the
australian
physicist

A PUBLICATION OF THE AUSTRALIAN INSTITUTE OF PHYSICS

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Vol. 10, number 3
MARCH 1973

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Registered for posting as a periodical—Category B
The Australian Physicist

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on

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Dr Frederick J. Jacka, Director of the Mawson Institute for Antarctic Research at the University of Adelaide, has been elected President of the Australian Institute of Physics. This was announced at the Annual General Meeting in Brisbane on 8 February. Other members elected to the Executive Committee are:

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Dr Jacka, aged 47, was educated at the Gordon Institute of Technology, Geelong, and the University of Melbourne. In 1946 he was a member of the first ANARE expedition to Heard Island. Later he became Assistant Director of the Antarctic Division, Department of External Affairs—in charge of the scientific program.

Dr Jacka is a member of the Australian National Committee for Antarctic Research and has represented Australia's Antarctic interests at a number of international meetings. He is engaged in teaching and research on the physics of the atmosphere; his special area of interest is the polar aurora and related upper atmosphere phenomena.

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ELEMENTARY DYNAMICS OF SPACECRAFT ORBITS

A. G. Klein
School of Physics, University of Melbourne
Lecture presented to the N.S.W. Branch, A.I.P., August, 1972

Introduction

In recent years we have witnessed the transformation of celestial mechanics into an applied science. The foundations of this science were laid by Johannes Kepler who published the first two of his celebrated Laws of Planetary Motion in 1609, followed by the third in 1619. Today, most students are familiar with simple calculations of such things as heights and periods of earth satellites but it may be of general, as well as pedagogical interest to note that the more complicated problems of trans-lunar and inter-planetary orbits are equally amenable to elementary analysis, based on Kepler’s laws. It turns out that considerable insight into these problems, and reasonable quantitative agreement with reality, may be obtained by systematically treating the trajectories of spacecraft as concatenations of simple, two-body Keplerian orbits. This is made possible by the following facts:

a. Spacecraft propulsion is applied over very short periods of time and can therefore be considered to give rise to impulsive changes in velocity in otherwise free orbits.

b. The mass ratios Moon/Earth and Earth/Sun are quite small (1.2 x 10^-5 and 3.0 x 10^-6 respectively) and therefore the influence of the lighter body is negligible over most of the journey.

c. The gravitational effects of the heavier body in the vicinity of the lighter body may, to a first order, be ‘cancelled out’ by a judicious change in the frame of reference.

Before going on to specific examples, it may be worth pointing out that such approximations are extensively used for carrying out feasibility studies of real space missions: The resulting trajectories are referred to, in NASA jargon, as ‘patched conics’.

Trans-Lunar Orbits

In order to reach the Moon’s orbit, approximately 60 Earth radii away, a spacecraft may be launched tangentially from an Earth parking orbit and will travel in the highly eccentric ellipse shown in figure 1, left. This orbit has a perigee distance equal to the radius of the Earth plus the height of the parking orbit (160 km, say), and an apogee distance equal to the radius of the Moon’s orbit. Since the major axis of the ellipse is roughly one half the diameter of the Moon’s orbit, it very quickly follows, using equation 4 of the inset, that the round-trip time would take roughly 27/2√2 ≈ 10 days. The departure velocity, i.e. the velocity at the perigee, is also easy to find, using equation 3; it comes to 10.95 kms^-1. Comparing this with the escape velocity, (obtained from the same equation, with a = ∞) which is 11.04 kms^-1, it becomes apparent that for a very modest increase in launch velocity the trip time can be reduced considerably. For this and other reasons the chosen trajectory usually overshoots the Moon’s orbit. We know from published data that the Apollo missions actually depart with a velocity around 10.97 kms^-1, on an elliptical trajectory whose major axis is almost 30 per cent. greater than the distance to the Moon. The one-way trip time is consequently reduced, to around 80 hours, because the slowest part of the elliptical orbit is not completed.

So far we have neglected the effect of the Moon itself, but the approximation is surprisingly good for most of the journey, while the Moon is a long way away. As the spacecraft and the Moon both approach their final

---

**Figure 1**

Left: Earth-centred trajectories to the Moon’s orbit. Centre: Moon-centred trajectories of spacecraft arriving from the earth. Right: Free return or “boomerang” trajectory compared with unperturbed orbit.

