(CH_3NH_3)PbX_3$ with X being iodine, bromine or chlorine, were first employed as the light-absorbing component in dye-sensitized solar cells in 2009. In these devices, the perovskites were coated onto the surface of a film made of titanium-dioxide (TiO_2) nanoparticles.

When the perovskite layer absorbs light, electrons and holes are generated. These charge carriers are subsequently transferred to different transport materials – TiO_2 for the electrons and to another material for the holes. The transport materials then carry the charges to separate electrodes and a voltage is produced. These solar cells have light-converting efficiencies of about 12–15% thanks to the large amount of perovskite packed into the TiO_2 film.

Now, two teams at Oxford led by Henry Snaith and Michael Johnston have joined forces to show that perovskites not only strongly absorb light, but also transport both electrons and holes. This new discovery means that the nanostructured architecture previously used in the dye-sensitized solar cells is no longer necessary, which simplifies the device structure greatly. Indeed, in the new device, the light-absorbing perovskites are simply sandwiched between electron- and hole-selective electrodes – a set-up that is, in fact, the same as that used in conventional planar solar cells. [M. Liu et al, Nature **501**, 395–398 (2013), doi:10.1038/nature12509]



Perovskite fabricated on a glass sheet

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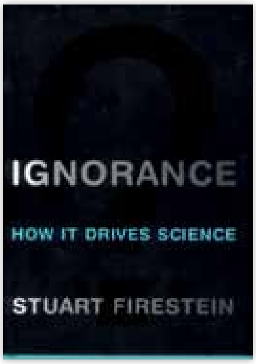
BOOK REVIEWS

Ignorance: How It Drives Science

by Stuart Firestein.
Oxford University Press Inc (2012), hardback, 208 pages
ISBN: 069115080X

Reviewed by Joanne Harrison, DSTO



The author is a neuroscientist who teaches a class called "Ignorance" at Columbia University. He talks in the beginning about the "contradiction between how science is pursued and how it is perceived". In essence: that science is perceived/portrayed as an orderly march towards a well-defined (and inevitable) goal, but that science is *pursued* in a way more akin to searching for a black cat in a dark room and there may not even be a cat (this analogy pops up frequently in the book).

The book is divided in to two sections. The first half is made up of what the author calls "musings with a point", the second half is made up of several case studies. I found the case studies interesting in parts, although the author probably should have stuck to material from his own field of expertise - the neurosciency one (about Parkinson's disease) was really good, the fundamental physics one not-so good.

The first half of the book left me in two minds. On the one hand – yes, science involves a lot of groping in the dark and it's not nearly as neat and tidy as media stories or journal articles or conference presentations would have you believe (but who cares?). On the other hand the message that what science *really* does is generate ignorance, not (or at least way more than) knowledge is (I think) a bad one. And a misleading one. It bothers me to think of this book in the hands of a science-denier. I can just picture such a person cherry-picking quotes from the book and gleefully declaring that "science is increasing our ignorance more than anything else – says so right here in this book, and this man is a *pee-aich-dee* in science!!!".

I'm left wondering if the (American) author was just deliberately trying to play to both sides. There's stuff to appease scientists (e.g. promoting the idea that curiosity-driven research *should* be funded), while simultaneously not rocking the science-denier boat. As far as I can tell, it's his first popular science book and pandering to science-deniers in the US is probably a smart move from a marketing perspective.

He says at the outset that the book is "largely written for non-scientists". It's difficult for me to judge whether a non-scientist would gain any insight about the real life practice of science by reading it. Maybe I'll give it to a non-scientist friend and see what they make of it. Perhaps it will give them a greater understanding and/or appreciation of science, which is what a good pop science book should do. It didn't do that for me, which is disappointing because I recommended this book to the AIP in the first place (d'oh!). It does have some interesting bits, and I did learn some stuff, but overall I would say that the text didn't live up to the (what I now see as gimmicky) title.

Tweeting the Universe: Tiny Explanations of Very Big Ideas

Marcus Chown and Govert Schilling
Faber and Faber (2011), hardback, 320 pages
ISBN 978-0-571-27843-5

Reviewed by Helen Maynard-Casely, ANSTO.

To understand this book it's probably a good start to understand what the phenomenon of Twitter itself actually is. Started in 2006, it's a social media site where users communicate through 'tweets', messages of 140 characters or less. It's this brevity that has been key to the success of this website, and the format lends itself well to a number of spheres – including talking about physics. Tweets are broadcast through a user's twitter handle (@ username) which also enables other members of the site to direct their conversations. The growth of twitter has been astonishing, and now perhaps is one of the most popular channels for the spread of ideas and conversations.

