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The Australian Institute of Physics

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President's Column

This is the last column I will be writing as president, so that it is perhaps appropriate that I give some sort of State of the Union message. (I cannot call it a swansong, since swans are supposed to be mute before that final vocal effort.)

The fortunes of the Institute, as you will have read in the Annual Report, stand firm, thanks in large measure to the efforts of Branch Committees and of that really hardworking trio, the Secretary, Treasurer and Registrar, within the Federal Executive. It has been a real pleasure to discuss plans, problems and achievements at Council meetings, and I would like to pass on my warmest thanks to all these colleagues. Similar thanks must go to the editorial staff of "The Australian Physicist" for keeping us all in touch and promoting Australian physicists as a community. Institute membership has been maintained and even increased in some categories, our finances are stable once we have made some allowance for inflation, and, though attendance at branch meetings sometimes fails to meet expectations, both National Congresses and specialist meetings are in a state of healthy growth.

Are there then, any clouds on the horizon? (And, in parentheses, I should remark that while clouds signify change, the rain that they bring may be welcome!). The drought situation for tertiary education funding, alas, shows no signs of breaking, and, even though Physics maintained its share of the ARGS cake for 1983, the size of that cake becomes a little less each year. These are two matters that must continue to be of prime concern to the Institute in coming years.

The clouds of change are a little more obvious above the organization of Physics in Australia, and it is by no means clear yet how things will turn out. Within the traditional discipline of Physics, the Acousticians and the Medical Physicists have already set up autonomous organizations of their own, while at the other end of the scale the Solid-State Physicists do not even want a formal Group but rather prefer to organize their annual Wagga meeting under the general umbrella of the Institute. Nuclear and Particle Physics is a formal group, while Laser Physics and Gaseous Electronics have Institute sponsorship but no formal structure within the Institute. Recently there have been moves to form an Australian Optical Society, as distinct from an Institute Group, but the outcome of these discussions is still not clear.

It seems to me that the key policy for the Institute must be to remain flexible on all these matters. Physics itself is such a basic science that its principles and practice underlie many more specialized disciplines which rely also, in their turn, upon biology or mathematics or engineering for much of their subject matter. We should, I believe, to maintain the closest possible links with each of these progeny, without trying to tailor their development to a Procrustean bed of our own devising.

In the absence of a Physical Society to deal with Basic Physics (whatever that is), there should always remain a large core of physicists whose primary affiliation is with the Institute itself, but the Institute might also follow in part the American model and serve as a federated organization for a group of kindred societies. In numbers, as I have written before, there is a strength and the possibility of concerted action. We must remain flexible and outward-looking enough as an organization to attract these numbers.

To the incoming President and Executive I leave these and many other problems with my very best wishes. Each two-year term is too short to accomplish much, but the Institute represents at any time the collective aspirations of Australian physicists and, if we all work together whether in agreement or dissent, we will make steady progress.

Editorial

A very long article in this issue should not be taken as an encouragement to prospective authors to do likewise — the AIP likes to publish the Pawsey Lecture in full, and there will be another similar article, probably in May. Shorter articles will receive swifter publications and will enable The Australian Physicist to continue to appeal to a wide audience.

We welcome comments on anything in the journal, and would like to establish the "letters" section as an interactive forum. But please be honest and to the point. I believe that most controversy is due to different perceptions of reality combined with a paucity of facts. Those involved, however, often see the opposing argument as a deliberate distortion of the facts for the purpose of personal profit or aggrandisement. In dealing with the point at issue, can we assume good will on both sides? Everyone, even one's opponent, has a stake in the future.

Clive Coogan recently drew my attention to some nice graffiti from the lavatory at Melbourne University: "Heisenberg was probably here." If you have heard about the recent advent of the W particle at CERN, you may have been thinking he was there, too. The reported frequency of finding the postulated event was 5 in 10^8. This may be visualized as 10 seconds in a lifetime, or 1 cm² in a hectare. And yet it is possibly a key to a basic understanding of nature. One of the glories of physics is the way it spans the universe from the sublime to the ridiculous, from the incredible to the everyday.

J. GRAHAM

The Australian Physicist, Vol. 20, March 1983 — Page 33
Dear Sir,

The review by John Nicholas of 'Physics in Australia, 1981' (Australian Physicist, December 1982) is a constructive and sharp comment on the Academy report, and in many ways we agree with the views and suggestions he has put forward. However our intention, at present, is for the next issue of this report to look closely and critically at a smaller area (smaller even than 'physics' as the report sees it) rather than to present a more accurate version of its predecessor. There is an urgent need to scrutinize critically and in detail many branches of the subject, so that future planning can be properly supported. The type of general survey already carried out performs only one of the many functions that the Academy hopes to achieve. This means that the sins of omission perpetuated by the 1981 report will be on view for some time and so I should like to answer some of the harsher judgements that were made.

First of all the opening remark that the report is deceitful, although perhaps meant to be playful, creates an unpleasant impression that even later kinder remarks do not remove. I can assure the reviewer that no contributor to that report set out to deceive anyone, and all statements were made in what I believe to be complete honesty.

The reasons for this pejorative judgement appear to be twofold. First of all the report though claiming to cover physics has omitted many branches of what people generally believe to be part of the subject, and secondly, even within the context of the physics covered many people and institutions appear to have been overlooked. To some extent the reviewer has presented the arguments from the report which attempted to forestall these criticisms, but perhaps these answers should be made again and rather more forcefully.

The question of what areas to cover was not really a difficult one. The report was prepared by the National Committee for Physics which is the Australian body coordinated with the International Union of Pure and Applied Physics, which is part of the International Council of Scientific Unions. It is a reasonable presumption that under the latter comes the whole of science, and consequently the whole of Australian science is covered by the set of all National Committees. And if one looks at the list of disciplines which were not covered in the report (despite the reviewer's remark, physics education has a whole chapter devoted to it, written by Professor Mainsbridge, an acknowledged Australian authority) one sees that they are all specifically covered by one or other of the other National Committees. So the only grounds for objecting to their not being covered would be that the other National Committees have so far not produced their reports. It would be very nice if the 32 committees all produced their reports at once, but if they did it would beggar the Academy. The detailed objection that a report entitled 'Physics...' should not omit such subjects is hard to understand. Astronomers or crystallographers do not call themselves physicists — their profession and their organizations are named exactly as they are. It would be absurd to try to cover their activities under the heading of 'physics', and if IUPAP does not call itself 'IU of some PAP', then why should the Academy Committee and its report?

The second criticism is that many people have been omitted when they should have been included. There may be some grounds for this but the report cannot simply be condemned out of hand. Each chapter was assigned to an acknowledged expert and the contributors worked very hard to cover the field as they knew it. They were often subjected to very frustrating delays by people who were either in no hurry to answer or were constrained by governmental or commercial controls. If some people were not even contacted then perhaps one would infer that such people were not sufficiently active in their field to come to notice. If no papers in journals or at conferences appear then it is not surprising that the work is overlooked. Also in the examples cited many of the names hardly look like physics. 'Protein chemistry, chemical technology, soils etc.' are not names that would suggest a lot of people working on questions in physics.

However, as a result of this review and other communications received, such groups are now noted and the next attempt to write about physics in Australian, perhaps entitled 'Some More Physics in Australia' or 'Almost All Physics in Australia' will certainly search much more widely and deeply than it was able to in the time available to prepare this report.

C.A. Hurst
University of Adelaide

Dear Sir,

I would like to correct some inaccuracies in "The Australian Physicist", Vol. 19 December 1982, pages 231 and 232 in an article titled "Bionic Ear — Nearing Completion".

During the second stage the development cost plan and market survey were prepared by Telecommunications Pty. Limited (one of the Nucleus group of companies) for the Australian Government. These were examined by the Price Waterhouse Associates who prepared a report for the Australian Government.

Nucleus Limited won the contract on a competitive basis to develop the system to its present stage where preliminary clinical trials are underway.

The next phase is a wide scale clinical trial to demonstrate the safety and effectiveness of the system and to obtain approval to market from the appropriate international government authorities.

This project is an excellent example of what may be achieved by cooperation between Universities, Governments and Industry.

David Money
Cochlear Project Leader
Nucleus Limited

I have just had the honor of leading a trade mission on scientific instruments to France and Germany. The instruments we took as a sample of what is available from Australia were all the fruit of Australian invention and initiative.

Some were the best of their type in the world — some undoubtedly so, being the only instruments of their type in the world.

At the giant international Mesurca exhibition in Paris (measuring and control instruments) all received surprise, respect and acclaim, "Do you really make this kind of thing in Australia?"... "I suppose that this is Australia's entire output in instruments?"... and similar expressions of amazement were commonplace.

For some instruments, long queues developed of firms wishing to take an agency in their country.

Page 34 — The Australian Physicist, Vol. 20, March 1983
One device, an unpretentious pig-fat monitor, which can measure the thickness of fat on back or belly of the live pig, topped the list with over 30 applicants from 10 countries.

So, we can do it! But we must choose our targets well. And the scientific instrument field is such a suitable target.

It isn’t a Mickey Mouse industry — the profits are there. But the giants can’t block our scientific inventiveness; ironically only Australian Governments can do that by inappropriate education.

We need wholehearted Government support, state and federal, at this crucial time, to establish the industry firmly as an Australian speciality. We need immediate financial incentives, and long-term we need rehabilitation in Australian schools of the teaching of mathematics, physics, chemistry and English.

Unlike many of our tired industries, we have a great opportunity facing us in Australia in sectors of high-technology industry if we get our act together rather than trying to move forward as a lot of fragmented pieces. The instrument industry sees this, and is indulging in unprecedented co-operation. May our Governments see it too? Remember the opportunity we lost with the Hartnett car?

Let’s not talk for ever about venture and venture capital. Let’s venture.

C.K. Googan
Chairman, Australian Scientific Industry Association
(selections from a letter to the Melbourne Herald)

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International Solar Energy Congress planned for Western Australia

Perth, Western Australia, has been selected as the venue for the 1983 Solar World Congress and International Solar Energy Exhibition. The Congress will take place from August 14-19, 1983 and promises to be one of the most exciting scientific events ever held in the Southern Hemisphere.

The Congress is sponsored and organised by the International Solar Energy Society (ISES). Every two years ISES stages a major world forum of particular interest to solar energy enthusiasts, researchers, designers and manufacturers. The 1981 Congress was held in Brighton, U.K. and the 1985 Congress will take place in Canada.

The 1983 Congress will attract over 1000 of the world’s foremost authorities on renewable energy. The technical sessions will consist of addresses, symposia, workshops and poster sessions in such subjects areas as thermal applications for building and industry, electricity and mechanical work, materials/chemical/biological systems, resources and wind energy systems, solar energy in developing systems, resources and wind energy systems, solar energy in developing countries and such non-technical issues as the economic, environmental and legal aspects of solar energy.

The International Solar Energy Exhibition will comprise solar energy systems, equipment and related hardware and will represent researchers, designers, manufacturers and private individuals from around the world.

 Already over 600 abstracts in a variety of subject areas have been received, and more than 80% of the exhibition space has been reserved.

Congress headquarters will be established on the campus of the University of Western Australia which

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Engineers examine a 2.6kW Martin Marietta solar collector comprising Fresnel lens and photovoltaic panels. The Solar Energy Research Institute of Western Australia (SERIWA) is monitoring the system at its solar testing site, but plans to install it later at a remote homestead.

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50kW Canadian D.A.F vertical axis and M.A.N. 33kW horizontal axis wind generators under test by SERIWA at Rottnest Island, Western Australia. The units are the largest currently operating in Australia.

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is located on the shores of the Swan River, just ten minutes from the centre of Perth. The Exhibition will be located at Gloucester Park with a shuttle bus, operating between the University, the Exhibition and several city venues.

Technical tours to various solar research and demonstration projects in and around Perth have been arranged. Many of these projects are sponsored by the Solar Energy Research Institute of Western Australia (SERIWA) which has been appointed the Congress Secretariat.

Due largely to SERIWA’s efforts, Western Australia is recognised as a leader in solar energy research and development. By world standards, the State has a high level of solar insolation and particularly good potential to use solar energy in many remote areas. Recognising this potential, the Western Australian Government established SERIWA in 1977 to encourage, promote and co-ordinate solar energy research and development activities within the State.

Since its inception, SERIWA has supported over 60 projects involving solar energy, wind power and the production of alternative fuels. SERIWA also acts as a resource base and operates a Solar Testing Centre.

Each of the following research and demonstration projects can be visited as part of the “Technical Tours Programme” of the Solar World Congress Perth 1983.

Bart J. Bok, professor emeritus of the University of Arizona, has been presented with the Award of the Dorothea Klumpke-Roberts award of the Astronomical Society of the Pacific.

This award is given annually by the Society in recognition of outstanding contributions to the public understanding of astronomy.

Bok’s research interests have included dark nebulae, star formation, the spiral structure of the Galaxy, the clouds of Magellan, and radio astronomy. Small dark condensations now believed to be the sites where new stars clump, are called “Bok Globules” in his honor. He has been involved at all levels in the education of young astronomers and remains active as a lecturer, writer and advocate of astronomy. He is perhaps best known for the classic book, *The Milky Way*, which he co-wrote with his wife Priscilla Bok in 1941. Bok has also argued forcefully against astrology, maintaining that scientists have a responsibility to distinguish science from superstition.