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1. Geometrical Properties of Ellipse

\[ r_p = a(1 - e) \]
\[ r_a = a(1 + e) \]

where \( r_p = \text{FP} \) = distance to pericentre (closest approach)
\( r_a = \text{FA} \) = distance to apocentre (farthest distance)
2a = major axis; 2b = minor axis; e = eccentricity.

2. Kepler’s 2nd Law

Radius vector \( r \) sweeps out equal areas \( dS \) in equal times \( dt \):

\[ \frac{dS}{dt} = \frac{1}{2} \frac{r^2}{2} \frac{d\theta}{dt} = \frac{1}{2} \frac{r^2 \omega}{2m} = \frac{L}{2m} = \text{constant} \]

where \( L \) is the angular momentum: a constant of the motion.

3. Energy Equation

The total energy (Kinetic + Potential) at any point is:

\[ E = \frac{1}{2} mv^2 - \frac{GMm}{r} \]

At the pericentre \( P \) and apocentre \( A \), where \( v \) is perpendicular to \( r \), we have: \( L = mv_a \ r_a = mv_p \ r_p \)

Substituting in the energy equation we get

\[ E = \frac{L^2}{2mr_p^2} \frac{GMm}{r_p} = \frac{L^2}{2mra^2} \frac{GMm}{r_a} \]

Eliminating \( L \) we obtain the important result:

\[ E = -\frac{GMm}{2a} \]

which shows the energy of an orbit depends only on the length of its major axis, i.e. all orbits with a given major axis have the same total energy.

Solving for \( L \) we get

\[ L = mb\sqrt[4]{\frac{GM}{a}} \]

which relates the angular momentum to the length of the minor axis for orbits of a given energy.

Substituting equation 1 into the energy equation we get the famous ‘vis viva’ equation:

\[ v^2 = GM \left( \frac{2}{r} - \frac{1}{a} \right) \]

which relates the velocity at any given point in an orbit to the radius vector at that point.

4. Kepler’s 3rd Law

Integrating the expression for Kepler’s 2nd Law over a complete revolution:

\[ S = \frac{L}{2m} T \]

where \( T \) is the period of revolution, and \( S = \pi ab \) is the area of the ellipse.

Substituting for \( L \) from equation 2 we get

\[ T^2 = \frac{4\pi^2 a^3}{GM} \]

This is Kepler’s 3rd Law, which relates the period of the revolution with the length of the major axis.
meeting point however, their interaction can no longer be ignored. To continue the analysis we now note that by this time the Earth is quite a long way away, so that from some point onwards we should change from an Earth-centred frame of reference to a Moon-centred one. Our new frame of reference rotates around the Earth, with the Earth's gravity supplying the centripetal force.

To a good approximation, the Earth's gravitational field may therefore be neglected in this frame of reference and we only have the Moon's field to deal with. We re-calculate the spacecraft velocity with respect to the Moon by (vectorially) adding the velocity of the Moon in its orbit (1.02 kms⁻¹). If we substitute this velocity into equation 3 we get a negative value for the major axis of the Moon-centred orbit, indicating the hyperbolic path shown in figure 1, centre. This is confirmed if we re-normalise the total energy, with respect to the Moon: We get a positive value, indicating an unbound orbit.

The equations shown in the inset apply to hyperbolic orbits as well, so that the size of the semi-major axis depends on the total energy alone. (This is a fairly sensitive function of launch velocity and to a large extent governs its choice.) The shape of the hyperbola, on the other hand, e.g. the angle between its asymptotes, is determined by the angular momentum which, in turn, is governed by the distance of closest approach.

Since the distance of closest approach is usually small compared with the radius of the Moon (1738 km), we can proceed to calculate, roughly, the arrival velocity of the spacecraft on the assumption that the point of closest approach (the pericynthion) is actually grazing the surface of the Moon. Then, in our Moon-based frame of reference, the kinetic energy of the spacecraft is composed of two parts: One is due to the Moon-spacecraft relative velocity, which we can approximately equate to the Moon's orbital velocity v₀,M (Note that we have neglected the residual Earth-centred velocity of the spacecraft, since it is comparatively small by the time the spacecraft is near the Moon, and does not contribute much to the kinetic energy there). The other part is equal to the potential energy converted in falling, effectively from infinity, up to the Moon's surface.

