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Cover
Superconductivity at liquid-nitrogen temperature where three tiny household magnets, joined by wooden toothpicks, levitate over a dish filled with yttrium–barium–copper oxide pellets cooled by liquid nitrogen. This illustration of the Meissner effect — the expulsion of magnetic flux from superconductors — has become the basic test for true superconductivity. [courtesy: Pamela Patterson and Lawrence Berkeley National Laboratory]

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EDITORIAL

Congratulations to Brian Schmidt

We were finalising the corrections to this issue when we heard the fantastic news that Brian Schmidt has been awarded the 2011 Nobel Prize for Physics. Unfortunately the production of this issue is too far advanced to do justice to Brian’s achievement. However, there is no need to guess what our cover story will be for our next issue!

In a previous issue we celebrated the centenary of the discovery of the atomic nucleus by Ernest Rutherford and his group at Manchester. As noted, the significance of Rutherford’s discovery was not properly appreciated at the time and no special awards came his way. There was another discovery made in 1911 of almost equal importance – superconductivity by Kamerlingh Onnes at the University of Leiden. However, as explained by Mukunda Das (ANU) in his review article on page 137, the importance of Onnes discovery was recognised immediately and he was awarded the Nobel Prize for Physics just two years later.

In our second article, Rob Short and colleagues at UniSA explore how the physics and chemistry of plasmas are closely intertwined. The third article by Chris Blake (Swinburne) ties in nicely with the work of Brian Schmidt. It describes current progress on the curiously named WiggleZ survey, which has used the Australian Astronomical Telescope to measure the redshifts of thousands of galaxies. The survey is attempting to identify small variations or ‘wiggles’ in the distribution of galaxy redshift $Z$ to provide a clue as to the nature of dark energy; hence the name.

The primary purpose of Australian Physics magazine is to enable the AIP to promote physics in Australia and to communicate with its members. However, our institutional subscribers are also very important to us. We have only a handful of international subscribers but, what is worse, less than a half of physics libraries in Australian universities and government labs have a current subscription to the magazine.

This is a lamentable statistic. Every physicist across the country should have easy access to their national magazine, regardless of whether or not they are AIP members. How can we recruit new AIP members if they are not aware of our magazine?

This month we are starting a subscription drive to increase the number of institutional subscribers. You can help by checking whether your library has a current subscription. If not, could you help by talking to your librarian or head of department?

Peter Robertson
PRESIDENT’S COLUMN

Strategic Roadmap for Australian Research Infrastructure

Just as this issue was about to go to press we received the wonderful news that Brian Schmidt from the Research School for Astronomy and Astrophysics at the ANU has shared the 2011 Nobel Prize for Physics for the discovery of the accelerating expansion of the universe. As a result of this discovery 75% of the universe, that was previously unknown, is made up of what is now called dark energy. The current Women in Physics national lecture tour by Tamara Davis and the WiggleZ article in this issue are thus very timely. On behalf of the AIP I congratulate Brian on his outstanding achievement. He is a worthy Nobel Laureate and will be a superb ambassador for Australian science.

Earlier this year I wrote, on behalf of the AIP, to Senator Carr (Minister for Innovation, Industry, Science and Research) expressing deep concern regarding the demise of the International Science Linkages Program activities, and particularly the Access to Major Research Facilities Program (AMRFP), as a result of the cessation of funding for the program in the May budget. The AMRFP has been a tremendous success for Australia, enabling our researchers to maintain effective contact with and involvement in the major world-leading scientific activities in a very cost-effective way. It enabled Australian researchers to engage in activities at major accelerators, like those at CERN in Geneva, in major fusion experiments overseas and at major astronomical facilities. AMRFP was extremely important in assisting our graduate students to gain access to international activities as an integral part of their training.

Indeed AMRFP was the envy of other similar-sized countries that are seeking to pursue competitive research.

All of these activities had been supported, for very modest cost through travel and accommodation funding, to undertake those experiments or observations that cannot be made domestically. The proposals had been through international peer-review at least as stringent as that applied at home. This had clearly been a very cost effective use of research funding.

Senator Carr replied indicating that the Government was not planning a replacement program for the AMRFP due to “the current tight fiscal constraints”, but that he was “committed to ensuring that Australian researchers continue to engage with the global scientific community”. He noted that his Department was developing a Strategic Roadmap for Australian Research Infrastructure and he believed “that Australia needs a long term strategy for coordinated access to major research infrastructure, both in Australia and internationally” and he encouraged the AIP to engage in the Roadmap process.

On 30 September the Minister announced the release of the Roadmap. I only had time to scan the report before writing this column, but noted a number of items of significance to the Physics community. There is expected support for the SKA but also support for the Synchrotron, the Opal reactor and space science. However, the document just sets guidelines for priorities without any commitment of funding levels and relies heavily on documents that preceded it, including discipline decadal plans and the Government’s own Strategic Framework for Research Infrastructure Investment.

I was disappointed to find virtually no reference to funding for access to major facilities that could replace the AMRFP. Under the astronomy section there is a statement that “research funding programs, as opposed to research infrastructure programs, should consider requests for funding individual Australian researchers’ access to overseas facilities”. This funding model does not take into account that granting of access to international facilities doesn’t sit well with Australian funding cycles and is often on a shorter timescale. Furthermore funds will not be available to researchers who normally don’t have access to these national funding schemes. Later in the Roadmap, when discussing the Australian Synchrotron, there is a very weak statement: “In addition, further support for Australian researchers to access international synchrotrons should be considered”, which promises nothing.

Clearly the Roadmap needs to be read thoroughly, but my initial reaction is one of disappointment about the lack of direction regarding funding of access to international facilities.

Marc Duldig
We know you receive *Australian Physics* magazine —but does your Department? Here are six good reasons why it should…

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SKA project unveils site selection process

The Founding Board of the Square Kilometre Array telescope project reported at the SKA Forum 2011 — held in Banff, Canada in early July — that significant progress has been made on the process and timeline for selection of the host site for the telescope. The SKA Forum brought together scientists, industrialists, policy makers and representatives of government departments and funding agencies who have joined forces to advance the multi-faceted implementation plan for the SKA.

The SKA is a €1.5 billion global science project to build the world’s largest and most sensitive radio telescope. Sites in South Africa and Australia have been short-listed to host the central core of the SKA telescope. A final decision on the location is expected to be made in early 2012 by the SKA Board of Directors.

The technical assessment and evaluation phase of the site selection process is being overseen by the SKA Siting Group (SSG), which reports to the SKA Founding Board. The first step in this phase is information gathering where the candidate sites will make submissions covering:

- Science and technical factors
- Other factors including legal, customs and security
- Plans and costs of implementing infrastructure, including power supply and distribution.

The SKA Site Advisory Committee (SSAC) of independent experts will make a recommendation on the preferred site based on reports from expert panels and consultants together with the submissions from the candidate sites. The SKA Board of Directors is expected to make the final site decision in early 2012.

Professor Richard Schilizzi, Director of the SKA, said: “Selection of the host site for the SKA will be made in terms of characteristics for the best science as well as the capability and cost of supporting a very large infrastructure, taking the political and working

ARC announces Laureate Fellowships

Four of the 17 Laureate Fellowships announced recently by the Australian Research Council were awarded in physics, space science and astronomy. The prestigious awards provide funding over the period 2011–16 and in most cases are worth approximately $2.5 million over the life of the project.

Mahandanda Dasgupta (Australian National University) was awarded the inaugural Georgina Sweet Australian Laureate Fellowship for science and technology. She is an experimental physicist in accelerator-based nuclear fusion and fission. Her project will develop new Australian capabilities to understand quantum interactions. Nanda was recently appointed a fellow of the Australian Academy of Science [see AP 47(6), 135 (2010)].

Two of the Laureate Fellowships were awarded to astronomers. Martin Asplund is a director at the Max Planck Institute for Astrophysics in Germany, who also holds an appointment at the ANU. His project aims to unravel the history of the Milky Way galaxy and discover how planets form around stars.

The project lead by Stuart Wyithe (University of Melbourne) will make a comprehensive study of the formation of the first galaxies, and provide answers to the questions of how and when the first generation of galaxies formed, and what they looked like.

Philip Bland is at Imperial College, London and is an adjunct in geology at Curtin University. His project will study meteorites and reveal new information on how the solar system was formed.
environment into account.”

Selection factors that will be considered in the decision-making process include levels of radio frequency interference, the long-term sustainability of a radio quiet zone, the physical characteristics of the site, data network connectivity across the vast distances covered by the telescope as well as operating and infrastructure costs.

The site selection timeline and process will be:
- Mar–Sept 2011: The candidate sites submit information to the SKA head office (SPDO)
- July–Nov 2011: The submitted information is analysed by independent consultants, expert panels and the SPDO
- Nov–Dec 2011: The SSAC of independent experts evaluates the findings of the analysis and recommends a preferred site
- Jan–Feb 2012: The SKA Board of Directors receives the final report and recommendation
- Late Feb 2012: The SKA Board of Directors makes the site decision.

In April nine national government and research organisations signed a ‘Letter of Intent’ in Rome. The organisations from Australia, China, France, Germany, Italy, The Netherlands, New Zealand, South Africa and the UK declared their common ambition to see the SKA built, and agreed to work together to secure funding for the next phase of the SKA project.

**ANU plasma thruster set for blast off**

The ANU has won a $3.1 million grant from the Federal Government to help propel Australian satellite technology and exploratory missions into the furthest reaches of deep space. The ANU will partner with national and international bodies to make a revolutionary plasma thruster engine, invented and developed at the ANU, ready for spaceflight. If successful, the engine could be used in satellites and deep space missions as soon as 2013.