Dr Obert Rogers, the recipient of a $238 000 Australian Industrial Research and Development grant from the Department of Science and Technology, has won an important award for his work in developing a new technique of ceramic bonding in dentistry.

The Award of Honour for an outstanding innovation to Dr Rogers was made at the Technologieforum in Berlin — a major world forum for the presentation of new technology.

The technique consists of electrolytically depositing a layer of gold on matrices and bases for porcelain jacket crowns pontics and inlays. The same technique can be used with a variety of alloys and with different porcelains. Tests have shown increases of bond strength of roughly 50 per cent and the technique also improves the aesthetic qualities of the finished product.

The Inaugural Australian Ceramic Society Award was presented to Associate Professor E.R. McCartney, for his major contribution to ceramic education and research.

Professor McCartney’s teaching areas are: Chemistry and Physics of Ceramics; Ceramic Engineering; Applied Kinetics and Materials Science. His research field covers Nucleation and Crystal Growth; Diffusion, Sintering; the mechanical, electrical and magnetic properties of ceramic materials and prosthetic ceramic materials.

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'1 found that in fact sharks swim like aeroplanes fly, whereas fish with bladders have neutral buoyancy and swim like airships fly.

'I think I was the first to put it like this, and my paper seemed to help palaeontologists to explain some of the fossil record. One of them, the curator of fish at the Peabody Museum, wrote in commentary that my paper came on him “like a great ray of illumination” because he hadn’t been able to make head or tail of the available evidence until then. That was one of those warming experiences you have in your life: that at least there’s someone who’s benefited from your work.'

Associate Professor John Simons, who retired recently from the Zoology Department, Sydney University.
VOYAGER AND THE ORIGIN OF THE SOLAR SYSTEM

A.J.R. Prentice, Department of Mathematics, Monash University, Clayton, Victoria, 3168

The 17th Pawsey Memorial Lecture delivered to the Queensland Branch of the Australian Institute of Physics at the University of Queensland, on October 22nd, 1981

1. Introduction

The journeys of the Voyager 1 and 2 spacecrafts to Jupiter and Saturn have greatly strengthened the view that these two giant gaseous planets and their regular satellite systems were formed by the same physical processes which led to the formation of the sun and its family of planets, some $4.6 \times 10^9$ yr ago. In this lecture, given in commemoration of the life and work of the late Dr J.L. Pawsey, I shall discuss the discoveries made by Voyager which led to the above conclusion. First, I shall outline a theory for the origin of the solar system which is based on the original nebular hypothesis of P.S. de Laplace (1796), mathematical redevelopment of which has led to predictions about the chemical compositions and masses of the satellite systems of Jupiter and Saturn which have been confirmed by the Voyager missions. This theory, which has as its cornerstone the concept of supersonic turbulent convection, suggests that both planetary and regular satellite systems are formed through condensation from a concentric system of orbiting gas rings shed by the primitive rotating clouds which contract gravitationally to form each central parent body (Prentice 1973, 1974, 1977, 1978a, 1978b, 1980a, 1980b, 1981a, 1981b; Prentice and ter Haar, 1979a, 1979b).

Apart from the Voyager missions, the modern Laplacian theory (MLT) has also been independently tested with numerical experiments on the gravitational accretion of orbiting streams of particles. These experiments have been performed by Dr. K. Hourigan of Monash University (Hourigan 1977; Hourigan and Prentice 1978; Hourigan 1981a, 1981b). Hourigan's work has shown that it is only by adopting the gas ring configuration that one can understand the focussing of planetary material into a few well defined orbits and the subsequent emergence of a single planetary embryo on each of these main orbits. It is, perhaps, worth pointing out that alternative quantitative explanations of the process of planetary accretion, or of the Titius-Bode law of planetary distances, or of the broad distributions of mass in each of the planetary and regular satellite systems, or of the observed chemical compositions of these systems have not been generally forthcoming (cf. Hughes, 1976; Henbest, 1981).

2. The Original Laplacian Hypothesis

Angular Momentum Difficulty

The original nebular hypothesis of Laplace (1796), which is pictorially illustrated in Fig. 1, was abandoned late last century because of difficulties in accounting for the observed distributions of mass and angular momentum in the solar system (cf. Fouche, 1884; Brush, 1978). If, as Laplace had proposed, the planets had formed from rings of material shed by the primitive cloud which contracted to form the sun, then the angular momentum of the planets should match that lost by the sun. The difficulty, however, is that the planetary system is far too light in mass compared to the sun to have taken up the last angular momentum. If the sun were re-

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Fig 1: Visual impressions of the original Laplacian nebula hypothesis. The gravitationally contracting and rotating protostar cloud sheds a concentric system of gaseous rings from which the planets later condense. [From drawings by Scriven Bolton F.R.A.S., Fig 158 of Whipple, 1963.]

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TABLE 1: Mass fractions of the major condensing species in solar material.

<table>
<thead>
<tr>
<th>Index</th>
<th>Chemical species name</th>
<th>Mass fraction (%)</th>
<th>Cumulative fraction</th>
<th>Density $\rho$ (77K) g/cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Anhydrous rock (MgO, SiO$_2$, FeO, FeS, Al$_2$O$_3$, CaO, NiS, Na$_2$O, Cr$_2$O$_3$, P$_2$O$_5$, MnO, NaCl, K$_2$O, TiO$_2$, CoS, ZnS, CuS, CaF$_2$, V$_2$O$_5$)</td>
<td>0.574</td>
<td>0.0057</td>
<td>3.361*</td>
</tr>
<tr>
<td>1</td>
<td>H$_2$O</td>
<td>0.950</td>
<td>0.0152</td>
<td>0.934</td>
</tr>
<tr>
<td>2</td>
<td>NH$_3$</td>
<td>0.129</td>
<td>0.0165</td>
<td>0.838</td>
</tr>
<tr>
<td>3</td>
<td>CH$_4$ (as CH$_4$: 5.75 H$_2$O)</td>
<td>0.147</td>
<td>0.0180</td>
<td>0.507</td>
</tr>
<tr>
<td>4</td>
<td>CH$_4$ (total)</td>
<td>0.583</td>
<td>0.0224</td>
<td>0.507</td>
</tr>
</tbody>
</table>


Expanded to the orbit of Neptune and the angular momentum of the planets stored back inside, the centrifugal force at the equator would barely rise to one per cent of the required amount.

In 1960, Hoyle pointed out that the angular momentum difficulty was not as severe as originally stated since the present mass of the planetary system may represent only a small fraction of the original mass of gas and dust which was present at the time of the formation of the solar system. The bulk of solar material, some 98 per cent, consists of hydrogen and helium. The remainder, some 2 per cent, contains the heavy elements from which most of the planets are made. Table 1 lists the mass fraction of the major condensing compounds which can form solar material. It is based on the Ross-Aller compilation of solar abundances (Ross and Aller, 1976) with more recent measurements of C, N, O and the elements Na to Ca.

From Table 1 we see that in order to create planets like Uranus or Neptune which have masses 14.5 M$\oplus$ (M$\oplus$ = Earth mass, M$\odot$ = Sun mass) and 17.2 M$\oplus$, respectively, and densities which suggest a composition consisting of low density ices of H$_2$O, NH$_3$ and CH$_4$, as well as rock, about 10$^4$ M$\oplus$ of solar material is required for each planet. Supposing then that each of the planets accreted from roughly comparable masses of gas, as suggested by the nearly equal masses of Uranus and Neptune, the total mass of material shed by the protosolar cloud between the orbits of Neptune and Mercury is estimated to be

$$m_{\text{ao}} \approx 8000 \text{M} \oplus - 0.027 \text{M} \odot.$$  

In contrast, the mass of material that needs to be shed by a rotating globe of mass M for it to safely contract from orbital radius R$_0$ to R$_e$, whilst maintaining a Keplerian velocity $v_{\text{Ker}} = (GM/R_e)^{1/2}$ at its equator, of radius R$_e$, is

$$m_{\text{ao}} = \frac{1}{2} M f \ln(R_0/R_e),$$  

(Prentice, 1978a)

Here $f$ is called the moment-of-inertia coefficient. It is a measure of the relative spatial distribution of mass inside the cloud. For a uniform sphere $f = \frac{2}{5}$, whilst for a very centrally condensed object $f < < 1$. Setting $M = M \oplus$ and $R_0/R_e = 77.7$, corresponding to the ratio of orbital radii of Neptune and Mercury, we find from equations (1) and (2) that

$$f \approx 0.01.$$  

(3)

Thus the protosolar cloud could have given up its excess angular momentum through the creation of a planetary system as light as the one observed, only if it had been very centrally condensed, with most of the mass residing near the centre. The same conclusion also applies to the clouds which formed Jupiter and Saturn. Analyses of the mass distributions and orbital radii of the Galilean and Saturnian moon systems yields values of $f$ in the range of 0.01 to 0.02 (Prentice, 1977; Prentice and ter Haar, 1979a,b). Fig. 2 is a Voyager 1 image of Jupiter with Io and Europa in the foreground. The image shows just how small these moons are compared to their parent even though each moon is as large or our Moon.

![Jupiter and two of its satellites on the left and Europa at right, are visible in this Voyager I picture taken on February 13, 1979. Io's surface is reddish in colour, probably due to compounds of sulphur while Europa has a thin veneer of water ice. Both satellites are dwarfed by Jupiter and its Great Red Spot. (Photograph courtesy of Jet Propulsion Laboratory, Pasadena.)](image)

Jeans (1928) was aware of the above conclusion regarding the size of f but could see no way of achieving such small values within the existing theory of stellar structure. The value of f for a normal adiabatic convective structure is 0.205. This is more than 10 times the required amount.

Other difficulties

Apart from the above main difficulty, there was the more obvious problem of explaining why a contracting gas cloud would throw off a discrete system of gas rings rather than shedding a continuous gaseous disc, as is more commonly assumed nowadays (cf. Ringwood, 1981). And, of course, as Clerk Maxwell (1859) first noted, it is not at all clear how an orbiting system of material can coalesce to form a single body.
3. The Modern Laplacian Theory

Supersonic turbulent stress

In 1973 I published a set of calculations (Prentice, 1973) which indicated that many of the difficulties which had plagued the original version of the Laplacian hypothesis could be overcome if there had existed a turbulent stress within the interior of the young forming sun which was many times larger than the normal gas pressure. It was proposed that this stress was created by the motions of rising convective elements whose speeds were some 10 times larger than the local speed of sound. Mathematically, the turbulent stress is given by

\[ \langle q_i v_i \rangle = \beta \rho(r) G M(r)/r \]  

(4)

Here \( \rho(r) \) and \( M(r) \) denote the gas density and interior mass at radius \( r \) in the cloud, whilst \( \beta \approx 0.1 \) is the so-called turbulence parameter.

We see from equation (4) that the turbulent stress is greatest in the outer regions of the cloud and least at the centre. Its effect on the cloud's structure is to cause the outer tenuous layers to expand greatly outwards, leaving the central dense region practically unchanged. The net result is that the cloud acquires the appearance of being very centrally condensed. In the case of a non-rotating globe consisting of molecular hydrogen, for example, introduction of turbulent stress causes the moment-of-inertia coefficient to fall from 0.112 to 0.011 as \( \beta \) increases from 0 to 0.1, as we see in Fig. 3. This is exactly the fall in magnitude required to overcome the angular momentum difficulty with the original Laplacian hypothesis.

The shedding of gas rings

The turbulent stress also leads to the development of a very dense shell of non-turbulent gas at the photosurface of the cloud. The density of this shell is some 100 times larger than that of the turbulent gas beneath it. When rotation is taken into account, the shell evolves into a belt-like structure which, because it lacks turbulent viscosity, has a uniform angular momentum density rather than a uniform angular velocity. The belt continues to grow in mass as the cloud contracts until the centrifugal acceleration at the equator matches the inward gravitational acceleration at orbital radius \( R_s \). After this stage is reached, the belt is unable to contract any further with the cloud but is left behind in a circular Keplerian orbit, whilst the cloud contracts inwards, stabilizing itself rotationally by extruding fresh material to the equator under conditions of uniform rotation, maintained by the interior turbulent viscosity.

Fig. 3: The moment-of-inertia coefficient \( J(r) \) of non-rotating turbulent polytropic structures of index \( n = 1.5 \) and 2.5 plotted as a function of the turbulence parameter \( \beta \). [From Prentice, 1978a.]

Fig. 4: Meridional cross-sections of the protostar cloud and its system of orbiting gaseous rings at various stages of the cloud's gravitational contraction. Commencing at the top of the diagram, the dimensions of the cloud exceed the orbit of Neptune but rotational forces are small. As the radius of the cloud decreases, the ratio of centrifugal force to gravitational force at the equator steadily increases and the cloud disperses its excess spin angular momentum by shedding a discrete system of gaseous rings. [From Prentice, 1974.]

