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PHILIPS
69 Clarence Street, Sydney, N.S.W. 2000
The Turbo-Molecular Pump—A Modern Means for Producing Clean Ultra-High Vacua

J. W. Kelly
A.A.E.C. Research Establishment, Lucas Heights, N.S.W.

Introduction

In the period 1905 to 1916 several major steps in the development of high vacuum pumps occurred. In 1905 W. Kaufmann and W. Gaede introduced the rotary mercury pump which, when backed by an oil-sealed piston pump, produced pressures of about 10^{-4} torr. In 1913 Gaede introduced the molecular-drag pump, in which there is no positive displacement as in the earlier pumps, and produced pressures of about 10^{-6} torr. Then in 1915 Gaede, and independently in 1916 Langmuir, introduced what is now known as the diffusion pump which attained similar pressure levels. Since then the diffusion pump has become the backbone of most high vacuum systems; new pumping systems such as getter-ion pumping and cryopumping have been developed to produce ultra-high vacuum (~ 10^{-11} torr) while interest in molecular-drag pumping has languished for nearly 50 years for reasons of high cost, mechanical drawbacks and low pumping speed.

Recently, however, there has been a revival of interest in molecular-drag pumping because it provides directly a vapour-free vacuum which is free from unwanted contaminants and at the same time avoids the inert gas pumping problems inherent in getter-ion pumps. This has led to the development of the turbo-molecular pump (T.M.P.), a purely mechanical, molecular-drag pump attaining an ultimate vacuum of about 10^{-10} torr when backed by a conventional mechanical rotary pump.

Molecular-drag Pumping Principle

The operation of Gaede’s molecular pump can be understood by reference to Figure 1. A cylindrical rotor spins in a casing in which there is a circumferential channel of radial depth (h), length (L) and negligible clearance elsewhere. Thus, at rest, there is an open passage between inlet and outlet. Gaede (1913) showed that if the rotor is spun a pressure difference is developed between the inlet and outlet ports as a result of the transfer of some angular momentum from the rotor to impinging molecules. A drift velocity is thus imparted to the molecules which are physically ‘dragged’ from P₁ to P₂—hence the name, molecular-drag pump.

The effectiveness of the device as a vacuum pump depends upon the pressure range of operation.

Viscous Flow Conditions (mean free path \( \lambda < h \))

The application of viscosity theory leads to the relation:

\[ P_2 - P_1 = \frac{6 \eta r \omega L}{h^2} \]  

(1)

where \( \eta \) is the gas viscosity, \( r \) the radius of the rotor and \( \omega \) its angular velocity. If low pressures (P₂) are to be attained, \( P_1 - P_2 \) must be large.
When reasonable practical values are substituted in the above equation e.g. \( \eta = 1.8 \times 10^{-4} \) poise at room temperature; \( r = 127 \text{ mm} \); \( \omega / 2\pi = 8,000 \text{ rev/min} \); \( L = 635 \text{ mm} \) and \( h = 12.7 \text{ mm} \) we find \( P_2 = P_1 = 0.3 \text{ torr} \). Hence, if \( P_1 = 0.01 \text{ torr} \), \( 0.31 \geq P_2 > 0.3 \text{ torr} \). Since control of the fore-pressure to this accuracy is difficult in practice, a molecular-drag pump cannot produce a high vacuum (large \( P_2/P_1 \)) without an excessive number of stages when the pumping channels are operated in the viscous flow region.

**Molecular Flow (Free Molecule) Conditions**  
\( \lambda >> h \)

Using the criterion of balance mass flow at the ultimate pressure of the pump, it can be shown that:

\[ P_2/P_1 = \exp \left( \text{const.} \cdot r L / h \right) \quad (2) \]

Thus the pressure ratio \( P_2/P_1 \) is now independent of \( P_1 \) and if the above values of the parameters are substituted into (2), it is found that \( P_2/P_1 \sim 10^8 \) (for air). This is a very high pressure ratio which would not be attained in practice because of leakage across seals and particularly leakage back through the running clearance \( a \) of the rotor in the casing. Nevertheless, even with leakage, it is still a large figure and is the basis of all the early molecular-drag pumps.

The most noteworthy features of the Gaede pump are:

(a) its high running speed (8,000 to 10,000 rev/min);

(b) its fine running clearance (a \( \sim 0.1 \text{ mm} \))—which makes it prone to seizure owing to dust entrapment;

(c) its low pumping speed; and

(d) its 'clean' vacuum, owing to the absence of pumping fluids, etc.

**The Holweck Pump**

Holweck (1923) designed a molecular pump with the channels in the casing instead of in the rotor, increased channel length (a spiral) and with running clearances reduced from 0.1 mm to 0.025 mm. This was a mechanically simpler design than Gaede's and produced pressure ratios \( P_2/P_1 = 10^7 \sim 10^8 \). At rotor speeds of about 10,000 rev/min there was no improvement in pumping speed and it was more prone to seizure because of the reduced running clearances.

**The Siegbahn Pump**

Siegbahn (1940) described a large pump in which the rotor was a spinning disc (see Figure 3). The pumping channel was a spiral groove of variable depth cut in the casing. Significant parameters for this pump were: \( r = 27 \text{ cm} \); \( \omega / 2\pi = 4,000 \text{ rev/min} \); \( a = 0.025 \text{ mm} \) and \( h = 22 \text{ mm} \) to 1 mm.

The maximum pressure ratio obtained was \( P_2/P_1 \sim 10^7 \) with \( P_1 \sim 10^{-6} \text{ torr} \).

The most significant feature of the pump, apart from its size, was the increased pumping speed (a maximum of 75 litres/sec), obtained partly as a result of there being three 'parallel' pumping spirals instead of one in the casing.

**The Turbo-Molecular Pump—A Modern Molecular-drag Pump**

When the high speeds and mechanical simplicity of the diffusion pump are compared with the corresponding low speeds and complexity of the molecular-drag pump, the reasons for the latter's obscurity are obvious. Recently, however, two factors have removed it from this position. They are:

(a) the development of the aircraft turbine compressor, and

(b) the realization in the early 1950's of the need for clean (hydrocarbon-free) high vacua e.g. in plasma experiments.