Project leader Professor Rod Boswell, from the Plasma Research Laboratory, said the engine will be based on the helicon double-layer thruster (HDLT), developed by colleague Professor Christine Charles. “The HDLT is the first thruster of its kind in the world and can be used to keep satellites in their desired orbit, as well as in interplanetary travel. It is an elegant, almost fuel-independent, as well as energy and cost effective, propulsion system.”

Boswell added: “Plasma thruster engines are set to be the future of all space exploration and satellite activities. They have characteristics that will eventually lead to their wide deployment as space propulsion systems. They are much less powerful than conventional chemical rocket engines, but in principle are more efficient, for long periods of time, making them ideal for deep space missions. In the long term, the development of plasma thruster technology will extend the range of human as well as robotic exploration into the solar system and beyond.”

The grant won by Boswell and colleagues in the Plasma Research Laboratory will also help build a Space Simulation Facility at the ANU. Based at the Mt Stromlo Observatory in Canberra, the facility will incorporate a thermal–vacuum device which will enable testing of the HDLT and other satellites in space-like conditions.

The facility will also be made available to other scientists, astronomers and industry bodies seeking to develop space equipment. The grant to the ANU forms part of a $6.1 million investment in space research and education announced last month by Innovation Minister, Senator Kim Carr.
SUPERCONDUCTIVITY:
One Hundred Years of Discovery

Mukunda P. Das

Superconductivity is an unanticipated phenomenon and its hundred-year history is a fascinating subject in physical science. The fact that certain materials below a critical temperature lose their electrical resistance and repel a magnet remained a miracle until a microscopic explanation became available in 1957. In this pedagogic article we present a brief overview of the important landmarks and major advances in this exciting and difficult area of research.

Influenced by Lord Kelvin’s zeroth law of thermodynamics and J. D. Van der Waals’ equation of state, on 10 July 1908 Heike Kamerlingh Onnes at Leiden succeeded in liquefying helium at a record low temperature of 4.2 K, at ambient pressure. Until then the normal electrical resistance of metals had always shown a linear relation to temperature. Onnes believed that, at extremely low temperature, resistance would follow one of three trends:
(i) \( R(T) \rightarrow 0 \) as \( T \rightarrow 0 \); (ii) \( R(T) \rightarrow \) constant (residual resistance) as \( T \rightarrow 0 \); or (iii) \( R(T) \) may have a resistance minimum as \( T \) decreases.

Onnes chose mercury, a liquid metal that he could purify up to 99.99%. Contrary to the above suggestions, Onnes and his assistant Gilles Holst (see Fig. 1), on 8 April 1911, discovered that the resistance of Hg abruptly drops to zero at \( T_c = 4.18 \) K to within some hundredth of a degree (Fig. 2). This was the birth of superconductivity. In 1913 Onnes also noted the reappearance of electrical resistance (below \( T_c \)), when a magnetic field is applied above a threshold value, implying that superconductivity and magnetism are mutually related.

During the following four decades, most of the important quantum physicists put their mind to explaining the miracle of superconductivity. The list includes Albert Einstein, Niels Bohr, Werner Heisenberg, Wolfgang Pauli, Felix Bloch and Richard Feynman. Unfortunately, all their ideas and attempts failed to make any dent on the microscopic mechanism towards understanding the phenomenon of superconductivity. Fig. 3 presents the path of discovery of superconductivity over the past 100 years.

![Fig. 1. Heike Kamerlingh Onnes and his assistant Gilles Holst [courtesy: AIP Emilio Segre Visual Archives].](image-url)
years, in terms of the critical temperature $T_c$ measured over time.

**A brief history**

In 1913 Onnes received the Nobel Prize in Physics “for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium.” In his Nobel lecture Onnes mentioned the 1911 discovery of superconductivity as a novel phenomenon which by then he had observed in Hg, Pb, Nb and some other metals. In 1933 Walther Meissner and Robert Ochsenfeld at Berlin reported that any applied magnetic field (below a critical field $H_c$) is totally expelled by the superconductor kept below its superconducting transition temperature $T_c$. This observation radically changed the view of superconductors. Not only are they resistance-less (ideal) metals; at the same time they are also perfect diamagnets (with magnetic susceptibility $\chi < 0$). Fig. 4 shows this in stark form, the levitation of a magnet above a superconductor below its $T_c$.

The twin results of perfect conduction and perfect diamagnetism together implied that a superconductor represents a new thermodynamic phase of matter. During 1930–34 Willem Kissom and co-workers at Leiden found a sharp discontinuity in the specific heat for tin, which was later understood as a defining signature of a new thermodynamic phase.

Further results showed that a critical magnetic field $H_c(T)$ destroys superconductivity – given approximately by Tuyn’s law: $H_c = H_0(1 - (TT')^2)$, where $H_0$ is the field at $T = 0$ K. In Fig. 5 the magnetisation $-M$ is shown as the applied magnetic field varies. At $H_c$ the magnetisation drops to zero and then becomes positive, showing a transition to a normal state. Below the critical field $H_c$ the magnetic induction $B$ (dashed line) vanishes, implying the presence of perfect diamagnetism (the Meissner state).

The jump in the system Gibbs free energy is $H_c^2/8\pi$ per unit volume. Thus, going from the Meissner to the normal state, the superconducting transition is discontinuous (of first order, as for water freezing to ice) and requires latent heat. This type of superconductor is known as type I or ‘soft’ superconductor. Their critical fields $H_c$ being very small (~0.1 T), these materials are not very useful for practical applications, as we shall see later.

However, in the late 1930s Lev Shubnikov and his
team in Kharkov studied a variety of superconducting alloys, known as *type II* or ‘hard’ superconductors. The magnetic response of this type is different from type I as shown in Fig. 5 (continuous line). Now there are two distinct critical fields, $H_{c1}$ and $H_{c2}$. Below $H_{c1}$ the system is in the Meissner state, with complete magnetic field exclusion. Above $H_{c2}$, there is the usual normal state. But between these two critical fields a new state appears, which allows the magnetic field to penetrate the superconductor in a unique fashion. We shall return to this point below.

In 1935 a phenomenological theory was proposed by the London brothers, Fritz and Heinz. This is a macroscopically correct electrodynamic theory, notable as an important development in the theory of superconductivity. It shows that $\mathbf{J}$, the current density in a superconductor, is proportional to the magnetic vector potential, $\mathbf{A}$. The proportionality constant is $-1/4\pi\lambda^2$, where $\lambda$ is the London penetration depth: a fundamental quantity in superconductivity that measures the superfluid density $n_s$, as $\lambda^2 \propto n_s$. The London brothers’ relation both implies zero resistance and leads to a consistent explanation of the Meissner effect.

The postwar year of 1950 was an important time for superconductivity. The isotope effect was a major discovery by two American groups, E. Maxwell at MIT and C. Reynolds, B. Serin and co-workers at Rutgers University. These experiments suggested that $T_c$ of a superconductor changes inversely with the isotopic mass $M$, namely $T_c \propto M^{-\alpha}$ where $\alpha \approx 0.5$. As emphasised by Herbert Fröhlich of Liverpool University, these results gave a clear demonstration that the electron–phonon interaction must be involved in the effect.

In the same year 1950 Vitaly Ginzburg and Lev Landau gave their celebrated phenomenological theory of superconductivity (their GL theory is also known as $\Psi$ theory) by invoking an ‘order parameter’ $\Psi$ that encodes the nature of superconductivity through the symmetry of the system. To this day the GL theory remains a powerful practical tool that succinctly explains all the thermo- and electrodynamic properties of a superconductor. It also leads to a second fundamentally significant length $\xi$, describing the spatial scale over which the order parameter varies.

Here it is worth giving a little more detail. A quantity $\kappa$ defined by $\kappa = \lambda/\xi$ (the ratio of magnetic penetration depth to coherence length), known as the GL parameter, identifies the type of superconductivity (type I or type II) from the relation $\kappa < 1/\sqrt{2}$ or $> 1/\sqrt{2}$. Brian Pippard, from Cambridge, suggested that $\xi$ relates to the Fermi velocity $v_F$ and the energy gap $\Delta$: $\xi = h v_F / 2\pi \Delta$. The range of $\xi$ can be varied by doping impurities through the electron mean free path, hence the value of $\kappa$ can be changed as desired.

Again in 1950 Fritz London, using semi-classical arguments, predicted that the magnetic flux $\Phi$ passing through a superconducting ring should be quantised in integer units of $\hbar c/e^2$, where $e^2$ is the unit of charge circulating in a closed loop. By 1961 B. S. Deaver and W. M. Fairbank, and R. Doll and M. Nabauer, had measured the quantised flux and established that $e^2 = 2e$, strongly supporting the pair-binding picture of electrons within a superconductor. The unit of flux quantum is a small number: $2.0678 \times 10^{-7}$ Gauss cm$^2$. Both theory and experiment tell us that $\Phi$ varies by these tiny but discrete quantum steps as the magnetic field varies.

We have noted earlier that the specific heat measured in a superconductor has a jump at $T_c$. If one removes from this the phonon-background contribution (the $\beta T^3$ term) and plots the electronic specific heat alone, the relation is found to be $C_v(T) = \exp(-\Delta/k_B T)$. Here $\Delta$ is the energy gap between the ground state and the lowest excited state. This gap itself is $k_BT_c^2$. There were other experimental estimates for $\Delta$ from microwave and infrared measurements. Basically, the energy gap is the photon energy threshold to release an electron from its bound pair in the superconducting state. For $T \ll T_c$ the transition is sharp. In Fig. 6 the ratio $\Delta(T)/\Delta(0)$ is plotted against $T/T_c$ for various superconductors. The change in $\Delta(T)$ goes continuously to zero as $T$ approaches $T_c$ from below.