This book was conceived by Netherland's based Astronomy writer Govert Schilling, who had been answering questions about the mysteries of the universe through the twitter format every Friday night. Distilling his ideas into 15 tweets on a question posed by readers, followers of Schilling's twitter feed (@GovertTweets) undertook a short course in Astronomy every week in Dutch. As interest in the project grew, Schilling teamed up with Marus Chown (@MarcusChown - author of amongst other things *Quantum Theory Cannot Hurt You)* to produce and expand upon these tweets into a book in English.

The book is divided into topic sections ranging from 'The Sky' to 'Life in the Universe' and within these broad topics questions are posed from 'Why does the moon not

fall down' to 'What are galaxies'. Each of the questions are answered by up to fifteen 140 character tweets, mini paragraphs of very condensed information.

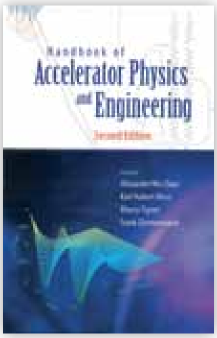
So as a book it's perhaps a little disjointed, and the overall affect is perhaps closer to a science poetry book than any other non-fiction book I have read. The authors seem to embrace this, with some of the questions answered in a very lyrical style. Of the possibility of our sun becoming a white dwarf we are told 'A white dwarf is about the size Earth (sugar cube of its matter heavy family car). It's stellar ember, cooling & fading into invisibility.' And in explaining how astronomers untwinkle the stars they set the problem with 'Result: stars twinkle, jitter, sparkle and may even appear to change colour. Nice for romantic lovers; disastrous for astronomers'.

Who would you buy this book for? Yourself if you were interested in what can be accomplished in explaining physical phenomena in 140 characters. Or, if you wanted a repository of terrifyingly elegant and simple sentences for forming your own explanations of the universe, this could also be the book for you. It could be purchased for a budding physicist, the concise and engaging format enough to capture the attention of even the most distracted of minds. But this latter recommendation comes with a warning. Perhaps the thing the book is most lacking of (surprising given the brevity of the format) is links and suggestions to further reading. So beware, give this book to an aspiring scientist and you may yourself be bombarded with questions!

Handbook of Accelerator Physics and Engineering, Second Edition

Edited by Alexander Wu Chao, Karl Hubert Mess, Maury Tigner and Frank Zimmermann
World Scientific (2013), paperback, 802 pages
ISBN 978-981-4417-17-4

Review by Mark J Boland, Australian Synchrotron



To say that the particle accelerators at the Australian Synchrotron were commissioned using the *Handbook of Accelerator Physics and Engineering* would be an exaggeration but it was extremely useful nonetheless. This second edition, published fourteen years after the first edition, has added two new editors from CERN in Europe to compliment the original two who work in the USA and are still active in the field and continue as editors of this volume. Perhaps this is by coincidence but it almost feels like a tipping of the hat by the Americans, who for a long time dominated accelerator physics, to the Europeans, who now operate the World's largest and most powerful particle accelerator: the Large Hadron Collider (LHC).

Coming back to the first point, the young Australian members of the team who commissioned the electron accelerators (the 100 MeV linac, the 0.1-3 GeV booster synchrotron and the 3 GeV storage ring) at the Australian Synchrotron from 2003 to 2007 did make wide use of "the handbook". One of the reasons that it was so handy is that the physics is presented in a compact form with the essential formulas for a back of the envelope calculation, followed by a detailed list of references to get the complete picture and to do further reading if required. In fact, turn to almost any two page spread in the handbook and you will find a dozen or more references in the two-column per page format. Moreover a great number of the references are from open access sources since they are often contained in technical reports from the major laboratories around the world or in the extensive proceedings from the particle accelerator conferences which date back to the 1960s. Indeed these open access proceedings are the preferred method of publishing and sharing of findings in the accelerator physics community, much to the chagrin of those counting H-index and impact factors.

One of the problems with publishing in the field of particle accelerators is revealed by the title of the handbook, which rightly includes the word engineering. To a university physics department it often looks like engineering while the engineering department says to work with accelerators one needs to know about electrodynamics and special relativity, so clearly it is physics! The handbook has a nice balance between the fundamental physics, the computer simulations and the practical engineering required to design, build and optimise all the components of just about any type of particle accelerator you can imagine.