If the turbulence is sufficiently strong, the mass of material that needs to be extruded to the equator to maintain pressure equilibrium greatly exceeds the amount needed to ensure rotational stability. The net result is that the parent cloud cataclysmically withdraws to a smaller radius thus abandoning its equatorial ring in a discontinuous manner at orbital radius \( R_s \). The cloud continues its gravitational contraction and eventually a new ring is shed at Radius \( R_s \) and so on as shown in Fig. 4. Consideration of conservation of mass and angular momentum show that the orbital radii \( R_s \) (\( n = 0, 1, 2, \ldots \)) satisfy the equation

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\[ R_j / R_{\text{eq}} = [1 + m_j / M_{\text{eq}}]^{1/j}, \quad (5) \]

where \( m_j \) and \( M_{\text{eq}} \) denote the mass of the shed gas ring and residual cloud mass at radius \( R_j \) \((\text{Prentice, 1974, 1978a, 1978b})\).

If the contraction of the cloud occurs uniformly, so that both \( f \) and \( m_j / M_{\text{eq}} \) remain constant, the sequence \( R_{\text{eq}} \) is a geometric one. That is, we have accounted for the modern version of the Titius-Bode law of planetary and satellite distances (ter Haar, 1967). More importantly, with \( \beta = 0.1 \), we have \( f = 0.01 \) and equation \((5)\) yields a mass for each gas ring shed by the protosolar cloud

\[ m_j \simeq 0.3 M_f \simeq 0.003 M_{\odot} \simeq 1,000 M_{\odot} \quad (6) \]

This is precisely the amount, mentioned earlier, which is needed to account for the observed mass distribution of the planetary system.

**Physical structure of the gas rings (Prentice, 1974, 1978a, 1978b)**

A gas ring which is centred on the mean orbital radius \( R_e \) has a density which is a maximum \( \rho_0 \) on this orbit and decreases with distance \( \xi \) measured off the mean orbit according to the equation

\[ \rho_0(\xi) = \rho_0 \exp(-\frac{\xi}{2\sigma_e \xi / R_e}). \quad (7) \]

Here \( \sigma_e = \mu G M / R T_{\text{e, ring}} \) is a dimensionless number, essentially equal to the ratio of the gravitational to thermal energy of the gas ring. \( \mu \) is the mean gas molecular weight, \( R \) is the gas constant, and \( T_{\text{e, ring}} \) is the mean temperature of the gas ring. The toroidal structure of the gas ring, which follows from equation \((7)\) and is sketched in Fig. 5, is due to the differential orbital angular velocity distribution of the gas, given by

\[ \omega(s, z) = \omega_e R_e s. \quad (8) \]

Here \( s, z \) refer to cylindrical polar co-ordinates referred to the axis of the ring and \( \omega_e = \sqrt{GM/R_e^3} \) is the Keplerian angular velocity at radius \( R_e \).

If the contraction of the parent cloud takes place uniformly, as evidenced by the geometric spacing of the planetary and satellite orbits, then \( \sigma_e \) is a constant for each cloud. The temperatures of the gas rings at the time of detachment from the parent cloud of mass \( M \), thus vary nearly inversely with the orbital radius \( R_e \) as

\[ T_{\text{e, ring}} = \mu G M / \sigma_e R_{\text{eq}} \sim 1 / R_e. \quad (9) \]

The mass of the parent cloud barely changes from one orbit to the next since the masses \( m_j \) of the detached gas rings are so small. Since the \( m_j \) are each about equal, it follows from equation \((7)\) that the set of central densities \( \rho_0 \) scale with orbital radius as

\[ \rho_0 \sim \alpha e m_j / 4 \pi R_e^3 \sim 1 / R_e^3. \quad (10) \]

**Condensation and Accumulation of the Planetary and Satellite Material**

After a gas ring has been detached by the parent cloud, the various condensable chemical species in the gas begin to nucleate and condense off the gas forming small solid grains. All condensing grains begin to settle onto the mean circular orbit of the gas ring through the combined action of unbalanced gravitational force and gaseous drag. This remarkable focusing property of the gas ring, which is discussed in more detail elsewhere, is illustrated schematically in Fig. 5 (Prentice, 1974, 1978a, 1980a). Hourigan has independently confirmed this phenomenon with a detailed numerical model taking into account collisions between the grains, as shown in Fig. 6. Commencing at the top of the diagram, the right hand
side shows the orbital evolution of an initially circular stream of particles in the absence of an embedded gas ring. The particles become quickly dispersed off the mean orbit through collisions with one another and planetary formation is prevented. The left hand side of the diagram shows the effect of the gas. All grains move onto the one well-defined circular orbit, namely the mean orbit of the gas ring.

Hourigan (1981a, 1981b) has shown that once the torus of settling grains becomes sufficiently compressed, gravitational instabilities set along the direction of the mean orbit, causing the stream to break up into isolated fragments. These fragments compact radially under their own gravitational attraction to form planetesimals. The planetesimals continue to grow by sweeping up fresh grains and smaller planetesimals. It turns out that as the bigger planetesimals grow at a faster rate than the smaller ones, a runaway takes place with the growth of the largest member. The net result is the emergence of a single largest planetesimal, called the planetary embryo, which is some 10^9 to 10^10 larger than the next member. As we shall discuss later, it is likely that Titan was a secondary embryo which accreted on the same orbit as Saturn and was later captured by that planet. Similarly, Triton and Pluto were probably secondary embryos to Neptune, the former having been successfully captured.

In summary, the MLT provides a well-defined path for studying the process of planetary accretion from the initial grain state.

4. The chemical composition of the planetary and satellite systems and the hypothesis of a universal proportion of turbulent energy in all protoplanetary clouds

One of the most satisfying aspects of the MLT is its ability to predict the bulk chemical composition of any particular satellite or planet. This predictive ability stems in part from the fact that the temperature and pressure within each gas ring are well-defined. It also stems from the important focusing property of the gas rings which ensures that all grains are directed onto the one common orbit. The bulk composition of any planet satellite embryo is thus uniquely determined by the condensation conditions within its own formative gas ring. There is no mixing of planetary material from one orbit to the next as in conventional disk models (cf. Wetherill, 1980, 1981; Ringwood, 1981). The planetary and satellite compositions thus truly reflect the thermal state of the contracting parent cloud when the equatorial radius of the latter coincides with the orbital radius of the satellite. We assume that the rate of accretion of the satellite is very much faster than the rate of radial contraction of the cloud.

The temperatures and pressures of the gas rings at the time of detachment from the parent cloud depend on the choice of the parameters $\alpha$ and $\beta$. One of these parameters is fixed from the condition that the mean ratio $\langle R/R_{\text{sat}} \rangle$ of adjacent orbital radii matches the observed spacings of the satellites. The other parameter is fixed by calibrating the temperature law (eqn. (9)) against a known compositional feature within the satellite system.

Condensation point of H$_2$O ice

The most important compositional aspect of any satellite system is the location of the ice-point of H$_2$O. In the case of the planetary system this point is known to have been situated between the orbits of the asteroids and Jupiter. That is, the asteroids are known to be rocky in composition whilst planetary structure calculations (Slattery, 1977; Hubbard and MacFarlane, 1980) and spacecraft measurements (Anderson et al., 1980) show that each of Jupiter, Saturn, Uranus and Neptune contain a rock/ice core having mass in the range 15 to 20 M$\odot$. These masses are precisely the ones expected for low temperature condensation from gas rings having mass 1000 M$\odot$ and solar composition as given by Table 1 and predicted by the MLT (Prentice, 1974).

The densities and masses of the 4 Galilean moons of Jupiter indicate that the ice-point of H$_2$O was located between the orbits of Europa and Ganymede (Prentice and ter Haar, 1979a).

Now the temperature at which H$_2$O vapour condenses is given by

$$T_{\text{H}_2\text{O}} = 2673[7.572 - \log_{10}(p_{\text{H}_2\text{O}}/18.016)] \text{ K},$$

(Haudenschild, 1971) \hspace{1cm} (11)

where $p$ denotes the total gas pressure and $X_{\text{H}_2\text{O}}$ the mass fraction of H$_2$O. Equating $T_{\text{H}_2\text{O}}$ with the temperature at the equator of the protoplanetary cloud, given by equation (9), one can compute bounds on the value of the turbulence parameter $\beta$ which ensure that the ice-point lies between the required orbital radii. The higher the degree of turbulence in the cloud, the lower the thermal energy and surface temperature. Taking $\mu = 2.222$, corresponding to a gas with H and He mass fractions 0.8 and 0.2, as measured by Voyager at Jupiter (Gautier et al., 1981), we find (Prentice 1981a, 1981b)

$$0.101 < \beta \odot < 0.113,$$

$$0.100 < \beta < 0.111.$$ \hspace{1cm} (12) \hspace{1cm} (13)

It is noteworthy that the two ranges of values which describe the condensation of H$_2$O within the two systems nearly coincide. This suggests that $\beta$ has the same value in both clouds. Physically, $\beta$ equals twice the ratio of turbulent kinetic energy to gravitational potential energy in the cloud.

Evidence from other condensing species

Considerations of other condensing compounds also support the conclusion that the value of $\beta$ was common to both the protojovian and protosolar cloud. In 1972, John Lewis (1972a) pointed out that the 1 per cent difference between the uncompressed densities of Earth and Venus could be attributed to the retention of S at the Earth's orbit as metal sulphides, principally FeS. Modelling this datum leads to the bounds

$$0.102 < \beta \odot < 0.109.$$ \hspace{1cm} (14)

Similarly, the discovery of sulphurous volcanoes and plains in Io by Voyager (Smith et al., 1979a; cf. Lewis, 1982) implies that no free S can exist in the interior of this satellite and hence that $\beta \geq 0.1053$. Lastly, the fact that there exists no planet interior to the orbit of Mercury, despite the fact that a gas ring was shed near an orbital radius of 50 R$_\oplus$, implies that the temperature at this orbit exceeded the condensation point of the refractory oxides CaO and TiO$_2$. This leads to the constraint $\beta \leq 0.1074$.

Combining the above data, it would seem that there exists a universal choice

$$\beta = 0.1065 \pm 0.001$$ \hspace{1cm} (15)

which simultaneously describes the evolution of all protoplanetary clouds. That is, the data suggests that all protoplanetary clouds possess a common fraction of...
turbulent kinetic energy, equal to about 5 per cent of the total gravitational potential energy in each cloud.

Fig. 7: Surface temperatures $T_s$ of the primitive turbulent gaseous clouds which contrasted to form Saturn Jupiter and the sun, plotted as the solid lines, versus equatorial size $R_e$, which is expressed in units of the present equatorial radius $R_e$. Each cloud has the same $H$ and $H_e$ mass fractions $X$ and $Y$ respectively, and the same relative fraction of supersonic turbulent kinetic energy, measured by the parameter $\beta$, which is defined in the text, the broken curves define the equilibrium condensation temperatures of the major chemical species, derived in part from the data of Lewis (1972b).

Fig. 7 shows the detailed chemical condensation sequence amongst the systems of gas rings shed by the protosolar, protosolar and protosolar Saturn and the sum based on the hypothesis $\beta = 0.1065$. The continuous lines define the temperatures $T_s$ of the gas rings at the moment of detachment from the parent cloud. The dashed lines give the condensation temperatures $T_{	ext{cond}}$ of the major chemical species in the gas, based on the formalism developed by Lewis (1972a,b). Condensation of a given species occurs as long as $T_s < T_{\text{cond}}$. In the case of Saturn, normalizing the mass fraction of heavy elements in the gas ring against the mass of Rhea ($M_{\text{ring}} = 2.49 \times 10^8$ g) — Tyler et al., 1981, leads to the conclusion that $X_s \approx 0.3X_0$. That is, the formation of Saturn's central core of rock, H$_2$O and NH$_3$ ices from the protosolar gas ring apparently led to a 3-fold reduction in the abundance of these elements in the proto-saturnian envelope. Fig. 7, which was published prior to the Voyager 2 encounter at Saturn (Prentice, 1981a,b), can be used to read off the expected bulk composition of any planetary core or satellite of Jupiter and Saturn.

