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FRONT COVER: Neocera system: The front cover shows the plasma plume generated during pulsed laser deposition (PLD) of a YBa2Cu3O7 superconducting multi-layer film. Photo courtesy of Neocera Incorporated.

Laser pulses from an excimer laser operating at 248nm are used to vapourise a target surface under vacuum producing a plume of the same composition as the target. The plume condenses onto a heated ceramic substrate forming a thin film.

Neocera is represented in Australia by Coherent Scientific Pty Ltd. For more information please refer to page 225. The back cover of this issue details the range of products available from Coherent Scientific and Neocera.

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On 24th November will be the FASTS ‘Meet the Parliamentarians Day’ in Canberra, the first event of its type ever held. Members will be pleased to know that the Institute is sponsoring the participation of 23 members, in addition to Ken Baldwin who will be representing FASTS. The AIP contingent is the largest of any society and this was achieved in part by arranging for the Annual Heads of Physics Departments Meeting to be held on 22nd and 23rd of November in Canberra.

More than 170 scientists will meet in pairs with more than 140 Federal politicians and, wherever possible, we will meet our own local member. The briefing on Tuesday 23rd November will involve representatives of the Coalition, Labor and the Democrats and a number of government and political advisors. There is to be a Parliamentary Reception on the Tuesday evening.

Thus we will not be pressing the case for any particular discipline nor seeking as an immediate outcome support for more funding for science. Rather we will emphasise the importance of basic science in Australia and seek to raise the awareness of the politicians regarding the inevitable consequences for Australia of allowing the erosion of science and science funding, particularly in the universities, to continue unabated.

With regard to the emphasis on science policy issues this year, I have previously pointed out that the Executive changed the structure of the Science Policy Committee by replacing Branch Correspondents with Branch Chairs. This change worked well and in preparing the response to the Green Paper I can report that every Branch responded!

It is my hope that all of those amongst the 23 members who will be at Parliament House who are not members of the Science Policy Committee will make themselves available to participate in future science policy matters in support of the Institute.

As you will be aware, my Columns this year have focussed on science policy matters. In 2000 it is my intention to concentrate on a membership drive and benefits to members, while not losing our cutting edge in the policy area.

Two weeks ago during a meeting in Hangzhou, China I became acquainted with the English language newspaper, the ‘China Daily’ and was most impressed by feature articles on the importance of science and also a strong message from the Chinese Government to its physics community about the importance of physics. The Chinese are making up ground fast and, in areas of research I know about, are already a major force in the Asian region. I saw some excellent work being undertaken in a Physics Department in Shanghai on semiconductor device fabrication that was of a very high standard indeed, supported by local industry and government.

Some months ago I was elected to Fellowship of the IOP and appointed a Chartered Physicist for the duration of my Presidency, free of charge. To reciprocate that arrangement, I am pleased to report that Sir Gareth Roberts FRS, President of the IOP, has accepted our invitation to become a Fellow of the AIP under the same conditions.

The Executive Members join me in wishing you all a safe and happy time during Christmas and the New Year.

John Pilbrow
EDITORIAL

Whither AIP? Off like a Rocket?

I was recently flipping through the Annual Report of a company I had invested in and found that they had a Strategic Plan. Though this is a fairly common practice it is rather unusual to find in a Company Report so I had a closer look. They had drawn up a table with a list of things that they wanted to achieve during the following year and, in a separate column, those things that they had to do in order to reach the various goals.

I got to wondering whether the AIP had a similar plan. So I thought I should look at their web site. My first problem was to find it. I surfed around till I came to www.physics.usyd.edu.au/aipaustr/index.html. Hopefully one day soon we shall be www.aip.org.au, but not yet. Maintaining a web site is an enormous job (I just had a ‘phone call telling me that something on it was out of date) and we should all be grateful to Pal Fekete for giving us what is there.

I came across a document “Advancing the AIP” by Ken Baldwin, ACT Branch Chairman. This seemed to be what I was looking for. But I could not ascertain how old it was (apparently a year or so).

I asked myself ‘Why hasn’t this document crossed my consciousness before?’ It starts with some pertinent questions:

Satisfied with the role of the AIP?
Getting value for your subscription?
Been to a congress lately?
Is the Physicist up to scratch?

Why does Physics have such a poor public image?

I will never forget being cornered by Bea Miles* in a Sydney bus when I was a student. When she ascertained that I was studying Physics, she proclaimed to the whole bus in a loud voice what a terrible thing it was that this young fellow was studying nuclear physics so that he could one day destroy the world!

Why doesn’t Physics have better PR? What can the AIP do about it? Is it getting any better? Maybe the many members who have their ARC grants refused may not suffer so much loss of self-esteem if the public thought they were doing an important and praiseworthy job. Maybe then more of them would get their grant applications funded in the first place!

More importantly, why are employers not clamouring for our graduates? It is often said that Physics graduates have more highly developed problem solving skills than others. Is this really true or is it a myth? If it is true, can we identify which parts of the courses we teach achieve this result? We should have this information in case we accidentally throw them out during a syllabus revision!

There seems to be a tendency, maybe more pronounced in Australia, for physicists to have a very narrow focus. They will go to a talk or seminar in their area of study but rarely will they bother with one in a different area of physics. This can be seen even within one’s own organisation, but also at AIP Branch meetings. The ‘Advance document’ worries about the future of the AIP Congress. The next Congress will be held in Adelaide, 10-15 December 2000. I notice in the program that there are 14 plenary talks - very much an emphasis on broadening our knowledge. I hope that this will be well supported - maybe as a gift to ourselves for Christmas 2000!

One thing that the public does expect from physicists is correct information when needed in a controversy. In this very issue we air a controversy over the possible storage of nuclear waste in Australia. We have here two physicists presenting opposing viewpoints. This is acceptable providing that the facts they present are correct and/or properly qualified. I would very much hope that our readers will write to us if any correction or qualification should be made to what they have said. Recently I saw a movie about some young boys who became enthralled by the building of rockets. Their leader eventually won a science competition with his work. While surfing around I found an organisation in Australia which does similar work at an even higher level but also encourages students to participate and to do it safely. It is great that there are people willing to give time to fuel young people’s enthusiasm in this way. Details may be found in ‘Around the Traps’.

One recommendation out of the report mentioned above was that a greater sense of ownership of their Institute should be sought from members. A large number of Letters to the Editor on any of the subjects mentioned above would be one way of expressing this - maybe just a short note by e-mail.

Robert Stening ("Editor on the Ground")
R.Stening@unsw.edu.au

* Bea Miles was an eccentric lady who used to travel around Sydney in buses and taxis, never paying her fare, wearing an old army greatcoat and a sandwich board offering quotations from Shakespeare at a range of prices.

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Rocket Program Success

The Australian Space Research Institute carried out a series of small rocket launches in October at its Woomera launch site. Eight rockets were launched watched by a total of 203 people. Included were projects from students who can be seen in the picture. More information on these activities can be found at www.asri.org.au.

Asteroid watch

The research school of astronomy and astrophysics at ANU will collaborate with the lunar and planetary laboratory of the University of Arizona in upgrading the Upshall Schmidt telescope at Siding Springs, NSW, to watch for asteroids which may be dangerous for earth dwellers.

The upgraded telescope will then have a sensitivity similar to its companion in Arizona, able to detect objects of the 20th magnitude which is near to the level of light scattered by dust and to the natural airglow in the ionosphere. This work will fill a southern hemisphere gap in NASA's program to identify 90% of potentially dangerous asteroids larger than 1 km diameter within the next 10 years.

The Australian 25-26 September and 17 November 1999

Copyright concern

A copyright amendment bill before Federal Parliament would have disastrous effects on schools, libraries and universities, warned the Australian Vice-Chancellors Committee. The amendment proposes that copyright charges be levied every time a digital document is viewed electronically, by the Internet for example. Presently such charges only occur when a physical copy is made.

Though a bonanza for authors, such an arrangement would be a disaster for students and would discourage the use of digital information in libraries.

The Australian 20 October 1999

A new mine safety system

CSIRO Exploration and Mining is testing a new system known as LAMPS (Location and Monitoring for Personal Safety System). Each underground worker will carry a transponder which sends information every 100 seconds detailing the worker's identity, their position in the mine and their heart and respiration rate. Wireless beacons throughout the mine pick up the information operating in the 433MHz range. A variety of parallel paths are available so that the system will continue to work even if part of the network is damaged by an accident. The system is presently being trialed at Gympie's El Dorado gold mine.

www.csiro.au

Two grants for Melrose

Professor Don Melrose of Sydney University's Research Centre for Theoretical Astrophysics was involved in two large ARC grants awarded in the recent round. One grant is for investigation of the radio emission from pulsars. While pulsars have a mass similar to our Sun, their diameter is only about 20 km. Their rapid rotation combines with their intense magnetic field to accelerate electrons and positrons to relativistic energies. The project investigates the radio emission associated with this.

A second grant, led by Dr Iver Cairns, is for the study of Type II radio bursts from the Sun.

Pollution tracked across Bass Strait

The atmospheric monitoring station at Cape Grim, north-west Tasmania, has detected the refrigerant gases CFCs, HCFCs and HFCs which originated in Melbourne. The picture shows the passage of an air pollution plume southward from Melbourne. PhD students Michelle Cox and Bronwyn Dunse, working at CSIRO Atmospheric Research, can detect just a few kilograms per day released from the distant site.

www.csiro.au

Readers are invited to send items which might be of interest for this news column either to the Editor or to one of the Associate Editors.

Peruvian villages use new CSIRO battery

Dr Russell Newnham of CSIRO's Novel Battery Technology Group has been working to produce an efficient energy system for villages in Peru's remote Amazonia region. Central to the system is a new battery in which the liquid acid is replaced by an acidic gel. The new battery is both cheaper and has a superior cycle life. It produces negligible gas emission and requires no special ventilation. The work is performed in collaboration with Battery Energy South Pacific. The Peruvians prefer their RAPS (remote area power supply) because it does not have the environmental problems associated with the diesel generators they were previously using.

www.csiro.au

Beowulf gauges monster lattices at Adelaide

A successful ARC RIEF application announced in the current round was for a new “super-computing” facility called the “National Computing Facility for Lattice Gauge Theory”. It will consist of a 128-node Beowulf cluster sited at the University of Adelaide. Each node will consist of a dual processor Pentium III 450 computer, connected at 100 Mbit/sec to other nodes, with a total 32 Gbyte RAM and 45 Gbyte hard disk. The theoretical peak speed is 128 Gflop, and a similar system, ‘Avalon’ at Los Alamos, is already rated as the 113th fastest computer in the world. Participants in the project are Tony Williams, Derek Leinweber and Tony Thomas of the Special Research Centre for the Subatomic Structure of Matter at Adelaide, Bruce McKellar at Melbourne and Chris Hamer at New South Wales. The major advantage of these systems is that they are about one-third of the cost of an equivalent proprietary system.
SWIMMING BACK FROM THE SUPERHEAVY ISLAND

GEORGE DRACOULIS
Department of Nuclear Physics
Australian National University

What's next in the series 108, 109, 110, 111, 112, ... ?

The answer a couple of years ago looked like being not much. But major ripples are spreading in the Nuclear Physics community as news of the recent discoveries of the Superheavy element Z=118 and its daughters Z=116 and Z=114 was announced by a Berkeley group led by Victor Ninov [1]. Several pieces of news about Z=114 from studies at Dubna promoted by Yuri Oganessian [2,3] were circulating at about the same time.

The "not much" answer was because increasingly heroic efforts seemed to be needed to produce and identify each heavier element in the series. The problem is that such nuclei, if they exist in a stable or quasi-stable form are prone to fission, and so are any nuclei one might conceive as making to provide a path to one's nucleus of choice. The favoured reaction process used to make them is heavy-ion fusion which involves bombarding target nuclei of $^{208}$Pb (proton number \(Z=82\)), $^{244}$U (\(Z=92\)) or even $^{244}$Pu (\(Z=94\)) with medium weight (and relatively neutron-rich) beams such as $^{48}$Ca (\(Z=20\)) and $^{86}$Kr (\(Z=36\)) nuclei, accelerated to energies near or just above the Coulomb barrier, with the hope of the two nuclei overlapping and combining because of the highly attractive (strong) nuclear force. The catch is that putting sufficient energy in to get the nuclei together leaves the compound nucleus with excitation energy and spin, which dramatically increase its probability to fission, and therefore not survive further. As you go lower in beam energy, the probability for the initial fusion drops precipitously since the nuclei have to tunnel through a potential barrier caused by the repulsive Coulomb force between the nuclear charges, in order to make contact. Somewhere between the dramatically falling probability for fusion and steeply increasing probability for fission might be a window of production and survival.

You can see this from the collection (figure 1) of measured cross-sections for reactions on $^{208}$Pb targets with various beams under conditions which led to the evaporation of a single neutron, taken from what is now a historical series of measurements aimed at making very heavy nuclei [4]. These were led by Sigurd Hoffman and his collaborators, and carried out at the Gesellschaft für Schwerionenforschung (GSI). The energies have been shifted to account for the increasing Coulomb barrier compared to the lowest-Z beam in this set, $^{48}$Ti. All fall just below the nominal Coulomb barrier, with an order of magnitude drop in cross-section, already measured down to units of picobarns, at each increase in \(Z\) of two. (The cross-sectional area of a nucleus like $^{208}$Pb is about 1.5 barns, where a barn = $10^{-28}$ cm$^2$.)

In fact, in the charged liquid drop model of the nucleus, there will be no barrier to fission when the parameter \(Z/A\) (proportional to the ratio of Coulomb to surface energies) reaches 50. Hence in that model, even nuclei with \(Z\) approaching 100 (and \(A \sim 200\)) would not exist. Clearly, that is not the case, but it is a warning that difficulties are likely to be encountered. The surviving cross-section is seen to diminish by an order of magnitude for each small step towards unity in the value of \(Z/A\), shown in parentheses in figure 1. One is presently limited to the use of stable beams and targets and this gives another constraint since the natural result of combining two lower-\(Z\) nuclei

Figure 1 Compilation of measured cross-sections for selected systems leading to heavy elements. The beam energies have been adjusted to account for the differences in Coulomb barrier with respect to the $^{48}$Ti case. See ref. [11] for original data sources.

George Dracoulis is a graduate of Melbourne University (B.Sc Honors) where he completed a PhD in nuclear physics in 1970, before going on to a Research Associateship at the Schuster Laboratory of the University of Manchester. He returned to Australia in 1973 when he joined the Department of Nuclear Physics at the Australian National University as a Research Fellow. He was appointed to a Chair in Physics in 1991, and has been Head of the Nuclear Physics Department since 1992.

He is a Fellow of the Australian Institute of Physics, a Fellow of the American Physical Society, and a Fellow of the Australian Academy of Science. His main research interests are in Nuclear Structure and Nuclear Spectroscopy, much of that research being carried out on the ANU Heavy Ion Accelerator Facility.
is to make a compound nucleus which is relatively neutron-deficient, and therefore more fissile, since \( A \) is lower. Extrapolation of these cross-sections to the production and identification of even heavier nuclei would obviously lead one to be sceptical of further success, hence the pessimism expressed in the opening lines.

The real situation is complicated by the dynamics (excitation energies, angular momentum, deformation paths etc.) and it is controlled, most importantly, by shell-correction energies that have their origin in the quantum many-body nature of the nuclear system and the nucleon-nucleon forces [5]. This is why there is more than a passing interest.

Paradoxically, very heavy nuclei may have lifetimes against spontaneous fission which are shorter than predicted by the liquid drop model, but they may also have structure in the fission barrier as a function of deformation, leading to fission isomers and the like. Superheavy nuclei are ones whose stability owes nothing to the liquid drop energy but arises only from the shell-correction energy. Calculation of these energies is then a stringent test of nuclear models and nuclear structure. Prediction of an island of superheavy nuclei well beyond the stable heavy ions has been at the centre of nearly three decades of searches (some in nature) and attempts to synthesise such nuclei. A typical terrain of binding energies is shown in figure 2 where nuclei stable against spontaneous fission are predicted near \( Z = 114 \) and \( N = 184 \) (giving \( Z + N = A = 298 \)), on an island separated from the mainland by what is known respectfully, as the sea of instability. In the lower panel, they are connected to that mainland by a peninsula, the difference being caused by details of the potentials used to describe the mean-field. Such calculations are sensitive to the allowed degrees of freedom, the parametrisation of the deformation, as well as approximations in the methods and importantly, the precise nature of the forces used. Predicted lifetimes that depend on calculation of tunnelling probabilities and a competition between decay modes, can vary by many orders of magnitude. Not surprisingly, large additional binding is predicted for superheavy spherical systems at the spherical proton and neutron shell closures (beyond \( Z=82 \) and \( N=126 \)) but while some theories predict \( Z=114 \) and \( N=184 \) as the likely island, others favour \( Z=120 \) or \( Z=126 \).

One possible signature of having landed on the island would be an extended sequence of high-energy \( \alpha \)-particles, ending in spontaneous fission as the nuclei follow a path back from the island, only to vanish in the sea of instability. In normal reactions used for forming new nuclei where fission is not a problem, experiments would be carried out above the Coulomb barrier, resulting in excitation energies in the compound nucleus of about 40 MeV, which leads to the evaporation of three to

Figure 2 Schematic view of the binding energy contours showing the prediction of a Superheavy island.

Figure 3 Alpha-particle energy spectra recorded in the focal plane of the Berkeley gas separator, showing the successive removal of events as conditions are applied. Panel (a) shows all events while panel (d) shows the final spectrum of \( \alpha \)-particles correlated in position and within one second of an implant. See ref [1] for details.
Beam energies which are not as far below the Coulomb barrier as would otherwise be the case, can therefore be used. The separator deflects the beam particles and transports residual nuclei formed in reactions to the focal plane of the spectrometer where they are implanted in detectors which can measure and follow in time, the subsequent decays. Rejection of scattered beam and other particles is of paramount importance since random coincidences will easily obliterate any evidence for individual decay sequences that may extend over many minutes. Examples of how the spectra are improved by elimination of events, most of the events in fact, which do not satisfy various conditions are shown in Figure 3. After several experiments involving a total dose of about $3 \times 10^{14}$ ions the Berkeley group isolated three events which are the coincidence of the detection of a residue followed by a localised chain of six α-particles, as shown in figure 4. The production rate corresponds to a cross-section $\sim 2$ picobarns, orders of magnitude below the predictions! No known nuclei exhibit the observed decay sequence of energies which begins with a 12.4 MeV α-decay, or the observed lifetimes. The energies and approximate lifetimes agree with predictions for element-118 and the authors argue that the compound nucleus 291118 is likely to emit a single neutron, so they assign the primary α-decay to 291118, yielding the first synthesis and observation of the superheavy elements 291118, 291116, 291114, 291112, 291110 291118 (Z=108) and 291112/2. Not a bad haul for three events.