The experimental implication of the electron–phonon interaction as a mechanism provided a great clue to the final formulation of a microscopic theory and Fröhlich’s early work was very important in this respect. In 1954–
55 David Pines and John Bardeen studied the nature of dielectric screening in a metal and there was a strong indication that, near the Fermi surface, the dynamics of the dielectric function can change the net interaction between two electrons to be, in effect, attractive. This happens when the dynamically screened Coulomb interaction is overcome by the electron–phonon interaction, which creates a local distortion of the positive-ion lattice in resonance with the electronic motion.

**Microscopic theory/theories**

Based on the above experimental and conceptual background, Bardeen became fully convinced that an important key to the superconductivity puzzle is the existence of an attractive interaction, no matter how weak, between electron pairs near the Fermi surface. That possibility was cleverly confirmed by Leon Cooper (1956), a postdoc with Bardeen. Cooper showed that a normal Fermi liquid (as in a metal), in the presence of even the weakest attractive force close to the Fermi surface, leads to a bound-state pairing with a discrete, negative energy relative to the Fermi surface. The components of the pair retain their Fermi velocities, yet the pair as a quantised entity has zero total momentum and zero total spin.

With no loss of time Bardeen, Cooper and Robert Schrieffer (a graduate student of Bardeen) formulated what would happen when the electron states near the Fermi surface condense into macroscopically many ‘Cooper pairs’: bound states at the Fermi surface. In 1957, this was a wholly new unorthodox way to generate a ground state – one separated from the normal ground state by an energy gap. This is the BCS theory: a state of matter totally unforeseen.

The BCS theory successfully explained and unified a host of separate experimental observations and predicted novel superconducting properties. Almost all known properties of superconductivity: excited states; specific heat; critical field(s); ultrasonic attenuation; Meissner effect; penetration depth; etc. were calculated in this detailed and celebrated paper.

In addition there were predictions, such as the precise values \( \Delta(0)/k_B T_c = 1.76 \), the specific heat jump at \( T_c \), \( \Delta C/C_N = 1.43 \), the existence of an energy gap at the Fermi level strongly dependent on attractive interaction, and many others. In the fifteen years up to 1972 a large number of metallic and intermetallic superconductors were discovered. In 1972 Bardeen, Cooper and Schrieffer shared the Nobel Prize in Physics (see Fig. 7). This was Bardeen’s second Nobel after earlier sharing the prize in 1956 with Walter Brattain and William Shockley for the invention of the transistor.

Soon after the discovery Philip Anderson, an influential condensed-matter physicist of the past six decades, noted that the central character of superconductivity extends well beyond the domain of the BCS theory itself. He raised more fundamental issues such as broken gauge symmetry, which was further investigated by Yoichiro Nambu in 1961. Another aspect was the rigidity of the wave function that London had envisaged; it connects the superfluid density \( \eta \) with the vector potential \( \mathbf{A} \). We mention briefly that BCS, with its many stunning successes, also had weaknesses (no theory is ever perfect!). Clarifications of the BCS pairing mechanism and simplifications of its derivation were advanced in 1958 by Nicolai Bogoliubov and John Valatin.

We pointed out above that the GL theory is our best phenomenological theory in this area, with many advantages for working out the real properties of superconducting inhomogeneous materials. This theory is commonly used in a variety of problems in other areas of physics, namely nonlinear optics, high energy physics, gauge theory and others. In 1958–59 Lev Gorkov (a student of Landau) not only re-derived the theory of su-
perconductivity in the language of quantum field theory, but he also produced the explicit relationship between the order parameter $\Psi$ in GL theory and the superconducting energy gap $\Delta$ of BCS. One may note that, curiously, there is no mention of the GL theory in the 1957 BCS paper.

It will not be out of place to recall that there were two parallel movements towards an eventual microscopic theory of superconductivity. We have described the BCS as one development, but mention may be made of the advance in understanding superfluidity in $^4$He after the end of World War II. Following London’s phenomenological hydrodynamic approach to superfluidity, Nikolai Bogoliubov and Lev Landau (USSR) and Richard Feynman (USA) made impressive contributions to superfluidity and the nature of bosonic excitations in $^4$He. Against this background the other development of superconductivity was driven by M. Schafroth, then at the University of Sydney. A former student of Pauli and an associate of Fröhlich, Schafroth proposed a two-electron resonant state in 1954, conceived as a charged-pair boson. This is in contrast with the bound-fermion Cooper pair of BCS theory.

This idea was soon developed in detail in 1957 by John Blatt, Stuart Butler and Schafroth himself in Sydney, as the quasi-chemical equilibrium theory of superconductivity, where electron pairs form up as bosons and then condense into a Bose–Einstein collective macroscopic state. Essentially this identifies the superconducting state as a state of charged superfluid. Despite similarities (and some differences) with the BCS theory, the theory of Schafroth and colleagues could not gain popularity in the period when superconductivity for metallic materials was still dominant in the consensus.

**Type I and type II superconductors**

Earlier we mentioned two types of superconductors. Fig. 8 shows the phase diagrams of these superconductors. Type I satisfies $\kappa < 1/\sqrt{2}$. Note that $\kappa$ is defined above as $\kappa = \lambda/\xi$. In this case for a normal and a superconductor in contact, the interfacial energy is positive. As a result the magnetic flux remains outside the superconductor, maintaining the superconductor in the Meissner state below $H_c$. Type II satisfies $\kappa > 1/\sqrt{2}$. Here the interfacial energy is negative above a certain critical field $H_{c1}$. In this situation there is an energy gain when the magnetic flux (vortex) can penetrate the superconductor in quantised form, with each flux quantum taking the value $\Phi_0 = \hbar c/2\pi$ (Fig. 8, continuous line).

A flux quantum (called a vortex) has a centre at which the order parameter $\Psi$ vanishes, while the full magnetic field $\mathbf{b}$ passes through its centre. Here $\Psi(r)$ decays over the range of $\xi$, and $\hbar(r)$ over the range of $\lambda$. A circulating current $j(r)$ gives rise to $\mathbf{b}(r)$. Alexei Abrikosov (a student of Landau, who shared the Nobel Prize with Vitaly Ginzburg and Anthony Leggett in 2003) used the GL theory to show that these vortices form an ordered structure of vortex rods parallel to the field direction. If we observe the plane normal to the field, the vortices form a triangular lattice (known as the Abrikosov lattice). The simple picture of magnetic field-temperature phase diagrams of type II superconductors are very complex for most of the novel superconductors (cuprates, pnictides, etc.).

If these vortices are pinned in the superconductor and immobile in an applied electric field, one can have a large critical current without much dissipation of energy. This is an essential requirement for a superconductor for practical high-current applications. The study of vortex structures in type II superconductors is an important area of fundamental and applied research that continues vigorously today.

**World of new superconductors**

As one will notice from Fig. 3, the highest $T_c$ of metallic superconductors remained at 23.2 K for a dozen years. A great surprise took place in 1986 when Georg Bednorz and Alex Müller from IBM in Zurich, discovered superconductivity in a ceramic material La–Ba–Cu–O with an onset $T_c$ of 35 K. The parent material of this superconductor is La$_2$CuO$_4$, an anti-ferromagnetic insulator. The material belongs to the class of perovskites, a layer-structured material.

Under doping with Ba or Sr in place of La in a range
0.05–0.30 of fractional composition, superconductivity in this material occurs with a highest $T_c \sim 35$ K. In the following years a big race was on. The value of $T_c$ kept on rising, up to a (brief) record for $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (91 K), overtaken by $\text{Bi}_2(\text{SrCa})_4\text{Cu}_9\text{O}_{10}$ (112 K), and soon after by $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (120 K) and $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+x}$ (133 K). Finally $T_c$ rose to its highest reproducible value of 165 K for $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+x}$ under pressure. In 1987 Bednorz and Müller received the Nobel Prize for their discovery of high $T_c$ superconductors (Fig. 9).

Over the subsequent twenty-five years, many signal events have occurred in the world of superconductors (see again Fig. 3). Apart from the cuprates, a variety of new superconducting materials has been discovered: the rare-earth nickel boro-carbides ($\text{YNi}_2\text{B}_2\text{C}$); $\text{MgB}_2$; a variety of organic superconductors (alkali doped-C$^{60}$); pnictides ($\text{LaOFeAs}$); doped-penicene ($\text{MnC}_{22}\text{H}_{13}$), and still others. While some of them (such as $\text{MgB}_2$) appear to be BCS phonon-mediated superconductors, the majority of the novel superconductors are unconventional. Under suitably controlled doping, pressure and similar physical parameters, many superconducting and normal properties are observed to behave anomalously relative to the standard BCS model. Discussing them would go outside the scope of this article.

Applications

Over the century many possible applications of superconductivity have been touted. To mention in brief, the main applications are in electronics, computers, magnets, energy storage, electric power transmission, magnetic-resonance imaging (MRI), and transportation. Note that many of these call for high current (and high magnetic field) applications. On the other hand, there have been some very successful small current applications, namely superconducting quantum interference devices (SQUIDs), Josephson devices, semiconductor–superconductor hybrids and many others. Apart from that there are large-current applications such as the magnets employed in the Large Hadron Collider at CERN and magnetically levitated trains.

Summary

In view of the enormity of the subject we have had to leave out some very important topics, such as the Giaever (1960) and Josephson (1962) effects. Moreover, current theoretical ideas on various – perhaps rather exotic – microscopic mechanisms have been deliberately omitted to keep the article simple and pedagogic.

This year 2011, the centenary of the discovery of superconductivity, celebrations have been planned all over the world. Superconductivity is one of the most miraculous macroscopic phenomena of the quantum world. It will always remain fascinating to experts and non-experts alike. Here we have emphasised the historical developments and discoveries culminating in the first successful microscopic theory.