![Image of Saturn and its moons](https://example.com/saturn_moons.png)

**Table 2:** Gas ring characteristics and the computed satellite compositions and densities of the Saturn System.

<table>
<thead>
<tr>
<th>Name</th>
<th>Radius (km)</th>
<th>Orbit Radius $R_e/R_S$</th>
<th>Gas ring temp. $T_e^*(K)$</th>
<th>Gas pressure $P_{\text{bar}}$</th>
<th>Condensate mass fractions $f_{\text{H}<em>2O}$ $f</em>{\text{NH}<em>3}$ $f</em>{\text{H}_2}$</th>
<th>Satellite densities Theoretical $\rho_{\text{comp}}$ $\rho_{\text{sat}}$</th>
<th>g/cm$^3$ Observed $\rho_{\text{sat}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980 S28</td>
<td>$-15$</td>
<td>2.282</td>
<td>275</td>
<td>9.2</td>
<td>0.86 0.14 0.14</td>
<td>2.46 2.46</td>
<td>2.46 2.46</td>
</tr>
<tr>
<td>1980 S27</td>
<td>$-50$</td>
<td>2.33</td>
<td>275</td>
<td>9.0</td>
<td>0.86 0.14 0.14</td>
<td>2.46 2.46</td>
<td>2.46 2.46</td>
</tr>
<tr>
<td>1980 S26</td>
<td>$-100$</td>
<td>2.51</td>
<td>274</td>
<td>8.4</td>
<td>0.86 0.14 0.14</td>
<td>2.46 2.46</td>
<td>2.46 2.46</td>
</tr>
<tr>
<td>Mimas</td>
<td>196.3</td>
<td>3.075</td>
<td>241</td>
<td>4.84</td>
<td>0.425 0.575 0.575</td>
<td>1.347 1.349</td>
<td>1.44 ± 0.18</td>
</tr>
<tr>
<td>Enceladus</td>
<td>250 ± 10</td>
<td>3.946</td>
<td>188</td>
<td>1.79</td>
<td>0.377 0.623 0.623</td>
<td>1.283 1.286</td>
<td>(1.16 ± 0.55) ±</td>
</tr>
<tr>
<td>Tethys</td>
<td>525 ± 10(V1)</td>
<td>4.884</td>
<td>153</td>
<td>0.76</td>
<td>0.351 0.582 0.067</td>
<td>1.239 1.246</td>
<td>1.25 ± 0.17</td>
</tr>
<tr>
<td>530 ± 10(V2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dione</td>
<td>650 ± 5</td>
<td>6.256</td>
<td>121</td>
<td>0.28</td>
<td>0.347 0.575 0.078</td>
<td>1.232 1.243</td>
<td>(1.43 ± 0.06) ±</td>
</tr>
<tr>
<td>Rhea</td>
<td>765 ± 5</td>
<td>8.737</td>
<td>90</td>
<td>0.075</td>
<td>0.347 0.575 0.078</td>
<td>1.232 1.328</td>
<td>1.33 ± 0.09</td>
</tr>
<tr>
<td>Iapetus</td>
<td>730 ± 10</td>
<td>11.36$^\S$</td>
<td>75</td>
<td>0.026</td>
<td>0.319 0.527 0.072</td>
<td>1.107 1.161</td>
<td>1.16 ± 0.09</td>
</tr>
</tbody>
</table>

†V1 and V2 denote Voyager 1 and Voyager 2 measurements, respectively.
‡Based on non-Voyager mass estimates (Kozai, 1976).
§Assumed original orbit radius.

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5. The Voyager findings at Saturn versus the predictions of the model

In the remainder of this lecture I shall compare the predictions of the model for the compositions and densities of Saturn’s satellites with the results obtained from the two Voyager encounters. A montage of the Saturn system as seen by Voyager 1 appears in Fig. 8.

The temperatures $T_r$ and pressures $p_r$ on the mean orbits of the gas rings shed by the proto-Saturnian cloud are listed in Table 2. It is assumed that a gas ring was shed at the orbits of each of the satellites Mimas through Rhea, whose orbital radii $R_r$ are expressed in units of $R_0 = 6.033 \times 10^9$ cm, the present equatorial radius of Saturn. The parameter $\alpha = 227$ given in equation (9) is chosen so that the mean ratio $\langle R/\sigma \rangle_{-\infty}$ given by the model matches the observed mean value, namely 1.298.

Since the background temperature due to the sun at Saturn’s orbit at the time of Saturn’s formation was $T_{sfr} \approx 60 \, \text{K}$, the actual ring temperature is $T_r^* = (T_r^2 + T_{sfr}^2)^{1/2}$. Here $T_r$ is given from equation (9) as

$$T_r \approx 742(\text{R}_r/\text{R}_0) \, \text{K}.$$  \hspace{1cm} (16)

The process of shedding gas rings cannot commence until $T_r \geq 60 \, \text{K}$ or, equivalently, until the radius of the cloud has shrank to $\sim 12 \, \text{R}_0$. It is possible, therefore, that the cloud shed its very first gas ring adjacent to the orbit of Rhea at orbital radius $11.4 \, \text{R}_0$, noting that $\langle R/\sigma \rangle_{-\infty} = 1.30$. We propose that Iapetus formed from that first shed ring.

Gas rings are also shed at the orbits of the small irregular satellites discovered by Voyager between the outer edge of the A ring ($2.265 \, \text{R}_0$) and Mimas’ orbit. These small bodies, which include the two shepherd satellites 1980 S26 and 1980 S27 and the co-orbital pair 1980 S1 and 1980 S3, are predicted from Fig. 7 to have condensed above the H$_2$O ice point. They should thus consist mostly of hydrated silicates and have mean density close to $2.4 \, \text{g/cm}^3$ (Prentice, 1980c). Voyager was unable to measure the densities of these moons but did discover that most of them had darker surfaces than the icy rims of the principal satellites.

Given $T_r^*$ and $p_r$, the mass fractions of the main condensing species in each orbit can now be computed. These are listed in the table, along with the uncompressed density of the condensate, given by

$$\rho_{\text{uc}} = \sum_{ \text{species} } \rho_{\text{uc}}$$  \hspace{1cm} (17)

Here the index $i$ refers to the different species, as listed in Table 1. In computing the factors $\rho_i$ for each gas ring it is necessary to take into account the decline in gas pressure with minor radius $\xi$, as given in equation (7). Thus in the case of Mimas, H$_2$O is unable to condense in the outer fringes of its formative gas ring even though it condenses on the dense mean orbit. Mimas, which is a class I object consisting of rock and water ice, thus has a higher-than-solar mass fraction of rock and hence higher-than-normal density. Enceladus is a normal class I object.

The 2nd last column in Table 2 gives the expected satellite density when account is taken of self-compression due to gravity. Data on the compressibilities of rock and ices are taken from Lupo and Lewis (1979, 1980). The satellites are sufficiently small that significant fractionation of rock and ice is unlikely to have occurred (Consolmagno and Lewis, 1978). The final column shows the Voyager-determined satellite densities $\rho_{\text{Voy}}$ (Smith et al., 1981, 1982; Tyler et al., 1981, 1982). The densities of Enceladus and Dione, shown in parentheses, are based on the non-Voyager mass estimates (Kozai, 1976). A plot of the theoretical uncompressed density function $\rho_{\text{uc}}$ against orbital radius appears in Fig. 9, along with the observed uncompressed satellite densities.

![Fig. 9: Uncompressed densities of Saturn's small icy satellites and the predicted density function of homogeneously accreted condensate material. The heavy curve is based on the gas ring temperature and pressure distributions described in Figs. 7 and 8. It changes abruptly with distance as the stability fields of the various condensable ices, namely H$_2$O, NH$_3$ (as NH$_4$H$_2$O), and CH$_4$ (as CH$_3$SH, H$_2$O), are entered. The dashed curve is the extension of class II when CH$_4$ is removed. Voyager-determined densities are indicated by the squares, while densities based on non-Voyager masses are shown by the circles (from Tyler et al., 1982).]

We see that the agreement of the predictions of the model with the Voyager observations is quite astounding, especially in the case of the larger and better determined satellites Rhea and Iapetus. All values lie well inside the published error bounds. The Voyager data thus endorse not only the satisfactory ability of the MLT in accounting for the observational data but also confirm that Saturn’s moons contain rock and ices in the same relative proportions as those observed in the sun. That is, both Saturn and the sun formed co-genetically from the same original cloud of material. This is an aesthetically satisfying state of affairs. We now make some comments about individual satellites.

**Rhea**

Although this satellite originally condensed as a class III object, containing 8% by weight CH$_4$ (as CH$_3$H, 3.75 H$_2$O), some $3 \times 10^8$ yr after its formation the temperature at Rhea’s orbit due to the thermal radiation of the proto-Saturnian cloud rose above the CH$_4$ triple point (0.907 K), causing the clathrate to decompose and the CH$_4$ to escape from the satellite through fissures in its mantle. Rhea, now, is thus a class II object containing rock, H$_2$O and NH$_3$ in normal solar proportions.

**Iapetus and the origin of Titan**

The density of Iapetus suggests that this moon has somehow retained its original store of CH$_4$. Today Iapetus occupies an orbit which is inclined at 68° to Saturn’s equatorial plane and has a radius of $60 \, \text{R}_0$, not $\sim 11.4 \, \text{R}_0$ as listed in Table 2. I have conjectured that Iapetus originally accreted much closer to Saturn, from the first shed gas ring at orbital radius $11.4 \, \text{R}_0$ (Prentice, 1981a,b). Soon after Iapetus formed, Titan entered the Saturn system and was captured by aerodynamic drag.
in the disc of gas which had been shed by the proto-
Saturnian cloud beyond the radius 12 R_e where the ring
sheding process could commence. As a result of a close
encounter with Titan, Iapetus was driven to its present
distant and thermally safe orbit. That is, Iapetus was
spared the later warm phase which drove the CH_4 from
Rhea.

If this conjecture is correct then Titan, whose mass
is 60 times too large to be accounted for as a naturally
condensed moon of Saturn using equation (5), must have
condensed from the gas ring shed by the protosun at
Saturn’s orbit. As such, we see from Fig. 7 that it should
have the same bulk chemical composition as Callisto.
This is indeed the case. Voyager 1 found that both
satellites have the same mass fraction of rock, namely
52 per cent (Tyler et al., 1981). These satellites are
sufficiently massive to have lost some of their original
inventory of ice through accretional heating, thereby
accounting for their higher-than-solar rock fraction.

Last, if Titan did accrete within the stability field of
NH_3 ice but above the condensation point of CH_4
clathrate, as indicated by Fig. 7, one would expect its
atmosphere to be dominated by N_2 rather than CH_4.
Again this result, which was anticipated prior to the
Voyager 1 flyby of Titan (Prentice, 1980c), was
confirmed by both Voyager radio science and ultraviolet
spectroscopy experiments (Tyler et al., 1981; Broadfoot
et al., 1981).

Tethys and Dione

According to Table 2, these two moons consist of rock,
H_2O and NH_3 ice and have a density close to 1.25 g/cm^3.
Prior to the Voyager 2 encounter at Saturn, however,
it was widely believed that Tethys consisted mostly of
H_2O ice, with a density of 1.0 ± 0.1 g/cm^3 (Smith et al.,
1981). This conclusion was based on a satellite mass of
(6.22 ± 0.13) x 10^{18} kg which had not been measured
directly but deduced from an Earth-based theory of
observed commensurabilities in the orbital motions of
Mimas and Tethys (Kozai, 1957). Similarly, the density
of Dione had been taken from a study of the forced
resonance in the eccentricity of Enceladus’ orbit
(Kozai, 1976).

In May 1981 I made the prediction that Voyager 2
would find the Tethys mass to be 20–25 per cent larger
than the ground-based value (Prentice, 1981a,b,c).
As this implied a 10 to 12 standard deviation (α) shift from
the Kozai value, most workers regarded this prediction
as extremely unlikely. On August 25, 1981 the Voyager
2 radio science experiment found that the mass of Tethys
was 21.4% larger than the previously accepted value
(Tyler et al., 1982). This led to a centre-point
density, on the basis of the satellite radius 525 km for
which the prediction had been made, of 1.246 g/cm^3 —
an agreement of better than 1 part in 10^4, as we see in
Table 2!

Satellite masses are obtained by using the doppler shift
in the radio signal transmitted by the spacecraft as a data
base for calculating the changes in the spacecraft
trajectory during passage of closest approach.
Unfortunately, neither Voyager 1 nor 2 came sufficiently
close to Dione or Enceladus to obtain mass estimates of
these bodies. Nonetheless, it is anticipated that future
space measurements will show the mass of Dione to be
(9.1 ± 0.3) x 10^{22} kg or (13 ± 3)% less than the
currently accepted value.

6. Conclusions

In this lecture I have presented an outline of a theory
for the origin of the solar system which is based on ideas
of supersonic convective turbulence and which indicates
that the original Laplacian nebular hypothesis may be
valid. A basic premise of this modern Laplacian theory
is that each of the primitive proto-planetary clouds which
formed Jupiter, Saturn and the sun possessed a common
proportion of turbulent kinetic energy, equal to
approximately 5 per cent of the cloud’s gravitational
potential energy. Predictions based on this premise for
planetary and satellite compositions and masses have,
in general, been confirmed by spacecraft observations.

The discovery by Voyager 2 in August 1981 that
Saturn’s family of regular satellites show the same general
trend for becoming increasingly rocky moving towards
the planet, as observed in the jovian and planetary
systems and as predicted by the model, overturns an
earlier conclusion regarding this planet. Had Voyager
confirmed an opposite trend in satellite density, then the
Saturn system would be unique in the solar system and
require a separate explanation for its origin (cf. Peale et
al., 1980). Instead the Voyager data have re-affirmed the
view that all planetary and regular satellite systems are
formed by the one common mechanism. It is a tribute
to the late Dr Pawsey that the techniques of radio-physics
which he pioneered some 40 years ago were essentially
the same as the ones employed by the Voyager spacecraft
to fathom the mysteries of the Saturn system. I wish to
record my thanks to Dr J.D. Anderson of the Jet
Propulsion Laboratory, Pasadena, for the unbounded
interest he has shown in my work and for the generous
hospitality and support he has given during several visits
to JPL.

REFERENCES

Anderson, J.D., Nicholls, W.G., Biller, E.D., Weng, S.K., Hubbard, W.B.


Gautier, D., Conrath, B.J., Fassier, M.F., Hanel, R.A. and Kundu, V.G.


389.


University Press).


79.

Courcier).