This quantity is related to the escape velocity from the Moon's surface, v.escape,M. Thus, we can write for the arrival velocity at pericynthis:

\[ v^2 = v_{escape,M}^2 + v_{0,M}^2 \]

This works out to 2.55 kms⁻¹ (cf. 2.32 kms⁻¹ for Moon escape). The velocity in a circular orbit just above the Moon's surface, on the other hand, is 1.65 kms⁻¹. Thus, a velocity change of about 0.90 kms⁻¹ is required to get into lunar orbit. At what point, and in what direction should rockets be fired to achieve this?

There is a general argument which may be brought in at this point, which leads to the conclusion that, whenever possible, orbital manoeuvres should be carried out by pointing the thrust along the current trajectory, i.e. tangentially. A rocket engine consumes a given amount of fuel to produce a given velocity change. In order to produce the maximum change in kinetic energy, the velocity change should be in the direction in which the velocity is already pointing.

\[ \Delta \text{K.E.} = \frac{1}{2} m v^2_{final} - \frac{1}{2} m v^2_{initial} = \frac{1}{2} m (v_f - v_i) \cdot (v_f - v_i) \]

\[ \frac{v_f + v_i}{2} = m \Delta v, \quad |\Delta v| = \frac{m}{v_{0,M} \cos \theta} \]

For maximum \( \Delta \text{K.E.} \), clearly \( \theta = 0 \); \( \cos \theta = 1 \).

This argument also shows that, for maximum effectiveness, the manoeuvres should take place at points where the velocity is greatest. In the case of the Lunar orbit insertion manoeuvre, this is at the pericynthion and this, indeed, is the place where it is carried out in the Apollo mission, in spite of the fact that this point is on the far side of the Moon, out of radio contact with Earth.

The Boomerang Trajectory

We have seen that a trans-lunar trajectory may be understood as an Earth-based elliptic orbit followed by a Moon-based hyperbolic orbit, joined together in an appropriate manner. It is an interesting fact that if the departure time and velocity are correctly chosen, the continuation of the hyperbolic orbit can join onto an elliptic Earth orbit which is in all respects similar to the outward-bound ellipse. This trajectory is capable of returning the spacecraft to the Earth without any additional propulsion, (except for minor mid-course corrections). This so-called free return or boomerang trajectory, shown in figure 1, right, is a beautiful example of applied celestial mechanics and is an important safety feature of Apollo missions. (It was successfully employed on the ill-fated Apollo-13.)

To understand the feasibility of such a trajectory, we return to the Moon-based frame of reference, in which the Earth rotates around the Moon, with a period of 27.3 days. If the spacecraft encounters the leading edge of the Moon, its path will be deflected in the same direction as the motion of the Earth. If, in addition, the angle between the asymptotes of the hyperbola is equal to the angle described by the Earth about the Moon over the duration of the round trip, we have, to a good approximation, satisfied the requirements of a boomerang trajectory (provided also that the major axis of the hyperbola points towards the Earth at the instant the spacecraft passes its pericynthion). The duration of the round trip is around 160 hours. We therefore require the angle between the asymptotes of the hyperbola to be

\[ \phi = \frac{160}{27.3 \times 24} = 88^\circ \]

We shall now calculate the actual angle directly from the dynamics of the hyperbolic orbit. From the general equation of conic sections in polar co-ordinates, viz.

\[ r = \frac{\text{const}}{1 + \epsilon \cos \theta} \]

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we obtain the following expression for the angle between the asymptotes of a hyperbola:
\[
\phi = 2 \arccos \frac{1}{e}
\]
where \(e\), the eccentricity, is given by
\[
e = 1 - \frac{r_p}{a}
\]
where \(r_p\) is the radius vector of the pericynthion and \(a\) is the semi-major axis (a negative number).

Substituting for \(e\) from equation 3 we get
\[
e = \frac{\nu^2 r_p}{2GM_E} - 1
\]
where \(\nu\) is the velocity at the pericynthion and was calculated before, subject to a few crude approximations. Proceeding algebraically, we have
\[
\nu^2 = \nu^2_{esc,M} + \nu^2_{esc,E} = \frac{2GM_M}{r_M} + \frac{GM_E}{R}
\]
where \(M_M\) and \(M_E\) are the masses of Moon and Earth respectively, \(r_M\) is the radius of the Moon, and \(R\) the radius of the Moon's orbit. Note also that we have equated \(r_p\) with \(r_M\).