The initial comparison with theory, which is reproduced in figure 5, shows good agreement with the recent work of Smolans'czuk [7] but not with others which reproduce the first step of the decay but deviate in predicted α-particle energy, and therefore relative binding energy, at $Z=114$.

The experimental work of the Dubna-Livermore collaboration has centred on element-114 produced in reactions of $^{48}Ca$ on isotopes of $^{249}Pu$ and $^{244}Pu$, using in this case a highly sensitive electrostatic recoil separator with similar time-correlated detection systems in its focal plane. Again, the cross-sections are in the picobarn region so that after a bombardment of about $5 \times 10^{14}$ $^{48}Ca$ ions on $^{249}Pu$ at energies which would lead to the evaporation of three neutrons (relatively hot reactions) they have one event assigned to 291114, with three sequential α-decays followed by spontaneous fission, a sequence beginning with a remarkable long lifetime of 30 seconds (much longer then the $\sim 1$ ms decay of 291114 observed in the Berkeley chain) and taking 34 minutes in all. After a bombardment of $5 \times 10^{14}$ $^{48}Ca$ ions on $^{249}Pu$, they assign two events to a short sequence beginning with an α-decay from 291114 and then spontaneous fission from the daughter 291112. It seems that 1 in $10^8$ is a handy rule-of-thumb for production cross-sections.

The shorter the α-chains, and the longer the lifetimes, the more difficult the identification, and the assignments rely on comparisons with theory since neither Z nor A has been measured directly. You might also have spotted Catch-22; the most stable superheavies could have extremely long lifetimes, years even, which would compromise any of the methods which have brought success so far, but could open the prospects for trapped-atom studies, and single-atom chemistry.
Whatever the difficulties, the results have stimulated yet more theoretical calculations as it is recognised how sensitive the predictions are to microscopic details, particularly as most of these new results pertain to odd-neutron nuclei. The specific orbit of the unpaired particle may affect the appearance of shell gaps, and depending on its quantum numbers, may govern between which states the α-decays proceed [8]. Odd-A nuclei can have several states close to ground so that Q-values have to be calculated for decays between related high-j states, for example, rather than between the orbits which coincidentally form the successive ground-states. Which orbits will be present depends critically on the nuclear shape, as does the extra stability that might be associated with the (non-spherical) sub-shell gaps that occur when nuclei are deformed. Heavy nuclei with $Z = 108$ and $N \sim 162$ are believed to be deformed, for example.

Nuclear structure plays another role then, and observation of ground states is only the first step in characterisation. Whether the nucleus is spherical or deformed is reflected in the pattern of excited states such as those corresponding to collective rotation. These of course are much harder to identify but just as there have been major advances in techniques for finding ground-state decays, very efficient arrays of γ-ray detectors, such as Gammasphere, have been developed for studying the excited states that precede population of the lowest state. When coupled to instruments such as the Fragment Mass Analyser at Argonne National Laboratory to select out the residual nuclei, even superheavy nuclei might be accessible. Those studies are quite a few-Z behind of course, but they have reached Z=102, with the recent identification of rotational bands in $^{258}$No [9].

On the local scene, one of the research groups at the Australian National University, whose members are recognised experts in how the fusion of heavy nuclei in the region of the Coulomb barrier is affected by the structure of the colliding nuclei [10], will soon be commissioning a superconducting solenoid to separate fission and fusion products with high sensitivities. The synthesis of very heavy elements will be one of the pursuits using beams from the coupled 14UD-LINAC accelerators now in operation. The new results are exciting but a lot more is needed to chart the superheavy island. Of course the real question is what is next in the series Hassium, Meitnerium, ...? I hope it’s something easy to say!

Further reading:
G.T. Seaborg and W. Loveland,  
*The Elements Beyond Uranium*  
(Wiley, New York, 1990)

S. Hofmann,  
*New elements-approaching Z=114*  

References


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**Postdoctoral Fellow (Fixed-Term) (In Bose-Einstein Condensation)**

Applications are invited for a Postdoctoral Fellowship to carry out research in experimental Bose Einstein condensation (BEC). Having produced Bose condensation, the Otago BEC Group is now investigating condensate properties as part of a newly forming atom-laser research programme. Our interests include condensate growth (in-system wave amplification), atom-laser coupling, and atom interferometry. In addition to making a substantial contribution to the research programme, the successful candidate will be expected to assist with the supervision of graduate students in the BEC Group. Applicants should be highly motivated, be comfortable working in a team environment, and have postdoctoral or PhD research experience in experimental atomic and laser physics. Preference will be given to candidates with experience in laser cooling, atom optics, and Bose condensation. The position is available from 1 February 2000, for a period of two years.

Salary: Appointment will be as a Postdoctoral Fellow at NZ$45,000 per annum.

Specific enquiries should be directed to Dr Andrew C. Wilson, Department of Physics, University of Otago, PO Box 56, Dunedin, New Zealand (Tel 64 3 479 8365, Fax 64 3 474 1660) or email aaron.barker@otago.ac.nz. Further information about the University of Otago can be found at our website at http://www.otago.ac.nz

Further details regarding this position, the University, and the application procedure are available from the Deputy Director, Personnel Services, University of Otago, PO Box 56, Dunedin, New Zealand (Tel 64 3 479 7749, Fax 64 3 479 0064, email avwolsc@otago.ac.nz). Further details about the University of Otago can be found at our website at http://www.otago.ac.nz

Applications should be sent to the University of Otago, instead of this journal. Equal opportunity to employment is University policy.
Establishment of Topical Groups within the AIP

1. Topical Groups may be established by the Executive in areas of significant general interest to the membership. The aims, objectives and activities of such groups should be consistent with those normally associated with the Institute.

2. The establishment of a Topical Group shall only be considered after a written submission to the Executive signed by not less than 5 financial members of the Institute. The annual council meeting will review the establishment of Topical Groups approved by the Executive.

3. While the Executive will consider any application for establishment of a Topical Group, an application is likely to be successful only if it is consistent with the guidelines listed below:
   (a) The application should detail the grounds for believing that the Group has the potential to attract a membership of at least 5% of the Institute within a period of not more than 3 years.
   (b) The Group should have identifiable office positions, named official office bearers (Chair, secretary and treasurer with full contact details) and a defined mechanism for election of future office bearers. These persons shall be responsible for conducting the affairs of the Group and reporting to the Executive on an annual basis on the activities and expenditure of the Group. Such reports should normally be provided no later than 31 December of each year.
   (c) If the Group raises funds through the AIP membership renewal process or if it otherwise is allocated funds through the Institute or obtains funds in any way through the use of its name, such funds will be held in accounts under the direct control of the Treasurer. Deviations from this rule will only be possible with the written permission of the President. Such written permission will only be given after passage of a resolution to this effect by the Executive on the motion of the Treasurer.
   (d) Annual fees charged by Topical Groups which are to be collected through the annual membership renewal process shall require approval of the Executive. Such approval shall normally require a submission to the Executive not later than 2 months before the end of the financial year and such submission should contain an indicative budget.
   (e) Topical Groups should present a written report to each annual AIP Council meeting.
   (f) A Topical Group should endeavour to promote its activities through active involvement in AIP Congresses. In general, this would normally mean the organisation of some form of session at the Congress unless other effective meeting arrangements are in place.
   (g) The membership of the Topical Group will comprise financial members of the Australian Institute of Physics.
   (h) A Topical Group may be disbanded by the Executive after a written request to this effect signed by at least two senior office Bearers of the Group. In the absence of such a request, a Group may be disbanded only by Council on a resolution proposed by the Executive. Such a resolution shall require the normal notice provisions of Council and shall in addition require written notice to the Office Bearers of the Group at least one month prior to the meeting of Council.
   (i) If a Topical Group ceases to exist, all funds and assets shall revert to the AIP.
   (j) These Guidelines may be amended from time to time by resolution of the Executive.

AIP Executive

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**Australian Journal of Physics**

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**1999 Walter Boas Medal**

It is the decision of the Australian Institute of Physics that the Walter Boas Medal will not be awarded this year.

Moira Welch,

Honorary Secretary
THE BAXTER REVOLUTION

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I review the revolutionary impact Rodney Baxter has had on statistical mechanics beginning with his solution of the 8-vertex model in 1971 and the invention of corner transfer matrices in 1976 to the creation of the RSOS models in 1984 and his continuing current work on the chiral Potts model.

Introduction

At the beginning of the 20th century statistical mechanics was conceived of as a microscopic way to understand the laws of thermodynamics and the kinetic theory of gases. In practice its scope was limited to the classical ideal gas, the perfect quantum gases and finally to a diagrammatic technique devised in the 30's for computing the low density properties of gases. At that time there was even debate as to whether the theory was in principle powerful enough to include phase transitions and dense liquids.

All of this changed in 1944 when Onsager [1] demonstrated that exact solutions of strongly interacting problems were possible by computing the free energy of the Ising model. But, while of the greatest importance in principle, this discovery did not radically alter the field of statistical mechanics in practice. However, starting with the beginning of the 70's Rodney Baxter took up the cause of exactly solvable models in statistical mechanics and from that time on the field has been so totally transformed that it may truly be said that a revolution has occurred. In this paper I will examine how this revolution came about.

The Eight Vertex model

Onsager's work of 1944 was monumental but cannot be said to be revolutionary because its consequences were so extremely limited. Kaufman and Onsager [2,3] reduced the computations to a free fermi problem in 1949 and after Yang [4] computed the spontaneous magnetization in 1952 there were no further developments. Indeed the reduction of the solution of the Ising model to a free fermi problem had the effect of suggesting that Onsager's techniques were so specialized that there might in fact not be any other statistical mechanical models which could be exactly solved.

It was therefore very important when in 1967 Lieb [5] introduced and solved (cases of) the six vertex model. This showed that other exactly solvable statistical mechanical problems did indeed exist. Lieb found that this statistical model had the very curious property that the eigenvectors of its transfer matrix were exactly the same as the eigenvectors of the quantum spin 1/2 anisotropic Heisenberg chain

$$ H = -\frac{1}{2} \sum_{\alpha} (\sigma_\alpha^x \sigma_{\alpha+1}^x + \sigma_\alpha^y \sigma_{\alpha+1}^y + \Delta \sigma_\alpha^z \sigma_{\alpha+1}^z) $$

which had been previously solved [6-9] by methods that went back to the work of Bethe [10] in 1931. This result is particularly striking because the six vertex model depends on one more parameter that does the XXZ spin chain. That extra parameter (which I will refer to as $v$) appears in the eigenvalues of the transfer matrix but not in the eigenvectors. The reasons for this curious relation between the quantum spin chain in one dimension and the problem in classical statistical mechanics in two dimensions were totally obscure.

At that time the author was a post doctoral fellow and he and his thesis advisor in a completely obscure paper[11] explained the relation between the quantum and classical system by demonstrating that the transfer matrix for the six vertex model $T(v)$ commutes for all $v$ with the Hamiltonian (1) of the XXZ model.

$$ [T(v), H] = 0 $$

This commutation relation guarantees that the eigenvectors of $T(v)$ are independent of $v$ and that they are equal to the eigenvectors of $H$ without having to explicitly compute the eigenvectors themselves.

The next year Sutherland[12] found an identical commutation relation between the quantum Hamiltonian of the XYZ model

$$ H_{XYZ} = \sum_{j=1}^N (J_1 \sigma_j^x \sigma_{j+1}^x + J_2 \sigma_j^y \sigma_{j+1}^y + J_3 \sigma_j^z \sigma_{j+1}^z) $$

and the transfer matrix of the eight-vertex model. But since neither the eight vertex model nor the XYZ model had been solved this commutation relation merely related two equally intractable problems.
All mysteries were resolved when in 1971 Baxter solved both the eight vertex model and the XYZ model [13-15] at the same time and moreover solved them by inventing methods of such power and generality that the course of research in statistical mechanics was permanently altered. This is the beginning of the Baxter revolution.

The first revolutionary advance made by Baxter [13-15] was the generalization of

$$ \left[ T(v), H \right] = 0 \quad \text{to} \quad \left[ T(v), T(v') \right] = 0 $$

(4)

and that as \( v \to 0 \)

$$ T(v) \sim T(0)(1 + cv + vH_{\text{asy}}) $$

(5)

This generalization is of great importance because it relates a model to itself and can be taken as a general criterion which selects out particular models of interest. Moreover, Baxter demonstrated the existence of this global commutation relation by means of a local relation between Boltzmann weights. Baxter called this local relation a star triangle relation because the first such relation had already been found by Onsager [1,16] in the Ising model and Onsager had referred to the relation as a star triangle equation. A related local equation had been known since the work of McGuire [17] and Yang [18] on the quantum delta function gases but its deep connection with the work of Onsager had not been understood. The search for solutions of the star triangle equation has been of major interest ever since and has led to the creation of the entirely new field of mathematics called “Quantum Groups” [19-20]. The Baxter revolution of 1971 is directly responsible for this new field of mathematics.

The second revolutionary step in Baxter’s paper [13] is that in addition to the commutation relation (4) he was able to obtain a functional equation for the eigenvalues of the transfer matrix and from this he could obtain equations which characterized the eigenvalues. In the limit where the eight vertex model becomes the six vertex model these equations reduced to the Bethe’s equations previously found by Lieb [5]. But Lieb found his equations by finding expressions for all of the eigenvectors of the problem whereas Baxter never considered eigenvectors at all. It is truly a revolutionary change in point of view to divorce the solution of the eigenvalue and eigenvector problems and to solve the former without knowing anything of the latter. This technique has proven to be of utmost generality and, in fact, for almost every solution which has been found to the star triangle equation a corresponding functional equation for eigenvalues has been found. On the other hand, the study of the eigenvectors, which was the heart of the solution of the six vertex and XXZ models has almost been abandoned.

The final technique introduced by Baxter is the thorough going use of elliptic functions. Elliptic functions, of course, have been used in physics since the days of the heavy symmetric top and are conspicuously used in Onsager’s solution of the Ising model. But even though elliptic functions appear in Onsager’s final expression for the free energy of the Ising model they play no role in either Onsager’s original algebraic solution or in Kaufman’s free fermi solution. On the other hand there are steps in Baxter’s solution where the elliptic functions are essential. It is quite fair to say that just as Onsager invented the loop group of \( g \), in his solution of the Ising model, Baxter in his 1971 paper first introduced the essential use of elliptic and modular functions into 20th century physics.

The corner transfer matrix

It took Onsager 5 years from the computation of the Ising model free energy before he made public his conjecture for the order parameter [21]. Baxter was much more prompt in the case of the eight vertex model and produced with Barber in 1973 a conjecture for the order parameter [22] a mere two years after the free energy was computed. For the Ising model it took another three years to go from the conjecture to a proof [4]. For the eight vertex model it also took Baxter three years to obtain a proof of the conjecture.

The details of Baxter’s proof are contained in two separate papers [23,24] and form the subject of chapter 13 of his 1982 book Exactly Solved Models in Statistical Mechanics [25]. It is even more revolutionary than the 1971 free energy computation. Baxter not only abandons the use of the eigenvectors of the row to row transfer matrix (which had been retained in his 1973 computation of the free energy of the six vertex model order parameter [26]) but he abandons the use of the row to row transfer matrix altogether. In its place he uses a completely new construct which had never been seen before and which had absolutely no precursors in the literature: the corner transfer matrix.

A transfer matrix builds up a large lattice one row at a time. In an \( L \times L \) lattice of a 2 state per site model it has dimension \( 2^L \). A corner transfer matrix builds up a lattice by adding one quadrant at a time and has dimension \( 2^{2L} \). The spin whose average is being computed lies at the corner common to all four quadrants. Order parameters are computed from the eigenvector of the ground state of the row to row transfer matrix. For the corner transfer matrix the order parameter is expressed in terms of the eigenvalues and the eigenvectors are not needed.

Thus far the philosophy of the order parameter computation has followed the spirit of the free energy computation in that all attention has been moved from eigenvectors to eigenvalues. But in order to make this a useful tool Baxter takes one more revolutionary step. He takes the thermodynamic limit before he obtains equations for the eigenvalues. This is exactly the opposite from what was done in the free energy computation where the equations are obtained first and only in the end is the thermodynamic limit taken.

This early introduction of the thermodynamic limit has a very dramatic impact on the eigenvalues of the corner transfer matrix. To see this we note that the matrix elements of the corner transfer matrix are all quasi-periodic functions of the spectral variable \( v \). This is of course also true for the row to row transfer matrix. It is thus a natural argument to make to say that a matrix with doubly periodic elements should have quasi-periodic eigenvalues and this is in fact true for the row to row transfer matrix. But for the corner transfer matrix the taking of the
thermodynamic limit has the astounding effect that the eigenvalues, instead of being elliptic functions all become simple exponentials $e^{\pm \lambda}$. Once these very simple exponential expressions for the eigenvalues are obtained it is a straightforward matter to obtain the final form for the spontaneous magnetization of the eight vertex model, but all along the way, it is fair to say, a great deal of magic has been worked.

The RSOS models

The next stage in the Baxter revolution is the discovery and solution of the RSOS model by Andrews, Baxter and Forrester in 1984 [27]. As in the case of the eight vertex model revolution in 1971 there were several precursor papers, this time all by Baxter himself.

It has been stressed in the preceding sections that Baxter made a revolutionary shift of point of view by discovering that the eigenvalue problems could be solved without solving the eigenvector problems. Therefore for the six vertex and XXZ model Baxter could obtain the Bethe's equations for the eigenvalues without recourse to the Bethe's form of the eigenvector

$$\psi(x_1, x_2, \ldots, x_n) = \sum_\tau A(\tau) e^{\sum_{i<j} \tau_{ij}}$$

(6)

In the previous work on the six vertex and XXZ models the restriction was made that all the $k_i$ were distinct. It was therefore quite a surprise when in 1973 Baxter discovered [28] that in the XXZ chain (1) when

$$\Delta = \frac{1}{2} (q + q^{-1}) \quad \text{and} \quad q^{2\tau} = 1$$

(7)

that there are in fact eigenvectors of the XXZ chain for which the $k_i$ of (6) are equal. For these solutions the $k_i$ obey

$$\Delta e^{\phi_i} - 1 - e^{\phi_i + k_i} = 0$$

(8)

and this case had been tacitly excluded in all previous work.