Since the molecular-drag pump is a compressor in that it develops a pressure differential across its inlet and outlet ports, it was natural that alternative forms of mechanical compressors should be examined for development as vacuum pumps employing the molecular-drag principle. The axial flow turbo-compressor used in modern aircraft engines is particularly interesting in this regard because it lends itself to easy multiple staging and is characterized by high flow rates (speed).
However, early analyses of the use of such machines at low pressures (and low Reynolds number) were not promising. Sohn (1956), for example, showed that with decreasing pressure, $P_1/P_0$ also decreased. Since, in a practical axial compressor of 15 stages, the pressure ratio developed across the whole machine was only about 5 (1.2 per stage), such machines appeared to have no use as practical high (and ultra-high) vacuum pumps.

It was not until 1958 that the errors in Sohn-like analyses were recognized independently by Hablanian (1958) and Becker (1958). The former realized that predictions based on viscous flow calculation did not apply when the machine was operated in the free molecular flow region; he built a small, 10-stage experimental axial compressor and demonstrated that the pressure ratio increased from about 1.2 at $10^{-4}$ torr to 7 at $10^{-4}$ torr, in direct contrast to Sohn's predictions.

In the same year Becker (1958) described what has become the first modern commercial molecular pump using axial flow compressor principles, now called the turbo-molecular pump. The layout of this pump is given diagrammatically in Figure 4. It consists of two turbo-compressors mounted back to back on the same shaft. Gas enters the centre of the pump at pressure $P_1$ and is pumped towards the ends so that the bearings are at the high pressure ($P_2$) end; this avoids the need for a high vacuum rotary seal. Comparative design parameters are: $a = 1$ mm (between walls and stages);

$$\omega/2\pi = 14,000 \text{ rev/min (max.)}; r = 85 \text{ mm};$$

length = 670 mm and no. of stages = 19 (40 blades per stage).

With this pump, Becker obtained a pressure ratio per stage of 2.3 (for air) an overall pressure ratio of $10^7$ and an ultimate pressure of about $10^{-9}$ torr (set by hydrogen). The speed of the pump varied with the fore-pressure: it was 150 litre/sec for air, higher for hydrogen (a light gas) and lower for Freon (a heavy gas). The ultimate pressure varied with the speed of the rotor, increasing with increasing rotor speed in an approximately parabolic manner. Pumps based on this design are now available commercially with speeds up to 4,000 litre/sec.

**Figure 3**

The Siegbahn Molecular Pump

**Figure 4**

Schematic layout of Becker's Turbo-molecular Pump

**Present Design Trends**

Apart from mechanical considerations, the design of a turbo-molecular pump resolves itself into the calculation of the probability that a molecule will be transmitted from the high vacuum side to the coarse vacuum side and vice versa. In principle this can be done by using the Clausing integral equation:

$$P = \int e^{P_a(x) - P_b(L)} \, dx + P_b(L)$$

for a pipe of length $L$, when $P_a(x)$ and $P_b(L)$ are functions of the radius $r$ of the pipe and $P(x)$ is an integral expression

$$P(x) = \int e^{P_a(\xi - x)} \, d\xi + P_b(L - x).$$

However, such calculations are exceedingly cumbersome even with the aid of modern high-speed digital computers.

In practice, use is made of the Monte Carlo method in which the path of individual molecules through the compressor is followed for a statistically significant number of molecules. This was first done by Davis (1960) who showed the major effect that relatively minor changes in geometry had on the conductance of short pipes, baffles, blocking plates, etc. (The conductance path of interest in the turbo-molecular pump is the short path from one side of a turbine stage to the other.) Detailed
calculations of this type have now been made by Kruger (1960), Wu (1965) and others for the turbo-molecular pump with the result that the advantages to be gained by increased rotor speeds, namely higher pumping speeds and higher pressure ratios per stage, are clear. Similarly, large increases in pressure ratios are to be gained by changing the blade shape from the present parallel-sided rectangular slab to shapes offering large transmission factors in one direction only, e.g. in present machines P/P, per stage is about 2.0, increasing to about 100 if the periphery of the blade travels at supersonic speeds: if the shape is optimised the pressure ratios can (theoretically) be increased further to at least 3 × 10^4. Since the constructional requirements of high speed must always be balanced against those of low ultimate pressures this means that both ultimate pressures and speed can be improved simultaneously relative to present-day machines.

**Advantages and Disadvantages of Turbo-molecular Pumps**

**Advantages**

Since the T.M.P. does not use hydrocarbon fluids (as in a diffusion pump), the residual vacuum is essentially hydrocarbon-free. Unlike getter-ion pumps, the T.M.P. enables the rare gases, particularly argon, to be pumped at about the same speed as nitrogen.

Since the pumping action is purely mechanical, there are no memory effects as in getter-ion pumps.

Ultra-high vacuum (p ~ 10^{-9} torr) can be attained without the use of cold traps which require frequent servicing.

Hydrocarbon-free atmospheres can be maintained indefinitely at relatively high pressures (10^{-4} to 10^{-5} torr); this is not feasible with a getter-ion pump.

**Disadvantages**

The T.M.P. has a low pumping speed for its size e.g. a diffusion pump with a 6in trap would have a speed at 10^{-7} torr of about 400 litre/sec whereas a 7in T.M.P. (Becker's pump) has a speed of only 150 litre/sec.

Cost of a T.M.P. is high when compared to a getter-ion pump and a trapped diffusion pump, all of similar speed; the ratio of the costs on a litre/sec basis is of the order 10:5:1.

Mechanical complexity coupled with high rotational speeds (14,000 rev/min in a 150 litre/sec pump decreasing to 8,000 rev/min in a 4,200 litre/sec pump) demands factory servicing.

Although the running clearances in the T.M.P. (~ 1 mm) are much higher than in Gaede's pump they are still small, and hence the T.M.P. cannot replace diffusion pumps for dusty environments.