Maxwell, J.C. (1859). The Scientific papers of James Clerk Maxwell


Prentice, A.J.R. (1974). In In the Beginning ... the Origin of Planets


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Australian Space Science at the Crossroads, pages
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Dr Andrew J.R. Prentice is a Senior Lecturer in Mathematics, Monash University, where his research interests lie in the field of planetary and satellite formation and solar evolution. He was educated in Melbourne and at Oxford (plasma physics and theoretical astrophysics respectively) and has spent two periods of research in the U.S.A. He is currently a council member of the Astronomical Society of Australia. He is married and has 2 daughters, and lists bush walking and house renovations as his hobbies.
The Cavendish Tradition in Australian Physics — Time for Change

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The Oxbridge influence was paramount in Australian Universities from the beginning; the coat-of-arms of the University of Sydney was composed symbolically of the open book of Oxford and the lion of Cambridge. Furthermore, two of the first three professorial appointments at Sydney University were scientists, including Morris Pell, Senior Wrangler at Cambridge in 1849 and Fellow of St. John's College, to the Chair of Mathematics and Natural Philosophy. At the University of Melbourne, which began teaching three years later in 1855, a professor of Natural Philosophy was not appointed until 1882, and even then the choice was limited to the only candidate for the chair, Henry Andrew, who did, however, have a Cambridge education.

The University of Adelaide was blessed by the appointment in 1875 of Horace Lamb, Fellow of Trinity College, Cambridge, as its first Professor of Mathematics. Lamb had been taught by Stokes and Maxwell and was familiar with the work of William Thomson as well as that of the European theorists. The Cavendish influence thus came into Australian physics from the very beginning.

There is no single, unique or even well-defined Cavendish tradition. Pippard (1974) has pointed out that "Cambridge was not the first university in the British Isles to encourage experimental physics, and if in its earliest years the Cavendish stood out from the rest, it was more because of its first two professors, Maxwell and Rayleigh, than for any notable difference in outlook." "Only after this, with the inspired appointment of J.J. Thomson at the age of 27, did the work begin to develop a special character." This character, which Thomson inspired during his 35-year occupancy of the Cavendish Chair, further developed and evolved under the leadership of Ernest Rutherford, who stayed from 1919 until his death 18 years later. It was the Cavendish of Thomson and Rutherford that had an especially powerful influence on Australian physics, and it is to the impact of that particular tradition that I want to refer.

This began in the 1880s when the second and most outstanding generation of physics professors were appointed to the three Australian universities: Richard Thrrellfall (to Sydney) and William Bragg (to Adelaide), both of whom arrived in 1886 with youth and impeccable Cambridge records, and Thomas Lyle, who sailed to Melbourne from Trinity College, Dublin in 1889. Thrrellfall was a close friend of J.J. Thomson and, after his return to England 1898, "became an important link between J.J. and military and industrial science" (Crowther, 1974).

It was unlikely that this triumvirate would be quickly equalled in later years, but on an individual basis Lyle's successor in Melbourne, Thomas Laby, outshone them all in terms of the contribution he and his department made to Australian Physics. Laby, too, was a Cavendish graduate.

With this brief introduction I now turn to the several examples I have chosen to illustrate my theme.

Bragg in Adelaide

William Henry Bragg graduated as Third Wrangler from Part II of the Cambridge Mathematics Tripos in 1884 and with first-class honours from Part III in 1885. During his later months at Cambridge Bragg attended some of J.J. Thomson's lectures, spent time in the Cavendish and played tennis regularly with the professor. It was "J.J." who suggested that he apply for the Adelaide Chair, which extended to cover physics as well as mathematics and which he took up early in 1886.

The outline of Bragg's subsequent career in Adelaide is well known, although the existing literature represents only very poorly the academic contributions he made in his first 17 years there. It is on Bragg's subsequent investigations of the nature of X- and $\gamma$-rays, however, that I wish to focus, and particularly on his vigorous disagreement with Barkla on this question; the first cause celebre in the history of Australian physics (Stuweer, 1971).

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Fig. 1: Rutherford and Thomson watching an annual Cavendish cricket match (from the Cavendish Collection, with permission).

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Fig. 2: Todd family, Adelaide 1897, W.H. Bragg second from left back row, his wife Gertrudine front Todd second from left centre row, and their two sons (William Lawrence and Robert Charles) front row (from the South Australian Archives Collection, Ref. B28760, with permission).
From the beginning the Cambridge physicists were mechanical in their outlook, and this applied to their theoretical as well as their experimental investigations. Maxwell's early writings on electricity and magnetism were based on the hypothesis that electric and magnetic phenomena could be understood in terms of the actions of a mechanical medium; ultimately (but only outwardly) the models disappeared altogether and only the mathematics remained.

This tradition was actively carried forward by Thomson. We all remember his "plum-pudding" model of the atom, whose value, however, is commonly underrated and whose nature is often misunderstood. He deplored the great tendency among students to regard Maxwell's theory as a set of differential equations instead of attempting a "mental picture" of what was taking place. Thomson strove constantly for the concrete image as the starting point for all physical understanding (McCormach, 1967).

Some of these powerful influences were surely at work when Bragg suggested in Adelaide in 1907 that X-rays and γ-rays consisted of material particles. Others had made a similar suggestion, but Bragg's neutral-pair hypothesis, which pictured high-energy radiation as an electron or positron particle together with a beta or negative particle, became the focus of this point of view. It was a natural outgrowth of his earlier radioactivity studies.

Such a particle pair would have great penetrating power, though ionising powers, be influenced by magnetic or electric fields and show no refraction. Furthermore, Bragg noted that in a violent encounter with matter such a neutral pair would be resolved into separate positive and negative particles, the beta particle appearing in the forward direction as a secondary ray.

X-rays behaved somewhat differently. In his earlier X-ray experiments, Charles Barkla found no such asymmetry in the scattered X-rays, a result in accord with the ether-pulse theories of Stokes, Weichert and Thomson, where X-rays were pictured as a stream of independently-moving, transverse electromagnetic waves or pulses. It was not surprising therefore that Bragg's corpuscular model brought a sharp response, particularly as Bragg stated that the evidence for the pulse theory was "indirect" and "a little over-rated". How could spreading pulses, for example, concentrate enough energy on one atom to ionize it in the first place, Bragg asked.

We can now see that the two angular distributions that were being measured were quite different: Barkla primarily of Thomson-scattered soft X-rays, Bragg largely the forward-peaked Compton-recoil electrons; but the dispute continued without this benefit of hindsight. In 1908 Bragg altered the alpha-electron pair to a positive-negative electron pair, and in 1910 to an electron and a "quantity of positive electricity which adds little to its mass"; in 1909 he had returned to England.

The discovery of X-ray diffraction in 1912 did not deflect Bragg from his primary belief, for in 1913 he wrote: "The problem remains to discover how two hypotheses so different in appearance can be so closely linked together". It was yet another decade before Compton, Bohr, Heisenberg and others provided a solution; and it is fitting that it was Bragg who then distilled the essence of the matter in his famous remark that physicists use the wave theory on Mondays, Wednesdays and Fridays, and the particle theory on Tuesdays, Thursdays and Saturdays.

**Laby in Melbourne**

The life of Thomas Howell Laby is sufficiently well known to require little elaboration here. The reward for his early exceptional independence and originality was the award to him in 1904 of the Sydney 1851 Exhibition Science Research Scholarship. After consultations with Ramsay in London and Poynting in Birmingham, Laby took up his scholarship in Thomson's Cavendish Laboratory. The research he undertook, the experiences he enjoyed and the friends he made there profoundly influenced his life. His work also brought him into contact with Rutherford, with whom he formed a life-long friendship. This was also important, for Laby later sent a stream of postgraduate students to the Cavendish in Rutherford's time, and it also kept him in constant touch with developments in physics overseas. During the twenty years between the World Wars no less than 12 of the 21 1851 Scholarships awarded to Melbourne University went to Laby's students, and all of these men (plus Massey and several others) undertook their studies at Cambridge. Earlier, Bragg had sent his two best research students (Kleeman and Glasson) there on 1851 Scholarships, and Laby had spent two from Wellington in New Zealand (Burbridge and Hecules); thus was the Cambridge connection continuously cemented. By contrast, not a single Australian, to my knowledge, joined Bohr's Institute in Copenhagen, then the world centre for ambitious young theoreticians.

Laby succeeded Lyle as Professor of Natural Philosophy in the University of Melbourne in March 1915, and in one particular and noteworthy aspect of Laby's work there, his basic and practical upbringing was more influential than his Cambridge education. I refer to the two-pronged character of much of his studies: research for its own sake, but also research into the physics of problems of a very practical nature. I want to centre particularly on Laby's most active participation in the development and use of X-ray spectroscopy for the quantitative chemical analysis of practical samples, and on his consequent dispute with Hevesy, the second cause celebre in the history of Australian physics.

It was towards the end of the 1920s that Laby, Eddy and Turner turned their attention to quantitative chemical or elemental analysis, a problem that had been brought to their attention by Dr. Ian Wark of the Electrolytic Zinc Company of Australia (1929). They listed the advantages of X-ray emission spectroscopy and suggested that the doubts thrown on the method by other recent experiments that had provided erroneous identifications were unjustified, since such errors could be avoided by a more careful experimental approach. The major problem remaining was one of making the technique quantitative rather than qualitative. But before Laby could report further on the work, the atmosphere suddenly became rather foggy, due to the arrival of a paper by Gyorgy Hevesy, a most prominent and respected member of the scientific community and a formidable opponent.

Hevesy's Johannesburg paper (1929) pointed out that he and Coster had, in their hafnium work, used quantitative X-ray spectroscopy to test the efficiency of a chemical separation method. In cases other than refractory oxides, however, Hevesy suggested, appreciable difficulties were encountered. Many of the errors induced could be eliminated, he continued, by exciting the sample of interest not by electrons in an X-ray tube but rather by allowing X-rays from a standard tube to impinge on the sample; the secondary
rather than primary X-rays then being analyzed. Hevesy had discovered the technique of X-ray fluorescence analysis.

Laby and Eddy were not to be so easily cast aside; however, during 1930 they would publish four papers in strong support of the value of the "primary" method. The experimental difficulties were considerable, they conceded, but, as they had previously demonstrated, a much higher sensitivity than found by others was possible. Hevesy responded: "I must . . . entirely disagree with their statement that the entire X-ray spectrum of an element can be obtained (particularly) at concentrations less than 0.0001 per cent," and he reported the accusation that Laby and Eddy's method was only successful in "special cases".

The next volley was fired by Laby in the May 31 (1930) issue of Nature. He admitted that the "primary" method was not as sensitive as previously stated for non-metals; and then, turning from defense to attack: "Has Prof. Hevesy evidence that the sensitiveness mentioned cannot be obtained with a metal?"

At the end, both Laby and Hevesy were correct. Hevesy's X-ray fluorescence spectroscopy certainly became an analytical tool of very wide-ranging use. But Laby also established convincingly that, with his care and precision, it was possible to achieve the sensitivity which he claimed. In recent years, the advent of new levels of instrumental and theoretical sophistication have prompted renewed interest in this formerly discarded method, not for elemental analysis* but for studying the electronic properties of metals and alloys. Laby would surely have been pleased.

Rutherfordian Influences

I now want to make a number of remarks arising from my own experiences in Australian physics, dating from the late 1950s. I want to suggest that the Cavendish-Rutherford influence has been a major significance, and that this influence has not always been a healthy one.

Like us all, Rutherford too was a product of his time. Most of his firm views and beliefs, which he saw no need to hide, were not appropriate for the early decades of this century; the few that were, were laughed off, for Rutherford's depreciations or depreciations were usually expressed with a twinkle in the words, in the voice and in the eye. But Rutherford, through the multitude of his students and colleagues, exercised an enormous influence on the world-wide development of physics (including Australia), and his prestige was such that a casual remark from Rutherford became a dogma in lesser men's minds. Rutherford died in 1937 when the Second World War was just around the corner. As so many of his Cavendish colleagues pointed out, it was the end of an epoch; but this message took longer to reach the antipodes. Let me illustrate with four examples.

(a) Applied Physics

With regard to the Cavendish of J.J. Thomson, Crowther has stated (perhaps overstated): "The professor and the staff had never had anything to do with the application of science, in industry or in war. They had pursued physics as part of the cultural equipment of nineteenth and twentieth century educated society" (Crowther, 1974). Kapitza has said: "Rutherford . . . never took any interest in technical problems and I even had the impression that he was prejudiced about applied problems." C.P. Snow (1965) has written: "Pure scientists have by and large been dim-witted about engineers and applied science. They couldn't get interested. They wouldn't recognise that many of the problems were as intellectually exacting as pure problems, and that many of the solutions in was satisfying and beautiful. Their instinct . . . was that applied science was an occupation for second-rate minds." Rutherford was attacked personally from time to time on this matter; nor am I convinced by Oliphant's rejoinder that "these criticisms . . . were seen to be baseless when former research students from the Cavendish Laboratory contributed so much to central wartime developments . . ." (Oliphant, 1982). What happened in the exceptional circumstances of two World Wars is hardly the point.

Thomson and Rutherford had little need to apologize; their laboratories specialised in pure research for its own sake, and did it superbly well. It is quite another question, however, as to whether all the universities in Australia should attempt exclusively to follow that lead. I need not detail in this paper, I hope, that the Americans, for example, have adopted a substantially different point of view, to their credit and to their great advantage.