In [28] Baxter generalized the root of unity condition (7) of the six vertex model to the eight vertex model and he found an entire basis of eigenvectors which in a sense makes maximal use of the violation of the previously assumed condition $k_i \neq k_j$.

Baxter is thus able to re-express these root of unity eight vertex models in terms of what he calls in his 1973 paper an "Ising-like model."

Baxter's next encounter with root of unity models was in 1981 when he solved the hard hexagon model [29]. In this most remarkable paper Baxter uses his corner transfer matrices to compute the order parameter of the problem and in the course of the computation discovers the identities of Rogers [30] and Ramanujan [31] which were first found in 1894

$$\sum_{k} \frac{q^{(a+x)k}}{(q)_k} = \frac{1}{(q)_x} \sum_{k} q^{a(k+1)+xk} - q^{a(k+2)+x(k+1)}$$

(9)

where $(q)_x = \prod_{i=0}^{x-1} (1-q^i)$ and $a = 0, 1$. Baxter was clearly impressed that these classic identities appeared naturally in a statistical mechanics problem because he put the term "Rogers-Ramanujan" in the title of the paper. Because the right hand side of (9) is obviously written as the difference of two theta functions we once again see that modular functions appear naturally in statistical mechanics.

But neither the 1973 nor the 1981 papers can be called genuinely revolutionary because neither of them was seen to have general applicability.

The revolution that allowed the general applicability of Baxter's techniques is carried out in the paper of 1984 with Andrews and Forrester [27] and the companion paper by Forrester and Baxter [32] in which it was shown that the hard hexagon model of [29] is obtained from a special case of the "Ising-like models" found in the root of unity eight vertex models in 1973 and 1981. These Ising-like models are now called eight vertex solid-on-solid models and the restriction needed to obtain the hard hexagon model is in the general case called the restricted solid-on-solid model. Starting from this formulation of the RSOS models the order parameters are computed by a direct application of the corner transfer matrix method and at the step where in the hard hexagon model the identity (9) was obtained the authors of [27,32] instead solve a path counting problem and find the general result

$$\frac{1}{q_x} \sum_{k} (q^{(a+x)k}-q^{a(k+1)+xk})$$

(10)

where the relatively prime integers $p$ and $p'$ effectively parameterize the root of unity condition $\Delta$. This sum in this result is obviously the difference of two Jacobi theta functions and thus we see that all the RSOS models lead to theta functions. But most remarkably the exact same expression (10) was discovered at the same time to arise in the expression of the characters [33,34] of the minimal models $M(p,p')$ of conformal field theory [35] and these models were soon thereafter obtained as cosets [36] of the affine Lie algebra $A_{1}(q)$.

It thus became clear that the statistical mechanics of RSOS models, conformal field theory, and affine Lie algebras are all part of the same subject and from this point forth the results of statistical mechanics appear in such apparently unrelated fields as string theory, number theory and knot theory. Baxter's corner transfer matrix was seen to be intimately related to constructions in the theory of affine Lie algebras involving null vectors and the corner transfer matrix computations of Baxter's statistical models were rapidly generalized from the affine Lie algebra $A_{1}(q)$ to all affine Lie algebras. Solvable statistical mechanical models were now seen everywhere in physics and Baxter's methods were subject to vast generalization.

The chiral Potts model

For a few years it was thought that the revolution was complete and that corner transfer matrix methods and group theory could solve all problems which started out from commuting transfer matrices. This was changed however when the chiral Potts model was discovered in 1987 [37]. This model does indeed satisfy the condition of commuting transfer matrices (4) and the Boltzmann weights do obey a star triangle equation but
unlike all previously seen models the Boltzmann weights are not parameterized either by trigonometric or elliptic functions but rather are functions on some higher genus spectral curve. There is a modulus like variable $k$ in the model and when $N=3$ the genus of the curve is 10 if $k \neq 0, 1$ and if $k = 1$ the curve is the very symmetric elliptic curve $x^3 + y^3 = z^3$. If $N = 4$ and $k = 1$ the curve is the fourth order Fermat curve $x^4 + y^4 = z^4$ which has genus three [38].

As would be expected Baxter rapidly became interested in this problem and soon Baxter, Perk and Au-Yang [39] found that for arbitrary $N$ and $k$ the spectral curve has the very simple form

$$a^N + kb^N = k'c^N \quad \text{and} \quad ka^N + b^N = k'c^N$$

(11)

with $k' = k^N$. When $N = 2$ this curve reduces to an elliptic curve and the chiral Potts model reduces to the Ising model. However, in general for $k \neq 0, 1$ the curve has genus $N^2 - 2N + 1$ and for $k = 1$ the curve reduces to the Nth order Fermat curve of genus $(N-1)(N-2)/2$.

The first thing to attempt after finding the Boltzmann weights for the chiral Potts model is to repeat what had been done so many times before and to obtain a functional equation for the eigenvalues. That was soon done [40-44] but the next step in Baxter's program was not so easy because the methods of solution of this functional equation which relied on the properties of genus 1 elliptic functions did not work. Solutions for the free energy which bypassed the elliptic functions were soon found [40-44] but the fact that new methods were needed indicated that the revolution was not yet complete.

The greatest puzzle was set up in 1989 when after generalizing earlier work on the $N=3$ state model [46] it was conjectured [46] on the basis of extensive series expansions that the order parameters of the $N$ state chiral Potts model are given by

$$M_n = (1 - k')^{2N-n-2} \text{ for } 1 \leq n \leq N - 1$$

(12)

This remarkably simple expression reduces to the result of Onsager [21] and Yang [4] for the Ising model when $N = 2$ and is a great deal simpler than the order parameters for the RSOS models [27,32]. The first expectation was that Baxter's corner transfer matrix methods could be applied to prove the conjecture true and the first attempt to do this was made by Baxter in [48]. In this paper Baxter gives a new and very transparent derivation of the corner transfer matrix methods and he reduces the computation of the order parameter to a problem of the evaluation of a path ordered exponential of non-commuting operators over a Riemann surface. Such a formulation sounds as if methods of non Abelian field theory could now be applied to solve the problem. Unfortunately to quote Baxter in a subsequent paper [49] "Surprisingly the method completely fails for the chiral Potts model."

The reason for the failure of the method is that the introduction of the higher genus curve into the problem has destroyed a property used by Baxter and all subsequent authors in the application of corner transfer matrix methods. This property is the so called difference property which is the property, shared by the plane and torus but by no curve of higher genus, of having an infinite automorphism group (the translations). It is this property which was used to reduce the eigenvalues to exponentials in the spectral variable and it is not present in the chiral Potts model.

**Future Prospects**

The discovery of the chiral Potts model has now made it clear that the Baxter revolution has met up with problems in algebraic geometry which have proven intractable for almost 150 years. Baxter has investigated these problems now for almost a decade [48-52] and it is clear that the solution of these physics problems will make a major advance in mathematics. But even with this evaluation of current problems the impact of Baxter's revolution is clearly seen. Mathematics is no longer treated as a closed finished subject by physicists. More than anyone else Baxter has taught us that physics guides mathematics and not the other way around. This is of course the way things were in the 17th century when Newton and Leibnitz invented calculus to study mechanics. Perhaps in the intervening centuries in the name of being experimental scientists we physicists drifted away from away from doing creative mathematics. The work of Rodney Baxter serves now and will serve in the future as a beacon of inspiration to all those who believe that there is a unity in physics and mathematics which provides inspiration that can be obtained in no other way.

**Acknowledgments**

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**References**

Quantum Computer Research Centre Announced

The ARC recently announced funding for a Commonwealth Special Research Centre for Quantum Computer Technology.

80 scientists will take part drawn from the Schools of Physics and Electrical Engineering at the University of NSW, the Schools of Physics at the University of Queensland and the University of Melbourne, and in the U.S., the Los Alamos National Laboratory and the University of Maryland (Bruce Kane).

The Centre will be directed by Professor Bob Clark of UNSW with Professor Gerard Milburn of UQ the Deputy Director.

The prime aims of the centre are to firstly establish a two quantum bit (qubit) operation and secondly to develop industrially robust techniques to scale this elementary component up to a large computer.

The fundamental bits of the computer will be realised as up or down spins of phosphorus nuclei introduced into a silicon substrate. A method must be devised to place the phosphorus atoms in a regular array with the atoms about 20 nm apart. The spins can then be brought into coherence with each other resulting in quantum entanglement and a superposition of correlated quantum states. With a large number of Phosphorus atoms parallel computing becomes possible.

Professor Clark explains it in this way: suppose a hotel detective needs to find a missing briefcase but he has no idea which of the 100 hotel rooms it is in. He will have to look in each room separately. But with quantum-related hotel rooms, there will be a unique quantum state of the hotel for the briefcase in Room 42. The detective has only to look at the hotel state as a whole and he knows immediately which room holds the briefcase! The phosphorus nuclei will relate in a similar way.

A significant problem to be solved is how to read out the states of the nuclei without destroying their information. UNSW will be working on a single electron transistor method. Los Alamos is studying a mechanical readout mechanism using a femtogram cantilever while UQ is investigating optical readout methods.

The diagram shows the plan for the UNSW prototype. The A gates, located above each Phosphorus atom, change the spin orientations by means of a pulse of RF field tuned to the Stark-shifted resonance frequency for the particular spin. The J gates control the interaction between the atoms by means of an applied voltage. Each gate will need to be individually calibrated and the calibration information stored on a chip.

The parallelism of the quantum computer is so powerful that an array of 30 qubits will rival one of today’s supercomputers. A full scale computer with a million qubits will make unimaginable power available.

Professor Clark emphasises how this project can only become possible because of the teamwork involved with many people working on different aspects of the problem. He is also concerned to see that the benefits arising from such a fairly high risk investigation should accrue to Australia.

Teleporting using Quiet Light

The possibility of teleporting objects like precious stones or artworks is being investigated by Professor Hans Bachor and Dr Ping Koy Lam at the ANU.

Normal light beams will always contain some noise due to the quantum nature of light and Heisenberg’s Uncertainty Principle. Recall that a light wave may be expressed as

$$X(t) = X_0 \sin(\omega t) + X_2 \cos(\omega t)$$

Methods now exist to “squeeze” the noise into one of these components so that the noise in the other component becomes negligibly small. In this way information can be transmitted without the introduction of noise and so a perfect copy can be “teleported”.

If another person tries to tap into the signal, then this can be detected when it is received. It is not possible to covertly monitor the information being transferred.

The Australian 5 October 1999
THE NOBEL PRIZE IN PHYSICS 1999

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What's it all about, Alfred?

Since the end of the Second World War to 1998, there have been thirteen Nobel prizes awarded to experimental particle physics, but only five awarded to theoretical work:

* 1949 to H Yukawa, for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces.
* 1957 to T D Lee and C N Yang, for their penetrating investigation of the parity laws, which has led to important discoveries regarding elementary particles.
* 1965 to S Tomonaga, J Schwinger and R P Feynman, for their fundamental work on quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles.
* 1969 to M Gell-Mann for his contributions and discoveries concerning the classification of elementary particles and their interactions.
* 1979 to S Glashow, A Salam and S Weinberg, for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including inter alia the prediction of the weak neutral current.

To this distinguished list we may now add

* 1999 to G't Hooft and M Veltman, for elucidating the quantum structure of electroweak interactions.

More fully, the Royal Swedish Academy of Sciences citation reads: "The two researchers are being awarded the Nobel Prize for having placed particle physics theory on a firmer mathematical foundation. They have in particular shown how the theory may be used for precise calculations of physical quantities. Experiments at accelerator laboratories in Europe and the USA have recently confirmed many of the calculated results."

To non-experts in particle physics there are a few terms which require explanation: (i) how have they elucidated electroweak theory, (ii) in what way have they firmed up particle physics theory, and (iii) what accelerator experiments have confirmed many of the calculated results? To provide an answer to all of these questions it is good to stand back and take a panoramic view of mainstream particle physics to perceive where 'tHooft and Veltman's seminal work fits in. (I'll have practically nothing to say about strong, nuclear interactions and will steer clear of concepts like supersymmetry and string theory - although those ideas are elegant and have many loyal adherents, they are still some way off making contact with experimental data, and it's not for want of trying!)

There are at least three separate strands (often interwoven) to theoretical particle physics, namely (a) the formal development of relativistic quantum field theory, (b) its perturbative expansion and techniques of calculation, (c) its application to models of elementary particle interactions. In my view 'tHooft and Veltman's research falls under category (b). In this talk I will attempt to cover the period from about 1945 to 1975, indicating the main players in the development of the subject - and there are a lot as you will see from the references. Hopefully I'll be able to show you the significance of 'tHooft and Veltman's contributions within the grand scheme, viz. how they provided precise calculation methods and tools for evaluating processes in (spontaneously broken) gauge models of elementary particles; how recent experiments at accelerator laboratories are now able to probe accurately the principal predictions of theory and how the results have passed the test with flying colours in every case so far. Now for the details...

Quantum electrodynamics

The 1965 Nobel prize was awarded to Feynman, Tomonaga and Schwinger for their 1940s development of quantum electrodynamics (QED): the interactions between charged particles and the electromagnetic field. There are four key features of their work [1] which are highly relevant to this year's prize:

* The theory contains a small dimensionless parameter called the fine structure constant, \( \alpha = e^2/4\pi\hbar c \equiv 1/137.036 \). Measurable quantities \( Q \) are all expressed via a perturbation expansion, \( Q = \Sigma \alpha^n Q_n \).
* The coefficients \( Q_n \) above are most simply evaluated through Feynman diagrams - pictures which encapsulate precise calculational information and which provide a nice physical description of the processes. Calculations have so

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1 The series in \( \alpha \) is actually an asymptotic one [2] and breaks down at large enough \( \alpha \). For strong interactions where the parameter \( \alpha \) is larger, convergence becomes more serious.
far been done to order $\alpha^4$ and can predict the experimental results to 1 part in 1 billion or better, making this most accurately tested theory we have, excepting pulsar timing studies perhaps.

* QED is an example of a ‘gauge theory’: it possesses an (Abelian) invariance under local changes of phase of the charged fields. We now know that there are other important physical theories which are gauge-invariant, namely gravitation (local Lorentz invariance), quantum chromodynamics (colour phase invariance) and electroweak theory - which we will look at soon.

* QED is an example of ‘renormalizable theory’ [3]. What this means is that certain of the Feynman diagrams produce infinities - like logarithmic $\int d^4k/(k^2-M^2)$ — which require ‘regularization’, but luckily these only occur in particular varieties and can be dully accommodated; they amount to a redefinition of the physical parameters (mass and charge) and scales of the fields.

To expand, let me firstly concentrate on the ‘gauge property’ of QED as it plays a big role in the award of the 1999 Price. Electrodynamics is governed by the Lagrangian,

$$L = \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}e A_{\mu}A^{\mu} - j_{\mu}A_{\mu},$$

where $e$ & $m$ are the electronic charge & mass, $\psi$ is the (complex, spinor) electron field and $A$ is the (vector) electromagnetic potential which leads to the Maxwell field $F$. One can easily check that this Lagrangian possesses a quite astonishing property: it stays the same under local phase variations, $\psi(x)\rightarrow\exp(ie\Lambda(x))\psi(x)$, provided that also the ‘messenger’ field $A(x)\rightarrow A(x) - \Lambda(x)$. This is called a gauge transformation of the fields, and the physical results must remain blind to such variations since they do not affect the Lagrangian. Observe that the electromagnetic field is essential for the gauge cancellation to occur. Notice also that successive phase changes commute: they can be carried out in any order and constitute an Abelian group. The combination $D = \partial + ieA$ is called the covariant derivative and ensures that the field derivative $D\psi = \exp(ie\Lambda(x))D\psi$ transforms nicely. The gauge freedom is something of a hindrance when one comes to quantize the electromagnetic field: in practice one chooses a particular gauge, corresponding to some condition on $A$; this is done by adding a ‘gauge-fixing’ term to $L$ that looks as though it will spoil the gauge invariance; nevertheless, one can prove [4] that physical results are not affected by the fixing, because of electromagnetic current conservation, and that measurable or ‘on-shell’ quantities remain properly gauge-independent.

Secondly, I want to say something about the renormalizability of QED as this is what makes for reliable perturbative calculations. Rules exist for evaluating Feynman graphs: these involve sewing three-vertex points (associated with the interaction $e\psi\gamma^\mu A$) with propagator lines of the electron, $S(p) = 1/(p^2 - m)$, or of the photon, $\gamma(p) = -\eta_{\mu\nu}p^\mu/p^\nu$ (in the Feynman gauge say). The photon has only 2 physical transverse degrees of freedom, whereas the photon propagator seems to contain 4 components through its vector indices; the contradiction is resolved by realizing that the longitudinal spatial contributions of the photon cancel those of its time-like components. This ensures that processes conserve probability, or that the $S$-matrix is ‘unitary’ in standard jargon. Because the high momenta behaviour of the lines is $-1/p$ for electrons and $-1/p^2$ for photons, it turns out that only a few processes can give birth to infinite amplitudes and these only depend on the number and nature of the external particles. This is a great blessing, because the infinities are only attached with an electron line, a photon line or with the electron-photon vertex, allowing us to absorb them into redefinitions of mass and charge - redefinitions which would have to be done anyhow, except that they happen to be infinite in QED. After renormalization all processes to any loop order produce finite results and, as mentioned already, they have been verified to unprecedented accuracy. A good (but not sufficient) rule for knowing when a theory is renormalizable is to check whether there occur any coupling constants with natural $(\hbar = c = 1)$ dimensions of ‘inverse mass’; in QED the electron charge $e$ is dimensionless, so we are safe.

Thirdly, I should mention that the generalization from an Abelian to a non-Abelian phase group is far from trivial. It was first achieved by Yang & Mills and Shaw [5]. Suppose for simplicity that the gauge group is the rotation group SU(2), operating on a doublet of states. Because elements of the gauge group are non-commuting (like the spin matrices in quantum mechanics) the covariant derivative generalization to $D = \partial + ig A \cdot \hat{T}$, where $T = \sigma/2$ are the generators, no longer commute. This means that the corresponding

$$[D_{\mu}, D_{\nu}] / g = \hat{T}_{\mu\nu} = \hat{T}_{\mu}, \hat{A}_{\nu} - \hat{A}_{\mu}, + g \hat{A}_{\mu} \times \hat{A}_{\nu},$$

contains a quadratic $A$ term, which never arises in QED. In the late 50s, several attempts were made to apply this idea to strong interactions, where an isospin group is known to operate between neutrons and protons, but without much success: for one reason, no vector mesons were discovered then and for another reason, the vector mesons which did eventually rear up are certainly not massless as Yang-Mills theory demands. Thus this non-Abelian extension remained dormant for a good while until it was revived in the early 70s in the context of electroweak theory [6]. The first convincing proofs that that massless non-Abelian gauge theory is renormalizable were provided by ‘Hooft, Lee and Taylor[7], despite its low-energy difficulties. These proofs made use of the fact that it is crucial to include ‘ghost’ fields [8] in order to restore probability conservation for intermediate states which enter the Feynman diagram calculations. Without the ghosts and their couplings to the gauge fields, everything goes away, and the same remark applies to quantized gravity.