**Some Applications of Turbo-molecular Pumps**

Van de Graaff accelerators are usually run at pressures of about 5 × 10^{-3} torr to ensure long life of tube and target. This is easily done with a T.M.P. (but not with a diffusion pump) by injecting hydrogen into the fore-pressure side of the pump. By relatively coarse control of the high fore-pressure, the pressure is finely controlled by the compression ratio of the T.M.P.

In fusion research the different compression ratios for light and heavy molecules of a T.M.P. may be used such that the light gases of interest (H2 and D2) may be bled into the fusion device which is simultaneously being continuously stripped of unwanted heavy molecule impurities.

It is being used increasingly in the field of surface and environmental physics where both low ultimate pressures and hydrocarbon-free atmospheres are essential.

Finally, in systems where frequent pump-down of the system from atmosphere to ultra-high vacuum occurs, and conversely in systems where unforeseen rapid pressure rises to atmosphere may occur (as in accelerator target chambers), the T.M.P. offers both continuously available pumping capacity and prompt recovery which is impossible with systems having liquid nitrogen traps. In such cases low running costs outweigh high capital costs.

**References**


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**The Calendar**

**August 1969**


18–22 ANZAAS Congress, Adelaide. Annual Dinner of S.A. Branch A.I.P.

25 Nuclear Magnetic Resonance (N.S.W.-A.I.P. 7.45 p.m.); Prof. C. P. Slichter, University of Illinois.

**September 1969**

9 Science, Technology and the Community (N.S.W.-A.I.P. 7.45 p.m.); Prof. S. Encel, University of N.S.W.

**October 1969**

10 Industrial Visit, Newcastle (John Lysaght). Physics in Industry; Dr D. Cameron.

Dr. D. J. Martyn, President of the Australian Academy of Science

At the recent annual general meeting of the Australian Academy of Science, David Forbes Martyn was elected the fifth President. The Australian Institute of Physics takes pleasure in congratulating Dr. Martyn, a Fellow of the Institute, on this honour. Dr. Martyn took his Ph.D. from the University of London in 1928 and D.Sc. in 1936. He joined the staff of the Radio Research Board in Australia in 1929 and has been associated with C.S.I.R.O. for most of the intervening years. At present he is Head of the Upper Atmosphere Section at Camden, N.S.W.

His researches have centred on the ionosphere and have led to an explanation of the interaction of radio waves, and to the first valid model of the atmosphere above 50 km. He showed that, surprisingly, the temperature drops from a high value near this level to its lowest value (about 160 K) near 80 km and then rises again to extremely high values (about 1000 K) at heights above 250 km. He also showed that diffusive equilibrium is prevented by turbulence so that the chemical composition does not change greatly, as had been assumed previously.

In the postwar years Martyn showed that ionospheric F region experiences a large semidiurnal lunar oscillation. He showed that this is due not to local winds, but to electric fields generated by polarization in the lower 'dynamo' or E region and communicated upwards along the highly conducting geomagnetic field lines. He also was the first to give a clear description of the perturbations in F region which are associated with geomagnetic storms.

Martyn's studies of the 'dynamo' electric field showed that the existing theory, based on tidal oscillations, was inadequate because of neglect of Hall conductivity. With W. G. Baker, he placed the theory on a sound quantitative basis and incidentally accounted for the curious equatorial electrojet and other ionospheric anomalies.

In 1946 Martyn became interested in solar radio astronomy and showed experimentally that sunspot radiation has a large component of circular polarization. He also studied the theoretical problem of the radio thermal emission and showed that at meter wavelengths the corona should give black-body emission at $10^6$ K, falling to $10^4$ K at centimetre wavelengths. These predictions were soon confirmed.

Martyn has played an important part in the organization of science in Australia and on an international basis. In 1939 he set up the Radiophysics Laboratory in Sydney to develop wartime radar, and later was director of operational research for the Australian armed services. He has served successively as Chairman of the Radio Astronomy Commission of the Union Radio Scientifique Internationale, then as Chairman of that body's Radio Astronomy and Ionosphere Commissions. With Sir Mark Oliphant he had a leading role in founding the Australian Academy of Science. He also served as chairman of national committees of Antarctic and Space research. In 1962 he became chairman of the United Nations Scientific and Technical Committee on the Peaceful Uses of Outer Space.

He was elected a fellow of the Royal Society of London in 1950 and in 1955 he was awarded the Chree Medal of the Institute of Physics and the Physical Society. He has been a Fellow of the Institute of Physics since 1935, is a foundation Fellow of the Australian Institute of Physics, and was Chairman of the Geophysics Group in 1967.

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14th MEETING OF COUNCIL

The 14th Council Meeting was held on 29 and 30 May 1969 in Clunies Ross House, Parkville, Victoria. The President, Mr. A. F. A. Harper, was in the chair and all Branches except Tasmania were represented.

Finance

The budget prepared at the 13th Council Meeting, reported in The Australian Physicist (November 1968) allowed for a deficit in 1969 to offset the surpluses of recent years and to ensure that present members were getting full value from their subscriptions. The Hon. Treasurer, in his report to the present Council Meeting, estimated that the deficit for 1969 would be in the vicinity of $4,000. In order to assist Branches and Groups the Hon. Treasurer also presented a clear statement of budget allocations, special grants and reserve funds. Councillors expressed the opinion that this was most helpful and should be a regular feature of the Treasurer’s report to Council.

A list of 37 members whose 1968 subscriptions were still unpaid (nineteen months overdue) was tabled and Council set a date of 31 August 1969 after which removal from the Register under Clause 13 of the Articles of Association would be considered.

Because the cost to the Institute of supplying the Australian Journal of Physics to those members desiring it has increased beyond their subscription of $2 p.a., it was decided that this subscription should be $2.50 from 1970.