The BCS theory has done far more than resolve the enigma of superconductivity, explaining and predicting various aspects of conventional (low $T_c$) superconductors. Its philosophical influence in other areas of physics – nuclear structure, nuclear matter, neutron stars, astrophysics, quark–gluon matter and colour superconductivity – is overwhelming. Volumes have been, and many more will be, written on its unprecedented fertility.
PLASMA RESEARCH AT UniSA: 

Reconnecting the Physics with the Chemistry?

Jason Whittle, David Steele, Andrew Michelmore and Robert Short

For the last 40 years, chemists have overlooked the physics of the plasma environment in trying to explain how functional polymer films form in low temperature plasma. At the University of South Australia we are challenging this orthodoxy and discovering how the physical and chemical properties of plasmas are intertwined. There is a lot that we know we don’t know, but plenty of new discoveries and opportunities.

Many material properties are dominated by surface effects. As the philosopher Rudolf Carnap once said “In science there are no ‘depths’, there is surface everywhere.” Historically, the search for new surfaces has paralleled the quest for new materials, and in the modern age, as miniaturisation continues apace, the surface has become the material. The domination of surface effects on materials performance in many areas of technology has lent new urgency to scientists and engineers working in this field to understand how to tailor surface properties for optimal performance.

Globally, more than $10 trillion worth of products per year incorporate surface treatments of one kind or another. Over the last two decades, surface treatments have become more sophisticated and the technology underpinning these treatments has become more complex and refined. Previously it was sufficient to provide coatings with properties such as hardness or impermeability. Increasingly there is a drive to incorporate chemical, electrical or biological functionality into surface coatings.

One of the techniques utilised to achieve this uses low temperature plasmas of small organic compounds to deposit thin polymeric films onto various types of substrate [1]. These plasma polymers are capable of having diverse chemical and physical properties, and have been applied in many technological areas – composites, electronics, wound healing, medical diagnostics and textiles.

Our current problem is, quite simply, that our ability to make novel surfaces by plasma has far exceeded our understanding of the underlying mechanisms of formation. Even on an industrial scale, trial and error is the way new processes are developed, and the lack of a clear understanding leads to difficulties in processing and quality control. This limits the progress of the technology at a time when applications are become more demanding in terms of surface performance. A clear framework is required to link intrinsic process variables directly to film properties.

Plasma polymers
Plasma polymerisation is a gas-phase process in which a substrate is exposed to electrically-driven plasma formed from a gaseous precursor – see Fig. 1. Externally the operator can control properties such as the input power, the precursor flow rate, the system pressure and temperature.
Properties such as reactor geometry, power coupling and pumping are typically fixed at design-time, but also have a very significant impact on the nature of the glow discharge and the resulting film.

Much of the terminology surrounding plasma polymerisation is drawn from polymer chemistry, although plasma polymers are not polymers in the conventional sense. The action of the plasma can disrupt structural elements present in precursor compounds, and remodel them to introduce new chemical functional groups in the product. Chain growth may be highly branched, which leads to the formation of insoluble deposits of indeterminate molecular weight.

Early attempts to describe the processes used terminology taken from physical chemistry, with precursor flow rate as a proxy for the concentration of reactants, power as a proxy for heat and deposition rate as the measurement of conversion of precursor into product. But these models fail to capture the complexity of plasma processes. The plasma environment is a rich soup of intact precursor, neutral fragments, ions, reactive radicals, electrons and photons (visible and UV). Moreover, at the plasma boundary, the local electrical fields change the transport properties and interactions of these species and hence dominate the character of the deposit.

Whilst the mechanisms of plasma polymerisation were fairly well researched up until the 1970s, for some reason after this – perhaps because everything was thought to be known – most fundamental research into plasma polymer film growth stopped and industrial application rushed full steam ahead. Pick up any textbook or review on the topic of growing organic ‘polymeric’ films from plasma (occasionally referred to as glow discharge) and it is likely that film growth is attributed to radical chemistry within the discharge and within the growing film.

In 1985 Hirotsugu Yasuda [2] proposed that plasma polymerisation was due to ‘rapid stepwise growth polymerisation’ (RSGP) involving only radical and neutral species. Ions were not directly involved in film growth, but might initiate surface radical sites during impact for neutral species to adsorb to. However, polymerisation was viewed as predominantly a gas-phase, radical process. The RSGP model is probably the most cited in the field.

We believe that overlooking ions has been a big mistake. It may have happened because of the low abundance in the plasma (typically one ion particle per 30,000 neutral species in plasma phase), or possibly because the RSGP model closely resembled the known and well established pathways for conventional synthetic polymerisation.

However, since the seminal works of Yasuda and others in the 1970s there have been some significant shifts within the field. First, there has been a growing trend to the use of radio-frequency (RF) sustained plasmas for polymer deposition. RF affords greater control and on a practical level, as electrodes are external, do not require cleaning. Second has been a reduction in the plasma input power employed by researchers. This has allowed the fabrication of films from functionalised organic compounds (compounds that contain oxygen, nitrogen or sulphur functional groups) in which both the structure and functional groups are retained from the starting compound.

This raises an interesting point, as according to the classical model of plasma polymerisation, films cannot be grown from oxygen containing precursors where the oxygen functionality remains intact in the product. Of course the fact that this does not account for functionalised films has not restricted industrial product development. Where the model fails, trial and error is used.

**New applications – Old problems**

In fact the realisation that functional films *can* be grown from plasma has significantly expanded the number of potential applications for plasma polymer films since the mid 1980s. One area where significant effort has been devoted in the last twenty years is the fabrication of soft, ‘organic’ coatings for biological applications [3] – with landmark successes, for example, in the coating of contact lenses that allow extended wear.

Most recently, plasma polymerisation is being utilised in cooperation with other technologies such as nanopatterning, 3D scaffolds, microfluidics and for microparticle encapsulation. For such high-end applications, trial and error methods are at best laborious and time-consuming,
and our fundamental lack of understanding of the reaction pathways in plasmas is being exposed. Examples from our own work are shown in two case studies—see the break-out box.

Perhaps the most remarkable feature of existing models is the absence of any physical consideration of the plasma. Working this back into the model of how polymers form from plasma is driving our plasma research at UniSA.

**Physics of low temperature plasmas**

As any physics undergraduate will know, plasma comprises a weakly ionised gas containing electrons, ions, metastables, excited state species and photons, as well as neutral species. As a consequence of their low mass, electrons are accelerated within RF plasma and therefore gain energy very quickly. The energy distribution is commonly Maxwellian, with a mean electron temperature of around 3 eV, but a high energy tail with energies in excess of 10 eV.

Due to their higher mass, ions, reactive radicals and neutral species remain close to room temperature and thus are out of equilibrium with the electrons. Most of the work in initiating and maintaining the plasma is done by the electrons. Overall, electrical neutrality is conserved in the plasma and the density of ions is approximately equal to the density of electrons. As the ion density is very low compared to the radicals and neutrals, chemists assumed that the flux of ions to surfaces was also extremely low—driven by kinetic gas theory.

This is where the physical properties of the system become important. The vast difference in ion and electron mobility leads to the establishment of a large negative potential and a sheath of positive space-charge around materials placed in the plasma. The potentials develop as higher temperature electrons flow out of the plasma to the surface faster than ions. The surfaces develop a negative potential relative to the bulk so that the net current flow is zero. As a consequence, a sheath region of positive charge in the space adjacent to the surface is established, where low energy electrons are repelled from the surface and positively charged ions are attracted to the surface. The sheath is a region of net positive charge and the boundary of the sheath is marked by the point where the electron density and positive ion density are matched. This is typically in the range of 20–100 μm from the surface.

There is a more important point which is often overlooked. Just beyond the sheath lies another region known as the pre-sheath. In 1949 David Bohm recognised that for the sheath to be a stable region of positive charge, the electron density must decrease more rapidly than the positive ion density as they approach the surface [4]. Combined with the boundary condition at the sheath edge, Bohm determined that in this pre-sheath region, ions are accelerated such that they enter the sheath region with kinetic energy proportional to the square root of the electron temperature. Known as the Bohm Criterion, it infers a flux of ions to the surface 10–100 times greater than that calculated on the basis of thermal flux.

There is another factor that has been overlooked and that is the occurrence of ion–molecule reactions in the gas phase during plasma polymerisation [5]. In RSGP it is assumed that as power is applied there is an ‘atomisation’ of the starting compound, following which a polymer grows by radical grafting. However, at low power this initial fragmentation is limited, and therefore ions created in the plasma can react with neutral species within the plasma. Whilst these reactions were first observed in plasmas of functionalised monomers by mass spectrometry in the mid 1990s, it is only in the last few years that we have been able to validate the feasibility of schemes previously suggested using selected ion flow tube (SIFT) experiments. This specialised type of study is being carried out in conjunction with researchers at the University of Birmingham. In an ion flow tube, ions are reacted with molecules (in the absence of plasma) under controlled conditions and the products and reaction rates determined. SIFT experiments have shown that in plasmas we can expect ion–molecule reactions to proceed with very high reaction rates and are capable of producing very large molecules.

This is supported by plasma-phase mass spectrometry, which has revealed that very large ions up to four times the mass of the precursor persist in the plasma. These observations demonstrate that not only are reactions in the plasma phase important, but also hint that there may be a variety of different reaction pathways which lead to formation of polymers. Moreover, the ionic component is very much molecular, as opposed to atomic, or low mass.

“Globally, more than $10$ trillion worth of products per year incorporate surface treatments of one kind or another.”
AFM and ToF–SIMS for characterising the deposited plasma polymer films.