From weak to electroweak

All that time weak interactions remained problematic. It took much toll for experimentalists and theorists to converge on the correct (vector-axial) nature of the Fermi weak coupling between 4 fermions involved in the $\beta$-interaction, e.g. the neutron decay Lagrangian,

$$\mathcal{L}_\nu = G_F [\bar{\nu}(1 + i\gamma_5)\nu][\bar{\nu}(1 - i\gamma_5)\nu]/\sqrt{2}.$$
Despite the nice features [9] that \( \mathcal{L}_e \) is invariant under fermion reshuffling, is maximally parity-violating and is consistent with a massless left-handed neutrino, it was soon realized that the dimensional nature on the Fermi coupling \( G_F \) (293 GeV){superscript}\(^2\), produced unmanageable or unrenormalizable quantum infinities that get ever worse in higher orders of \( G_F \) expansion; hence predictability is lost.

The solution to this problem lies in invoking weak bosons as the carriers of the weak beta-force, in analogy to mesons being the carriers of the strong force and photons being the carriers of the electromagnetic force. Again it took a dozen years for the proper version [6] of this 'electroweak' theory to be put out and it is a story worth retelling in its own right, since it represents another Nobel Prize (1979). I can only highlight its main features here.

- Fields are characterised into two types: of right- or left-chirality (chirality means spin along direction of motion for massless particles). The neutrinos produced in beta decays seem to be left-handed while charged leptons and quarks, which make up the hadrons, exist in both chiralities, because they are definitely massive.
- The leptons and their own neutrinos are grouped into left-handed doublets, so are the quarks. Thus we meet generations of doublets like

\[
\left( \begin{array}{c}
\nu_c \\
\varepsilon
\end{array} \right); \quad \left( \begin{array}{c}
u_d \\
ad
\end{array} \right); \quad \left( \begin{array}{c}
u_u \\
ad
\end{array} \right); \quad \left( \begin{array}{c}
u_d \\
ud
\end{array} \right);
\]

The remaining right-handed (charged) fields are regarded as singlets.
- An SU(2) gauge group is invoked to act on the left-handed fields and a U(1) charge group on left- and right- fields equally. To ensure that the Lagrangian stays gauge invariant, it is necessary to include a triplet of weak bosons \( W^+, W^0, W^- \) and a singlet \( Z^0 \) boson, with their own Yang-Mills interactions.
- The Lagrangian of these left-handed doublets and right-handed singlets produces massless particles in the first instance, because a mass term like \( m(\bar{\psi}_L \psi_R + \bar{\psi}_R \psi_L) \) is banned, being a source of gauge symmetry-breaking.

\[
\mathcal{L} = \bar{\psi}_L \{(i\partial + g\tilde{W}^a T^a + g' V^0)\psi_L + \bar{\psi}_R \{(i\partial + g' V^0)\psi_R - [\bar{F}_{\mu\nu} F^{\mu\nu} + G_{\mu\nu} G^{\mu\nu}] / 4\}
\]

The lack of a mass term presented a big obstacle to progress initially.

- In order for the fermions and bosons to acquire mass it is necessary for the gauge symmetry to be broken spontaneously [10]. This means that even though local invariance is always present, the ground state of the system is not globally symmetric; it points along some direction of group space, rather like a ferromagnetic domain has some direction of spontaneous magnetization, even though the spin-spin interactions which induce the ferromagnetism are rotationally symmetric. Thus the local gauge symmetry gets hidden. This vital ingredient of electroweak theory is most easily implemented by adding a scalar field (called the Higgs boson) which acquires a vacuum expectation value \( \langle \phi \rangle = f \); this is readily arranged through a renormalizable interaction like \( \mathcal{L}_4 = \lambda \phi^4 - f \phi \). In electroweak theory [11] the Higgs scalar \( \phi \) is a doublet; its interactions with the gauge fields and with the fermions automatically induces their masses:

\[
\mathcal{L}_{\phi^4} = [(i\partial + g\tilde{W}^a T^a + g' V^0)\phi]^2 + g_4 (\bar{\psi}_L \phi \psi_R + \bar{\psi}_R \phi^\dagger \psi_L).
\]

* This model yields massive charged vector bosons, which were subsequently discovered, and leads to mixing between the neutral vector mesons. One of the mixed states is the usual massless photon, the other is a massive particle called \( Z^0 \) which was also found at CERN and which led to a hitherto unsuspected weak neutral current[12].

* Current conservation plays a predominant role and must be preserved at all costs. However, regularisation/renormalization introduces a mass scale which can jeopardise gauge invariance by spawning 'anomalous' quantum loop effects; these potentially violate the conservation laws, and especially so for the axial current which couples in part to the weak bosons [13]. It is nothing short of miraculous that such 'axial current' anomalies cancel for the particle multiplet content of the standard model [14].

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**What 'tHooft and Veltman did**

Most people will admit that the electroweak model is not really pretty and many regard it as a stepping stone to something better. Thus it was not until the early seventies that electroweak theory started to gain credibility and a significant following. Before then Veltman had persisted with his research into the renormalization of massive Yang-Mills theory, where the vector mass is effectively put in by hand, thereby spoiling the gauge symmetry. He was confronted by the problem that a massive vector particle propagator,

\[
D_{\mu\nu}(p) = (\eta_{\mu\nu} + p_{\mu} p_{\nu} / m^2) / (p^2 - m^2)
\]

naively behaves as \( \lim_{p^2 \to m^2} D(p) = 1 \), because of the longitudinal \( pp \) piece in the numerator of \( D(p) \). Veltman [15] was able to show that one could cope with one-loop infinities, but that one cannot realistically handle the higher loop infinities. In his words and despite his best efforts "...with respect to renormalization, the situation is not yet clear."

Bouwets [15] provided further confirmation that massive non-Abelian theory was unrenormalizable when a vector mass term is simply planted into \( \mathcal{L} \).

This problem was taken up in 1971 by 'tHooft, Veltman's graduate student. He began by studying massless Yang-Mills theory and showing that it was renormalizable (as did others [7]) provided the infinities were cancelled out so as to preserve the gauge invariance. He gave a combinatorial proof that intermediate states involving longitudinal vectors are always cancelled out by the ghost fields, thereby safeguarding unitarity; being concerned that the proof should work to all orders of perturbation theory, he introduced the concept of working in a five-

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[3] Another aspect of mixing impinges on weak interactions of quarks and on the disparity between strong and weak eigenstates; avoidance of flavour-changing neutral currents requires a specific cancellation mechanism [12].

[4] This kind of term can also arise in massive QED but is not dangerous because of current conservation: \( p \cdot J^\mu = 0 \), whereas in non-Abelian theory the current is conserved, \( p \cdot J^\mu \neq 0 \), and the longitudinal piece becomes a source.
dimensional space to ensure gauge-invariant regularization of the divergent integrals. Later on that year [16] he made the vital breakthrough, by proving that spontaneously broken non-Abelian gauge theory, including the standard model, is indeed renormalizable. The vital ingredients for success are (a) the introduction of the scalar Higgs boson, which provides the vector and spinor particles with masses without destroying the local gauge invariance, and (b) the choice of a particular gauge (called the ‘tHooft gauge’) for guaranteeing high energy behaviour of the vector and scalar propagators. In this way he established that loop calculations in electroweak theory can be carried out to any order in g and give reliable answers that can be checked against experiment, much like QED. ‘tHooft hit the nail on the head when he stated: “Our most important conclusion from the foregoing is that a basic principle like gauge invariance can lead to renormalizable, unitary theories with massive, charged vector particles.”

In 1972 two more significant papers by ‘tHooft and Veltman [17] put the icing on the cake. In the first one they introduced the idea of dimensional regularization for preserving gauge invariance - which they tested to 2-loop order on a difficult overlapping divergence. The idea [18] is to continue the Lagrangian and the associated Feynman integrals to arbitrary dimensions D and pick out the correct infinities which arise as first order poles, 1/(D - 4). There is only a limited set of such infinities, which can be removed by redefining the masses and coupling constants, and the remaining quantum amplitudes are completely predictable. Indeed, dimensional regularization has now become the method of choice. In the second paper they showed that no matter how the gauge is fixed (covariantly, non-covariantly or nonlinearly), the generalized gauge identities ensure that probability is conserved. Their combinatorial proof, which is replete with figures, led to a couple of nice monographs, entitled ‘Diagrammar’ and ‘Diagrammatica’ [20].

Table 1, taken from Pich’s recent review [21], shows the first loop order improvements. I hope it will convince you.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Naive Tree</th>
<th>Improved Tree</th>
<th>1-loop SM fit</th>
<th>Experimental value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_W/\text{GeV}$</td>
<td>80.94</td>
<td>79.96</td>
<td>80.30</td>
<td>80.39 ± 0.04</td>
</tr>
<tr>
<td>$\sin^2 \theta_W$</td>
<td>0.2122</td>
<td>0.2311</td>
<td>0.2315±0.0002</td>
<td></td>
</tr>
<tr>
<td>$\Gamma/Z/\text{GeV}$</td>
<td>2.474</td>
<td>2.490</td>
<td>2.496</td>
<td>2.494±0.002</td>
</tr>
<tr>
<td>$\sigma_{hadrons}/nb$</td>
<td>42.13</td>
<td>41.38</td>
<td>41.48</td>
<td>41.54±0.004</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>0.066</td>
<td>0.017</td>
<td>0.016</td>
<td>0.017±0.001</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>0.210</td>
<td>0.105</td>
<td>0.103</td>
<td>0.099±0.002</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>0.162</td>
<td>0.075</td>
<td>0.074</td>
<td>0.069±0.004</td>
</tr>
<tr>
<td>$P_{vector}$</td>
<td>-0.296</td>
<td>-0.150</td>
<td>-0.147</td>
<td>-0.150±0.002</td>
</tr>
<tr>
<td>$P_{\tau}$</td>
<td>-0.947</td>
<td>-0.936</td>
<td>-0.935</td>
<td>-0.905±0.026</td>
</tr>
<tr>
<td>$P_{\nu}$</td>
<td>-0.731</td>
<td>-0.669</td>
<td>-0.668</td>
<td>-0.655±0.027</td>
</tr>
<tr>
<td>$R_{FB}$</td>
<td>0.209</td>
<td>0.208</td>
<td>0.203</td>
<td>0.207±0.002</td>
</tr>
<tr>
<td>$R_\phi$</td>
<td>0.219</td>
<td>0.220</td>
<td>0.216</td>
<td>0.216±0.001</td>
</tr>
<tr>
<td>$R_\rho$</td>
<td>0.172</td>
<td>0.170</td>
<td>0.172</td>
<td>0.167±0.004</td>
</tr>
</tbody>
</table>

Well, what are the 1999 prize recipients doing today? Veltman is engaged in investigating [22] how the Higgs boson—the last piece of the electroweak jigsaw, whose mass is deemed to lie in the range 100 to 200 GeV – will show its face, while ‘tHooft [23] has turned to the unification of gravity and electroweak theory. Both are extremely worthwhile endeavours.

Reference


For a somewhat simpler description the reader is referred to: www.nobel.se/announcement-99/physics99.html

THE YEAR 2000 EUREKA PRIZES

The Australian Museum is proud to announce the launch of the 2000 Eureka Prizes, winners of which will be announced at a ceremony during National Science Week 2000.

From their modest beginning in 1990, when three prizes were awarded, the prestigious Eureka Prizes have grown into Australia’s leading national science awards. In 1999, eleven prizes worth $100,000 were awarded.

The Eureka Prizes are a unique cooperative venture between the federal government, the NSW state government, educational institutions and a range of high profile private sector companies and organisations. The Prizes raise the profile of the science in the community by acknowledging and rewarding outstanding achievements in Australian scientific and environmental research, science communication and journalism, and the promotion of science.

While the final lineup of the 2000 Eureka Prizes is still being finalised, the prospects are for a record number of prizes in this, the tenth anniversary series.

Entries and nominations are now invited for:

* The $10,000 Allen Strom Eureka Prize for Environmental Education Program
* The Australian Museum Eureka Prize for Industry
* The $10,000 Australian Skeptics Eureka Prize for Critical Thinking
* The $10,000 Environment Australia Peter Hunt Eureka Prize for Environmental Journalism
* The $10,000 POL Eureka Prize for Environmental Research
* The $11,000 University of Sydney Eureka Schools Prize for Biological Sciences.

Entries for all prizes (other than the Eureka Schools Prize) close on 11 February 2000. Candidates can either enter themselves or be nominated by others.

Entry forms and full details of the 2000 Eureka Prizes are available at the Museum’s webpage at http://www.austmus.gov.au/eureka or from Roger Muller on 02 9320 6230.

Roger Muller
Associate Director's Office
Australian Museum

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AUSTRALIAN CONTRIBUTIONS TO INERTIAL FUSION ENERGY

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We show how a small team has studied the theory of laser driven inertial fusion energy in Australia with the aim of evaluating the easily achievable volume ignition process and the role of the nonlinear (ponderomotive) force in laser-plasma interaction. This force was found to produce a picosecond stochastic pulsation. A method of suppressing this pulsation by appropriate smoothing of the laser radiation has been proposed and is of relevance to the very big experiments under development.

Energy Problem

There is no question that the pollution of the earth's atmosphere with 20 Billion tons of carbon dioxide per year is not acceptable in the long run though we have to acknowledge the benefits of fossil energy sources as the basis of our technological wealth since the invention of James Watt's steam engine. Alternative energy sources are now in view where about 20% of the world's electric power is produced from nuclear fission and about 1% from "renewable" sources (see J. Harris, AINSEE Conf. Dec. 1998). The latter sources constitute a fast growing billion dollar business where power stations of more than 400 MW can be run from turbines driven by the steam generated by solar collectors. Wind mills are also promoted despite their economic insufficiencies while solar cells are profitable for remote telecommunication and similar applications.

While the developed countries have access to adequate energy resources, there are different views in developing countries on the future of power generation. A few years ago China was considering the use of coal, but now has changed in favour of 700 nuclear power stations in order to reach the level of industrialized countries. Yet the ultimate Chinese goal is to develop viable fusion energy. It is worthwhile to ask why this research has been supported so much more in China than in other larger developed world economies.

Worldwide more than $30 Billion has been spent on fusion energy research over the past 40 years. However, the initial progress was much slower than expected with the energy input in early experiments far exceeding the energy output. Nevertheless, persistence has paid off and the energy gains from fusion have increased by many orders of magnitude so that now we are nearly at break-even point. In 1998 the most advanced experiment with the JET (Joint European Torus in Culham, England) produced 16 MW of fusion energy with a 40:60 D-T plasma confined in a magnetic torus, bombarded with 21 MW neutral deuterium beams and subjected to 3 MW RF heating. The gain of 66% ignores the energy needed to produce the confined plasma. This experiment may be called a beam-fusion experiment. In 1996 the generation of 2x10^14 D-T neutrons from 30 kJ laser pulses gave rise to the transfer of about 1.8 kJ energy into the reacting core, a core gain of 30%. The budget for inertial confinement laser fusion research is nearly ten times less than that for research with magnetic confinement.

The present work is concentrated on big new facilities, the National Ignition Facility (NIF) in Livermore, California, USA and the Large Megajoule (LMI) laser near Bordeaux in France, each costing about $2 Billion. Contributions to this research in Australia have been on a more modest scale. Notable achievements include the discovery of the volume ignition process for laser compression of pellets and the simulation of picosecond stochastic pulsations due to the laser-plasma interaction. The latter effect was predicted in 1974 (see Chapter 10.3 of Ref.), and first measured by Lubin et al in 1975 (see reference). Further details have recently been confirmed. Numerical simulations have shown that laser radiation can be transferred into a plasma with little reflection loss if broadband smoothing of the laser beam is used. Calculations with a genuine two fluid inhomogeneous plasma, including the internal electric fields, have yielded related unique results. This work not only revealed a new resonance but also gave information on laser acceleration of electrons by laser beams in vacuum and on the emission of electrons from laser beams with a forward scattering. This work also studied multiphoton ionization according to a correspondence principle of interaction and the concept of the cluster laser was developed.
Early Work on Laser Driven Inertial Confinement Fusion

While we would wish full success to those working on magnetic confinement fusion, its very crucial problems of wall erosion and other unsolved physics remain. In 1951 Lyman Spitzer gave a physically and mathematically correct demonstration that D beams incident on a D target would never result in a favourable fusion gain because the cross section for the reaction with the electrons was so very much larger than that for reaction with deuterium nuclei. This destroyed the hope of using beam fusion held by the most famous contemporary coryphae. However it turned out that these hopes were justified and Spitzer's argument was completely wrong since it was based on linear physical interactions. Richard Feynman contributed to the later discussion of the error in terms of a new principle of nonlinear physics which, after some theoretical and computational work, lead to completely new and hitherto undreamed innovations for mankind (see also p. 378 of Ref.5).

With all these confusing and basically wrong positions in the background, the enthusiasm surrounding the invention of lasers in 1960 broke down all these barriers. It is remarkable that Andrei Sakharov, in his comments accompanying the publication of his collected papers in 1960, also had the idea of using lasers for the production of controlled inertial confinement fusion energy. This followed after his own fundamental publication on lasers in 1948. In reports, originally classified, we find similar support also from Edward Teller and John L. Nuckolls and from Gan-Chuang Wang, the father of Chinese nuclear research who undertook his Ph.D. under Lise Meitner in Berlin. The first published paper by Basov and Khokhin in 1963 was received like an earthquake. It was repeated with some added computation by John M. Dawson. The first optimized computations for calculating the core fusion gain G proceeded by calculating the ratio of the fusion energy generated divided by the input energy $E_0$ assuming an initially adiabatically compressed volume $V_0$ of radius $R_0$ with maximum density $\rho_0$ (per solid state density $\rho_0$) which subsequently expands. This gave the fusion gain formula (Hora and Pfirrach 1970)

$$G=(E_0/E_{\text{tot}})^{2/3}(\rho_0/n_0)^{1/3}$$

Here the temperature accompanying maximum compression must have an optimum value of 17 keV. A lower temperature gives much lower gains due to the fusion cross sections becoming too small while higher temperatures lead to the adiabatic expansion running too fast with much lower gains resulting. The gains computed by Basov and Krookin and by Dawson agreed with our computations (Hora 1964) but were very much below the optimum values specified by equation (1). The most disappointing result was that the break-even energy $E_{\text{br}}$ for the DT reaction was 6 MJ at a time when laser pulses of nanosecond duration were available with only a few Joules energy. The exponent $1/3$ in (1) was a further disappointment. But the exponent $2/3$ in (1) gave hope: compressing the plasma to 1000 times the solid state density needed one million times less energy for the same gain.