Membership

The Hon. Registrar reported that corporate membership had increased to 1133 and total membership to 1454. As a first step towards improved recruitment of student members Branch Committees had been asked to nominate a member in each teaching institution in their State willing to co-operate with the Hon. Registrar in establishing contact with students. By this means over 300 copies of a letter from the President pointing out the advantages of membership together with General Information Booklets and Application Forms had been distributed so far this year.

A feature of requests for election to the corporate grade of Graduate in recent years has been the increasing number of applications from secondary school teachers. In response to a request from the Hon. Registrar seeking clarification of the requirements for the 'one year's experience' clause Council resolved that 'experience in teaching in secondary schools of science with a content of physics may be deemed appropriate for the purposes of Clause 9(b) of the Articles of Association.'

Company Subscribers

The number of Company Subscribers had increased to 34 at the time of the Council Meeting and the President drew attention to the admission of the Department of Education, N.S.W., and expressed the hope that other States might follow their example.

Lectures, Conferences and Exhibitions

The A.C.T. Branch was congratulated and thanked for its organization of the 1969 Pawsey Memorial Lecture, delivered by the Astronomer Royal, Sir Richard Woolley (to be published in The Australian Physicist). The Victorian Branch has been invited to organize this Lecture for 1970.

The 1969 Summer School and Conference, organized by the Victorian Branch and held at La Trobe University in February was well attended and generally considered a very successful affair. (The Australian Physicist, May 1969). The 1970 Summer School and Conference is expected to be held in Brisbane.

It was noted that the N.S.W. Branch had organized a successful Exhibition of Scientific Instruments with associated lectures on modern developments in instrumentation in May.

Forthcoming conferences under the Institute’s auspices include those on Magneto-Sphere-Ionosphere Interactions (S.A. Branch, Adelaide, August 1969), Geophysics of the Earth and the Oceans (N.S.W. Branch, Sydney, January 1970), and the Symposium on Crustal Studies in the Australian Region (Geophysics Group, Adelaide, August 1969). Preliminary consideration was given to the organization of an International Conference on Low Temperature Physics in Sydney in 1970.

Group Activities

Representatives from each Group attended the relevant portions of the meeting. The Biophysics Group reported that plans were well advanced for the Ninth Annual Meeting of Physics in Medicine and Biology which is to be held in Perth from 25 to 29 August this year. The Hon. Group Secretary also reported that following the decision of the Council of the Australian Academy of Science to adhere to the International Union of Pure and Applied Biophysics a National Committee had been set up which included several members of the Institute.

The Geophysics Group reported that the Stable Auroral Red Arcs Project was continuing and that arrangements had been made for the collation and analysis of data on the events so far recorded. Preparations for Symposia on Crustal Studies and Earthquake Engineering were reported to be progressing satisfactorily.

The Education Group continues to be active in organizing Summer Schools and Symposia in three States.
The Vacuum Physics Group has decided to cease publication of its monthly newsletter and in future will submit regular contributions for publication in *The Australian Physicist*. An application for the Group to affiliate with the International Union for Vacuum Science, Technique and Applications was approved by Council.

In order to ensure regular and efficient communication between Branches and Groups the Branch Chairmen were invited to discuss with their Committees means of achieving efficient contact with State Representatives of the various Groups.

**Equal Pay for Women Physicists**

The result of a postal ballot of Councillors on the subject of equal pay for women physicists was tabled at the meeting. The Chairman of the Victorian Branch reported that his Branch had expressed support for the principle but had not been in favour of the Institute expressing an opinion. The question of the form of a letter to be sent to the Prime Minister by the President informing him of the Institute's support for the principle was also discussed. A motion that the letter not be sent was defeated by 12 votes to 5 and after further discussion a suitable form for the letter was agreed. It was decided not to send copies of the letter to the advocates who conducted the case.

**Administrative Arrangements**

The Institute shares its Registered Office and staff in Clunies Ross House with the Australian Institute of Refrigeration, Air Conditioning and Heating. To lighten the workload on the Assistant Secretary it has been found necessary to appoint two part-time assistants. A check is in progress to ensure there is an equitable division of labour between the two Institutes.

**15th Council Meeting**

Tentative dates for the 15th Council Meeting were set as 30 and 31 October 1969.

**ADDRESS UNKNOWN**

The Registrar would be grateful for any assistance that readers could give in locating the following members whose present addresses are not known to the Institute:

Mr G. C. Jack (Associate, Canada, late of N.S.W. *).

Miss H. J. Ampt (Student, N.S.W. *).

Mr R. A. de Szoeki (Student, N.S.W. *).

Mr J. O. Alemian (Subscriber, N.S.W. *).

* Last known address.

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**Notes and News**

**Chest X-rays**

A subcommittee of the N.S.W. Branch Committee has prepared a report to assess whether any danger may arise from compulsory mass X-rays. The members of the subcommittee were agreed on the following points:

1. The death rate from tuberculosis in 1967 was 23 per million of population in Australia.
2. Of the forty natural cases of leukemia per million of population per annum about two could, on certain assumptions, be attributed to natural background ionizing radiation.
3. The number of additional cases of leukemia and other cancers attributable on the same basis to the effects of mass miniature chest X-rays at their present actual frequency is 0.3 per million per annum. This assumes that the average for Australia of 1 irradiation every six years applies uniformly.

There was disagreement among members of the subcommittee when they considered the hazard to a foetus due to a mother undergoing a chest X-ray. There are believed to be periods during gestation when the foetus is particularly sensitive to irradiation. The duration of these periods is unknown, and the disagreement arose over interpretation of the effects of the X-ray if received during these sensitive periods. It was agreed that averaged over the whole gestation period the foetus is about five times as sensitive as an adult, and that the dosage received by the foetus from natural radioactive sources in the mother's body during the whole pregnancy is at least 900 times the dosage it receives during a chest X-ray of the mother.

Copies of the report may be obtained from the N.S.W. Branch Secretary.

**The Ninth Annual Meeting of Physics in Medicine and Biology**

The Ninth Annual Meeting of Physics in Medicine and Biology will be held in Perth from 25-29 August, 1969, the week following the ANZAAS Congress in Adelaide. Subject coverage will include some or all of the following: Physics in Physiology, Membrane Studies, Radioisotope Studies, Ultrasonics in Biological Tissue, Radiation Studies (X, γ, B, U.V. and I.R.), Computer Applications. The Meeting will also include visits to laboratories of interest.