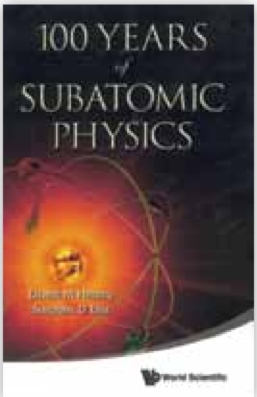
The overarching impression one is left with having worked with or even just picked up a copy of the *Handbook of Accelerator Physics and Engineering* is the staggeringly comprehensive breadth of the topics covered in just eight chapters and just over eight hundred pages. A valid criticism of the handbook might be the mixture of the CGS and MSK units and a general lack of clarity of the use of the variables in the equation notation, however this is perhaps to be expected with over two hundred authors covering so much ground. While dining with one

of the editors recently I questioned him on this point and there is some effort to try to stick to MKS units in the future. Possibly with the addition of two new editors this may become a reality for future editions. In the meantime, the handbook continues to be an outstanding reference and provides almost all the answers and clues for anyone working with particle accelerators, be they medical, nuclear, high energy colliders or synchrotron radiation light sources.

100 Years of Subatomic Physics

Edited by Ernest M Henley and Stephen D Ellis
World Scientific (2013), paperback, 560 pages
ISBN: 9789814425803

Reviewed by Lee Weissel, Trinity Anglican College



The contributors to this collection of essays. are renowned physicists writing authoritatively about subatomic physics, their field of expertise. This book is dedicated to the 100th anniversary of Rutherford's model of the atom — one of the most important foundations of modern physics. Authors include S Weinberg, L McLerran, K Hagino, G Garvey, U G Meissner, L Wolfenstein, J Schwarz, C. Tully and other world renowned physicists.

The extensive area of work to be covered, is divided into two sections; nuclear physics and particle physics. Beginning with Rutherford and his work, the first essay, written by Steven Weinberg, quickly brings the reader up to date with the major themes of the last century and their relationship with one another. Weinberg demonstrates his ability to very ably take large ideas and compress them into snapshots in history. This sets the tone for the rest of the work. The science of the early years of nuclear physics is more fully filled out by the editors, before moving into mass measurements and models, symmetries, fission and other topics to complete the picture. The reader quickly is given the picture how from the very early, and indeed mysterious beginnings, nuclear physics has diversified into an impressive array of subfields of physics with strong connections to astrophysics and cosmology. The final works on chiral symmetry and exotic nuclei and the reflections from their authors show some of the promising areas of research yet to happen.

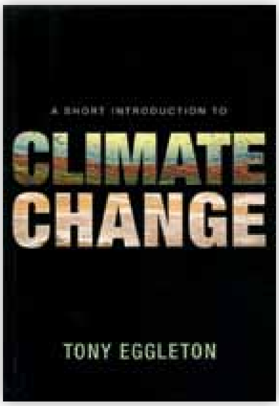
The second section of the book, focused on particle physics, begins with another historical overview, describing the construction and purpose of colliders. A lot of material is covered, but in an easily accessible way. Andreas Kronfeld in *Lattice Gauge Theory* and the *Origin of Mass*, mentions the 'recent observation of a Higgs-like particle' before proceeding to discuss the lattice gauge theory. Digging deeper into particle research the reader is shown a wide range of topics, and each discusses very ably what it contributes to our overall understanding of matter. Knowing, and being familiar with the Standard Model of Matter is very helpful, and the discussions move quite quickly to the forefront of current research. The referencing for each essay is done extremely well, with the texts and papers cited being easily accessible. The final paper in this work takes the reader into the heart of current understanding with String–Theory and M-Theory. The paper's author John Schwarz helpfully navigates this field well, explaining each point as the reader works their way through this up-to date presentation.

Difficulties in following certain parts of the work can be attributed to the passion of the authors. Their papers can assume previous and deep knowledge in their particular area of focus, reflecting the interests of the author and leaving the reader wanting other material filled in. Nevertheless, each essay's overall breadth and understanding are impressive, and the separate chapters combine to make this work an unprecedented survey of sub-atomic physics research spanning the last 100 years, with insights into where it might head in the century to come.

A Short Introduction to Climate Science

By Tony Eggleton
Cambridge University Press (2013), paperback, 246 pages
ISBN 978-1-107-61876-3

Reviewed by Emeritus Professor Paul Edwards, University of Canberra.