It should be mentioned that

$$E_0 = \text{const. } \rho_0/(4\pi R_0)^3$$

so that equation (1) reads

$$G = \text{const. } R_0 \rho_0$$

as formulated by Kidder in 1974. Here special attention again is required with respect to the optimum temperature when (nR) values are considered in an uncritical way. Kidder underlined that this gain value (as correctly used in the earlier form (1)) is a corresponding criterion for inertial confinement fusion in place of the Lawson criterion for magnetic confinement. The generation of very high densities by laser driven ablation of the plasma surface gives rise to a recoil to thick layers in the plasma interior. This was first derived numerically by Mulser and by Rehm in 1970. Later, in formerly classified work, Nuckolls used temporally tailored laser pulses and spherical geometry to achieve more than $10^4$ times solid state density. Yet, even with this compression, the gains were still too low and from then on the concept of spark ignition was pursued at nearly all research centres. This involved the production of a high temperature and modest density in the central range of the radius $R_0$ of the laser irradiated pellet and a low temperature and very high density in the pellet for larger radii. At $R_0$, a fusion detonation wave would then be generated and the net reaction energy should give a very high gain. The fusion detonation wave was also of interest for classified applications.

Discovery of Volume Ignition

An alternative procedure (applicable only to the controlled production of fusion energy and lacking any classified application) was suggested in Australia from 1975 onwards. This is known as volume ignition in contrast to spark ignition. The computations mentioned earlier which led to Eq. (1) and also to Kidder's (nR) formula were very simplified: they did not include (a) the losses from bremsstrahlung emission, (b) depletion of fuel or (c) the heat (or self-heat) of the plasma by alphas, neutrons and protons produced in the fusion reactions. With these processes included we proceed to plot in Fig. 1 a series of graphs of fusion gain G against input energy $E_0$ for various fixed values of initial volume $V_0$ and maximum ion density $n_i$ at the optimum temperature. Curves of constant $n_i$ are drawn as envelopes (or asymptotes) to these parabolas and curves of constant $V_0$ are drawn through the maxima of the parabolas. The parabolic shape is explained by noting that initially the gain increases with increasing input energy due to a larger number of reactions occurring, but, for higher energies, the expansion becomes so fast that adiabatic cooling sets in and the reaction rate decreases. It is remarkable that, for $10^4$ times solid state density at $E_0$ near 0.5 MeV, for example, the initial standard parabola is deformed and has a very steep jump upwards. These deformations were first reported in 1976 (P.S. Ray and H. Hora). The jump can be explained by examining the time dependence of the average energy of the plasma ions (equal to 2/3 of the temperature) as shown in Fig. 2. The
foot of the jump corresponds to the lowest curve in Fig. 2 where the plasma temperature is nearly constant with time and drops later resulting in a low gain of 0.77. The middle curve in Fig. 2 is for a little higher input energy $E_2$ where the ion temperature first rises very slowly but, due to the strong selfheat, rises to over 200 keV then rapidly drops due to adiabatic expansion but yields the very high gain of 1900. This corresponds to the maximum of the deformed "parabola" in Fig. 1. If a little higher input energy is used, the 200 keV ion energy is reached more quickly, but the shorter reaction time and fast expansion gives a somewhat lower gain of 1100 which corresponds to a point at the right hand side of the maximum of the deformed parabola.

When volume ignition occurs, the parabolas are generally deformed when DT-gains are greater than 8. The main feature of the volume ignition process is that the very high temperature created, much higher than with spark ignition where the temperature at the fusion detonation front has very sensibly to be kept within a small range of only a few keV. The reason that very high gains can be achieved with volume ignition, compared to the volume burn used earlier, is that Eq. (1) is valid only approximately for $G>8$ and the reheat is so strong that it provides a very large additional energy input to the reaction.

The reaction is further improved by the partial re-absorption of the bremsstrahlung. However this happens only at very high densities and temperatures so that the optimized ignition temperature falls to below 4.5 keV (where usually the generated fusion energy is equal to the bremsstrahlung loss). This Low Temperature Ignition (LTI) range is conservatively estimated by the line 'LTI' in Fig. 1: above this line the reabsorption of bremsstrahlung is of importance. This betterment of inertial confinement fusion was first noted in the literature by Frey et al and was also indicated in some global estimations by Caruso. It should be underlined, however, that the discovery of the high ion temperature and very high gains, mostly due to self-heat, were not mentioned prior to a conference at the Rensselaer Polytechnic Institute in Troy, NY, in November 1976 and published in 1978. Though most attention was given to spark ignition, volume ignition was further studied by Kirkpatrick and John A. Wheeler (the "Wheeler modes"), by He, Martinez-Val, Sarris and recently by Atzeni, Anisimov, Nishihara and further authors and associates (see Ref.'). The advantage over spark ignition is that the adiabatic compression is most natural, it is "robust" against small fluctuations and asymmetries of the drive (K.S.Lackner, S.A. Colgate et al 1994). On the other hand, for spark ignition, the treatment of the hot spot requires very complicated radial temperature and density profiles which must be identical in all radial directions. If this is not so the detonation wave propagates in only one direction. The achievement of high gains by volume ignition has been verified in detail and numerous criticisms have been dealt with. Volume ignition is perhaps not the most elegant solution but is a very realistic and reliable basis on which the design of a laser-fusion power station could be founded using present technology.

The computer code (based on the initial code of 1964) has the advantage that wide ranges of parameters can be studied easily while calculations for specific input energies need very much more sophisticated codes. A key requirement for the improved gains associated with volume ignition is that local thermal equilibrium is not attained. An example of the computations of Martinez-Val et al is shown in Fig. 3. The initial computations of volume burn with adiabatically uniform compression before
The collision frequency ν and the incident laser electromagnetic fields E and H have a frequency ω. The nontransient force was derived in 1969 using momentum conservation while the complete transient force was derived in 1985 and the final generality was later proved from Lorentz and gauge invariance (T. Rowlands 1990).

This force immediately explained the Z-dependence of the keV ions if ponderomotive self-focusing with a threshold at about 1 MW laser power was also included. An explanation of the MeV ions observed required relativistic self-focusing. A discussion of the latter results in terms of the Lorentz force, the ponderomotive potential and the general nonlinear forces is given in a text book. When the nonlinear force is dominant during laser irradiation, the plasma electron density initially increases monotonically but then develops a density minimum and a profile steepening near the critical (cut-off) density region, as discovered numerically by Shearer, Kidder and Zink 1969 (see Section 10.3 of Ref. ). This minimum, later called a “caviton”, is characteristic of the action of the nonlinear force and has been experimentally observed by Zakharov et al, by Fedoseevs et al, and by Azechi et al (see Chapter 10 of Ref., or Chapter 4.3 of Ref.). As in a WKB approximation, the electric field amplitude in a plasma is increased by a factor S to S|E| where S=1/n and S values up to 25 have been measured with microwaves irradiating plasma (Wong and Stenzel 1975). An excellent demonstration of the nonlinear force is found in the Boreham experiment where, at low densities, only the electrons are involved. But when the Debye length becomes less than the laser focus diameter, the electron current no longer increases linearly, indicating the attachment of the ions to the accelerated electrons and a transition to the nonlinear plasma acceleration.

When laser fusion was first studied, the numerous anomalous interaction mechanisms leading to the MeV ions, their Z-dependence, emission of electron bursts, high reflectivity etc., were very disappointing. Most of these anomalies are dominated by the nonlinear force. F.F. Chen (see Ref.) has presented a helpful and unified description of most of the leading laser-driven (microscopic) parametric instabilities, all based on the nonlinear force. But to suppress all these anomalies a concept, both simple and ingenious, was proposed by Teller and Nuckolls. Their suggestion was to encapsulate the fusion pellet into a high-Z mantle, send the laser radiation into this capsule so that the walls convert the radiation to x-rays and let these compress and heat the pellet. This hohlraum or indirect drive concept is one of the current lines of research in laser fusion.

A resurgence of the direct drive laser fusion process became possible when it was realized that one of the main problems of the interaction was the stochastic pulsation. Refined hydrodynamic computations in 1974 at the Institute of Laser Energetics at the University of Rochester/NY included the nonlinear force and first demonstrated a devastating fact: The laser light first penetrates into the plasma corona to the critical density region where a small fraction of the laser intensity is reflected, putting, as desired, most of the laser energy into the plasma for the fusion process. But the partially reflected light produces a standing wave field in the corona which pushes the plasma into...
the nodes of the standing waves by means of the nonlinear force. This then produces, within picoseconds, a self-made ideal Laue-Bragg grating which causes a very high reflection of the incoming light within the very low density plasma corona (see Fig. 10.10 of Ref.5) so that radiation no longer penetrates into the plasma. The plasma reacts in every way to prevent the incorporation of laser energy. After some picoseconds, the density ripple relaxes, the light again propagates to the critical density position and the whole process begins again as before. This pulsation of the reflectivity, of between a few percent and more than 95%, was observed by Lubin et al (1976) but was not followed up seriously as most attention was focussed on parametric instabilities.

Suppression of the Stochastic Picosecond
Pulsation by Smoothing

It has turned out that the above-mentioned pulsations may be the main evil of laser-plasma interaction which endangers the direct drive process for laser fusion rather than the parametric instabilities. A systematic study of the pulsations has been performed by Maddever and Luther-Davies6 who approached the problem by observing 4 angstrom fully modulated back scattering spectra. They observed that the pulsation begins when there is low reflectivity in the critical density region and the corona is accelerated to velocities of the order of 10^5 cm/s in the opposite direction to the incident laser light. The reflectivity then increases to nearly 99%, the acceleration stops and, only after several more picoseconds, the reflectivity falls to a low value, the light penetrates again to the critical density region and the corona receives a further push to the same high velocities. The bouncing of the place of reflection was clearly observed6 to occur between the critical density region and the outermost part of the corona in a cycle lasting a few picoseconds. The time resolved spectra were then no longer modulated but consisted of a series of the same spectra only they were Doppler shifted corresponding to the different successive corona groups.

Using a genuine two-fluid code7, the generation of the density ripple, the low reflectivity, and the increase in the ion velocity during the first few picoseconds were reproduced. The acceleration stopped when there was almost no light in the corona (as seen in the plot of the electromagnetic density energy in Fig. 4). During this time the thermal motion in the corona washed out the density ripple until the next time the light penetrated to the critical density region, the next plasma acceleration occurred and everything repeated from the beginning with the generation of the density ripple etc.. The periodicity of this pulsation changed stochastically between 5 and 20 ps due to the complicated hydrodynamic processes which accompany laser irradiation of intensity 10^15 W/cm^2 at neodymium glass wavelengths8 (see Fig. 4).

However when broad band laser irradiation of 0.5% band width was used in the computation, the standing wave rippling was not produced by the laser field and a perfect low reflection transfer of the laser radiation occurred leading to direct drive for laser fusion. This relates to the smoothing of laser beams by random phase plates (Kato et al 1994) or temporal incoherence (Lehmborg et al 1983) which were suggested a few years earlier. The aim was to suppress filamentation by self focussing but the measurements of Christine Laboume et al in 1992 clearly showed that not only filamentation but also the pulsation of the whole corona front disappeared when the appropriate fine raster of a random phase plate was used9. Since equipment to produce 2 MJ laser pulses costs $2 Billion, the use of NIF or LMI operating with twice the laser pulse energy in the red colour should be possible if the appropriate low cost smoothing for direct drive is developed based on the analysis above9,11.

Conclusions

The main stream of laser fusion research has been accompanied by the Australian activities in a way that, despite of the limited size of our teams, noticeable contributions have been made. In response to the problems with spark ignition, the Australian discovery of adiabatic volume ignition for generating inertial fusion energy is an easily achievable robust solution. The very complex problems of the laser plasma interaction were studied mostly using the nonlinear force and macroscopic genuine two-fluid codes for the plasma dynamics. It has now been shown that the problems of the laser-plasma interaction are not so much due to microscopic parametric instabi-
ties or filamentation but rather to the picosecond stochastic pulsation. This was first investigated numerically in 1974, given a detailed experimental examination by Maddever and Luther Davies, and then analyzed using our very realistic genuine two fluid codes. The conclusion, based on numerical results, is that appropriate smoothing of the laser beam can overcome the pulsations. This leads to a highly efficient direct drive process to give inertial fusion energy with lasers.

References

Aluminium Free Diodes from Coherent Semiconductor Group

Coherent Semiconductor Group (CSG) manufactures laser diodes with aluminium free active area. Removal of aluminium in the active area leads to increased lifetimes as there is no oxidation at the facet - the leading failure mechanism in conventional laser diodes.

CSG’s range of laser diodes includes:
- 30W Fibre / Diode Array Package (FAP)

Fibre delivered for easy integration, FAP devices offer the simplest and easiest way to deliver up to 30W of laser output to your application.

The following centre wavelengths can be specified: 680nm ± 10nm, 810nm ± 10nm & 995nm ± 5nm.

Compact, fibre-coupled, single-stripe devices are available in both IR and red wavelengths with output powers ranging from 280mW to 1.6W. An integrated monitor package allows you to read both the light output and the temperature of the laser diode. Devices are also available with optional external thermo electric cooler (TEC) for complete wavelength control.

Available centre wavelength specifications are: 675nm ± 5nm, 810nm ± 10nm & 830nm ± 10nm.

Diode Arrays

Diode arrays are available with CW output powers between 15W and 40W. For higher output powers CSG also offer water-cooled diode arrays.

The following centre wavelength specifications are available: 680nm ± 10nm, 790nm ± 10nm, 810nm ± 10nm & 830nm ± 10nm.

Applications for the above laser diodes include:
- Pumping of solid-state media
- Medical - therapeutic
- Marking
- Materials processing

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Burle Industries Inc. acquires Galileo Corp. Scientific Products Division

Burle Industries, Inc. has announced the purchase of Galileo Corporation’s Scientific Detectors and Spectroscopy Products (“SDP”) business located in Sturbridge, Massachusetts.

As a result, the following Galileo products will now be sold under the Burle Electro-Optics label:
- Microchannel plates
- Channeltron® single channel detectors
- Microchannel plate-based detectors
- Flexible fibreoptic lightguides
- Glass-coated wire
- Remote spectroscopy products

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UV Optical Systems and Components

MicroLas is a German company that specialises in the design and manufacture of complex UV optics and beam delivery systems. MicroLas work closely with Lambda Physik (Germany) to produce high resolution imaging components and systems specifically for UV micromachining and marking applications.

In general, MicroLas optical systems consist of an illumination module and an imaging objective. The illumination module “shapes” the laser beam to the critical parameters required to illuminate a specific mask. The imaging objective then images the mask pattern onto the substrate to be processed. To achieve optimal results the illumination and imaging optics have to be adapted precisely to the end users task.
TRENDS IN SCIENCE EDUCATION: A basis for the Future Planning of Australia's Science Resources

The Australian Council of Deans of Science (ACDS) representing 35 universities in Australia met in Canberra on October 6-8. The major agenda item was the receipt and consideration of its commissioned report on Trends in Science Education: Learning, Teaching and Outcomes 1989-1997.

The ACDS report highlights the need for Australia to develop a scientifically trained workforce that will enable Australia to seize the advantages in already existing industries and those inherent in as yet still unrecognised areas of science and technology. Australia must grasp its opportunities by wholeheartedly embracing a knowledge-based economy, so clearly dependent on a strong Science and Technology sector.

The ACDS views with concern the decline of student numbers in both the Secondary and Tertiary sectors in the basic (enabling) sciences and mathematics as demonstrated in this report and further elaborated in the accompanying paper, Who is Studying Science.

These enabling sciences will be necessary for the future scientific community to grasp the opportunities offered by such areas as nanotechnology, biotechnology and information technology. The ACDS at its annual meeting devised a set of strategies that it expects, with cooperation among state and Commonwealth governments and industry, will reverse this serious threat to Australia’s future economic development.

The ACDS in full Council resolved to take action in three principal areas.

1. Enhanced and Continuing Monitoring of “Trends” in science by:
Collection and analysis of further science-related data on an ongoing basis

It is proposed that this analysis will be undertaken with the assistance and cooperation of and support from appropriate Commonwealth (DETYA and DISR) and State Government (Departments of Education, etc) Agencies and will involve data related to educational and employment outcomes in Science.

Enhancement and Clarification of Data sets
ACDS will identify to Universities, and Commonwealth and State agencies, those areas where additional, enhanced or more clearly defined data collection is necessary in order to properly monitor the health of science enrolments, educational trends and graduate employment levels in Australia. Such proposals are to be seen as improving the utility of these data sets and as allowing more readily the recognition of the economy-threatening trends revealed in our latest report.

2. Commentary on and Raising Awareness of Trends in Science
Occasional Papers
The ACDS will produce a series of occasional papers (such as the Who is Studying Science paper) from the current and future compilations of data in order to highlight both advances and deficiencies in the Australian science scene.

Consultation and Lobbying
Through its own auspices and in association with bodies such as Federation of Australian Science and Technological Societies (FASTS), the Australian Science Teachers Association (ASTA) and the Australian Academy of Science, ACDS will ensure that the Chief Scientist, appropriate Ministers of Science and Education at both Commonwealth and State level and their officers who administer Science and Education policy are alerted to the concerns and aspirations concerning teaching and research in Science.

The first step in this process will be the distribution of the Report and the first Occasional Paper to the all relevant Commonwealth and State Minister, the Chief Scientist, FASTS its constituent bodies, the Academy of Science and the Australian Vice-Chancellors Committee (AV-CC). The next step will be personal representations by the Executive Members of the ACDS Board.