Further information is available from Mr R. W. Stanford, Department of Medical Physics, Royal Perth Hospital, Box X 2213, G.P.O., Perth, W.A. 6001.

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Earthquake Engineering Symposium
The Institution of Engineers in association with the Geophysics Group of the Australian Institute of Physics will conduct a Symposium on earthquake engineering at the Savoy Plaza Hotel, Melbourne, on Thursday, 16 October, Friday, 17 October and the morning of Saturday, 18 October, 1969.

The objectives of the Symposium are to—
(a) bring together engineers and seismologists interested or involved in the design of structures for New Guinea, New Zealand and other seismically active areas,
(b) provide a forum for engineers and seismologists interested in discussing and formulating an objective appraisal of Australian seismicity in relation to structural design,
(c) form a National Committee on Earthquake Engineering which would hold membership in the International Association for Earthquake Engineering.

Speakers will be expert seismologists and structural engineers from Australia, U.S.A. and New Zealand, including E. O. Stephenson, Chief Structural Engineer of the American Iron and Steel Institute and M. Fintel of the Portland Cement Association, U.S.A. Further information may be obtained from the Secretary, Institution of Engineers, Victoria Division, 101 Royal Parade, Parkville, Vic. 3052.

Symposium on Magnetosphere-Ionosphere Interactions
Adelaide—26-27 August, 1969

This symposium is planned for the week following the 41st ANZAAS Congress. The programme provides for five review type papers, allowing 60 minutes each for presentation and discussion, and ten to fifteen contributed papers, allowing 30 minutes each, on cognate topics.

The review papers are:
The Magnetosphere—K. D. Cole or J. H. Piddington.
The Topside Ionosphere—P. L. Dyson.
Auroral Phenomena—F. Jacka.
Micropulsations—C. D. Ellyett.

Contributed papers are invited. Abstracts must reach F. Jacka (Chairman, S.A. Branch, A.I.P.), Mawson Institute for Antarctic Research, University of Adelaide, S.A. 5001, as soon as possible. (The closing date was 25 July. We apologize for any inconvenience that the late publication of this journal may have caused.)

Book Reviews


Reviewed by H. F. Symmons, National Standards Laboratory, Sydney.

The author is a physicist with the Thermal Radiation Branch of the U.S. Naval Radiological Defense Laboratory, San Francisco according to the blurb, which also informs us that both his Bachelor and Master degrees were in electrical engineering. This has great relevance to the book he has written, which is, in the main, concerned with the techniques of E.P.R. Here the author is at his best. He has thoughtfully brought into one volume the results of much reading and many visits to and discussions with leading E.P.R. spectroscopists. The book is thus a mine of information on components, and the configurations thereof, suitable to the various purposes of E.P.R. spectrometers, and in nearly all cases includes a reasonable discussion of pros, cons, and sometimes of the 'folk-lore' endemic to the profession.

It can only be regarded as a pity that Mr Alger was not content to leave it at that, for when he essays into the theory of paramagnetic resonance, particularly of inorganic single crystals, he is clearly out of his depth and so is frequently unclear and sometimes incorrect. Nevertheless the book is very well worth having, especially to those who wish to build, or improve, a spectrometer, or who wish to know in detail what makes an E.P.R. spectrometer tick.

The book resorts occasionally to a somewhat 'racy' style, but this is kept well within bounds and is never objectionable. Indeed the 500 odd pages are surprisingly readable considering the nature of the material. The free-hand illustrations so beautifully drawn by Ichiro Hayashi are a delight—at first.

As a postscript, it should be added that if this book is likely to come into the hands of students about to engage in research, the conscientious supervisor might be advised to seal Chapter II and certain later pages.

(Book Reviews continued on Page 112)
During the past 15 years the methods of experimental physics have undergone an enormous change, so that virtually all modern experimental physics leans heavily on the art and ingenuity of the electronics engineer. Whether one is investigating the details of a nuclear reaction in a research laboratory, or testing cotton fibres in a quality-control laboratory, it is likely that the measurements are being made with the aid of electronic measuring equipment. It is probably fair to say that an awareness of the scope and flexibility of electronic techniques is just as important a part of a competent physicist’s equipment as, say, an understanding of statistical methods or matrix algebra.

With this philosophy in mind, the Physics Department of the University of Adelaide has developed during the past two years a course in experimental electronics, which provides at a practical level an introduction to such professional electronic methods. At the same time, the course offers a laboratory environment which is quite different in atmosphere from the conventional undergraduate physics laboratory. The students, who are final-year undergraduates, taking the course as part of their third-year practical physics programme, are provided with ample resources, and invited to find their way at their own pace through a sequential programme of investigation. Students attend for three hours each week for two terms a well equipped electronics laboratory, in which each student is provided with a work bench, soldering iron, multimeter, oscilloscope, signal generator, and space to store unfinished projects from week to week. There are no formal lectures, although the demonstrators, who are all senior staff members, freely call their group to the blackboard to discuss collectively common problems or points which emerge; each demonstrator handles a group of up to ten students. The laboratory notes consist of a mixture of experimental instructions, circuit diagrams, discussion of circuits, theory, suggestions for further investigations, and questions to reinforce the significant points.

The course, which makes use of semiconductors exclusively, divides naturally into two halves. After study of the static output characteristics of a transistor, the students investigate a single-stage amplifier, negative feedback, two-stage amplifier with feedback, and the emitter follower and develop an empirical understanding and familiarity with the concepts of bandwidth, risetime, distortion, and input and output impedance. This is followed by the differential amplifier, and the whole sequence is summarized in the development of a series-regulated low-voltage power supply. The second half of the course is devoted to switching circuits, and includes the investigation of multivibrators, bistables, amplitude discriminators, coincidence circuits, and logic gates. Again, through direct experience, the students develop naturally an understanding of concepts such as regeneration, switching times, factors controlling pulse duration, delays in switching circuits and so on.