Geologist Tony Eggleton wrote this introduction to climate change in response to a query from a non-scientific friend, concerned by a website that proclaimed global warming to be a fallacy. My reason for reading his book is similar: I was asked for my opinion of the arguments advanced against anthropogenic global warming (AGW) by another geologist, prominent cli-

mate change sceptic, Professor Bob Carter, in his recently published book, *Taxing Air*. Eggleton takes issue with both Carter and another sceptical geologist, Ian Plimer, in Chapter 11 of this book (*Denial*).

Until put on the spot I had accepted without question the conventional wisdom on climate change as reported by the IPCC, the Intergovernmental Panel on Climate Change. Like many of us I suppose, I took the science for granted and assumed that climate change sceptics were simply ignorant of the science and of the scientific method. After all, I knew something about the greenhouse effect myself after lecturing and researching atmospheric physics and radiative transfer related topics for many years!

To my surprise, I found myself taking a much more critical view of the science of climate change after reading this book. My epiphany actually came rather late in the book, in Chapter 12, where the hotly debated issue of the "climate sensitivity" of carbon dioxide is finally aired. This is usually expressed as the change in global surface temperature forced by a doubling of the CO_2 concentration, from its pre-industrial value of 278 ppm to 556 ppm. (It is currently over 390 ppm at Cape Grim, increasing by about 2 ppm per year).

In quoting estimates ranging over more than an order of magnitude, from 0.7 °C to 8 °C, Eggleton states the obvious: "the value is not yet well known". Even the IPCC's 2007 assessment of a mean of 3 °C, hedged in a tighter range from 2 to 4.5 °C, did not abate my surprise at the large uncertainty.

Physicist Garth Paltridge clarified the issue for me in his elegantly written little volume, *The Climate Caper*. He points out that while the generally accepted open loop sensitivity is close to 1.2 °C, the large uncertainty in the closed loop sensitivity arises from the spread in loop gains used to characterise the various positive (& negative) climatic feedback processes invoked to model future climate. Evidently the responses to temperature change of atmospheric water vapour, cloud, surface albedo and lapse rate remain to be quantified more precisely.

Other uncertainties, briefly touched on in Eggleton's book, relate to the direct & indirect effects of solar activity, likely to be revisited in the 5th IPCC report to be released in September this year (this review was written before the release - Ed).

Discussion of greenhouse mechanisms is postponed until Chapter 4 (*The Thermostat*). The blanketing role of the greenhouse gases, water vapour, carbon dioxide & methane in warming the planetary surface is outlined for the non-scientific reader, although probably not adequately for many physicists. For example, an early controversy regarding radiative heat transport in the optically thick 15 micron carbon dioxide infra-red absorption band is glossed over, a missed opportunity to clarify an important conceptual issue. Also, in the *Greenhouse Gases* section of this chapter, the logarithmic dependence of surface warming on CO_2 content is mistakenly attributed to the Beer-Lambert Law which is itself incorrectly stated.

In summary, this book is a useful introduction to climate change and climate science for the general reader. However, to my mind it is not a particularly convincing refutation of the AGW sceptics' position for those with an interest in the physics underlying the uncertain science of climate change.

PRODUCT NEWS

COHERENT
New Nd:YAG laser with automated phase-matching

Quantel has released the new Q-Smart 850, a high-energy Nd:YAG laser delivering 850mJ pulses at 1064 nm and 10 Hz repetition rate. A full range of harmonic options is available including 532 nm , 355 nm, 266 nm and 213 nm.

Q-Smart builds on the success of the earlier Brilliant B laser which featured compact design, modular harmonics and excellent beam properties. The new laser is even easier to use as a result of the new Q-touch interface and completely automated optimisation of harmonics phase-matching. Changing wavelengths and tuning of harmonics is straightforward and can be completed in a matter of minutes.

Q-Smart is compact and highly portable, with easy disconnect of the laser head from the electronics when required. The laser includes a comprehensive 2-year warranty and flashlamp lifetime of 100 million shots.

Low-cost fluorescence lifetime spectrometer

Edinburgh Instruments' mini-τ (Mini-Tau) is an ultra-compact filter-based fluorescence lifetime spectrometer designed to familiarise students with the principles of fluorescence lifetime spectroscopy and in particular time correlated single photon counting (TCSPC).

The mini-τ provides an insight into the applications of fluorescence lifetimes and time-resolved fluorescence anisotropy and introduces students to TCSPC as a simple, fast and straightforward data acquisition technology.