One important part of the ACDS strategy will be participation in the Science Meets Parliament Day being sponsored by FASTS in November this year. Another important contribution, in addition to the provision of this report to the Chief Scientist, will be consultation with him on the recently announced Review on Science Capabilities in Australia.

3. Secondary School Teaching of the Enabling Sciences and Mathematics
Enhancement of Currency of Knowledge of Secondary School Teachers
ACDS will seek urgent discussions with the Australian Science Teachers Association (ASTA) and State and Commonwealth Departments of Education on methods whereby ACDS can assist current Science Teachers to enhance their knowledge, specially with relevance to developing technologies, and providing innovative means of presentation of the key enabling disciplines (Physics, Chemistry and Mathematics).

One such process will be proposals for new (or modification and facilitation of existing) programs of postgraduate study (e.g., GradDipScience or modular MSc programs) such programs would provide activities as problem-based teaching projects, development of suitable teaching aids, and exposure of current teachers to science-in-action in both industry and university environments.

Support for Enhanced Training for Science Teachers
ACDS will seek Commonwealth and State support for the provision of HECS (or fee) exemption Scholarships for Secondary Teachers undertaking “upgrading programs” such as those proposed immediately above.

Recognition of Enhanced Training of Science Teachers
ACDS will request State Governments (Ministers of Education) to recognise in a tangible way, those Secondary Teachers who undertake upgrading programs.

Recruitment of Secondary Science Teachers
ACDS will continue its moves to have differential HECS for practising Science Teachers removed and pursues with ASTA all appropriate programs for addressing the impending shortage of suitably qualified Secondary Science Teachers across Australia.

The papers referred to in this release can be found on the ACDS Website at www.acds.edu.au/issues.htm.

Limited hard copies of the Reports or a CD-ROM version can be obtained through the Secretary of ACDS, Professor Brian Collins, Faculty of Science, Curtin University (Tel. 08 9266 2838, Fax. 08 9266 3747, email B.Collins@info.curtin.edu.au).

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Pawsey and his colleagues succeeded in developing the technology for increasing resolution in the radio. The Hubble Space Telescope has done this for optical astronomy. To measure distances of galaxies, Hubble and others before him and since used the method of standard candles. Cepheid variable stars are good standard candles. A Cepheid which varies in brightness with a certain period, say 20 days, has a fixed power output, like a 100 watt light globe. If we measure how bright such a star appears in a distant galaxy, we are able to measure the distance of that galaxy. If a 20 day Cepheid appears 100,000 times (10^5) fainter in the Virgo galaxy M100 than it is in the Large Magellanic Cloud, our nearest galaxy, then M100 is 102.5 times further away than the LMC.

That is how our team, the Hubble Space Telescope Key Project team, has measured the value of the Hubble Constant, the ratio of galaxies' recession velocities to their distances. The velocities were known; the distances have been measured by finding Cepheids in galaxies to the limit of HST's resolution, which is ten times what can be achieved from the ground. Perhaps I should say could be achieved, because the Gemini telescope opened this year has started to outresolve Hubble in the infrared.

Measuring Cepheid distances is not the end of the story in our project, however. They only take us to roughly 25 megaparsecs (75 million light years), before we strike the limit of what HST can do. So we have used Cepheid distances to calibrate four other standard candles which are measurable to much larger distances.

The first of these more powerful standard candles is a dynamical relation for spiral galaxies, called the Tully-Fisher relation. Spiral galaxies, like our own, support themselves against their own gravitational forces by rotation. Larger galaxies rotate faster. A galaxy with a rotation speed of, say, 200 km/sec (similar to the rate the sun is moving around the centre of the Milky Way) is a standard candle. Our HST project has told us the total power of this standard candle by measuring the distances of some of them. Henceforward, wherever we see such galaxies, we know their distances.

Joe Pawsey would have been interested in this work, because the way we measure the rotation speed of galaxies is from the 21 cm emission line of hydrogen gas, which is abundant in galaxies. He pioneered the detection of this line using Australian radio telescopes, although Dutch and U.S. radio astronomers achieved the detection first.

The Tully Fisher relation, calibrated by Cepheid distances measured with HST, allows us to measure the distance of galaxies up to 150 megaparsecs away, the limit of the Arecibo radio telescope.

A second standard candle we have calibrated in a basically similar way is the equivalent dynamical relation for elliptical galaxies, which support themselves in their gravitational "well" by the random motions of their stars. Ellipticals have no Cepheid variable stars, and we have to base their distances on association with spiral galaxies in clusters, like the well-known Fornax cluster, the closest big cluster of galaxies in the south.

 Supernovae are the third standard candle calibrated by Cepheid distances. These stellar explosions are visible to immense distances across the Universe, as Brian Schmidt of the ANU showed last year. In part of this project we have had competition from a second team, but we find results from supernovae consistent with the other three standard candles. I say "other three" standard candles, because time doesn’t permit me to go into detail about our calibration of the resolvability of elliptical galaxies.

Combining the constraints on the Hubble Constant from these four distance indicators, we obtain a slope for the velocity/distance relation of 71 +/- 6 km/sec/megaparsec. That’s our bottom line. Or almost our bottom line. We have asked ourselves whether Cepheids are simple standard candles, whose power is dependent on period alone, or whether perhaps Cepheids with chemical composition different from those in the Large Magellanic Cloud might have slightly different luminosities. There is a hint that there is such an effect, a weak one, which should be corrected for. When we do that, we obtain H0 = 68 +/- 6 km/sec/Mpc.

Of course, what people are more interested in than the expansion rate of the Universe is the age of the Universe. To know that, we have to know the history of the expansion. If we make the simplest of all assumptions about the expansion, that it has always proceeded at the rate we observe today, then 14.3 billion years (+/- 10%) have elapsed since the Big Bang.

But there are other assumptions that we could make instead. One is that the expansion is decelerating due to the gravitational attraction of the galaxies. The most elegant of these models supposes that the expansion will come to a dead stop if we wait an infinite time. This is the Einstein de Sitter Universe. Another is that the Universe is accelerating. Observations of distant supernovae suggest this. We could call this model the Schmidt-Perlmutter model after the astronomers who have led this supernova research.
My preference is to make none of these assumptions, but to find the age of the Universe another way. The ages of the oldest stars in the Milky Way have been measured to 10% accuracy. Australian astronomers have been very prominent in this line of research too, thanks to an effort begun in the 1970s by Dr. Don Faulkner of the ANU. If we multiply the Hubble Constant, which has dimensions of reciprocal time, by the age of the oldest stars, we get a dimensionless number (1.0 +/- 0.3 with 95% confidence), which is a guide to the correct model of the universe. The Einstein de Sitter model predicts that that number should be two-thirds. The Schmidt Perlmutter model, if that is what we are going to call it, comes out about right.

Of course, we have to sharpen up this work. We need more accurate distances and more accurate ages. We can expect these in the next decade from space missions currently being planned.

In conclusion, I would like to thank the Australian Institute of Physics for the honour of presenting this year's lecture in memory of a great Australian physicist and astronomer, Joe Pawsey.

Robert Sang

TASMANIA

Two talks were presented at a branch meeting held on 15 October. This is part of a series of talks the branch has introduced where local members can present their work to the rest of the physics community.

The first talk was entitled "Health Physics" with a more specific subtitle "Radiation Protection for Occupationaly Exposed Persons and the General Public". It was presented by Dr. Stephen Newbery, one of the Health Physicists at the Tasmanian Department of Health and Human Services and also the branch Secretary. Stephen opened with a brief history of the discovery of X-rays and their almost immediate use as a diagnostic tool in medicine. He described the first recognition of radiation damage to tissue. Health Physics developed as a discipline after the second world war and it was from that time that risk assessment against dosage was calculated with ever increasing accuracy and complexity. Stephen showed the risk of developing a fatal cancer for various radiation treatments ranging from 1 in a million for a limb or tooth x-ray (equivalent to less than 1.5 days of natural radiation exposure) up to 1 in 1100 (or 8 years natural dose) for a Myocardial perusion. These figures are approximate lifetime risks for adults 16-69 years old. They reduce by a factor of 5 for older patients but increased by a factor of 2 for younger patients. The overall lifetime risk of developing a fatal cancer is approximately 0.05 per Sv and typical background radiation levels are in the range 1.5 to 7.5 mSv. Stephen completed his talk by describing some of the industrial and medical sites that are regularly monitored and how that monitoring is undertaken. He even included the testing around nuclear powered warship anchorages which his department participates in with Commonwealth government authorities.

The second talk was given by Paul Fox-Hughes, a severe weather forecaster from the Bureau of Meteorology. The title was "Severe Weather in the Southern Oceania". The main job of the severe weather forecast unit in Tasmania is prediction related to fire weather and inland gale warnings. Flooding is also an issue. Very occasionally severe thunderstorms are also forecast as these are rare in Tasmania. Paul described the forecasting process which is based on observations from a network of automatic weather stations and on observer reports from various locations. Other inputs to the modelling include satellite images at optical and infra-red wavelengths, weather radar and radio-sonde balloons. In cases where a severe weather warning is issued the Bureau also liaises with various local authorities such as the fire services, State Emergency Service, Forestry Tasmania, Parks and Wildlife and the Health Department. Paul described some of the most severe weather occurrences of recent years. The ability to forecast on much smaller scales has been emerging and this trend is likely to continue in the future. It is likely that highly localised regional forecasts, such as for segments of the Derwent estuary near Hobart, will become a reality in the next few years. Finally Paul pointed out the obvious difficulties in forecasting for Tasmania compared to much of the rest of Australia because of the lack of observations to the West. This is more of a problem for Tasmania than for the rest of the south-eastern states because of the more changeable nature of the approaching weather systems.

Marc Duldig

Annual General Meeting

The Tasmanian branch held its AGM on November 11 and elected the following Committee for the next year:

President: Dr Gary Burns
Vice-President: Dr Elizabeth Chelkowski
Treasurer: Dr John Humble
Secretary: Dr Stephen Newbery
Committee: Prof Bob Delbouroy, Dr Marc Duldig, Dr Andrew Kiekoziuk, Dr Ian Newman

A student representative to the committee is yet to be appointed.

The Chairman's report to the Branch summarized the year's activities, which have been reported in these pages already. The report also expressed special thanks to a number of continuing committee members and to Dr Jo Jacka who was standing down from the committee after a number of years of very valuable service to the branch. The full text of the Chairman's report is expected to be published in a later edition of the Physicist together with other branch reports.

A small annual dinner after the meeting was followed by a public lecture from our national President Prof John Pilbrow on the topic "Physics in Australia: Past successes, future opportunities". The President plans to report much of what he said in a later issue of the Physicist and so a very brief outline only is given here. The President discussed the "good times" of increased funding and new universities of the 1960's and early 1970's and the subsequent decline in funds and downsizing in Physics departments. He showed that the pendulum was swinging back toward basic research in the UK and USA where it was being recognised that wealth creation was underpinned by basic science and engineering. The President also presented the main arguments and recommendations made by the AIP in its response to the Government green paper on research funding. He closed with the comment that we had to understand what was happening around us if we were to influence the future of our discipline but that it should be viewed as a challenge and an opportunity.

Marc Duldig

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BRITISH RADIOACTIVE WASTE AT HOME AND IN ANTIPODEAN AUSTRALIA

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Pangea' Australian Resources Pty Ltd (PARPL) plans to export 250,000 tonnes of the North’s RADwaste to an international dump in Australia (2). Jobs and cash soothe Australian qualms about this monumental fill of lethal material in our backyard. My initial reaction to the logical absurdity of PARPL’S claim, that no RADwaste would escape into the biosphere for the next 10,000 years, turned to alarm when some eminent Australians came out in its favour.

A permanent repository has eluded Britain and the USA, principally because none of their states or counties wants it, yet PARPL aims higher: they want to impose it on a country without RADwaste of its own, except 4 tonnes from the Lucas Heights research reactor (4), which should be retained on site and not exported to South Australia.

This article is a geopolitical analysis of the North’s plan to dump their RADwaste on Australia, with emphasis on the geological aspects.

British RADwaste at home.

The Select Committee (9) concluded: “With the rejection in 1997 of the planning application for a rock characterization facility at Sellafield, as a step towards the development of a deep repository, the U.K. was left with no practical plan for the disposal of its nuclear waste ... phased disposal in a deep repository is feasible and desirable [and] would allow decisions to be taken in a considered way as technical confidence and expertise develop, and would avoid premature decisions which may be difficult to reverse. The future policy for nuclear waste management will require public acceptance. NIMBY rules in Britain.

After 30 years of confrontation and attrition, the British nuclear lions are lying down with the green lambs. In May 1999, a National Consensus Conference on RADwaste Management organised by the UK Centre for Economics and Environmental Development called witnesses from the nuclear industry, government, regulatory agencies, Ministry of Defence, Friends of the Earth, Greenpeace, and others (my emphasis). This followed a 2-day discussion forum on Geosciences and radioactive waste disposal organised by the Geological Society of London and the British Geological Survey. Dr David Falvey, Director of BGS, said that “total exclusion of potentially harmful radionuclides from the environment cannot be indefinitely guaranteed...but placement in the right subsurface geological setting can provide a relatively safe...containment.” This is an honest indication of the risk to be borne democratically by the country of origin of the waste (Geoscientist 9, May, p. 19, and August, p. 16).

Britain in Australia.

Safety first for Britain but not for Australia. The British Government, which owns 100% of British Nuclear Fuels Ltd (BNFL) that in turn owns 80% of PARPL (the Canadian Golder Associates/EHL and the Swiss NAGRA each have 10%) is nominating our wide open spaces for World listing as Terra nuclear. The British High Commission (7) boasts that “the British Government has no control, direct or indirect, over Pangea” and “BNFL makes commercial decisions on its own.” The official British policy “that British nuclear waste should be disposed of in Britain” is offset by PARPL’S unofficial policy. Official Australian policy was stated in the unanimous agreement of the Senate (3): “That the Senate notes the statements by the Minister for Industry, Science and Resources (Senator Minchin) on the ABC program ‘Four Corners’ that ‘We’re not interested in nuclear power and we’re not interested in being the world’s nuclear waste dump,' and that, ‘Australia won’t be that nation that accepts the waste’; and congratulates the Government on this decision not to allow an international nuclear waste dump in Australia like the one proposed by Pangea”. The British Government should heed the Senate’s resolution.

We have experience of Britain’s assurances. In their 1950’s and 1960’s atmospheric tests of fission devices at the Monte Bello Islands and at Emu and Maralinga (McClelland et al., 1985), Britain promised the most stringent safety precautions. E.W.
Titterton, then professor of Nuclear Physics at the ANU, was appointed by the Australian Government to chair the Atomic Weapons Tests Safety Committee set up to protect Australia. The Commission concluded “Titterton played a political as well as a safety role in the testing program ... He was prepared to conceal information from the Australian Government and his fellow committee members if he believed to do so would suit the interests of the UK Government and the testing program.” Sir Macfarlane Burnet had warned of this very dilemma: “any group of men directly concerned with the success of an enterprise will be inclined to minimise danger and to resent any safety precautions which will impede the enterprise.” The RADwaste, in particular, was grossly mismanaged; “the treatment of the plutonium-contaminated areas [at Maralinga] ... was inadequate, based on the wrong assumptions, and left the areas in a more difficult state for any future clean-up”. Light relief was provided “When Counsel assisting the Commission suggested to Stewart [a British witness] that appropriate places for the minor trials [in which 24.4 kg of plutonium were dispersed by burning or small explosions; Symonds, 1985, p. 557] might have been found in remote parts of Scotland, the witness replied: ‘I doubt if the people owning the estates in Scotland would look on that with very great favour. They are interested in pheasants and deer in Scotland.’”

The Commission recommended that Britain clean up the environment by isolating the RADwaste. Thirty years after the tests, and more than 10 years after the Commission’s findings, Britain is committing 25m pounds (AUS$60m), by some estimates roughly half the full cost, towards the cleanup at Maralinga.

PARPL carries on regardless.

Undeterred by the hostile Senate resolution, PARPL moved its office to Perth, nearer the proposed site. PARPL has engaged Australians to act as the thin edge of the wedge to win Australian acceptance. Dr Peter Cook is “a scientist and chairman of the scientific review group charged by Pangea with auditing the quality and nature of its science” (1). Members were chosen by PARPL apparently for their high standing in Australia as scientific state men and entrepreneurs - of those I know of, Dr Cook was recently Director of the British Geological Survey; Professor Brian Anderson is Director of the Research School of Information Sciences & Engineering at the ANU and President of the Australian Academy of Science; Sir Gustav Nossal, a consultant to PARPL, is an eminent director of biomedical research and past President of the Academy; Dr Phil Playford is past director of the Geological Survey of WA. On the TV program which exposed PARPL’s plans (2), Professor Anderson said; “I certainly believe there’s a chance for the proposal to get off the ground”. He went on to say that governments change and a negative position is not sustainable. Sir Gustav Nossal brings his infectious enthusiasm and medical prestige to the task: “We have an opportunity to offer the world an Australian solution to a global problem” (1) and is confident that PARPL’s experts have any risks under control. Apparently, Professor Anderson and Sir Gustav Nossal are swayed by their professional faith in the power of science and scientists to solve all problems.

This expression of scientific absolutism remains undiminished despite nuclear setbacks such as Chernobyl, and local technical failures in Sydney involving last year’s water-boiling exercise and the recent oil spill, non-delivery of gas in Victoria and of electricity in the CBD of Auckland, incidentally the site of the nuclear-connected sinking of the Greenpeace Warrior. This sentiment is a long way from the declaration of the UNESCO-ICSU (International Council for Science) World Conference on Science for the Twenty-First Century in Budapest June 1999 (10). The conference endorsed the idea of a new social contract with natural and human scientists, involving a code of ethics that would take into account not only honesty and human dignity but respect for the global environment and future generations. Science as the cutting edge of exploitation of nature would be balanced by care for the physical body of the Earth, and its practitioners would take a Hippocratic oath. The amazing thing is that this utopian declaration was co-sponsored by the hard-nosed ICSU, who has now added social responsibility to its charter with the express aim of attracting young people back to science. The local member of ICSU is the Australian Academy of Science, whose current and past presidents now have to balance their advocacy of PARPL against ICSU’s declaration. Incidentally, information on challenges to ethics and soundness in the geosciences is given in Welby & Gowen (1998).

Scientific argument for Australia as the proposed international RADwaste dump

The argument, as outlined by Dr Cook (1), boils down to:
1. The world has large amounts of nuclear waste to deal with.
2. Deep geological disposal is the only safe long-term solution.
3. Because waste has long-lived radioactivity, it must be isolated from the biosphere “for hundreds if not thousands of years”.