One particularly unique tool currently under construction is an improved diagnostic platform incorporating a suite of diagnostics mounted on an RF biased substrate. It is based upon an earlier design, shown in Fig. 2, built in conjunction with James Bradley at the University of Liverpool. The important feature of this collecting surface is that it allows the ion energy distribution to be measured and adjusted without perturbing the bulk plasma [6]. The mixture of physical and chemical characterisation is critical – the surface chemistry is the result of chemical reactions in the plasma and within the growing film at the surface, but these are driven by the physical environment both in the bulk plasma, and in the sheath region near the surface. The platform will allow researchers to look more closely at how these physical processes influence the chemical pathways in the plasma and at the surface.

Early results from these studies are helping bridge the divide between the physics and chemistry. For example, in the low power, low pressure plasmas typically used for plasma polymerisation, plasma densities have been shown

**Applications of Plasma Polymer Coatings: Two Case Studies**

**Skin Delivery Vehicle**

The UniSA group has developed a novel bandage for the delivery of skin in the treatment of severe burns, scaffolds and non-healing wounds. For example, in patients where burns are extensive there may not be sufficient skin for grafting, without threatening an already compromised patient. In such a circumstance a method developed by Reinwald and Green in the 1970s has involved the growing of skin (taken from a small biopsy) in the laboratory. This method has saved hundreds, possibly thousands of lives to date, but is very labour intensive and requires as many as 14 days to grow a confluent layer of skin that can be removed as a cell sheet, put into a bandage and taken to the clinic. In the late 1990s with Sheila MacNeil, our team developed a bandage on which cells could be grown directly and taken back to the patient where the cells on
to be in the range of $10^{14}$–$10^{16}$ ions/m$^3$. When compared with the total gas density which is of the order of $10^{18}$–$10^{20}$ molecules/m$^3$, this is approximately the ratio anticipated. However, the fluxes of positively charged ions to surfaces has been measured for a variety of plasmas and are typically of the order of $10^{19}$ ions/m$^2$/s. Recent studies in plasmas of hexamethyl disiloxane (HMDSO) [7] suggest that the ion flux is one to two orders of magnitude greater than anticipated based on $kT$.

Consequently, a simple ‘back of the envelope’ calculation of ion mass flux (ion flux times average ion mass) reveals that the ion mass is sufficient to account for anywhere between 25–100% of the final mass of the deposit for many systems. This result is compound specific, indicating that the molecular structure of the compound is also very important.

The sheath: ion energies
Accepting that there is a significant ion mass flux to surfaces, the next part of the puzzle is knowledge of how the surface affects the process. We need to know the energy of ions arriving at surfaces and how the composition of the surface might affect what happens upon impact. Ions in the plasma are close to room temperature, but their kinetic energy when they arrive at the surface is a few tens of eV as a result of acceleration through the pre-sheath and sheath to the negatively charged substrate.

Whilst we have been developing this idea that ions contribute to film growth from plasma, we have also application to the wound are gently released – see Fig. 4. The ‘secret’ to the bandage is a functionalised plasma polymer coating a few tens of nanometres thick, that allows both cell culture in the laboratory and cell delivery on the patient. This technology is now widely employed in the UK in burns centres. The same technology is being used to heal ‘difficult’ wounds that fail to respond to more established treatment methodologies.

Atmospheric Microplasmas
Plasmas can be used to modify the chemistry in microfluidic devices [9]. A microfluidic device is fabricated with additional guide channels into which molten gallium is injected and allowed to solidify – see Fig. 5. Passing helium through the microchannels and applying an alternating field across the electrodes ignites a plasma within the microchannels and causes modification of the interior surfaces. The technique can be used to provide microfluidic devices with localised modifications which can subsequently be used for protein capture, fluidic control by altered wettability and as chemical sensors. Research in this area is concentrated both on the fabrication of novel microfluidic devices using those technology, and on understanding exactly how these microplasmas modify the channel walls.
looked at the role of ions alone. In conjunction with Luke Hanley and his group at the University of Illinois, polymer films have been grown from hyperthermal (15–100 eV), polyatomic ion beams with known fluence. In the case of HMDSO, using the m/z 147 ion, polymer films have been deposited using energies similar to those found in plasma systems. Not only are the films chemically very similar to those grown from plasmas, as measured by XPS and ToF–SIMS, but it has been calculated that the sticking probability of the ions also increases with ion energy and is of the order of 20–50%. Comparing these sticking probabilities with deposition rate measurements from conventional plasmas suggests that ions may contribute as much as 50% of the mass of plasma polymers – a value which depends on chemical reaction pathways available with different precursors.

These types of studies are bringing ions back into the ‘game’ and we are now confident that there is a wide range of plasma conditions where ions play an important role (directly) in film growth, beyond creating free radicals in surfaces. As ions are accelerated at surfaces, it follows that the substrate may also be important.

The surface
The next part of the puzzle is the role of the surface itself. It has been largely assumed, and even categorically stated, that plasma polymerisation is completely independent of the substrate. However, our own recent experiments comparing amine-containing monomer deposition onto metallic and organic substrates have demonstrated that both the deposition rate and film chemistry in the first few nanometres of deposition are different [8]. As many new technological applications of plasma polymers such as microfluidic channel coating require ultra-thin films (<10 nm), this effect needs to be understood. To date we rationalise this result on the basis of how energy from ions accelerated across presheath/sheath is dissipated at the substrate.

A further assumption often quoted in regard to plasma polymer films is that they provide ideal, conformal and pinhole free films. Fig. 3 shows AFM images of two plasma polymer films grown from heptylamine onto silicon wafer under identical conditions except for the pressure in the chamber. As is shown, at high pressure the film is far from ideal with morphological features up to 10 nm high. This again hints that multiple reaction pathways may lead to film growth.

Conclusions
Now is an exciting time to be in this area of plasma research. Demands for new surfaces for cutting edge technologies mean that we must unravel the basic processes occurring within the plasma, and at the surface. In order to achieve this we need to combine knowledge of both the physics of low temperature plasmas, and organic plasma chemistry. There is a lot that we know, but there is much more that we don’t. Unlocking the truth will be a joint endeavour for physicists, chemists and materials scientists together. To misquote Einstein: “In plasma, chemistry without physics is lame, physics without chemistry is blind”.

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ABOUT THE AUTHORS
The authors are based at the Mawson Institute at the University of South Australia. David Steele (left), Jason Whittle, Robert Short (Institute Director) and Andrew Michelmore have research interests that span the fundamental mechanisms of polymeric film formation by plasma, novel plasma sources through to the use of plasma polymers for biomedical applications, particularly in tissue engineering for skin and eye.
Measuring dark energy using the WiggleZ Survey

Fig. 1. Astronomers think that the expansion of the universe is regulated by both the force of gravity, which acts to slow it down, and a mysterious dark energy, which pushes matter and space apart. In fact, dark energy is thought to be pushing the cosmos apart at faster and faster speeds, causing the Universe’s expansion to accelerate. In this artist’s conception, dark energy is represented by the purple grid above and gravity by the green grid below. Gravity emanates from all matter in the Universe, but its effects are localised and drop off quickly over large distances. [credit: NASA/JPL–Caltech]

Chris Blake

Observations by astronomers over the last fifteen years have produced one of the most startling discoveries in physical science: the expansion of the Universe, originally triggered by the Big Bang, has begun to speed up. According to the conventional laws of physics, the attractive force of gravity should slow down the cosmic expansion through the inward pull of gravity. In fact the reverse behaviour is observed. Astronomers have coined the term ‘dark energy’ to describe the unknown physics driving this phenomenon.

The action of dark energy in the Universe is as if you threw a ball in the air, but it did not return to Earth but rather kept speeding upwards faster and faster. An artist’s impression is shown in Fig. 1. Dark energy appears to be the dominant component of our Universe today and yet we still have no physical understanding of its existence or magnitude. This is considered one of the most important problems in astronomy because the nature of dark energy will unambiguously revolutionise our understanding of the laws of physics. In particular, dark energy is one of the only observable clues to the central dilemma of modern physics: quantum mechanics and Einstein’s gravity, the two great accomplishments of twentieth-century physics, are mutually incompatible.

Dark energy: Possible explanations

There are two possible explanations of dark energy. Both require astonishing changes in our understanding of the Universe in order to generate an anti-gravity to drive the accelerating expansion. Firstly, Einstein’s theory of gravity, General Relativity, could be modified on large cosmic scales to produce a repulsive gravitational...
force. Secondly, the Universe could be filled with a new, smooth material which, unlike any known form of matter or energy, counters the attractive force of gravity via its uncontrollable desire to expand. A great deal of effort is being expended by astronomers today in order to determine which of these possibilities is correct.

The leading candidate in the second category is the ‘cosmological constant’, a subject with a fascinating history. When Albert Einstein applied his equations of General Relativity to the Universe as a whole in 1917, he realised that a dynamic (expanding or contracting) Universe would naturally result, due to the action of gravity causing any equilibrium to be unstable. In the absence of clear observational evidence to the contrary at this time, Einstein preferred to construct a static, unchanging Universe and to do this he was compelled to add an extra term to his equations known as the cosmological constant, in order to counteract the effects of gravity. However, soon after Einstein developed this static theory, observations by Edwin Hubble and collaborators indicated that the Universe is demonstrably not static, but expanding.

Einstein later referred to his failure to predict the expansion of the Universe from theory as the ‘biggest blunder’ of his life. However, by the late 1990s a set of cosmological observations, most spectacularly those of the brightness of distant supernovae, had indicated that the expansion of the Universe is speeding up [1]. This is just the sort of situation that can be described by the cosmological constant, which provides a cosmic anti-gravity. Hence the cosmological constant was reintroduced as a term in the equations as one possible model for dark energy.

A possible physical model for generating a cosmological constant in nature is the energy of the quantum vacuum. Quantum theory informs us that even empty space is teeming with virtual particles, which appear and disappear in accordance with the Uncertainty Principle and provide a ‘zero-point’ energy. Indeed, the quantum vacuum may be observed in the laboratory using phenomena such as the Casimir effect.