That Australia followed the Cambridge tradition quite religiously is nowhere better demonstrated than in the recent extensive and passionate writings of Susan Davies (1981) on the setting up and preliminary discussions of the 1964-65 Martin Committee on the Future of Tertiary Education in Australia; a work which provided the initial inspiration for the present paper, which I gratefully acknowledge. Martin agreed wholeheartedly with Cockcroft, who called for the establishment of institutes of technology separate from the universities, and with the editors of Nature, who asked, in April 1961: "Would it not be of greater advantage to teach technology elsewhere rather than at a university?" It was no accident that Monash University was originally conceived as an institution to play such a role. After all, it was Martin who said in an interview in 1975: "Now, the education that I am aware of as a professor of physics (at Melbourne University) was good for turning out men who were going to do research — the best of them — and, of course, there would be the rump who would come out as B.Sc's and become teachers or turn into engineers or what have you!" Also significant is the fact that when Brian Pippard delivered his Inaugural Lecture as Cavendish Professor...
in October 1971 he pleaded for a change in direction of Cavendish research. He pointed out that physics had suffered a decline in prestige, something that would not have occurred if physicists had paid more attention to the needs of society, and that it was their duty to play a more positive role in it. Physics is not, he went on strongly, the fundamental science; its brilliant successes had been bought at the price of ignoring the infinite complexity of the real world. The justification of fundamental physics on the ground that it leads to valuable practical applications cannot withstand evaluation by even so blunt an instrument as cost-benefit analysis. These are hard-hitting, penetratingly severe and fundamentally important words that have received far too little attention in Australia.

(b) Physics funding

There is currently a crisis in the funding of university research in Australia, and I have already expressed some views on this topic (Jenkin, 1982).

In 1907 J.J. Thomson donated his accumulated lecturing fees (£24,000) towards the capital cost of an extension to the Cavendish, a noble and economical act which Crowther notes also consolidated the practice of running the laboratory on an excessively small budget. Rutherford occasionally agreed to large expenditures, but in general he believed that it was not necessary to have expensive apparatus to make important discoveries. His own incredible facility with simple apparatus is legendary, as are his remarks that “I could do research at the North Pole” and that “We’ve got no money, so we’ve got to think!”. Chadwick argued with Rutherford especially about money, and thought that Rutherford had a profound distaste or inhibition in asking for it. Chadwick, Blackett and Oliphant later left the Cavendish, partly to have their “own shows”, but partly because they were fed up with the lack of money.

In Australia we have still not progressed beyond the string-and-scaling-wax mentality, except in a very few specific areas. The money available to the ARC for physics is incredibly puny. I well remember a notable visitor to La Trobe University commending us on building so much of our own apparatus; only recently have we fully realised how quickly we are falling behind British, European and American scientists, who have been doing physics (on commercial instruments) while we have been struggling to upgrade our existing apparatus and to design and build new equipment. I am reminded often of the jealous ridicule heaped upon Harry Messel when he raised substantial amounts of money for physics at Sydney University at the time when I was a young graduate student.

(c) Mathematical physics

I have already given some attention to the Cavendish preference for experimental methods and mental pictures. Thomson “abhorred the worship of mathematics as the end-all of science”, and, although “he did not specify the persons whose work exemplified the super-analytic approach, it would be expected that he, like Maxwell, looked upon this regrettable trend as originating on the Continent” (in “Britain, there was not a single supporter of the quantum theory . . . until about 1912” (McCormmach, op. cit.).

Rutherford had a deep respect and affection for those who contributed, in the theoretical field, to the advancement of physics; but he too was suspicious of theoreticians nevertheless. His utterance are well recorded and remembered: Following a comment by Wien in 1910 that “No Anglo-Saxon can understand relativity”, Rutherford’s rejoinder “No, they have too much sense”; or, of theorists, “They play games with their symbols, but we in the Cavendish turn out the real solid facts of Nature”; or, in proposing a vote of thanks to Heisenberg for a lecture, “We are all much obliged for your exposition of a lot of interesting nonsense, which is most suggestive”. Crowther has commented that, following the Cavendish tradition, the theoretical education of experimentalists in Britain took a rather haphazard course, whereas in the United States a much higher level of theoretical instruction for experimental physicists has developed. And in Continental Europe it had been different for many years. One only has to think for a moment of the developments of quantum theory and wave mechanics to realize that there was something fundamentally different in German society, German education and the way they viewed the world. In Edinburgh Max Born was relegated to dark and gloomy rooms in an underground basement of the Physics building, and Rudolf Peierls to a wooden hut in Birmingham.

In Australia the record is an even sadder one. Courtenay Mohr was treated shabbily at Melbourne University, and I am reliably informed that the proposal to establish a Chair of Mathematical Physics at Sydney was opposed by important physicists, although the support of Leonard Huxley (an engineer by training) was ultimately successful. The arrival of Herbert Green to fill that Chair has been one of the highlights of theoretical physics in this country; and when Harry Messel, who was the first lecturer there, was appointed to Sydney, he brought in people like Stuart Butler and John Blatt, who certainly helped to establish a tradition of theoretical physics in Australia. But this vital area remains undervalued and under-supported throughout the country. Professor Green tells me that his department in Adelaide is at present under an implicit threat that, when he retires at the end of 1985, he will be replaced by an untutored lecturer, and there are similar situations elsewhere. There can surely be no clearer example than this of the place given to mathematical physics in Australia. And all of this in the face of Oliphant’s recent statement that “I came to appreciate the fact that mathematics applied to science was probably the highest form of human thinking” (Oliphant, 1979).

(d) Other disciplines

One of the problems of physics, it seems to me, has been the arrogance of its practitioners. Physics was not just worth studying, it was the best and often the only thing worth studying. It was Rutherford who said “all science is either physics or stamp collecting”, and it is often implied that it only needs another advance in physics to allow the deduction from first principles of the facts and laws of the lesser sciences like chemistry and biology. Lawrence Bragg, Rutherford’s successor at the Cavendish, endured sharp and persistent criticism from British physicists, who hardly recognised crystallography, and certainly not molecular biology, as physics. The Nobel awards to Perutz and Kendrew and to Crick and Watson comforted Bragg in his later years. Pippard, in his Inaugural Lecture, struck at this arrogance and complacency. Chemistry was not a mere branch of physics, he suggested, and it is a delusion to believe that the application of physical methods to biological systems will enable living processes to be reduced to the rule of physical law. Anthropology, he ventured, has more to say about the world in which we

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find ourselves, for that world is more than an assembly of particles; it consists of an assembly of men and women, of thinking and feeling beings. If physicists are to keep faith with their great heritage, they should take a cool look at the claims of their predecessors.

Conclusion

I have been deliberately critical of Australian physics in this paper, for which I offer no apology and for which I expect no mercy; and I have tried to suggest some of the origins and causes of our malaise. It seems to me that we need a very vigorous and a deeply considered re-evaluation of physics in this country, and that we need it now.

REFERENCES


An Economist's Overview of Science Policy

Professor S.P. Burley, School of Economics, La Trobe University, Bundoora, Vic. 3083

It has become something of a cliche to proclaim that science policy is no longer something which just concerns the scientists preoccupied with purely theoretical tasks. The costs and consequences have now become so big as to be a matter of active concern for the whole of society, seeking to tackle the enormous, and sometimes vital, questions involved with greater civic maturity.

This normally brings us immediately into the realm of politics; for the society in question is divided by conflicts, both of interest and of ideology. The social goals to be sought are multiple and inconsistent, and the theories as to how society works are multiple and confused. Thus, on one side, we have advocates of a technocratically planned society where scientific and other goals, and the means to achieve them, are to be set by the Government of the Nation State. On the other side, we have those who consider both science and society to be completely unplannable and so best left entirely to the hunches of the scientists and entrepreneurs on the job.

We shall argue that both of these outlooks are incomplete and lead to an under-investment in science. We advocate a more active role for governments in the area. We do this with an attitude of moderate hope that, beyond all the institutional and intellectual problems, general economic ideas can give to society some clearer understanding of both science and itself, and hence the possibility of taking further action to the benefit of both in a wider context. Other attitudes are logically possible, but seem to this writer to be either more hopeful than past experience warrants or less hopeful than the future deserves.

There is a scientific tradition which normally regards all such controversial and vague economic theorising as unprofitable. But, discussions about the funding of scientific projects increasingly indicate what would seem to be most justifiable claims in excess of the funds socially available. Hence there is a general funding and allocation problem which can only be rationally solved in terms of some implicit science policy. Interest in this area has certainly grown as the size of the corresponding financial problems has increased by orders of magnitude. But, despite this general interest, much hopeful talk about launching some new “Science of Science”, one cannot help being struck by a certain disappointment. There seems to be a persistent difference in intellectual character between science itself and decisions about science.

Here it seems pertinent to recall some seemingly forgotten views of von Neumann (1963).

“It is perfectly clear that we can assemble information which is more elaborate than ever before, and in larger quantities. In decision-making, the situation is somewhat different. There have been developed, especially in the last decade, theories of decision-making — the first step in its mechanisation. However, the indications are that in this area, the best mechanisation will do for a long time is to supply mechanical aids for decision-making while the process itself must remain human. The human intellect has many qualities for which no automatic approximation exists. The kind of logic involved, usually described by the word “intuitive”, is such that we do not even have a decent description of it. The best we can do is to divide all processes into those things which can be better done by machines and those which can be better done by humans, and then invent methods by which to pursue the two. Thus decisions in economic operation are made half by machine and half by a human. The two shares are intermeshed.”

Encouraged by the possibilities of modern data processing, science policy is often thought of in terms of three rather different operations:

(a) setting up a vast nation-wide data base containing all the accounting information concerning the costs of inputs into all scientific projects;
(b) calling for greater clarity concerning the national values of scientific projects, and
(c) establishing review bodies to compare (a) and (b) in some general cost benefit scheme.

This enterprise, which has a clear legitimation in terms of traditional accounting for public expenditures, is further encouraged by thinking analogous to that of the management of a commercial enterprise. A carefully defined and applied accounting is considered as establishing a goal for determining which science policy goals are being achieved at what cost.

But when we are dealing with science there are important differences between the economist’s and the accountant’s expectations of establishing clear relations between costs and benefits. From an economist's point of view scientific research differs essentially from normal
commercial activity in that the output is both “uncertain” and “inappropriate”. By this we mean that scientific investigation, rather like attempts at rainmaking, has the following properties:  
(a) You have very little idea as to what will come of it. 
(b) If it does work outsiders will benefit without having to pay for it. 
But rainmaking analogy does not go far enough, as scientific research has these characteristics to such an extent that the normal non-commercial arrangements for handling uncertainty and inappropriability collectively within the framework of the Nation State become seriously inadequate. Let us consider these two points separately. 

Uncertainty of outcome is not unique to scientific research, in moderate doses it is a normal fact of economic life. Most people take it in their stride provided they do not risk losses significant in relation to their total assets. In the latter case they tend to seek some sort of insurance to spread the potential losses around. The rationality of this behaviour has been clearly explained by modern mathematical models of decision-making under uncertainty. These were developed notably by von Neumann and Morgenstern (1944), although the basic notion, of expected utility, dates back to Daniel Bernoulli. 

In this sense it is perfectly rational for the nation as a whole to bear the risk of very costly scientific experiments which would seem to have a good chance of success, but which might fail completely. Still, as we know, there are increasingly important gambles of big science that only the wealthiest countries are willing to undertake (and any physicist could easily think of others even more costly and risky). Hence it is natural that some nations should sometimes club together to share these risks over their combined populations. Combined ventures by the (middle scale) European countries anxious to keep up with the super-powers big physics have become particularly notable. But according to the logic of expected utility theory there is a case for a complete world wide co-operation to achieve even greater expected gains. Such co-operation also has another rationale in terms of our second point about the nature of scientific output. 

As remarked earlier, scientific research also differs from normal commercial activity in providing benefits to “outsiders” who bear none of the cost of producing it. This is similar to the concept of “external economies of production” developed by English economists, notably Marshall (1922) and Pigou (1932), who also showed that if an individual thus makes a contribution of social welfare for which he receives no payment he is unlikely to engage in this activity to the extent that the interests of society would indicate. This is a case of the market’s failure to lead to an optimal allocation of society’s resources when there is a divergence between private and social costs and/or returns. This means that, when each individual pursues his own interests independently, then at least one will end up worse off than he would have under an (ideal) optimal arrangement. 

A solution to this problem of “market failure” in the case of “public goods” is to devise some (hopefully) ideal political mechanism for the whole of society to contribute to the cost of producing those benefits it automatically shares. Thus tax funds are often used to subsidise the training of apprentices by an employer; who otherwise might be reluctant to incur the cost of training so many skilled workers for the potential benefit of his competitors as well as himself. This idea is of course also behind the funding of industrial research by governments, cf. Burley and Morgenstern (1969). But, 
in the case of scientific research, the externalities go beyond the Nation State — potentially to the whole of mankind. Hence it would seem that science policy is concerned with international public goods and so should notionally be international, not national. Further, the smaller the country the less it will benefit (proportionally) from its scientific output and so the more strongly this argument holds. 

Scientific outlook and practice has, of course, long taken account of this, from the earliest days of the medieval “universitas” to the vast patchwork of modern international schemes for scientific co-operation. But it seems important to keep this idea to the forefront and not be side-tracked by the more limited goals of the governments of the Nation States. Their growing role seems increasingly questionable in an age where new externalities and improved communications created by science would suggest we think of more appropriate scales for certain types of social decision-making. 