4. The “right” geology should be very stable with no significant earthquake activity. The ground should be flat and low-lying, the geology simple - old sedimentary basins may be best. The area should not have been glaciated in the recent past or likely to be glaciated in the near future, nor should it be subject to a major increase in rainfall.

5. Political and economic stability in the host country.

Britain, other northern European countries, and Canada (a junior partner in PARPL) are self-exempted by their glacial past, so Australia gets the short straw and PARPL’s undivided attention. But the argument can be turned back on the Northerners. A kilometre of ice above a deep repository would immobilize groundwater while not significantly impeding access for repairs or replenishment. It would be a free natural process simulated at some expense in modern engineering practice by the cryogenic stabilizing of loose ground. In this view, Australia’s non-glacial past (and presumed future) would rule it out as a repository.

“It is, of course, for Australia to decide whether or not economic or other benefits justify accepting some of the world’s radioactive waste”, says Cook. But nowhere does he mention the supreme risk of disaster.

Risks.

The inevitable risk in the proposal stems from the magnitudes: 250,000 tonnes of enormously dangerous RADwaste in the northern hemisphere 20,000 km from its destined dump in Australia, where it must remain intact for at least 10,000 years. These magnitudes of tonnage, lethality, distance of transport, and time entail great inherent risk. Studies to eliminate the perceived risk would be futile. No amount of ingenuity could get around the logic of

\[ 250,000 \text{ tonnes} \times 10,000 \text{ years} \times (\text{error}>0) = \text{disaster for Australia}. \]

The only reply from a civil engineer asked to guarantee a bridge or tunnel or any other fixed structure for 100 years, let alone 10,000 years, would be “You’d have to be joking”. But Britain, whose backyard is already occupied by “pheasants and deer”, is deadly serious.

Dr Cook’s “hundreds if not thousands of years” was disingenuous; even 10,000 years is too short a span. The general rule is that RADwaste is dangerous for ten half-lives of each radioactive nuclide, after which only 0.1% remains (Rogers & Feiss, 1998). On this reckoning, plutonium 239 (half-life 24,400 years) should be stored for 250,000 years and americium 243 for 74,000 years.

Our job as Australian scientists is to apply due diligence to PARPL’s proposal.

Risk to the oceans from transport of nuclear waste.

The transport of nuclear waste away from its source, in PARPL’s example to the antipodes, entails an unnecessary additional risk: the viability of the world ocean. Dr Cook (2) argues that the magnitude of the risk “may turn out to be a very small number indeed”, and in any case would “be significantly less than the global nuclear risk arising from waste not being stored safely or securely”. This inverts the logic: because Northern nations made the waste without having a means of safe storage for it, and they prefer not to pollute their own ground, Australia is fingered as the “safe” place, even though it entails adding the separate global hazard of the 20,000 km voyage. The Uranium Information Centre points out (7) that 160 such voyages from Japan to Europe have proceeded without loss, so why worry? Because a long run of heads has no bearing on the next throw. RADwaste is exceptional because it is extraordinarily toxic. One cargo unaccountably going down would irreversibly damage the biosphere.

If PARPL really believed their proposed repository to be perfectly safe, they would site it at home. Their lust for our wide open spaces compares with the “environmentally harmless exercise” of the 1965-1995 French atomic tests at Mururoa. If the French believed their own words, they would have tested at home. But other folk’s backyards, especially in the distant South, turn out to be the best.

Australian protest against the 1995 round of tests was strident and universal. Nobody, including nuclear entrepreneurs, could resist the free thrill of condemning the French, even though Mururoa was 7,000 km away and the test underground. How odd then that in Australia in 1999, only the politicians have protested against the proposal to dump 250,000 tonnes of RADwaste in the middle of Australasia! Eminent biomedical and information scientists have gone out of their way to welcome PARPL. Why? Presumably because the money is right: scientific jobs and science-driven prosperity will accompany PARPL’s promised 1% boost to our GDP. But we have no need to take in the North’s dirty washing. The Australian economy, let alone science, is not on its knees. We should be looking forward to making the world a safer place with specifically Australian projects - to name two: Martin Green’s photovoltaics project at the University of NSW and Donne Wyborn’s hot dry rock geothermal energy project at the ANU.

Earthquakes.

According to Dr Cook (5), “if the risk [from earthquakes] appears to be significant then the scientific review group, and no doubt Pangea, will need to be reassured, or the area eliminated from further consideration.” If Dr Cook means what he says, then Pangea can go home now. Gauld et al. (1990) identified the proposed site in the Great Victoria Desert as an earthquake source zone (Richter M <5.9), with an offshoot to the Musgrave Ranges with the site of a 1986 earthquake of M 6.0. They estimated that peak ground intensity (Modified Mercalli scale for cities) in the proposed region is VI (some
structural damage) and to the east, in the Simpson Desert, VIII (moderate damage). These estimates correspond to a probability of 10% of being exceeded over a 50-year period and a return period of 500 years. The prediction from 1990 to 2040 is based on records for the past 100 or so years. To be valid, predictions longer than this would require correspondingly long records that sample thousand-year events. Seismologists (and weather prophets) do not predict longer spans, except to point out the greater expected intensity of the 10,000-year event. Crone et al. (1997) caution: “although they may be currently aseismic, faults in stable continental regions [as the Great Victoria Desert] that are favourably oriented for movement in the current stress field could produce damaging earthquakes, often in unexpected places.” Inescapably, predictions for the next 10,000 years would find the maximum credible earthquake (Yeats et al., 1997) to be much greater than the maximum recorded over the past 100 years.

Putting the casks in salt won’t help. Salt may act as a long-term cushion to the entomed casks but transmits earthquake waves instantly, and creates other problems, as outlined below.

Movement of groundwater.

This also defies valid prediction over the next 10,000 years. Dr Patrick De Decker (see Letters on p. XX) finds that some 6,000 years ago lakes in Victoria were full to overflowing. Data from the Great Victoria Desert are scanty, but the expected Greenhouse Effect and associated Global Warming would entail rising water tables.

According to PARPL’s plans for Western Australia and South Australia, the favoured burial place for the casks is in the 300-m-thick layer of rock salt in the Officer Basin, which indicates a dry state since deposition 800 million years ago. But the salt has moved into diapirs, as at Woolnough Hills, so casks of RADwaste could eventually pop up, worse for wear, at the surface. When, and even if, this would happen is of course uncertain: nobody can know, but we can be sure the probability is non-zero.

Roedder (1984) found that bedded salt may contain several percent total water in inclusions trapped between or within grains during evaporation. The heat from the RADwaste cask hot from the radioactivity absorbed in its walls - when introduced into the salt layer “will tend to concentrate at the cask the fluids from inclusions from some distance around. Estimates of the rates and total volumes of fluids that must be dealt with in a repository design are subject to rather large uncertainties.” This is hydrothermal brine, so efficacious in leaching and corroding metals. An unforeseeable change in the hydrological regime would lead to the same result.

Do not concentrate.

Cognate as they may be, these arguments themselves are overridden by a higher logical rule: don’t put all your eggs in the one basket. The superpowers disperse missile-bombs in silos on land, in submarines in the ocean, and in aircraft in the atmosphere. The rule applies no less to RADwaste.

Concentrating international waste in a single site in the Great Victoria Desert would be a huge single target for today’s terrorists or the next 10 millennia’s vandals, and Australians would be the first victims of the fallout.

What to do if you agree with my argument.

You should urge the people of WA and SA to press their parliamentary representatives to follow the Senate’s example in giving the British Government’s Pangea their marching orders by refusing exploration and development rights in the region. Only mischief can come from PARPL’s little science and huge budget. Also, you could urge Britain to avert another round of nuclear opprobrium by withdrawing PARPL and devoting its $50m to a thorough cleanup of Maralinga.

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I thank colleagues in the Division of Environmental & Life Sciences, Macquarie University, for references to the literature.

REPRINTED WITH PERMISSION FROM THE AUSTRALIAN GEOLOGIST
DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE IN AUSTRALIA

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INTRODUCTION

This article summarises the Pangea proposals for the disposal of high level waste in Australia. Who or what is Pangea? Pangea Resources Australia Pty Ltd is an Australian company, mainly funded by British Nuclear Fuels Limited (BNFL), but also by NAGRA (the waste disposal agency of the Swiss utilities) and Enterra Holdings Limited (EHL), a Canadian corporation.

What is all the fuss about Pangea? Pangea developed a concept and a business plan for the disposal of high level radioactive waste and of unprocessed spent fuel. This plan was leaked to the media late last year. The leak precipitated a great deal of political heat (but not much light!) and magically managed to attract hostility from politicians of all colours across both State and Federal systems, quite a rare achievement!

There are many topics that could be covered in a article which is broadly although not explicitly supportive of Pangea’s concept. These include the so-called morality and ethics of disposing of waste created overseas, the safety of the transport and disposal operations, the credibility of geological predictions about long-term stability of the disposal site, and many others. I will not cover any of these topics, since I am not qualified to do so.

This is a valuable opportunity to reach the physics community. I want to use it to give you some facts about Pangea (to the extent that I am familiar with them), and to refer to earlier discussions about waste operations in Australia. I will also touch on current activities by the Federal Government, and perhaps provide some talking points about analogous matters that might help in considering the Pangea concept. You will have to decide for yourself whether Pangea’s concept merits further investigation.

THE PANGEA CONCEPT

Background

I will refer later to some of Pangea’s antecedents. The Pangea concept, as it has been publicised during 1999, involves a possible international business opportunity in the disposal of various types of radioactive materials. The materials in question are:

* unprocessed spent fuel from civil nuclear power stations
* immobilised high level radioactive waste (HLW) - fission products and transuranics separated out by the reprocessing of spent fuel
* plutonium reclaimed from dismantled nuclear weapons and unsuitable for use as power station fuel.

In about thirty countries, civil nuclear power stations are used to generate electricity. Some of these countries have adopted a policy of reprocessing their spent fuel, others have equally firmly decided against reprocessing.

For those opting for reprocessing, there are effectively only two operating reprocessing plants, one each in Britain and France. The result of reprocessing is the separation and potential for recycling of plutonium (generated as a natural consequence of the irradiation of uranium in a reactor) and unused uranium. Reprocessing also results in the separation of HLW (as defined above). After a period of cooling, the HLW is calcined and incorporated into borosilicate glass to form a stable immobilisation medium. After a further cooling period, the glass blocks containing HLW are returned by the reprocessing plant to the original owner of the spent fuel, who retains ultimate responsibility for their disposal.

Amongst the majority of countries with nuclear power and a no-reprocessing policy, only Sweden has established the stages up to and including the long-term centralised storage of spent fuel on a national basis; a search is in progress for a disposal site. In the USA, there has been a twenty-year saga over the disposal of spent fuel. This epic has enriched generations of lawyers and kept all spent fuel in the at-reactor storage pools. The US Government may eventually take possession of spent fuel and place it in the proposed Yucca Mountain, Nevada, facility, but only when all investigation of the site and all legislative and judicial processes are complete and exhausted, whenever that might be!
There are various estimates for the volume of spent fuel already in existence in the thirty or so countries mentioned above, and for current annual arisings. On the basis of the expected lifetime of all existing power reactors, there will be about 300,000 tonnes of spent fuel in total, including the current annual generation rate of about 10,000 tonnes. This total effectively includes, on an equivalence basis, the immobilised HLW in glass blocks.

Pangea's founders were aware of these totals, and were also aware of the large sums of money which had already been literally sunk into repository investigations which had either failed or were going nowhere. One estimate was that some three billion US dollars had already been spent on such investigations, so far without positive result. The cause of this massive waste of funds was seen to be the selection of sites for investigation purely on political grounds and hardly at all for scientific and technical reasons. Not surprisingly, technical efforts to defend the political choices had proved very expensive and ultimately fruitless.

Pangea's founders were also familiar with costings for the transport and storage of spent fuel, and for the cost of reprocessing and immobilisation. It was clear that the owners would expect to spend at least one million US dollars per tonne to put either spent fuel or HLW into long-term storage. On this basis, there would be an industry worth at least three hundred billion US dollars involved in managing and disposing of the expected accumulation of spent fuel around the world.

Over recent years international disarmament initiatives have investigated how plutonium recovered from dismantled or decommissioned nuclear weapons could be prevented from finding its way back into such weapons. There are two ways in which this might be achieved: one is to use some of the plutonium by mixing it with uranium, both of them in oxide form, to provide mixed oxide (MOX) fuel for power station use. The other is to "denature" the plutonium by mixing it with HLW, immobilising and disposing of it along with other HLW and spent fuel. No costs for this process are available, but there is little doubt that substantial payments could be made for the effective removal of surplus plutonium.

**Pangea's Concept**

Pangea's concept is to establish a total waste management enterprise. This would take over at its source the spent fuel, HLW or other material. It would then provide internationally approved, specialised and heavily shielded waste containers and transport them over land and/or sea to a dedicated storage and disposal site in a host country. There the material would be conditioned before disposal and ultimately placed in the repository.

The enterprise would manufacture its own waste containers, meeting accepted international standards for safety, as well as the specialised double-hulled ships required for transport between overseas ports and a port in the host country. Suitable containers and shipping have already been in use for many years, for both national and international transfers of spent fuel and HLW.

Depending on the geography of the host country, a dedicated railway line would be provided between a new port and the repository complex. At the latter, a full range of facilities would enable all necessary decontamination, repackaging, conditioning, storage and ultimate disposal. When the limits of disposal volume were reached, the entire facility would be maintained in its dormant status for an agreed period of time. Subsequently the repository itself could be sealed off, or if long-term retrieval had been offered as an option, appropriate arrangements made.

Since the enterprise had been designed for international use, the host country might require international assistance for the permanent oversight and security of the facilities.

Pangea essentially proposed to undertake a feasibility study for this concept, the first stage of which is to identify a geological region technically suitable for the long-term isolation of radioactive material. Pangea suggested that such a region would be arid, isolated from major population centres and with extensive flat lying strata with either no water or highly saline water that moved only at a very slow rate. On very general grounds and knowledge of world geology, it was suggested that suitable regions existed in Argentina, Australia, China and South Africa/Namibia.

**Australia**

Since political and social stability were also seen as major positive factors, Pangea saw Australia as possibly the best candidate for their study. In fact, a broad swathe of desert country running roughly east-west across the Western Australia - South Australia border in the mid-north of the latter was expected to offer suitable geology. Pangea would conduct detailed investigations over the prospective region, to acquire detailed data for input to a comprehensive scientific and technical evaluation.

It appears as though Pangea has decided to concentrate on Western Australia, possibly in the expectation that the political climate there might be more favourable, and presumably for this reason has moved its base from Melbourne to Perth.

Doubtless Pangea hoped to find a welcome in Western Australia, given that it would potentially be offering a multi-billion dollar investment and revenue stream if its concept were realised. As with other large natural resource projects, the proponents normally expect to go through a sequence of events that may take many years between concept and fruition. These events include site identification and technical confirmation, economic feasibility, environmental assessment, native title procedures, discussions and negotiations with traditional owners, political and social acceptance and, ultimately, legislative approval.

After the media published the leaked story about Pangea, Federal Ministers were very quick to denounce Pangea's concept and to assert that such an enterprise would not - no, never, be permitted (is it a week, or never, which is a long time in politics?). Not surprisingly, all shades of Opposition politicians followed suit. At the State level, once Pangea's interest in Western Australia became clear, there was great haste on the part of both Government and Opposition to enact legislation
that would prohibit the introduction of radioactive waste from overseas and the transport of such materials within the State.

It should be quite clear that this rather unusual example of bipartisan politics is aimed, not at a proposal to build something, open up a mine, or import noxious materials, but at the very idea of a detailed study, and only a study, on the Pangea concept. Some cynics might say that offending both sides of politics is an indication that Pangea is on the right track!

SYNROC

In the 1970s, Ted Ringwood at ANU recognised that certain titanium minerals naturally retained radioactive particles. He then formulated a synthetic rock - Synroc - that he thought might be suitable for the immobilisation of the components of HLW from power station spent fuel, viz. fission products and transuranics. There are in fact several formulations, as Ringwood also recognised the potential for Synroc as an immobilising medium for other radioactive materials, for example the military waste stored in large quantities at Hanford, Washington and at other sites in the USA.

Development of Synroc technology has been carried out jointly by ANU and ANSTO using Government funding. The work includes testing of the immobilisation properties under typical conditions, the preparation of precursor materials and the manufacture of typical Synroc masses with incorporated waste simulants. Some work has been done with radioactive content but ANSTO's collaborators have carried out testing with realistic HLW overseas.

Synroc Study Group

In the late 1980s the Commonwealth Government encouraged a group of Australian companies to look at the potential for commercialisation of Synroc. The Synroc Study Group (SSG) comprised BHP, CRA, ERA and WMC. SSG realised that if Synroc was limited to the immobilisation of HLW from civil power reactors, it was totally dependent for its future on the two reprocessing plants, which already had a large investment in borosilicate glass as the immobilisation medium or waste form.

In its Progress Report, published in 1991, the Group proposed that further consideration should be given to the establishment of a waste management enterprise, with one option being an Australian location for the facilities. This concept took account of the fact that a significant proportion of the world's spent fuel was unlikely to be reprocessed, not only due to a limited capacity for reprocessing, but also because there was limited economic justification for reprocessing. Hence there was a potential for disposal of up to 300,000 tonnes or so of spent fuel, most of which would not be reprocessed. Further, the SSG concept provided for long-term retrievability in underground storage, whereby the original owner of the spent fuel might have an option for final disposal or for reprocessing.

This concept was well publicised in 1991 and attracted favourable comment from the media and public. The only comment from the relevant Federal Minister at the time was to the effect that the ALP's then policy did not permit the importation of radioactive waste. He found it possible nonetheless to provide supporting credentials for an SSG delegation to Japan, Korea and Taiwan, where SSG's concept was well received.

SSG's concept was known to the founders of Pangea, and played a part in the formulation of Pangea's current proposals.

NATIONAL RADIOACTIVE WASTE REPOSITORY

Australia has low and intermediate level radioactive waste as a result of research reactor operations and isotope production by ANSTO. HIFAR reactor spent fuel will be reprocessed in France, and the separated waste eventually returned as intermediate level or Category S waste. Smaller amounts of waste are present in every State, arising from a variety of medical, industrial and research activities.