Student reaction to this approach, in which each student 'learns through his hands' and acquires an individual and personal experience of the nature and limitations of common circuit configurations, has been most gratifying. The students are generally enthusiastic, and frequently develop a pride in their technical skill. This may be due in part to the fact that they have been invited to participate in the design of the course, by making suggestions for further exercises, and by commenting on features which they feel to be understressed, or too difficult, or which involve too much constructional work for too little educational return. The thought that they are contributing to a departmental experiment in teaching methods has certainly provided additional motivation for some.

There are of course always a few students who have had previous experience in electronics, and who finish the course well inside the prescribed two terms. These are encouraged to fill in the remainder of their time on suitable individual projects. They may, for example, go on to design and build a decade counter, or a single-channel analyser. The slower ones may not even finish the course, though if they do not, they are advised to read and understand whatever they have not completed, because the course is examined. So far examination questions have taken the form 'Discuss the general behaviour, design, and operation of the regulated power supply, whose circuit is given', or something of that sort.

The initial capital investment for this course was quite large. The laboratory can accommodate 11 students at a time, each with his own array of test
equipment, or 22 students, sharing the equipment in pairs, and is used for four sessions each week. Our experience has been that it is much better to handle the students in groups of 11, and use the laboratory twice as often, since each student needs his test equipment fairly continuously.

One gratifying outcome of the first year of the course was a deputation of students, who were returning to take an honours degree in physics, requesting an extension of the course as part of their honours year. In response to this request, the Physics Department now offers to honours and entering Ph.D. candidates, a separate course with quite different terms of reference. This is a specialist practical course in digital instrumentation and telemetry techniques, strongly flavoured by practices in our research laboratories, and intended to prepare students for entry into the post-graduate school. We believe that we have struck about the right compromise in assessing how much electronics training to include in our physics courses at both levels, and judging from the rate of expansion of consumption of electronic components, in our research laboratories, the courses we offer have profoundly effected the experimental approach of our Ph.D. students.

It is a pleasure to acknowledge the assistance of the electronic manufacturing industry in the development of this course, in particular Fairchild (Australia) Ltd, Philips Electrical Pty Ltd, Texas Instruments Australia Ltd, and the Plessey Group (Ducon Condenser Pty Ltd).

Society Memberships and Overseas Experience of Australian Physicists

J. M. Cowley (for the Victorian Branch)

During 1968 a National Survey of Qualified Physicists was carried out by the Department of Labour and National Service with the co-operation of the Australian Institute of Physics. The last page of the questionnaire booklet was a tear-out sheet containing questions said to be of particular interest to the A.I.P. and inserted at the Institute’s request. These pages were detached by the Department and forwarded to the Institute for tabulation and analysis, a task allotted to the Victorian Branch.

From comments heard during the survey and from a study of the replies received it is clear that some confusion was created by the omission of some of the answer boxes and a lack of clarity in the instructions. particularly for question 2. This may have reduced the number of useful answers in some cases but probably does not seriously affect the validity of the most clearly-indicated conclusions to be drawn from the results.

The following summaries, tabulations and comments have been kept within the limits which appear to be set by questions of relevance, significance and convenience for publication. A total of 1,852 returns was received, including 627 from members of the A.I.P. and 1,225 from others. These included 55 returns from people now overseas; 20 from A.I.P. members and 35 from others.

Question 1. Membership of professional associations and learned societies:

The answers from A.I.P. members and others are listed separately in Table I. Some indication of the response to the survey is given by comparing the numbers of replies from A.I.P. members with the total membership of the A.I.P. in April, 1968, namely: 159 Fellows, 374 Associates, 462 Graduates, 189 Students, 133 Subscribers: Total 1,317.

The distribution of memberships in the I.P.P.S. (Institute of Physics and Physical Society, London) follow expectations. A high proportion of senior A.I.P. members has retained membership in the I.P.P.S. from the time of creation of the A.I.P. Many of the younger A.I.P. members and most of the others listed are presumably people who have joined the I.P.P.S. while in England before moving or returning to Australia.

The memberships indicated for physics-associated societies suggest that, except in the case of Astronomy, the A.I.P. has gained the support of a good majority of the physicists belonging to the more specialized fields in and around physics. On the other hand it is perhaps disturbing to see the lack of support for the A.I.P. from physicists sufficiently distinguished to be Fellows of the Australian Academy of Science or of the Royal Society of London.

Question 2. Overseas experiences

Of the 627 A.I.P. members replying, 277 (or 44 per cent) have worked as physicists overseas. Of the others the corresponding number is 306 (or 25 per cent).

In Table 2(a) and (b) are summarized the opinions given as to the salaries and research facilities in other countries relative to those in Australia. The opinions based on the actual period during which the physicist worked overseas are collected into convenient ranges of years, while the opinions as to the present situation are collected under the heading “Now”.

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The Australian Institute of Physics has particularly asked that the following questions should be added. Your replies to them will be detached and sent to the Institute.

<table>
<thead>
<tr>
<th>Surname</th>
<th>Other Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Block letters, please)</td>
<td></td>
</tr>
</tbody>
</table>

1. Please list:
   - Names of Professional Associations or learned societies of which you are a member.
   - Level or class of your membership.

2. (i) Please indicate by ticking whether you have worked as a physicist overseas.
   - Yes [ ]
   - No [ ]

   (ii) If your answer is "yes", please indicate by ticking or otherwise, how salaries and research facilities in your position in the country in which you spent most time compare with those in Australia now, and in the reference year.
   - Name of Country
   - Title of your Position
   - Reference Year

   **A. Salary**
   - In foreign country
     - in reference year
     - currently
   - In Australia
     - in reference year
     - currently
   - No knowledge of Australian salaries in reference year [ ]
   - No knowledge of current salaries in foreign country [ ]

   **B. Research Facilities**
   - are/were*
     - (a) better than in Australia [ ]
     - (b) not as good as in Australia [ ]
     - (c) about the same [ ]
     - (d) difficult to say [ ]

   * Strike out whichever does not apply.