This view is strengthened when we turn to competitive national activities which have strong international diseconomies — notably the provision of military security. Scientific developments are often blamed for the proportions these activities have assumed. But by a converse of the above argument about external economies it can be shown that such activities will always be over-invested in unless they are organised collectively. The argument assumes a peculiar force in the case of powerful offensive weapons because of the strong negative externalities involved (ruin for the enemy in the case of conflict). 

The point is that, if they act collectively, all countries could gain enormously by spending different percentages of the G.N.P. in areas with strong international externalities. These gains could reasonably justify even very expensive international control mechanisms to ensure smaller arms budgets and bigger science budgets all round (than those dictated by an uncoordinated pursuit of national interests). 

Admittedly experience with the arms control problem indicates that many nations, and especially the great powers, are unwilling to surrender military sovereignty to an international order. But they do seem seriously willing to consider controlling their defence budgets at mutually lower levels. The major practical difficulty seems to be that only in free and open societies can the amount of information be gained which is needed for an effective international arms control. 

The converse science promotion problem would seem to have the same free and open societies requirement. But there might seem to be more prospects for progress here; as in this case it is the less free and open societies which are at a relative disadvantage. Hence they could reasonably be expected to concede some “opening up” as a condition for participating in expanded international scientific efforts which had this as a basis. 

REFERENCES 
BOOK REVIEWS


Reviewed by J.R. Pilbrow, Department of Physics, Monash University.

It is always good to come across a book which puts together, in one place, either different techniques applied to a particular problem or a range of similar techniques applied to a given class of problems. "Magnetic Resonance of Phase Transitions" is in the latter category and it brings together a number of contributions by recognised workers in the fields on a wide range of materials which undergo phase transitions. The editors wisely chose to begin the volume with introductory chapters on the theory of phase transitions and magnetic resonance and relaxation.

The bulk of magnetic resonance studies of phase transitions involves NMR since it can be carried out on pure material. There are, therefore, three chapters covering fluids, paramagnets and crystals as well as liquid crystals and ferro-electrics. Who better than Professor Bline could have been asked to contribute the chapter on KDP-type ferro-electronics. He is the undoubted authority in this field and he writes, as usual, with clarity and insight. His discussion of 'soft modes' is particularly good.

EPR suffers from the limitation that EPR probes generally must be impurities introduced either during crystal growth or by irradiation. In spite of that, Owens has managed to review a quite extensive body of literature. The final chapter on the Mossbauer Effect, by one of the Argonne group, is thorough and provides a good insight into the utility of this method for studying phase transitions.

The reviewer expects to make considerable use of this book and he has already done so. Perhaps it needs no better recommendation than that. The price, however, is such that this particular volume is unlikely to find itself on many private bookshelves but it is a must in any physics library.


Reviewed by J. Ottmaa, School of Physics, University of New South Wales.

The subject of lattice dynamics, although it has now reached a certain level of maturity, still continues to be an active area of research. The first two volumes of this series, published a few years ago, are now accepted as one of the most important reference works on the subject. The latest two volumes are welcome additions to the series and should certainly be essential acquisitions for any solid state physics library.

A variety of topics are covered in these two volumes. Volume 3 contains articles on the lattice dynamics of transition metals (Sinha), the role of phonons in superconductivity (Allen), light scattering from collective pair excitations (Fleury), and the interaction of phonons with magnetic ions (Luthi). Volume 4 contains articles on amorphous solids (Weaire and Taylor), disordered solids (Visscher and Guvenmiksn), morphic effects (Anastassakis) and infrared absorption by multiphonon processes (Mills, Duthler and Sparks).

All of the authors are recognized experts in their respective fields and the articles are all comprehensive and authoritative reviews of the various topics. The presentation is uniformly clear, and at a level which should be digestible by beginning graduate students working in either theoretical or experimental areas of lattice dynamics.


Reviewed by R.J. Petty, Dept. of Radiological Sciences, Alfred Hospital, Melbourne.

As usual, this book contains six unrelated contributions on fairly specialised subjects, though some are likely to be of general interest; for example the articles on Particle Beam Fusion and on The Free Electron Laser are excellent introductions to interesting areas of physics.

Of particular interest to this reviewer is an article by J. Frohlich on the biological effects of microwaves. The author does not discuss the well-known thermal effects but provides an excellent overview of the theoretical mechanisms for highly nonlinear non-thermal effects in which microwave absorption is viewed as a trigger for energy stored in which microwave absorption is viewed as a trigger for energy stored in collective excitations of biological systems. A survey of experimental evidence for these mechanisms is also included. The author assumes no prior knowledge on the part of the reader and leads him through both the physics and the biology of the problem in an extremely understandable manner. In view of current concern about such effects, this article is both timely and very useful to physicists with an interest in the field of microwave hazards.


Reviewed by B.M. Spicer, School of Physics, University of Melbourne.

This book grew out of a series of graduate level lectures given at Stanford University by the author; this statement correctly specifies the level of the book in the Australian context. Its contents as listed make it an ideal text book on atomic and molecular structure in that it treats most, if not all, that one could wish to have covered in a course on atomic and molecular systems.

The mathematical and quantum mechanical bases upon which the discussions of atoms and molecules are built have been separated out, and treated before any discussion of atomic or molecular properties. The mathematical treatment is certainly adequate, though
somewhat condensed, and the reader is referred to appropriate equations in it during the discussion of the physical systems.

As noted, many topics are treated in the four sections which deal with atomic and molecular properties. Considering its importance in atomic theory, it is felt that the discussion of the Hartree-Fock method of calculating electron wave functions and energies is far too brief. Also, the absence of the relativistic partner to it, the Hartree-Fock-Dirac method is hard to understand, especially as the author does deal with the Dirac equation for a single electron. The almost complete absence of comparison of results with experiment is also puzzling.

Eight appendices, mostly dealing with special mathematical functions, complete the volume. Again, it is felt that the treatment here is rather too terse.

Nevertheless, this book should be in the library of anyone working, experimentally or theoretically, in atomic or molecular physics and would certainly be a worthwhile addition to a graduate student's library. Its price just about allows the latter.

Reviewed by C. Pask, Dept. of Applied Mathematics, Research School of Physical Sciences, Australian National University.

Graded or continuously varying refractive indices are widespread in nature, the visual systems of invertebrates and vertebrates, including our own eye lens, and the earth's atmosphere providing important examples. However, as one might expect from an author based in the Research Laboratories of the Eastman Kodak Company, it is the recent advances and promises of modern optical technology which really motivate this book, although the spectacularly successful optical fibre is mentioned almost only in passing.

The author relies mostly on the methods of geometric optics and wave theory entering only in two sections dealing with antireflection coatings. A six page Historical Introduction gives the barest of historical details and introduces the basic ray equations. The chapters dealing with spherical, axial and radial gradients follow a clear and instructive plan: an examination of the general properties of the ray paths, some analytical examples and ideas for practical computational methods. Introductions to Aberration Theory, with the Wood lens as a detailed example, and to the practicalities of dealing with more general media prepare the reader for the major chapter, Lens Design with Gradient, where the author discusses the use of the extra freedom which gradient index components give to lens designers for eliminating aberrations and removing the need for aspheric surfaces. Interesting numerical examples are presented for single lenses. The two final short chapters introduce ideas but little detail relating to the manufacture and measurements of gradient index optical systems.

This book is technical and hardly suitable for a beginner in the field. At times I wondered whether terse or concise, austere or uncluttered were the appropriate descriptions. The book does conform to the author's stated purposes which were "(1) to describe, partly in detail and partly in summary, the present state of theory and practice related to gradient index lenses, and (2) to identify many of the sources of information related to this field". On balance, he has succeeded and produced a useful theoretical guide for researchers in optics.

Reviewed by I.B. Whittingham, Physics Department, James Cook University.

These proceedings of the Second Course of the International School of Physics of Exotic Atoms, held at the "Enrico Majorana" Centre for Scientific Culture, Erice, Sicily, March 25 — April 5, 1979, consist of general review lectures on Muonium and Positronium (V.W. Hughes), weak neutral currents in atoms (P.G.H. Sandars), quark atoms (T. Appelquist), baryonium (Chen Hong-Mo). Additional specialist lectures on muon capture and mesi chemistry lepton number conservation, tests of QCD in heavy quarkonium, and a comprehensive account of applications of muon spin rotation including muon motion in solids, semiconductors, ferromagnetics and semimetals, chemistry of muonic radicals, muon induced quadrupole moments etc.

The general reader may find the review lectures of some interest although several of these reviews are now out of date. The review of Appelquist suffers in that frequent reference is made to figures and tables contained in a previously published review, thus making this contribution exceedingly difficult to follow.

The strength of the book lies in the specialist contributions and consequently there is no place for this book in the general Physics collections of Australian libraries.

Reviewed by Prof. Geoffrey I. Opal, School of Physics, University of Melbourne.

This small volume is the fascinating autobiography of the Japanese Nobel Laureate, Hideki Yukawa, beginning with his earliest childhood (b. 1907) and ending with the publication of his seminal paper in 1935 entitled "On the Interaction of Elementary Particles I". In this paper, which is included in facsimile, Yukawa recognised that the nuclear force was a new kind of force, and gave an explanation of it in terms of a new field. Working by analogy with quantum electrodynamics, he predicted the existence of an exchange particle of about 200 electron masses, which was subsequently identified with the pi-meson of cosmic rays.

The book gives a detailed account of the inner and outer world of a shy, partially introverted child, youth, and man, growing up in pre-war Japan. The non-Japanese reader can learn much of the mores of this world, and of those forces, parental, societal, and educational, which shaped the mind of Yukawa, the theoretical physicist.

In the course of the book, one learns of the other men of Japanese Physics, such as Nishina, Kikuchi, Tomonaga, Sakata, some mentors, coworkers, and students of Yukawa.

Yukawa died in 1981. It was timely that World Scientific Publishing Co. saw fit to make this translation of his autobiography available to the English speaking world in 1982. I strongly recommend this book to anyone who has an interest in the history of science.

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SCIENCE POLICY COMMITTEE REPORT

Australian Research Grants Scheme Funding for the Physical Sciences 1983

1. TOTAL ARG'S FUNDING
1.1 For the first time since 1976, the 1983 ARG's allocation represents a decline in real funds. The total grant of $19.25 M expressed at 1982 levels represents $17.41 M compared with $17.98 M for 1979-82 (Figure 1).
1.2 The total number of grant applications fell from 2102 (1982) to 201 (2012). With the continuing emphasis on "excellence", the number of grants awarded fell more sharply, from 1347 (1982) to 1193 (1983) (Figure 2). Thus, the percentage of successful applications fell from 64% to 59%. As a consequence of the decrease in the number of grants awarded the average grant rose from $13,348 to $14,593 (1982 dollars).
1.3 Significant changes have occurred in the trends for the distribution of ARG's funding with reversals occurring in every discipline (Figure 4). The fraction allocated to the Biological Sciences (Molecular biology and cell metabolism) has the largest increase of 3.1%, but this is offset for the overall award to the Biological Sciences by a 1.3% decrease in Plant and Animal Biology. The Physical Sciences increased their share by 2.2%, whereas the Chemical Sciences have fallen by 1.5%. For the first time in eight years there has been a drop in the allocation to the Humanities and Economics (1.6%) and the Social Sciences (0.4%). The decreasing trend for the Earth Sciences has been reversed with a 0.8% increase, the second most significant change after the Physical Sciences. The 0.4% drop for Engineering and Applied Sciences is in keeping with the minor fluctuations in the allocation for this subcommittee over the past five years.
1.4 The fraction of the total amount of grant requests that the ARG's has been able to support has fallen in all disciplines and only Earth Sciences received more than half of the amount requested (Figure 3). Overall, the total amount awarded has fallen from 46% of that requested (1982) to 41%.
1.5 In terms of the percentage of the successful grant applications and the average grant awarded relative to that required, Earth Sciences was the most successful discipline (Figure 3). In spite of the improved allocation, the Physical Sciences, on average, were still only able to attract 63% of the support requested. The overall average was 68% compared with 74% in 1982. The Chemical Sciences have suffered the most severe cuts both in terms of the average grant and the number of grants awarded.

2. ARG'S FUNDING FOR THE PHYSICAL SCIENCES
2.1 In spite of its improved share of the overall grant allocation, the percentage of successful applications in the Physical Sciences continues to fall, and the average grant is still well below the amount requested.
2.2 Although the total number of applications made and approved are falling, it is encouraging that both have shown a slight increase for the Physical Sciences (Figure 2). Clearly, members of the Physics community must be encouraged to keep up their applications for ARG'S support.

2.3 A survey of the 1981/82 Report of the Science and Engineering Research Council indicates the relative levels of funding between physicists working in United Kingdom and Australian Universities have not changed in recent years in spite of the severe financial cut-backs imposed upon some United Kingdom Universities. A total of 139 grants worth £4,377 M (S7.421 M) were made by SERC for the 1981/82 period. Thus, although one must be careful in making direct comparisons between the two schemes, the average SERC grant of $53.4 K is far greater than the ARG'S 1982 value of $14.8 K and the 1983 value of $18.49 K ($16.71 in 1982 dollars).

Fig. 1: Total ARG's grant and average grants between 1972 and 1983.

Fig. 2: Total applications and applications in Physical Science made and approved from 1982 to 1983.
PHYSICS ROUNDBABOUT

CSIRO updates computer facilities

Australia's largest computer network, CSIRO's CSIRONET, is to update its computing facilities with one of the world's fastest and most powerful computers.