Commonwealth and State Governments agreed in the early 1980s to seek a site for a National Radioactive Waste Repository, but the process of confirming a site and establishing the Repository is yet to be completed. There has been an extensive and well-publicised evaluation carried out into candidate regions across the country. Note that the basic criteria used for regional selection for the Repository are similar to those suggested by Pangea and referred to in a previous paragraph. The Repository requires less emphasis on the lower lying geological strata since it will only be concerned with near-surface conditions.

One region was finally selected for further assessment, and test drilling is proceeding in an arid region of mid-north South Australia. It is expected that the Repository, which consists of trenches just below ground level, should be in operation within the next few years.

Criteria for the disposal of LLW (or Category A, B and C waste) are based on the low level of radioactivity and the relatively short-lived nature of this waste. Location in an arid region reduces the risk of waste being disturbed by surface water. The risk is further reduced by the integrity of the containers and by use of an impervious lining to the trenches. Once full, trenches will be backfilled and the facility covered with a layer of earth and reinforcing material to maintain its overall integrity. After some years, there would be no further need for surveillance and the site would be fenced off and only occasionally inspected.

Although no commitment seems to have been made as yet, a potential ILW/Category S store may be built on the same site as the National Repository. Such a store is likely to be a much more complex structure than the Repository, as it is likely to require shielded facilities for handling, inspection and cleaning of waste containers, possibly hot cells for loading or unloading of containers, and shielded storage facilities with security and surveillance. This range of facilities would be required even for a minimal volume of ILW, making the store disproportionately costly for its capacity.

Since there are no nuclear power stations in Australia, there is no locally generated spent fuel or HLW.
**FURTHER COMMENTS**

It is unquestionable today that any concept like Pangea’s, if put forward as an actual project, would be subject to very detailed examination and analysis and most probably to a full public inquiry. A very high standard of credibility would be demanded for each and every claim regarding safety, environment protection and other factors.

Note that there is no new technology involved in the transport, storage and disposal of the various classifications of waste; all the necessary technologies have been in existence for many years and have had an excellent safety record. One must therefore ask what political factors impel politicians to attempt to stifle this concept and prevent its public examination?

It may be noted that the geologically appropriate regions for deep waste disposal are not in the same countries where most nuclear power stations and their spent fuel are to be found. Is it a valid analogy to suggest that countries with mineral deposits do not in general withhold these essentials to contemporary life from countries that are less fortunate in their geology? We live in a highly connected world with trade barriers constantly under attack and most countries dependent in many ways on others.

The key to safety in disposal of radioactive waste is effectively groundwater. Other than physical movement of the waste itself, it can only be the presence and movement of groundwater that could transport waste, or some components, from the point of deposition to some other place. Emplacement in strata that remain devoid of water evidently assures the absence of a transport vector. It would be preferable, however, to emplace in strata where water is tightly held in interstices or water movement is measured, for example, in millimetres per century. In the latter case, not only would any transport vector be minimised, but there would also be low long-term risk of groundwater ingress changing the environment.

**IN CONCLUSION**

I have described the Pangea concept and the steps that would be required to progress this to an actual project. The evidence that the project would be acceptable on safety, environmental and other grounds remains to be presented. There are no new technologies involved, however; hence it is plausible that acceptance and approval could be obtained on scientific and technical grounds.

Some of those who oppose the concept itself argue that there are moral or ethical grounds for Australia to refuse to accept radioactive waste from other countries. There has been no public debate on these issues as yet, and indeed the idea that there could be moral or ethical issues associated with this topic will seem quite novel, but nonetheless worth examining.

Australia has played a prominent role in disarmament negotiations and in the formulation of non-proliferation policies and treaties. It would be performing a valuable international service if it were able to assist in the locking away of surplus plutonium, provided always that there was no detriment to Australia.

Australia is a developed country with all the industrial hazards that entails. We are quite comfortable with gas and petrol tankers alongside us in the traffic, for example, or living under aircraft flight paths even if we dislike the noise. There are hazards associated with all of these, but the risks have been assessed and we are in general prepared to accept these risks. The remote arrival and transportation of radioactive waste, and its remote disposal, are likely to offer much smaller risks, and should at least bear detailed assessment.

The author has no contractual or other obligations to Pangea, although he has previously carried out consulting work for them or their corporate associates.

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**STOP PRESS**

**"SCIENTISTS MEET THE PARLIAMENT DAY"**

24th November, Parliament House, Canberra

More than 170 scientists from member societies of FASTS met in Canberra this week and on Wednesday there were meetings with more than 140 Federal Politicians. The feedback was very positive and many of the meetings lasted well beyond the scheduled 30 minutes, in one case for 1 hour and 50 minutes, terminated only because the member had to attend question time! The coverage in The Australian the day after (25th November) was excellent and the editorial a very positive outcome from the meetings held the day before.

Physicists formed the largest contingent with 23 members nominated by the AIP. At one count there were about a further dozen physicists present under other auspices.

At the FASTS Board Meeting on November 25th, it was reported that several politicians asked if FASTS could make this an annual event. There will be a fuller account in the first issue of the Physicist next year.

In conclusion - a good day for science. May there be many more! Above all we want bi-partisan support for proper and internationally competitive levels of funding as one major outcome of the 'Scientists meet the Parliament Day'.

John Pilbrow
President

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*The Physicist* Volume 36, Number 6, November/December 1999 237
The New World of Mr Tompkins

It is coming up on sixty years since George Gamow's imaginative scientific best-seller "Mr Tompkins in Wonderland" was first published. It has been reprinted something like twenty times to meet the demand from readers anxious to learn the basic concepts and effects of relativity. Gamow, noted for his theory of alpha decay, then went on to write a companion volume "Mr Tompkins Explores the Atom" (and then, no doubt intoxicated with success, wrote another on sex education!). In 1965 the two physics presentations were updated and combined into a single volume. Even so, physics has progressed so much since 1965 that a completely revised version became necessary.

But George Gamow died in 1968 so the task fell to science populariser Russell Stannard, author of the Uncle Albert trilogy that presented the work of Einstein for adolescents (and their elders).

The result is a recently published volume "The New World of Mr Tompkins" which should be in the bookstores just in time for Christmas sales, where I have no doubt it will sell well. However I should warn that its presentation will bore many of today's young people. Stannard has preserved much of the quaintness and romance of Gamow's 1940's vintage writing. This will pose no problem to intelligent readers, who will readily grasp the physics. No, to appeal to those hip youngsters fed on a diet of Star Wars and Space Trek the approach might have been modernised more spaceships rather than bicycles.

By and large the latest physics is treated quite well, and concisely enough to fit within 250 pages. I was alarmed to note that (in a table) the charmed quark lacked charm, and disappointed that Stannard failed to spend a few paragraphs on lasers in the chapter where light emission from atoms is explained. There is a good glossary to assist those unfamiliar with the jargon of physics, but no index.

Subject to my comments on quaintness, I heartily welcome "The New World of Mr Tompkins". As a popularised introduction to many of the key concepts of twentieth-century physics it stands high. But, like the best in brain-food, the sub-atomic, warp-speed adventures of Mr Tompkins are not for the mentally lazy.

"The New World of Mr Tompkins" is published by Cambridge University Press. It costs £39.95 in hardcovers and bears the ISBN 0-521-63009-6. Every high school library in the land must acquire at least one copy.

Colin King
Reviews Editor.

Reviews

Renormalization: An Introduction
M Salmhofer
Springer, Berlin 1999
x + 231 pp., DM 79 (hardcover)
ISBN 3-540-64666-3

This book nicely fills a void between traditional physics textbook treatments of renormalization and a more mathematically rigorous approach. One still occasionally comes across mathematicians and physicists who, while mathematically literate, are uncomfortable or suspicious of the renormalization procedure in quantum field theories. Such individuals should be gently but firmly steered toward this book.

It is the traditional naive, unregulated formulation of quantum field theory with an a posteriori imposition of renormalization which can lead to confusion. Here regularization and renormalization are part of the formulation of quantum field theory from the outset and this puts the renormalization procedure in its appropriate and natural context. The author has attempted to simplify the presentation as far as possible without sacrificing mathematical rigour.

The text is intended to be accessible to physics and mathematics students from third year on, however the level is such that it would best be read after an introductory course in quantum field theory and with a good background in mathematics. The topics covered are the minimal set that the author felt was necessary in order to illustrate the main principles of renormalization. Hence the text is an excellent complement to a physics textbook treatment, but is not a replacement of it. Two minor shortcomings of the book are the lack of problem sets and the use of mathematical notation without always defining its meaning. The latter unnecessarily hinders readers who do not have adequate mathematical preparation and could easily be remedied by the author in a second edition.

In summary, this is an excellent reference text for anyone interested in the mathematical formulation of renormalization and quantum field theory and should be seriously considered as an addition to a professional or university library.

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Fluid Metals: The Liquid-Vapor Transition of Metals
F Hensel and W W Warren Jr
Princeton University Press, Princeton NJ 1999
xvii + 244 pp., SUS 70 (hardcover)
ISBN 0-691-05830-X

This book is perhaps too narrow in its topic coverage to appeal to a wide audience. It deals with the phase change from solid to liquid for 'metal' elements. It endeavours to be a general description of both the phase change and the critical phenomena. However, as is pointed out in the introductory sections, there are only a handful of elements for which this treatment is relevant.

It commences with a brief (7 page) introduction to the field and then launches into a description of the electronic structure of metals and fluids. This description exactly mirrors the content of any common solid state textbook on electronic structure of solids with only limited reference to its relevance to the fluid state.

Then a few different groups of materials have chapters devoted to them, commencing with alkali metals, mercury and 'chalcogens'. In the chapter on chalcogens, there is extensive coverage on the properties of selenium and only limited reference to sulphur and tellurium. Up to this point the material is almost an element specific review for a limited range of elements.

The final two chapters are where the much awaited action lies. Chapter 6 covers 'Critical Phenomena' dealing with the systematics of the critical density and temperature in selected liquids as well as the role of binary mixtures, and homogenous nucleation of supersaturated metal vapour.

The final chapter deals with High Temperature/High Pressure Experimental techniques. It covers principally electrical, NMR, optical and x-ray measurements.

I am not sure who would use this compendium of knowledge on fluid metals, but if you need it then you will have the lot at your fingertips.

D J O'Connor
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Quantum Philosophy: Understanding and Interpreting Contemporary Science
Roland Omnès, translated by Arturo Sangalli
Princeton University Press, Princeton 1999
xxiii + 296 pp., US$29.95 (hardcover)
ISBN 0-691-02787-0

Quantum Philosophy is a formidable treatise on philosophy, particularly the philosophy of knowledge and the importance of the major 20th-Century developments in physics and mathematics. Omnès shares with the reader his detailed knowledge of philosophy, physics and mathematics, as well as insights into the key developments over the centuries.

This historic introduction provides the reader with an excellent background to appreciate the present-day quandary arising largely from developments in quantum theory. As a major contributor to the consistent histories approach to quantum theory and interpretation, Omnès is eminently qualified to discuss the nexus between the philosophy of knowledge and the conundrums of quantum theory. Given his background, it is not surprising that Omnès employs consistent histories for interpreting quantum theory and addressing the key philosophical issues.

A reader with a background in physics should be able to read (and enjoy) this book. The book does not require a background in philosophy, and the first half of the book would be a useful summary of the philosophy of knowledge for any scientist's shelf. The mathematics is non-existent for most of the book and is introduced later to explain coherence and decoherence in quantum theory. The mathematics, which is presented only where necessary, is not beyond the level accessible to a senior undergraduate student in physics.

I enjoyed reading this book and appreciated the whimsical excursions throughout the text, which highlighted important issues and clarified concepts. At times Omnès employs fictional dialogue between sages and later the introduction of an angel who tries to understand the human approach to science. I recommend this book as an enjoyable introduction to the philosophy of knowledge and as a serious work, which addresses the dilemmas of philosophy posed by modern science and mathematics.

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More Things in Heaven and Earth - A Celebration of Physics at the Millennium
B Bederson (ed)
Springer APS, New York NY 1999,
xxi + 841 pp. US$79.00 (hardcover)
ISBN 0-387-98662-6

This volume was inspired by the 100th anniversary of the founding of the American Physical Society, and seeks to "display the vast canvas that encompasses a century of magnificent accomplishment in physics as we enter the new millennium." By and large this objective has been achieved.

After the introductory necessities, the first seven chapters are historical perspectives of the growth in different areas of physics. All are very tersely written, but nevertheless extremely interesting. Then follow ten sections relating to different areas of physics; these contain anything from one paper (Plasma Physics, Computational Physics) to six or seven papers (Particle Physics, Astrophysics, Atomic Molecular and Optical Physics, Condensed Matter Physics, Statistical Physics and Fluids and lastly Applications of Physics to Other Areas). The review of "The Standard Model of Particle Physics" was particularly well written, and clarified a number of concepts in my mind. Hidden away in the Condensed Matter Physics section was a quite fascinating account of "The Invention of the Transistor". The "Applications of Physics to Other Areas" section contained, among others, articles on "Physics and Applications of Medical Imaging", "Nuclear Fission Reactions", "A Nuclear Power - Fusion", and "Physics and US National Security" - a particularly well written piece by Sidney D Drell.

The section on "Nuclear Physics" was disappointing. The first paper, "Nuclear Physics at the End of the Century" by Henley and Schiffer, concentrated for the most part on nucleon structure and the rotational band structure of the heavy nuclei. In my view there was so much more that could have been discussed. It was followed by a very short paper by E E Salpeter on "Stellar Nucléosynthesis".

This volume would most likely find a place on the shelves of institutional libraries; the combination of the price and the wide range of topics covered would most likely dissuade many Australian physicists from purchasing it.

Brian Spicer
School of Physics
University of Melbourne

Solar Sailing - Technology, Dynamics and Mission Applications
Colin Robert Melinnes
Springer Praxis, Chichester UK 1999
xxvii + 296 pp., DM129 (hardcover)

This is a book to excite the imagination and stretch the intellect. Solar Sailing is about the use of the Sun's light to provide direct propulsive power for spacecraft. To many this might seem like science fiction, yet in the first chapter we are led through the history of the concept which started over 100 years ago.

The force imparted by solar photons at the Earth's orbit is indeed small, around 10 newton/km². To a sheet of aluminium Kapton 2 micrometres thick this force will impart an acceleration of only one mm/s². However with a sail some 1 x 100 m square a payload of 20 kg can reach solar escape velocity in around one year.

The physics of radiation pressure is followed by solar sail engineering design, covered qualitatively and descriptively. This is followed by detailed orbital dynamics, including non-Keplerian orbits, which are particularly suited to this type of spacecraft propulsion. Although second year University physics is required to fully analyse all the detail presented, there is enough verbal and diagrammatic content to convey the essential concepts.

The author does not gloss over the problems of solar spacecraft, the largest of which is the successful deployment of the huge solar sails. But he convincingly argues for the missions in which this propulsion mode excels - high energy and long duration flights.

Potential practical missions described include a space weather warning satellite, a solar polar orbiter and a Mercury observer. In the final chapter the author details solar driven laser propulsion of an interstellar sail.

The writing and layout are excellent. Each chapter starts with an overview and ends with a summary. The presentation is diverse both in topic and level. A primer for the novice and a working reference for the scientist and engineer. This book belongs in the top 1%.

John A Kennaway
Learnmonth Solar Observatory
IPS Radio and Space Services

The Physicist Volume 36, Number 6, November/December 1999 239
CONFERENCES & MEETINGS 2000

Jan 3-7  KRUSKAL 2000
Conference on Integrable Systems, in celebration of Martin Kruskal's 75th Birthday
University of Adelaide
Contact: Nalini Joshi, Email: Nalini.Joshi@adelaide.edu.au

Jan 17-28  13th ANU Summer School in Physics
Bose-Einstein Condensation: atomic physics to quantum liquids
Contacts: Craig Savage, Physics, Faculties, ANU
Mukunda Das, Theoretical Physics, RPSPhysSE, ANU

Feb 2-4  24th Annual Condensed Matter meeting of the AIP & NZIP Wagga Wagga
Registration & Abstracts due: 26 Nov 1999
Contact: Roger Lewis, Tel: (02) 4221 3517, Fax: (02) 4221 5944
Email: wagga@rutherford.scl.uow.edu.au

Feb 7-11  NUPP Summer School EL Lago Resort, The Entrance (NSW Central Coast)
Contact: A/Prof Lawrie Peak, Email: peak@physics.usyd.edu.au, or
nupp2000@physics.usyd.edu.au

Feb 13-17  ANZ Magnetic Resonance Society Conference Mt Buller Chalet, Mount Buller, Victoria
Contact: Dr Jenny Wilson, Ph: (03)9903 9617 Fax: (03)9903 9582
anzmog@edd.vcp.monash.edu.au  http://www.vcp.monash.edu.au/chemistry/anzmog2k

Feb 13-19  The Baxter Revolution in Mathematical Physics
Australian National University
Contact: Murray Batchelor (murrayb@maths.anu.edu.au)

Feb 21-25  International conference on Quark Nuclear Physics Hilton International, Adelaide
Contact: Prof Alf Thomas, CSSM, University of Adelaide
qnp2000@physics.adelaide.edu.au

Mar 13-17  3rd. International Symposium on Symmetries in Subatomic Physics
Hilton International, Adelaide
Contact: Prof Alf Thomas, CSSM

April 26-27  4th Australian Geomagnetism Workshop
Australian National University, Canberra
Contact: Heather McCreadie (Heather.McCreadie@ogso.gov.au)

May 14-19  Conference on Precision Electromagnetic Measurements, CPEM2000 Sydney

May 23-26  8th International Conference on Ground Penetrating Radar (GPR '2000) Gold Coast
Dr. David Noon, Dept of Computer Science & Elect. Eng., University of Qld., Qld 4072
Tel: (07) 3365 3693 Fax: (07) 3365 3684
Email: noon@csee.uq.edu.au

July 3-7  11th International Semiconducting and Insulating Materials Conference
SIM-XXI 2000 Canberra
Contact: Dr C. Jogadish, RPSPhysSE, ANU, Canberra ACT 0200
Ph: 61-2-6249-0363 Fax: 61-2-6249-0511 Email: simc2000@anu.edu.au

Oct 1-6  International Symposium on Metal-Hydrogen Systems Fundamentals and Applications
Noosa, Queensland
Contact: A/Prof Evan Gray, Griffith University, Ph: (07) 3875 7240, Fax: (07) 3875 7656,
email: E.Gray@scf.gu.edu.au, or
A/Prof Colin Skoll, University of New England, Ph: (02) 67 732 387 Fax: (02) 67 733 413,

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