Edinburgh's T900 advanced software has an easy-to-use graphical user interface that enables students to take measurements easily and watch their profiles build live on screen. Mini-τ can recover fluorescence lifetimes between ~50ps and 50us and utilising comprehensive data analysis software based on the established Marquardt-Levenberg algorithm, the software can accurately analyse complex decay kinetics with up to 4 lifetimes

This teaching spectrometer can help your students to explore novel, highly sensitive and highly selective techniques that they are likely to encounter in their future careers.

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

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LASTEK
Toptica DL pro HP; tune up your visible power!

The DL pro HP features a special resonator design, allowing for higher single-mode output powers from diode lasers in the visible region. Manual coarse tuning (~1-6 nm) is available over the gain spectrum of the incorporated diode and the systems have a typical mode-hop free tuning range of 20-50 GHz.

Standard models are available at 405, 425 and 633 nm, however other wavelengths between 370 and 640 nm can be provided upon special request. Optical isolation is included with the system for fibre coupling purposes and a wide range of control electronics can be utilised with the DL pro HP range.

Toptica has been successful in establishing itself as a provider of reliable, tunable, single-frequency lasers and now the product range expands with the DL pro HP, outperforming in power while providing a large tuning range and narrow linewidth.

- Up to 100 mW single frequency, tunable output
- Standard wavelengths: 405, 425, 633 nm
- Other wavelengths on request
- Extremely stable, low drift
- Linewidth <2 MHz

Horiba H20-UVL, Vacuum UV Monochromator

The H20-UVL is a monochromator especially designed for analysing 100-400 nm (3 to 12.4 eV) Vacuum Ultraviolet (VUV) range under vacuum, or 190-400 nm at atmospheric pressure. Its micrometric slits and its worm drive make its scans precise and fast. This short focal length vacuum monochromator is ideal for lighting samples if coupled with a VUV light source or for VUV low

resolution analysis when equipped with single channel detection.

Based on HORIBA Jobin Yvon's patented technology, the H20-UVL series is built around a single spherical holographic grating aberration corrected. Its 64° deviation angle makes this monochromator perfectly optimized in VUV range.

This simple optical design dramatically reduces astigmatism and results in excellent luminosity and spectral purity, even below 140 nm, where other instruments based on the Czerny Turner design loose their efficiency because of the number of internal reflections.

Features

- Single Grating design
- Type IV Grating
- MgF_2 coating UV optimized
- Low Astigmatism level
- High Vacuum compatible
- Automate drive
- Build-in USB2 interfaces
- HJY Slit Attachment

The first ever USB 3.0 Beam Profiling Camera from Gentec-EO

Gentec Electro-Optics and Lastek, are proud to launch the Beamage 3.0, the very first USB 3.0 camera dedicated to Laser Beam Profiling. This new CMOS-based camera comes with a completely redesigned software that features both a highly intuitive user interface and powerful data analysis tools. The USB 3.0 interface of the new Beamage 3.0 camera features a data transfer rate up to 10X faster than any USB 2.0 system. This incredible speed allows for much faster data transfer rates, up to 10 fps at 1 MPixels. USB 3.0 also features an improved communication architecture that reduces both data transmission latency and power consumption.

Thanks to its unique combination of high pixel density (2.2 MPixels) and large sensor size (11.3 x 6.0 mm), the Beamage 3.0 has the double advantage of accurately characterising both very small beams of only a few tens of microns to larger beams of several mm in width, thus effectively covering most applications in one device.

Completely redesigned software takes full advantage of today's best development tools. The simple interface is highly intuitive and yet comprises many useful functions, like Background Subtraction, Animation Tool, Signal Normalization, Filtering and Averaging Functions, External Triggering, Active Area Definition, Gaussian Fit and more.

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

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T: +61 8 8443 8668 ; F: +61 8 8443 8427
web: www.lastek.com.au

WARSASH SCIENTIFIC
508 PV™ UV-Vis-NIR Spectrophotometer

The 508 Perfect Vision™ from CRAIC Technologies is designed to be added to an open photoport of a microscope or probe station so that you can non-destructively analyse the spectra of many types of microscopic samples. It can acquire spectra by absorbance, reflectance, polarisation, luminescence and fluorescence, in addition to high-resolution colour images.

Numerous applications include characterisation of new materials, measurement of surface plasmon resonance, graphene, vitrinite reflectance of coal and high resolution colorimetric and relative intensity mapping of flat panel displays. Thin film thickness of microscopic areas can also be measured. Combined with suitable Traceable Standards, the 508 PV spectrophotometer is a cost-effective, micro-analysis tool for any laboratory or manufacturing facility.