If you have worked as a physicist in more than one overseas country, please indicate the names of the additional countries, and your comments on salaries and research facilities.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Title of Position</th>
<th>Salary</th>
<th>Research Facilities</th>
</tr>
</thead>
</table>

3. If you have left Australia at any time to work overseas as a physicist, please give a brief note on your reasons for going overseas.

4. If you are at present overseas, please tick appropriate box.
   - (a) Is your return dependent on obtaining an offer of suitable employment in Australia? [ ]
   - (b) If so, would you prefer a university position to any other type of position? [ ]

The final page of the questionnaire

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It is clear that in the U.S.A. and Canada both salaries and research facilities were and are better than in Australia. A factor of two in salaries was mentioned by a number of people. In the U.K. and other European countries salaries are generally considered to be worse, but research facilities are thought by a large majority to be better. There is a fair measure of agreement that in New Zealand and Asian and African countries both salaries and facilities are worse, although a few people received good salaries in underdeveloped countries, presumably from U.N. or other external sources.

One interesting point is that while the number of Australian physicists working in England has not noticeably increased in recent years but, at least among A.I.P. members, has tended to decline, the number working in the U.S.A. has increased in a spectacular manner since about 1965.

**Question 3. Reasons for going overseas**

The reasons given for physicists to go to work overseas were many and varied. Some people gave several reasons. Many gave none. In listing these we give the total number in each category and then, in brackets, the number of A.I.P. members plus the number of others.

The most common indication given was that the aim of the overseas work was to obtain broader experience in physics by study or research in a different, more diverse or more advanced environment. The variety of ways in which this type of reason was stated presumably reflects the variety of circumstances, attitudes and personalities of the people concerned. A subdivision may be made as follows: "Wanted experience" 140 (66 + 74); "Study leave or sabbatical leave" 101 (43 + 58); "Wanted contact with particular physicists or activi-
### TABLE 1. SOCIETY MEMBERSHIPS

<table>
<thead>
<tr>
<th>Physics Societies</th>
<th>A.I.P. members</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A.I.P.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fellows</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Associates</td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>Graduates</td>
<td>272</td>
<td></td>
</tr>
<tr>
<td>Students</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Subscribers</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td><strong>L.P.P.S.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fellows</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>Associates</td>
<td>94</td>
<td>19</td>
</tr>
<tr>
<td>Graduates</td>
<td>35</td>
<td>18</td>
</tr>
<tr>
<td>Licentiates: Subscribers</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Students</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>195</td>
<td>48</td>
</tr>
</tbody>
</table>

| **American Phy. soc.**  |                |        |
| (and Amer. Inst. Phys.) | 9              | 17     |
| **Canadian Assoc. Phys.** | —              | 2      |

### Physics-Associated Societies

| Geophysics              |                |        |
| Australian              | 9              | 2      |
| Overseas                | 29             | 25     |
| **Astronomy**           |                |        |
| Australian              | 19             | 32     |
| Overseas                | 15             | 36     |
| **Meteorology**         |                |        |
| Overseas                | 13             | 13     |
| **Biophysics**          |                |        |
| Crystallography         | 3              | —      |
| Overseas                | 3              | —      |
| **Acoustics**           |                |        |
| **Optics**              |                |        |
| Overseas                | 6              | —      |

**Other Sciences**

| Chemistry              |                |        |
| Mathematics and Statistics | 12            | 65     |
| Computing              | 6              | 28     |
| Geology                | 7              | 19     |
| Engineering            |                |        |
| General                | 24             | 26     |
| Electrical and Radio   | 46             | 42     |
| Metallurgy             | 11             | 11     |
| Other                  | 17             | 22     |

**General Science**

| Australian Academy of Science | 8           | 9      |
| ANZAAS                     | 15           | 9      |
| Royal Societies            | 2            | 4      |
| London                     | 6            | 7      |
| Australian States          | 2            | 10     |
| Sigma xi                   | 2            | 10     |

**Professional Associations**

| Professional Officers' Association | 11          | 29     |
| CSIROOA                        | 5            | 13     |
| Association of Professional Scientists, Australia | 3          | 2      |
| Educational Associations (Aust. College of Education, Staff Association) | 13         | 41     |

**Teachers' Associations**

| General |                |        |
|         | 5              | 113    |
| Science teachers | 32           | 204    |
| Maths. teachers | —             | 24     |

NOTES

1. In compiling this Table, no account was taken of memberships of approximately 200 societies or associations which were mentioned only once in the returns. In many cases these organizations were referred to only by an indiscernible combination of letters so that the correct classification could only be guessed.

2. It seems clear that the membership numbers quoted for the general professional associations do not give any real indication of the true situation, presumably because many of those making the returns were uncertain as to whether such memberships were relevant to the present investigation.

3. Such uncertainties were even more evident in relation to membership of university staff associations and graduate associations. The few returns relating to these bodies were therefore ignored.

4. The distinction between membership of Australian and overseas societies has been made only for those cases in which the overseas societies represent an appreciable part of the total membership. Where no indication has been given, most memberships are of Australian societies. Where only the label “Overseas” is used, no membership of an Australian society was indicated.

**Physics in physics** 37 (20 + 17); “Further study” 71 (44 + 27); “Sent by employers” 54 (38 + 16); “Went to Conference” 11 (8 + 3); “Went by invitation” 7 (7 + 0); “Went on scholarship” 13 (8 + 5).

Of those setting out to get (apparently) permanent employment overseas, the reasons given were:
- “Better conditions of employment” 31 (10 + 21);
- “Better salaries” 17 (7 + 10);
- “Better facilities” 23 (11 + 12).

Then there were specific professional reasons such as: “A specific experiment or project” 15 (7 + 8); “International aid program” 2 (1 + 1) and “Liaison” 2 (2 + 0), and there were various non-professional reasons such as “family matters”, “pleasure”, “travel” and “variety”.