However, it is extraordinarily difficult if not impossible for fundamental quantum theory to reproduce the observed amplitude of dark energy; when we add up the energy of all the available quantum states the integral
diverges to infinity. Even if we cut-off this integral at physically-motivated limits the theoretical prediction for the vacuum energy density exceeds the cosmological constant observed by astronomers by more than one hundred orders of magnitude. This is sometimes called ‘the worst prediction in theoretical physics’, and this failure has motivated a set of alternative suggestions in which dark energy is codified as a ‘scalar field’ which fills all space. Examples of other hypothesised scalar fields in physics include the mechanism which propelled cosmic inflation just after the Big Bang, and the Higgs field which may endow particles with mass.

In summary, dark energy is a precious clue in the quest to understand fundamental theory. Unravelling its origin is likely to entail a revolution in our understanding of physics, string theory and quantum gravity. A rich landscape of cosmological surveys has grown in recent years to meet this goal, measuring the influence of dark energy via a variety of observational techniques. The WiggleZ Dark Energy Survey at the Anglo-Australian Telescope in New South Wales is one of the earliest of this new generation of dark energy-focussed surveys, commencing in August 2006 and recently completed in January 2011 [2]. The observations were performed by a small core team of 14 Australian-based astronomers, together with a number of international collaborators (see Acknowledgments below).

How do we measure dark energy?
There are two important methods of tracking the effects of dark energy in the Universe. Firstly, we can measure the scale of the Universe: how far away are the distant galaxies? Dark energy will act as an anti-gravity and will fling these galaxies further away from us than we expected. Secondly, we can measure how strongly clumps of matter in the Universe are attracting each other – or, equivalently, how fast are clusters and superclusters growing by pulling in the surrounding matter? Dark energy will act as an anti-gravity and will slow down the rate of growth. Both measurements require observations of galaxies deep into the Universe’s past. Both measurements need to work in tandem to unequivocally determine the nature of dark energy, and both can be applied using large galaxy surveys.

In order to measure the scale of the Universe, we need a measuring stick which can tell us the distance to faint galaxies. Historically, the best measuring stick is to use distant supernovae as standard candles. Assuming all supernovae have the same luminosity, their apparent brightness tells us how far away they are. This method has provided the most spectacular evidence for dark energy, because the supernovae have been found to be dimmer than expected, being flung to greater distances through the action of dark energy. However, doubts still remain. How do we know that the supernovae all have the same luminosity? What if the nature of supernovae changed with time, or if distant supernovae were dimmer because their host galaxies were dustier than expected?

In order to address these concerns, a second method of measuring the scale of the Universe has been developed, and this second method has been exploited by the WiggleZ Survey team. This method uses as its measuring stick a standard ruler, not a standard candle (and so it is immune to the effects of dust). A standard ruler is an object of known size, whose apparent size tells us how far away it is. Specifically, we exploit a small preference for pairs of galaxies to be separated by a fixed distance – 490 million light-years. The concept of standard candles and rulers is illustrated in Fig. 2.

This preferred separation actually represents the echoes of sound waves in the plasma of the early hot, dense Universe. These sound waves have been observed most vividly by studying the temperature ripples in the Cosmic Microwave Background (CMB) radiation, which was released a few hundred thousand years after the Big Bang and which streams towards us across the sky. The temperature map of the CMB, measured by satellites such as the Wilkinson Microwave Anisotropy Probe, contains hot and cold spots which seed the later formation of structures in the Universe such as galaxies and clusters. The patterns of these hot and cold spots can be physically explained in terms of ‘acoustic oscillations’ or compression waves which propagate through the tightly-coupled plasma of radiation and electrons.

“The action of dark energy in the Universe is as if you threw a ball in the air, but it did not return to Earth but rather kept speeding upwards faster and faster.”
in the early Universe, gravitationally driven by dark matter clumps. When the Universe has cooled sufficiently, electrons and nuclei combine to form atoms in a process known to astronomers as ‘recombination’ and the sound waves are silenced. However, their characteristic signature is imprinted both into the radiation (released as the CMB) and into the distribution of atoms (which, together with dark matter, go on to form galaxies). This is important because we can use the CMB measurements to calibrate the acoustic scale, and determine that in today’s Universe it corresponds to a preferred separation of galaxy pairs of 490 million light-years [3].

“... our results provide a powerful alternative probe of dark energy in addition to distant supernovae.”

In order to apply the ruler, we need to measure the separations of a very large number of pairs of galaxies, which we can achieve by constructing a large-scale, three-dimensional map of the galaxy distribution by carrying out a large galaxy survey. This can be realised by measuring the spectra of hundreds of thousands of galaxies, and using the spectra to measure the ‘redshift’ or recession velocity of each galaxy, which indicates its distance in three-dimensional space. Prior to our survey, such maps had only been constructed in the relatively nearby Universe, about 3.5 billion light-years away, compared to the total size of the observable Universe which is 13.7 billion light-years. This was achieved by the Sloan Digital Sky Survey between 2000 and 2008.

Our project, which required 276 nights of observations at the Anglo-Australian Telescope between 2006 and 2011, has built a map stretching over 7 billion light-years, twice as far as had been previously achieved, and more than half-way back to the Big Bang. The measurement of the distribution of the separations of galaxy pairs obtained using our data [4] is plotted in Fig. 3, illustrating the preferred separation, and the inferred cosmic distances are displayed in Fig. 4.

Together with measuring the distance-scale of the Universe using galaxy pairs, our galaxy map allows us to probe the effects of dark energy in a different way: by measuring how fast clusters of galaxies are growing with time. Clusters and superclusters attract surrounding matter through the force of gravity, setting up coherent ‘bulk flows’ of galaxies through space. The velocities of these flows may be measured because they modify the redshift of each galaxy due to the Doppler effect, creating correlated patterns of redshift offsets between nearby galaxies which are referred to as ‘redshift-space distortions’. The velocity of infall is a direct test of the nature of dark energy because it depends on the force of gravity exerted by each cluster and supercluster. Our measurements [5] of the growth of cosmic structure are illustrated in Fig. 5.
Fig. 5. WiggleZ measurements (blue) of the growth rate of cosmic structure over the last 7 billion years of look-back time, compared with those of previous surveys. The curve is the growth rate predicted by a cosmological constant dark energy model, which slows down as time goes by owing to the anti-gravity effect of dark energy. The WiggleZ Survey has provided the most accurate and complete map of this growth history.

**Results from the WiggleZ Survey**

In order to determine which explanation for dark energy best fits our data, we combined our twin measurements of cosmic distances and cosmic growth, tracking the effects of dark energy much further back into the history of the Universe than was possible before. We found that Einstein’s theory of gravity, General Relativity, provides a good explanation of the gravitational forces that we measured, and that dark energy is well-described by the cosmological constant. Although we still do not understand the origin of this material or what causes it to fill space, we now know that it is smooth to about 1 part in 10 across the last 7 billion years of the history of the Universe. Our work should motivate new efforts by theorists to explain this material, and has increased our confidence that Einstein’s theory of gravity, General Relativity, is correct.

Furthermore, our results provide a powerful alternative probe of dark energy in addition to distant supernovae. Supernovae have been previously used as standard candles to provide the most spectacular evidence for dark energy. However, doubts could question whether supernovae were really standard candles? What if nearby and distant supernovae were different in nature, or the dustiness of the host galaxies varied with time, producing a confusing signal? Using entirely independent methods we have been able to confirm agreement with these supernovae measurements, increasing our confidence in the existence of dark energy as a real material. A slew of further galaxy surveys over the next decade should test this picture in even more detail.

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BOOK REVIEWS

The Eerie Silence – Renewing Our Search for Alien Intelligence
By Paul Davies
Reviewed by Joanne Turner, University of South Queensland

In 1960 a young astronomer Frank Drake started searching for alien radio signals after being prompted by an article published in Nature, spawning an international research program known as the Search for Extraterrestrial Intelligence (SETI). In 2010, this search celebrated its fiftieth anniversary. Paul Davies, who has long been involved with the project, explores all the ramifications of this search and why, for fifty years, we have not found even a hint of intelligent life out there.

This is the first book by Paul Davies that I have read, even though I knew he has plenty of other well known and respected publications. I was not sure what to expect, or what his style of writing was like, but I did know his books are relatively short, whether as a result of his lack of subject matter or being able to keep meanderings to a limit, I was yet to find out. Thankfully I found it was due to his concise, simple explanations that do not require long meandering through tangents outside of the topic at hand.

Davies considers the reasons we haven’t heard from ET, despite fifty years of searching the skies for radio signals. However, we soon find that just considering the possibility of extraterrestrial life cannot be answered unless we consider a whole host of other aspects, including: Is life universal to... well, the universe? How can we be sure there is life out there? More importantly, is it intelligent life? How long does it take for intelligent life to develop? Are we looking in the right places, using the right tools? Why do we think radio signals are the most appropriate form of evidence?

Davies explores and answers all these questions and more. He even tackles questions such as: If we find intelligent ET life – what should we say to them? Will they even be biological beings or something else? Who should be the spokesperson for Earth? What are the implications of finding ET? What are the implications of not finding ET?

Since Davies is involved in a task force that is considering all these questions, it is reassuring that he doesn’t preach his views, but rather explores each facet carefully and acknowledges his own personal opinions clearly with his logical processing of the facts at hand. I had always been of the opinion that the human race was arrogant to believe that we are the only intelligent beings – but Davies has given me much to think about on what the likelihood that ET is out there, at exactly the same time and in the same area of space as us?