Integrating Lightblades spectrophotometer (specifically designed for microscale analysis) with a sophisticated optical interface hardware and powerful, easy-to-use software, this new level of sensitivity and stability provides a flexible instrument that is custom designed to add to a microscope photoport and rapidly acquire high quality spectra from microscopic samples.

Sophisticated software, high resolution imaging, permanently calibrated variable apertures and other innovations yield a new level of sophistication for microanalysis.

New PI Range of Nanopositioning Systems

The new PI product line of P-630 stages have large clear aperture, high control dynamics, fast settling times and compact dimensions. They are perfectly suited for use in

sensor heads or precision motion of objects in optical and tactile metrology as well as for microstructuring.

With travel ranges up to 80 µm and a direct piezo actuator drive, the compact positioning stages reach high scanning frequencies and settling times of only a few milliseconds. At a width of only 50 mm, their clear aperture is relatively large with a diameter of 30 mm.

The drive technology of the highly dynamic piezo nanopositioning systems is based on all-ceramic insulated PICMA® piezo actuators. They have a proven longer lifetime and higher reliability than conventional polymer-insulated actuators.

The P-630 stages achieve nanometer-precise positioning accuracy and stability by using an integrated capacitive position sensor.

Optimum control properties are ensured via the high performance single-channel E-709.CHG Motion Controller. Its digital technology allows for refined linearization algorithms to improve accuracy; the operating parameters can easily be optimised via software.

Ultra-Compact 561 nm and 532 nm DPSS Lasers

Cobolt DPL™ lasers, ultra-compact SLM DPSS lasers at 532 nm and 561 nm are an extension to the 06-01 Series. The Series offers a wide wavelength span in a plug and play format and utilises the most ideal laser technology to achieve the wavelength whilst maintaining the form factor.

The technology is based on a diode-pumped solid-state laser offering optimum beam quality and excellent performance. Manufacturing using unique HTCure™ Technology ensures world-class quality reliability and lifetime and unmatched robustness.

Key Features

- Ultra-compact SLM yellow or green DPSS laser
- CW output power up to 50 mW at 561 nm
- CW output power up to 100 mW at 532 nm
- Fully integrated control electronics
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sales@warsash.com.au
www.warsash.com.au

Conferences 2013-14

2-6 February 2014
23rd Australian Conference on Microscopy and Microanalysis (ACMM23) and the International Conference on Nanoscience and Nanotechnology (ICONN 2014). Adelaide, SA
http://www.aomevents.com/ACMMICONN

4–7 February 2014
38th Annual Condensed Matter and Materials Meeting
Auckland, New Zealand
http://www.aip.org.au/info/?q=content/condensed-matter-materials-group-cmm

9-12 February 2014
Gaseous Electronics Meeting XVIII
Victor Harbour, SA
http://www.unisa.edu.au/IT-Engineering-and-the-Environment/Division-Information-Technology-Engineering-and-the-Environment/Gem-XVIII---Australia/

14 February 2014,
2014 VCE Physics Teachers Conference
La Trobe University, Victoria
http://www.sciencevictoria.com.au/confVCE.html

8–9 May 2014
Solar 2014 Conference and Expo
Melbourne Convention and Exhibition Centre
http://solarexhibition.com.au

20-21 May 2014
CRC Association National Conference: Innovating with Asia 2014
Perth, WA
http://conference.crca.asn.au

6 July 2014
19th OptoElectronics and Communications Conference/39th Australian Conference on Optical Fibre Technology (OECC/ACOFT 2014)
Melbourne Convention and Exhibition Centre, Vic
http://www.oecc-acoft-2014.org/

20-25 July 2014
6th Pacific Rim Conference on Rheology
The University of Melbourne
http://www.pacrimrheology.com/

21-26 September 2014
Joint International Conference on Hyperfine Interactions and Symposium on Nuclear Quadrupole Interactions 2014, Academy of Sciences, Canberra
http://www.hfinqi.consec.com.au/

2-5 December 2014
OSA Optics and Photonics Congress on Light, Energy and the Environment (LEE) ANU, Canberra
www.osa.org/energyOPC

7-11 December 2014
21st Australian Institute of Physics Congress. ANU, Canberra, ACT
http://aip2014.org.au

8-12 February 2015
AMN7 Advanced materials & Nanotechnology
Nelson, New Zealand
http://www.amn-7.com

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