**Question 4. Conditions for return to Australia**

Of the 55 (20 + 35) physicists now overseas who provided data, 39 (11 + 28) indicated that their return is dependent on an offer of suitable employment in Australia: 27 (21 + 6) expressed a preference for a university job, 9 (7 + 2) would prefer some other sort of job and 6 (2 + 4) are undecided.

**Comments**

A number of those making returns were moved to add unsolicited comments. Apart from those referring unfavourably on the nature or the details of the questionnaire, the following were notable:

- "Seems to me Australian universities are training physicists for work which only exists overseas, a somewhat different training being appropriate for places offered to physicists here."

- "The research facilities and salaries at the A.N.U. compare favourably with most overseas universities that I have visited. Other Australian universities are definitely worse, especially in geophysics."

- "Totally inadequate opportunities for advancement at (an Australian) University. Lack of goals and objectives in the Physics Department. Lack of research funds. Stifling to initiative."

Our thanks are due to Mr. K. Conner, who was responsible for most of the work of preparing the Survey in collaboration with the Department of Labour and National Service, and to Miss Deborah Cowley, who carried out the initial collection and analysis of the data from the returns.
The Register

Changes in Membership from 8 May to 9 June 1969

FELLOWSHIP
New Elections
Bird, J. R., Atomic Energy Commission, N.S.W.
Mainstone, J. S., University of Queensland.

ASSOCIATESHIP
New Elections
Finn, G. D., University of Queensland.
Frost, B. S., University of Queensland.
Kennett, R. H., Australian National University, A.C.T.
McIntosh, A. I., University of New England, Armidale, N.S.W.

GRADUATESHIP
(a) Transfers
(b) New Elections
Mason, J. P., St Aloysius College, Adelaide, S.A.

Mikosza, T. G., Weapons Research Establishment, Salisbury, S.A.
Salem, M. T. A. R., S.A. Institute of Technology.
Smallwood, E. T., High School, Strathalbyn, S.A.
Whiteley, I. D., Department of Health.

(c) Resignation
Harrison, N. L. (Vic.).

STUDENTS
New Elections
Peek, D. J. (Vic.).
Rimmer, R. J. (Vic.).
Withers, R. J. (Vic.).
Powell, W. D. (Qld.).

SUBSCRIBERS
(a) New Elections
Pyle, H. A. A. (N.S.W.).
Woodley, L. G. (S.A.).
(b) Resignation

THE AUSTRALIAN PHYSICIST, JULY 1969

111
THE MATHEMATICAL PAPERS OF ISAAC
£10/10/- in U.K., $US 40.00.

Reviewed by R. J. Gillings, University of New
South Wales.

Of the planned 8-volume publication of Sir
Isaac Newton’s mathematical papers, vol. I ap-
ppeared in 1967 and now in 1968 vol. II appears in
its chronological sequence. Newton’s appointments
as a Fellow of Trinity College, Cambridge, and as
Lucasian Professor of Mathematics both occurred in
the period covered by this volume.

No other man occupies more space in the history
of mathematics and biographies of science, except
maybe Archimedes and Gauss, and no one left so
many records, some still unpublished, so that the
Editor’s estimate of 8 large volumes is not surpris-
ing. To judge solely on the present vol. II one would
have to conclude that personal ownership of a full
set would appeal only to a Newton devotee, the
mathematical enthusiast, or the bibliophiles on
account of both the cost of the book and its bulk
(11 in × 8 in × 2 in, weight 5 lb).

The book has a general introduction and three
main parts each with its own introduction. For
convenience each page is headed with the relevant
part, section, and sub-section numbers. The whole
is produced with Newton’s original Latin on the
even numbered pages and the English translation
on the odd numbered pages. There are copious foot-
notes—page 303 is the first without a footnote.

Part 1 comprises an introduction followed by
three sections: the first of these on the classification
of 16 species of cubic curves, the second with the
general properties of curves, and the third with the
organic construction of curves.

Part 2 on Newton’s researches in calculus, after
a nine-page introduction, has a section on logarith-
ic computations in which, incidentally, he finds
log 1.02 to 57 places. This section is all in English.
Section 2 is on conics and the cycloid, in Latin with
translation. The third section, De Analysi per
Aequationes Infinitas, in Latin and English is fol-
lowed by Leibniz’s review thereof (in Latin only)
and Newton’s reply thereto (in English).

Part 3 is on Gerard Kinckhuyzen’s Algebra origin-
ally published in Low Dutch but here rendered
in Latin only. It is included here because of New-
ton’s detailed observations on it.

In Section 2 Newton considers the geometrical
construction of equations which with translation
and footnotes completes Volume II.

There is in the book a total of 1227 footnotes,
many as interesting as the text they are elucidating.
Facing page 488 is a full page reproduction in New-
ton’s own handwriting of his construction of the
general cubic as the intersection of a conic and a
circle—it is upside down. However, throughout the
book not one typographical error was detected.

The index contains names only and a compre-
hensive index will appear in Volume VIII.

PHYSICS FOR CHEMISTS AND BIOLOGISTS,
D. O. Hughes and J. L. Latham. Butterworths, Lon-
don, 1968. ix + 367 pp. $6.75.

Reviewed by W. K. T. Fowler, Department of
Medicine, University of Sydney.

This book is designed to refresh and develop the
physical knowledge of chemists and biologists who
left physics at matriculation or early undergraduate
level only to find a later need for it, particularly in
electronic or optical instrumentation. It is by no
means a mere handbook of circuits, spectrophoto-
meter designs, and the like but a clearly and eco-
nomically written review of the basic physics of
electronics, optics, and heat, with sufficient develop-
ment and application to indicate how good instru-
ment design is achieved.

Notably missing (for lack of space) are sections
on kinetic theory, diffusion, fluid flow, and vacuum
methods, which would be of great value to mem-
brane biologists, and respiratory and circulatory
physiologists. Let us hope that the authors may
later tackle these with that clarity which they have
achieved in the present volume.

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171 GILBERT STREET, ADELAIDE, S.A. 517404

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