I thoroughly enjoyed this book and I shall certainly read others by Paul Davies. It is thought-provoking and questioning, but it doesn’t beat down on the head of those religions that rely on the lack of ET as proof, acknowledging that believing there is life out there is almost akin to a religion itself. Not that this is highly important to me, but it makes a refreshing angle to look at it if you, like me, are interested in knowing if the search for ET should continue.

The Beautiful Invisible
By Giovanni Vignale
Reviewed by John Daicopoulos, James Cook University

Giovanni Vignale’s book pays homage to the abstractions of theoretical physics. For Vignale these abstractions are the necessary moments of clarity heard above the din of confusion allowing those with the courage to follow the imagery a deeper insight of reality.

The aim is far more precise and lofty than how we teach abstract physics. Demonstrating how being daring in imagery is essential to theoretical physicists, Vignale illustrates how these invisible worlds and intangible mathematical concepts require our creativity for understanding. Running parallel to these creative elements of theoretical physics is a subtext of how this craving for imagery is used by writers and artists to colour their illusory worlds.

The opening topic tackles the power of limits; how taking ideas well beyond what is reasonably expected in the ‘real-world’ to imagine the invisible. This...
promising start is filled with enjoyable elements from art and literature. There are chapters on our impulse for symmetry, our need to break it, and on the second law of thermodynamics, which makes for a perfect segue into the invisible quantum world that follows. Eventually all of the usual suspects of theoretical physics (entanglement, relativity, electron spin) are covered with convincing style.

There are a few weak points. To focus on the power of imagery Vignale wisely avoids the use of mathematics throughout much of the book; however, this proves an impediment when trying to illustrate the value of Hamiltonians with strained literary hand waving. Furthermore, there are a few unnecessary anthropomorphisms, particularly when explaining magnetism.

Most bizarre, he makes the strangest correlation with Nazism and the precepts of relativity – in fact I’m not sure how the editor let that comment pass, it must have been an interesting conversation between author and editor to say the least. Lastly, the frequency of his literary and artistic comparisons drops off dramatically in the latter half; it is almost as if he ran out of ideas. It weakens the book’s association with the power of creativity and imagery.

The infrequent use of mathematics, the stock-in-trade of the theoretical physicist, raises the issue of to whom the book is directed. To truly appreciate Vignale’s argument the reader needs more than an elementary comprehension of mathematics and physics, making it best suited for undergraduate and graduate students, particularly those with an interest in taking a path less worn by traditional thought. Physics teachers should also find elements worthy of discussion with senior high school students.

Fortunately, Vignale avoids the trap of associating theoretical physics with the likes of Taoism, Zen or going down rabbit holes. On that alone he deserves a great deal of credit for staying above the fray of silly populism, while still maintaining a tangible hold on the general reader. Creativity and imagination are part and parcel of the human endeavour with respect to the Arts; Vignale makes a strong case for its significance in Physics as well.

**Neutrino**

By Frank Close  
Reviewed by Joanne Turner, University of South Queensland

This book is a historical account of one of the most intriguing particles discovered in modern science. At first thought one would expect that the discovery of a particle would not be all that momentous. The story of the neutrino is remarkable because it was predicted to have zero charge, virtually no mass and, for all intents and purposes, to be invisible.

Frank Close takes us from the beginning of the neutrino journey to the end. The idea for the book was initiated when he was asked to write the obituary of Ray Davis, who was awarded the Nobel Prize in 2002 for his discovery of the neutrino. However, there are many others behind the prediction, discovery and proof of the elusive particle. In the first chapter, Close takes us from the time of Marie and Pierre Curie, Wilhelm Rontgen and Henri Becquerel, and other well-known figures, through to Niels Bohr, Wolfgang Pauli and Enrico Fermi, to the point where Pauli realised there must be a hidden particle, with no charge, that he dubbed the ‘little neutron’ or – in Italian – the ‘neutrino’.

Over the next few chapters Close weaves his way through the historical journey of the neutrino, including the work of Bruno Pontecorvo which had prompted Davis and others to begin their search for the elusive neutrino. From this point on, there were many contributors to the research on the neutrino.

I have always been a fan of books on the history of science, and found this a very enjoyable book. Close does a very good job of explaining the basic physics behind physical phenomena, but I suspect a reader with little physics background might find the explanations for the decay processes of high energy particles in the
latter part of the book not quite enough to get them through. However, this is not the kind of book where you need to understand all the nitty-gritty bits to enjoy the story. I learnt quite a lot, as I was not familiar with all those involved in the neutrino story.

I recommend this book to anyone interested in the history of science, whether scientists or non-scientists, as an excellent story and also as a tribute to those who contributed to one of the most intriguing discoveries in science.

Condensed Matter in a Nutshell
By Gerald D. Mahan
Reviewed by Roger Lewis,
University of Wollongong

As I told my solid-state honours students in the first lecture, “It is sobering to note that the first edition of our recommended textbook was published, not only before you were born, but before I was born.” [see Charles Kittel, ‘Introduction to Solid State Physics’, 8th edn, 2005].

ISSP has been around a long time and has gone through many editions. It has become the international standard solid-state text. Yet it is not without its critics – including some of those same honours students. (I should declare here that I have some interest in ISSP, having assisted in the review of the material for the 8th edition.) Are there better books available? In particular, is Mahan’s new book better and is, in the words of a previous reviewer, ‘the long search for a suitable text for a one-year graduate course on condensed matter’ finally over?

As the honours lectures proceeded, and I received a copy of this book by Mahan, I used it side by side with Kittel to see how the books compared. Here is what I found. Not too much should be read into the ‘in a Nutshell’ part of the title. The treatment is not as concise as the title might suggest – 590 pages is a fair-sized nutshell. The explanation is that this book is part of the ‘In a Nutshell’ series by Princeton University Press.

The book starts refreshingly with a taster chapter that overviews the development, conveys some of excitement, and invites the students to join the ongoing enterprise of condensed matter physics. To give an idea of the pace, Chapter 2 on ‘Crystal Structures’ very quickly (third page) introduces the reciprocal lattice and, later, scattering (x-ray, electron, neutron). In contrast, Kittel spends a whole chapter on the direct lattice, and then a whole chapter on the reciprocal.

The topical coverage is inviting. There are standard topics – energy bands, free electron metal, phonons, semiconductors, optical properties, magnetism, superconductivity and nanostructures. Some topics are less typical – electron–electron interactions, electron–phonon interactions and boson systems. The topics represent where condensed matter physics is now. Kittel, in contrast, is burdened with ‘older’ topics, which tend to be more of interest to engineers than physicists – such as point defects, dislocations, and alloys.

The order of topics is intriguing. Whereas Kittel starts with structure, moves on to phonons, gets to free electron metals only in Chapter 6 and to energy bands only in Chapter 7, Mahan is into energy bands in Chapter 3, but waits until Chapter 7 to discuss phonons. To my mind, the ordering of Kittel is more systematic and, in general, moves from the more basic to the more advanced; Mahan tends to chop back and forth. (Ashcroft and Mermin kick off with metals, but that’s another story.)

So, what’s the verdict? I see nothing wrong with Mahan, and would be very happy to teach using it. It has a freshness and uniformity of style that the last of a long run of Kittel editions cannot match. The problem set is better. But, overall, the fuller explanations of Kittel, the gentler pace of development, the more (to my mind) systematic arrangement of the material, and the comprehensive tables and graphs of data for reference and comparison with theory, mean that Kittel’s ISSP remains my preferred text.
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The iChrome TVIS laser system is a fibre laser with the flexibility to set automatically the laser output to any wavelength in the visible (488–640 nm). The coherent laser output ensures that the visible light exhibits the best intensity noise performance and the use of polarisation maintaining optical components a

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The new DL RFA SHG pro is a narrow-band tunable continuous wave laser for sodium cooling. The system is based on a near-IR diode laser in the successful ‘pro-design’ (DL 100/pro design, 1178 nm), with a subsequent Raman fibre amplifier (RFA) and a resonant frequency doubling stage (SHG pro).

The DL RFA SHG pro features a spectral linewidth below 1 MHz and 20 GHz mode-hop free tuning. For system operation, no water cooling and no external pump is required. The power scalable approach of the DL RFA SHG pro also offers solutions for other high power applications such as sodium LIDAR, medical therapy or super resolution microscopy. Customised systems with higher output powers up to 10 W are available on request. Wavelengths between 560 and 620 nm will soon be available as customised solutions.

FemtoFiber pro – the product family is expanded

After the successful introduction of the FemtoFiber pro IR, NIR and SCIR models, TOPTICA is now taking the final step to also include the remaining system variants such as tunable visible (TVIS), tunable near-infrared (TNIR) and tunable ultra compressed pulse (UCP). Options such as variable repetition rate (VAR) and a phase-locked loop Laser Repetition rate Control (LRC) by TOPTICA’s well-established PLL-electronics are rounding up the FemtoFiber pro product family.

The first and fastest of the new models, UCP, shows short pulses in the range down to 13 fs, the fastest available on the market from a turnkey SAM modelocked fibre laser system.

The TVIS expands the super-continuum generation (SCIR) by a tunable second harmonic generation and allows transferring femtosecond pulse generation into the visible wavelength range from 490 to 700 nm.

The TNIR variant finally adds a new feature to the FemtoFiber pro family. As opposed to the TVIS, it uses the high-band continuum (>1500 nm) for second harmonic generation. This continuum part is a solitonic pulse and therefore needs no pulse compression. The output wavelength can be tuned from 800 to 1100 nm. This variant was not previously available in the FFS product family.

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

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WARSASH SCIENTIFIC

Lightweight Benchtop Vibration Isolation

Warsash Scientific is pleased to announce a new lightweight benchtop vibration isolation system from Kinetic Systems, Inc. Specifically designed for portability, the ELpF can be easily repositioned on the benchtop, even with a load and in float. Its unique, self-contained design provides this without causing damage to the vibration isolators.