The Control Data CYBER 205 computer had been offered to CSIRO by Control Data Australia Pty Ltd as part of an agreement made in 1979 between the two organisations.

The Advanced CYBER 205 would be installed at the Division of Computing Research in Canberra and commissioned early next year.

The new computer is an advanced version of the CYBER 205 termed the 600 series.

Memory for this series is implemented using low power Complementary Metal Oxide Silicon technology. Each static random access chip holds 16,384 bits.

The CSIRO machine is configured at 16 million bytes, and is field upgradable to 64 million bytes. Virtual memory is implemented using a 48 bit address.

The central processing unit of the CYBER 205 machine comprises one scalar processor and two pipelined vector processors, and is field upgradable to four vector pipelines which about doubles peak performance.

With two pipelines the central processor is capable of carrying out more than 400 million additions or multiplications in a second.

A similar amount of computing would require about 100 seconds on CSIRONET's current CYBER 76 computer, which remains one of the fastest computers in Australia almost ten years after installation.

The Chief of CSIRO's Division of Computing Research, Dr Peter Claringbold described the machine as a major national resource for Australia's continued development.

The placement of this supercomputer at the apex of CSIRO's nation-wide CSIRONET service, will make it readily accessible nationally and even internationally.

Dr Claringbold said a supercomputer required substantial support infrastructure.

The existing CSIRONET facility could meet all these requirements or provide them at modest cost while duplication of this infrastructure elsewhere would at least double the overall cost of providing the facility.

"The most valuable supercomputer applications in Australia might well turn out to be the ones that have yet to be identified," Dr Claringbold said.

* * *

The National Plastics Industry Training Committee (NPTC) has released to the general public its book called "KNOW YOUR PLASTICS".

The book contains chapters on application, uses and design with plastics, Basic polymer chemistry, Identification of plastics, and their use and applications.

The price is $21.00 (post free), available from

The Director
National Plastics Industry Training Committee
PO Box 131 (157 Fitzroy Street)
ST KILDA WEST, 3122, VICTORIA.

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Coldest June Temperature at Australian Antarctic Station

Weather and temperature statistics, kept by the Bureau of Meteorology, show that mean June temperatures at Australia's Mawson and Davis Stations in Antarctica were some 6°C below normal.

The lowest-ever temperatures were recorded in June: -83.1°C at David and -34.0°C at Mawson. On the other end of the scale the maximum temperature at Mawson was -7.9°C and at Davis -10.9°C, with mean temperatures of -23.2°C and -22.2°C respectively.

Both Mawson and Davis Stations, although colder than Casey Station, enjoyed comparatively little wind. At Casey the maximum gust recorded was 98 knots or well over 180km/h. Casey also recorded the highest number of days of rain or snow, 12; ten days of gale winds (over 60 Km/h) and 15 days of strong winds (over 40 km/h).

Nearly 100 Australians, members of the Australian National Antarctic Research Expeditions, winter at the Stations each year. They conduct a wide range of scientific work and are currently also engaged in a station rebuilding program.

If you think that working outdoors in these temperatures is bad news you will not be impressed with the mean daily hours of sunshine either — 0.1 per day at Mawson and none at all at Davis and Casey!

— D.O.S.T. Newsletter

Questacon Successful

About 600 ACT and interstate students visit the highly successful Questacon project each week following a major expansion of its operation.

About 100 Canberra students are now involved in running the centre after attending a course of training lectures given by academics from the ANU, the Canberra College of Advanced Education and the Royal Military College, Duntroon.

Several ACT secondary colleges have included the Questacon science lectures in their programs and the 12 evening lectures given last year attracted large audiences.

Dr Gore was awarded a Churchill Fellowship in June to study overseas science centres. He attended a UNESCO science workshop in Bangkok in August, as the Australian representative by the Australian national Commission for UNESCO.

— ANU Reporter

Welch Foundation Scholarship 1984

A scholarship is offered to a promising scholar who wishes to contribute to the study of vacuum science techniques or their application in any field.

It is offered for a one-year period starting September 1, 1983.

Its value is approximately $7,000 US.

Applicants are asked to select a laboratory of their choice. Because of the international nature of the scholarship, strong preference will be given to applicants who propose to study in a foreign lab in which they have not yet studied.

Candidates for the scholarship should have at least a Bachelor's degree; a Doctor's degree is preferred. Candidates can obtain the necessary forms for the scholarship from the IUVSTA Welch Foundation Administrative Office:

Division of Electrical Engineering
Room 162, Building M-50
National Research Council
Ottawa, CANADA K1A 0R6

Candidates for the Welch Scholarship are invited to send their applications to the above-noted address BEFORE 15 April 1983.

An Urgent Appeal from Amnesty International

USSR: ANDREI SAKHAROV

Amnesty International has received reports that Soviet prisoner of conscience Andrei Sakharov, a physicist aged 61, is seriously ill and has been prevented from receiving appropriate medical treatment from his own doctors.

In 1980, Andrei Sakharov was sent into internal exile in Gorky for an indefinite period without having been tried or charged with any offence. He had a heart attack in 1978 and again in 1979 and continues to suffer heart problems. In addition, he is suffering from disease of the kidney and prostate. According to reports, he has been refused permission to see his own doctors in Moscow.

BACKGROUND INFORMATION

Before he became involved in the defence of human rights in the USSR, Andrei Sakharov, who is a member of the USSR Academy of Sciences, clashed with the authorities on the nuclear arms issue. Having made an important contribution to the development of the Soviet H-bomb in the early 1950's, he came into conflict with the CCPSU (communist party) First Secretary N.S. Krushchev when in 1961 he insisted that nuclear tests were technically unnecessary and would mean a renewal of the arms race. In 1966 he was one of those who signed a letter disputing the constitutionality of the introduction of Articles 190-1 ('circulation of anti-Soviet slander') and 190-3 ('participation in actions which violate the public order') into the Russian criminal code. During the 1970's Andrei Sakharov gradually became a leading spokesman of the human rights movement in the Soviet Union, and is known to have appealed for the release of at least 200 prisoners of conscience during these years. He was awarded the Nobel Prize for Peace in 1975 for his work in defence of human rights in the Soviet Union.

On 22 January, 1980 Andrei Sakharov was arrested in Moscow. He was stripped of his state honours and sent into exile to Gorky, a city closed to foreigners. Because he was exiled without trial, Andrei Sakharov does not enjoy the legal rights of those who are sent into internal exile after a court sentence. He has repeatedly stated his willingness to stand trial in order to be given the possibility of defending himself.

During the last three years Andrei Sakharov has been subjected to constant harassment, including house searches in his absence, anonymous threats to his life and repeated thefts of his manuscripts. He does not appear to have recovered from the effects of the hunger-strike he undertook at the end of 1981 to persuade to Soviet authorities to allow Elizaveta Alexeeva, the wife of Andrei Sakharov's stepson, to join him in the USA.
Recommended Action:
Telegrams/express letters/letters urging that Andrei Sakharov be granted permission to see his Moscow doctors and appealing for his release from internal exile. (Telegraphic addresses in capitals)

Appeals to:
Mr. A. M. REKUNOV
USSR Procurator-General
USSR Procuracy
UL PUSKINSKAVA 15A
MOSCOW, USSR.
The USSR Minister of Internal Affairs, V.V. Fedorchuk:
V.V. FEDORCHUK
USSR Minister of Internal Affairs
Ministry of Internal Affairs
UL. OGARIEVA 6
103099 MOSCOW, USSR

COPIES TO:
Chairman of USSR Academy of Sciences, A.P. Alexandrov:
A.P. Alexandrov
Chairman of the USSR Academy of Sciences
USSR Academy of Sciences
Leninsky prospckt 14
Moscow V-17, USSR
Gorky Deputy Regional Procurator, A.Z. Perelygin:
A.Z. Perelygin
Gorky Deputy Regional Procurator
ul. Sverdlovskaya 17
g. Gorky
RSFSR, USSR
and to Soviet diplomatic representatives in your country.
PLEASE SEND APPEALS AS SOON AS POSSIBLE.
Check with the International Secretariat if sending appeals after 11 March, 1983.

Coming of Age for the Parkes radiotelescope

The ‘grand old lady’ of radio-astronomy in Australia, the Parkes 64-metre telescope operated by CSIRO, came of age on October 31.

The gigantic steel and concrete structure, standing amid ripening wheatfields in rural western New South Wales, was considered an amazing feat of engineering ingenuity when it was formally commissioned by the then Governor-General, Lord De L'Isle, on October 31, 1961.

The Parkes radio telescope is used to study radio emissions from objects ranging from the Moon — so close that astronauts have been there — to galaxies and quasars so distant that the radio waves have taken 10,000 million years to reach the earth.

Over the years, scientists have used the telescope to make exciting discoveries about the universe, bringing international recognition to Australia.

The telescope has been responsible for several major discoveries; it played a major part in detecting the first quasar and was used by NASA for the Apollo missions to the moon.

Recently the Parkes telescope was used by a team of Australian and British astronomers who discovered a quasar at the edge of the universe.

A group of these scientists, together with some of the key personnel involved in the telescope’s construction, held a reunion at the radio telescope on the day.

People calling at the telescope during the day were offered tours of the facility arranged by CSIRO’s Visitors’ Centre at the telescope.

They were also able to see the results of extensive modifications which have been made to the telescope over the past few months.

These include the fitting of two new rings of perforated aluminium panels to the dish surface to enable the telescope to observe at higher radio frequencies.

The improved surface was made possible after a survey of the dish showed that its structure far exceeded the original design specifications.

Another major improvement has been the complete remodelling and re-equipping of the control room to allow for the installation of new computing facilities, control desk and work stations.

A less visible but important modification has also taken place in the aerial cabin situated at the focus of the paraboloid dish. The cabin houses the sensitive receivers which are cooled to around -260° centigrade.

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Some properties of radio galaxies in clusters. O.B. Slee, I.R.G. Wilson, and Betty C. Siegman 101
Conferences and Meetings

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May 16-20 5th Aust. Schools & Conf. on X-ray Analysis, Melbourne. Conference Secretary, P.O. Box 90, Parkville, Vic. 3052.


May 23-25 New Frontiers in Optics; Optics in Australia, Sydney Dr. W.H. Steel, CSIRO Divn. of Applied Physics, P.O. Box 218, Lindfield, 2070.


July 13 Seminar — Patents in Chemical Industry and Research, Melbourne Dr. G.B. Guise, RACI, P.O. Box 224, Belmont, Vic, 3216.


Sept 12-14 Millimetre and Sub-Millimetre Wave Research in Australia, Canberra Dr. J.A. How, R.S. Phys. S., ANU, P.O. Box 4, Canberra, 2600.


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Feb 12-16 14th Aust. Polymer Symposium, Ballarat Dr. G.B. Guise, RACI, P.O. Box 224, Belmont, Vic, 3216.

Aug 27-31 3rd Int. Conf. on Solid Films and Surfaces, Sydney Prof. D. Haneman, UNSW, P.O. Box 1, Kensington, N.S.W. 2033.

1985

Feb 11-14 Int. Symp. “Polymer 85”, Polymer characterisation and analysis, Melbourne Polymer 85, RACI, 191 Royal Pde., Parkville, Vic, 3052.

Lenihan and the Environment

On August 10th Professor J. Lenihan, Director of the Department of Clinical Physics and Bioengineering, West Scotland Health Boards addressed a Branch Meeting on the topic Pride and Prejudice or How to Live with the Environment. Professor Lenihan was a keynote speaker at the 22nd Conference on Physical Sciences and Engineering in Medicine and Biology held in Perth in August. His address was jointly sponsored by the Australasian College of Physical Scientists in Medicine, the Australasian Association of Physical Scientists in Medicine, the University of W.A. Extension and the W.A. Branch of the AIP.

Professor Lenihan traced our current concerns with the environment back to Lord Kelvin’s work at the University of Glasgow. A Royal Commission under Kelvin recommended controls over the quantity of arsenic in beer using the following rationale — (i) it could be achieved (ii) it could be easily measured and (iii) the specified level could be tolerated by rats!

Pride was related to our belief that we understand a lot about numbers and how to apply them statistically. A difficulty was that not all quantities are quite so easy to measure as we might wish. Thus, safe levels of toxic materials and effects of chemicals that are transformed in the body are difficult to quantify.

Our Prejudice was exposed as subscribing to the view that equilibrium is the only acceptable state of affairs. As long as the environment is in steady state we are content, whereas in fact stability is simply a lull in the struggle between opposing forces.

Several case studies were developed (e.g. Hg levels in the environment) to illustrate the points being made. A set of interesting data on perceived hazards in the environment were presented and showed that people tended to overestimate small hazards and underestimate large hazards.

The question of how the public comes to terms with a certain level of hazard acceptability was developed. Factors of cultural, social and hereditary origin were linked to the process.

Finally, the often forgotten matter of the increased hazards associated with the reduction of an identified hazard in the environment was well illustrated by example.

Professor Lenihan brought together a number of interesting aspects relating to man and the control of his environment. This task was executed with considerable skill, vigour and humour. As pointed out by Professor Street, the speaker was competing for an audience with ‘Brideshead Revisited’. The 60 people that attended would have left satisfied with their choice.

— Mervyn Lynch, WA Associate Editor