An economical alternative to heavy-weight models, the Ergonomic Low-Profile-Format platform provides vibration isolation for sensitive devices. It features a load capacity of 100 or 300 lbs. in a light-weight, ergonomic system.

The platform has a low profile (only 3” high), uses a small tabletop (16”x19” standard) and weighs 40 lb, making it very portable. Ergonomic features include gauges tilted upward for easier viewing and recessed handles for easy carrying.

Designed for use in laboratories and Class 100 cleanrooms, the ELpF platform is ideal for supporting atomic force microscopes, microhardness testers, analytical balances, profilometers, and audio equipment.

Self-leveling and active-air isolation give the platform low natural frequencies (1.75 Hz vertical, 2.0 Hz horizontal) and typical isolation efficiencies of 95% (vertical) and 92% (horizontal) at 10 Hz.

Other tabletop sizes can be customised per specifications. The top, which can be ordered with or without mounting holes, can be aluminium plate, ferromagnetic stainless steel, plastic laminate, or anti-static laminate.

For more details on this or other vibration isolation equipment, contact sales@warsash.com.au.

Real-Time Operating System for Systems Integration

PI (Physik Instrumente), the leading manufacturer of piezoceramic drives and positioning systems, offers a real-time module as an upgrade option for the host PC and also the connection of the GCS (PI General Command Set) software drivers. The module is based on Knoppix Linux in conjunction with a pre-configured Linux real-time extension (RTAI).

The use of real-time operating systems on the host PC allows it to communicate with other system components, e.g. a vision system, without time delays with discrete temporal behaviour and high system clock rate.

A library which is 100% compatible with all other PI GCS libraries is used for the communication with the real-time system. All PI GCS host software available for Linux can be run on this system.

The real-time system running in the real-time kernel can be used to integrate PI interfaces and additional data acquisition boards for control. Open functions to enable you to implement your own control algorithms are provided. Data, such as positions and voltages, is recorded in real time, and pre-defined tables, with positions, for example, are output in real time to the PI interface and to additional data acquisition boards.

You can program your own real-time functions in C/C++, MATLAB/ SIMULINK and SCILAB.

The system includes a PI GCS server, which allows the system to be operated as a blackbox using TCP/IP, via a Windows computer, for example.

The system can be installed on a PC or booted directly as a live version from the data carrier. A free demo version with restricted functionality is available.

For more information on the real time operating software or other PI positioning equipment, contact sales@warsash.com.au.

E-618: 3.2 kW Peak Power for New Piezo Amplifier

Available from Warsash Scientific is the new PI (Physik Instrumente) E-618 high power amplifier for ultra-high dynamics operation of PICMA® piezo actuators.

The amplifier can output and sink a peak current of 20 A in the voltage range between -30 and +130 V. The high bandwidth of over 15 kHz makes it possible to exploit the dynamics of the PICMA® actuators. This type of performance is required in active vibration cancellation and fast valve actuation applications.

The E-618 also comes with a temperature sensor input to shut down the amplifier if the maximum allowed temperature of the piezo ceramics has been exceeded. This is a valuable safety feature given the extremely high power output.

The E-618 is available in several open-loop and closed-loop versions with analogue and digital interfaces.

For more information on these and the range of other PI products, contact sales@warsash.com.au.

Warsash Scientific Pty Ltd
Tel: +61 2 9319 0122 Fax: +61 2 9318 2192
Web: www.warsash.com.au
New Sensors Improve Precision of S-340 Tip/Tilt Mirror

Warsash Scientific is pleased to announce the release of the new S-340 piezo tip/tilt mirror platform from PI (Physik Instrumente), equipped with new high-resolution strain gauge sensors.

The S-340 now achieves a resolution of 20 nanoradians (nrad) at angles of 2 mrad about both orthogonal axes.

This large mirror platform is used for optics with diameters of up to 100 mm (4 inches) and achieves a resonant frequency of 900 Hz for a mirror of 50 mm diameter.

The S-340 can be operated by the new, low-cost E-616 controller. Together, they form a compact, high-performance solution for beam control and image stabilisation as employed in astronomy, laser machining or optical metrology, for example.

For more information on the S-340 Tip/Tilt Mirror platform or other Positioning equipment from PI, contact sales@warsash.com.au.

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The SG384 uses a unique, innovative architecture (Rational Approximation Frequency Synthesis) to deliver ultra-high frequency resolution (1 μHz), excellent phase noise, and versatile modulation capabilities (AM, FM, øM, pulse modulation and sweeps) at a fraction of the cost of competing designs.

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The standard model SG384 produces sine waves from DC to 4.05 GHz. There is an optional frequency doubler (Opt 02) that extends the frequency range to 8.10 GHz. Low-jitter differential clock outputs (Opt 01) are available and an external I/Q modulation input (Opt 3) is also offered. For demanding applications, the SG384 can be ordered with a rubidium time base (Opt 04).

Stanford Research Systems Photon Counter

The SR400 Dual-Channel Gated Photon Counter from Stanford Research Systems offers a convenient, integrated approach to photon counting that avoids the complexity and expense of old counting systems. No longer is it necessary to mix and match amplifiers, discriminators, gate generators and counters. The SR400 combines all these modules into a single, integrated, microprocessor controller instrument. Complete measurement tasks such as background subtraction, synchronous detection, source compensation and pile-up correction can all be performed easily with the SR400.

Features:
- Two independent counting channels
- Count rates to 200 MHz
- 5 ns pulse-pair resolution
- Gated and continuous modes
- Gate scanning for time-resolved counting
- Built-in discriminators
- Gate and discriminator outputs
- GPIB and RS-232 interfaces.

Stanford Research Systems Multichannel Scaler

The SR430 is the first multichannel scaler which combines amplifiers, discriminators, bin clocks, and data analysis in a single, integrated instrument. With its many features and its easy-to-use menu driven interface, the SR430 simplifies time-resolved photon counting experiments. The SR430 Multichannel Scaler/Averager can be thought of as a photon counter that counts events as a function of time. A trigger starts the counter which segments photon count data into sequential time bins (up to 32k bins). The width of the bins can be set from 5 ns to 10 ms. The instrument records the number of photons that arrive in each bin.

Features:
- 5 ns to 10 ms bin width
- Count rates up to 100 MHz
- 1k to 32k bins per record
- Built-in discriminator
- No interchannel dead time
- On-screen data analysis
- Hardcopy output to printers/plotter
- DOS compatible 3.5-inch drive
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Features:
- EnergyMax-USB/RS sensors provide USB connectivity for
R&D and production environments, and USB 2.0 for OEM embedded applications
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• Truly synchronised dual unit operation to support ratiometry >1 kHz every pulse
• State-of-the-art EnergyMax Sensor Technology.

For further information on all four products, please contact
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AGILENT TECHNOLOGIES
High Resolution Wide Bandwidth Arbitrary Waveform Generator

Agilent Technologies has added a high-resolution, wide-bandwidth, 8- or 12-GSa/s modular instrument to its portfolio of arbitrary waveform generators. The new M8190A arbitrary waveform generator is able to deliver simultaneous high resolution and wide bandwidth along with spurious-free dynamic range and very low harmonic distortion.

This functionality allows radar, satellite and electronic warfare device designers to make reliable, repeatable measurements and create highly realistic signal scenarios to test their products.

The M8190A helps engineers:
• build a strong foundation for highly reliable satellite communications
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The M8190A offers:
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• reduced system size, weight and footprint with compact modular AXi AWG capability.

The high performance of the M8190A arbitrary waveform generator is made possible by a proprietary digital-to-analog converter (DAC) designed by the Agilent Measurement Research Lab. Fabricated with an advanced silicon–germanium BiCMOS process, the DAC operates at 8 GSa/s with 14-bit resolution and at 12 GSa/s with 12-bit resolution. At 8 GSa/s, the Agilent DAC delivers up to 80c-dB SFDR.

More information is available at www.agilent.com/find/M8190.

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The built-in suite of diagnostic tools, including meters, signal and measurement lists, markers, span zoom, zone span and spectrogram displays, makes it easy to monitor and investigate problem signals. The MXE is also an X-Series signal analyser capable of running a variety of measurement applications such as phase noise. By enhancing the analysis of noncompliant emissions, these capabilities enable EMI test engineers and consultants to evaluate signal details and deliver new insights about the products they test.

More information is available at www.agilent.com.au/find/MXE.
For further details, contact tm_ap@agilent.com.
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Australian Radiation Protection Society Conference
Melbourne, VIC

30 November – 2 December 2011
Solomonoff 85th Memorial Conference
Melbourne, VIC

31 January – 3 February 2012
Thirty-sixth Annual Condensed Matter & Materials Meeting
Charles Sturt University, Wagga Wagga, NSW

17 – 18 February 2012
Physics Teachers Conference
Monash University, Melbourne, VIC

25 February 2012
Queensland Astronomy Education Conference (QAEC)
Brisbane, QLD

4 – 11 July 2012
Thirty-sixth International Conference on High Energy Physics, ICHEP2012
Melbourne Convention and Exhibition Centre, VIC

30 July – 3 August 2012
ANU Nuclei in the Cosmos Winter School
ANU, Canberra, ACT

5 – 10 August 2012
Nuclei in the Cosmos 2012
Cairns Convention Centre, QLD

12 – 17 August 2012
Seventy-fifth Annual Meeting of the Meteoritical Society
Cairns Convention Centre, QLD

23 – 28 September 2012
Thirty-seventh International Conference on Infrared, Millimetre and Terahertz Waves
Wollongong, NSW

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Fifteenth International Conference on Small-angle Scattering, SAS 2012
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High Performance Nd:YAG & Tuneable Lasers

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