Using this expression for \(\nu^2\), we get
\[
e = 1 + \frac{M_E}{M_M} \frac{R}{r_M} = 1 + 81.3/221 = 1.37
\]
which finally leads to
\[
\phi = 2 \times \arccos \left( \frac{1}{1.37} \right) = 86^\circ
\]

This is in excellent agreement with the required 88°, showing that a free return trajectory is indeed feasible, with a pericynthion not very far above the Moon's surface.

The actual manoeuvre requires extreme precision, especially in the launch velocity, which is actually corrected by mid-course rocket burns to an accuracy of a fraction of a metre per second, i.e. a few parts per million. The reason for this enormous accuracy may be seen by differentiating equation 3. We obtain
\[
\Delta a = 2 \frac{\Delta r_p}{a} \frac{\Delta \nu}{\nu} \approx 120 \frac{\Delta \nu}{\nu}
\]
which shows that the elongation of the orbit is extremely sensitive to velocity errors. This is vividly illustrated in the three computed trajectories shown in Figure 2.

The free return trajectory is obtained, in this case, with a launch velocity of 10.980 kms\(^{-1}\). A launch velocity of 10.975 kms\(^{-1}\) gives rise to a trajectory which crashes into the Moon, while another 5 ms\(^{-1}\) less, at 10.970 kms\(^{-1}\), misses the Moon and is actually thrown out into the solar system.

These trajectories were computed and plotted on a small computer with CRT display, using the interactive language FOCAL-15. They represent a point-by-point integration of the equations of motion using the most straightforward technique.*

**Inter-Planetary Orbits**

The Earth and Moon-based frames of reference being in orbit around the Sun, allowed us to neglect the gravitational influence of the Sun in dealing with the trans-lunar trajectory. (The residual perturbations are relatively small but they must, of course, be taken into account in the real situation.) But if a spacecraft is given enough kinetic energy to escape the Earth's gravitational field, i.e. it is launched on a hyperbolic Earth orbit with a velocity in excess of 11.04 kms\(^{-1}\), it is still trapped in the Sun's gravitational field, on a Sun-centred inter-planetary orbit.

We therefore change to a heliocentric frame of reference and pick up about 29.5 kms\(^{-1}\) which represents the Earth's orbital velocity around the Sun. For maximum effectiveness, by the argument introduced earlier, the spacecraft should be launched in the direction of the Earth's orbital motion. The transfer orbit to another planet, therefore, starts out tangentially to the Earth's orbit. Since by equation 1 the total energy depends only on the major axis of the orbit, it follows that the transfer orbit should not overshoot the orbit of the target planet and should therefore arrive tangentially also. Such a transfer orbit, an ellipse tangent to both departure and arrival orbits, is called a Hohmann transfer ellipse—after the German spacecraft pioneer who first showed that it satisfies the criterion of maximum energy efficiency. On the simplifying assumption that planetary orbits are concentric circles, the total energy, hence the launch velocity and flight time in such orbits to Mars, Venus, etc. are easily calculated. In practice the actual orbits are influenced by the relative positions of the planets. Opportunities for minimum energy transfer orbits arise only when the Earth at departure

*Programme available from the author. A 16 mm movie film, produced by ABC TV Melbourne, showing the evolution of these trajectories may also be borrowed from the author.
OBITUARY

O. U. VONWILLER

Professor Emeritus Oscar Ulric Vonwiller died at the age of ninety years on July 30, 1972. He was Professor of Physics at the University of Sydney from 1923 until his retirement in 1946. He graduated in physics and mathematics at the University of Sydney in 1902 and immediately joined the staff of the Physics Department for a lifetime career.

As one of three lecturing staff (increasing to five in 1945), as acting head of department from 1914–1918 and later as head of department he was closely associated with the students and with the development of the department over a long period. With his predecessor (Professor Pollock) he prepared a practical physics manual, and as chairman of the Physics Syllabus Committee for the NSW Department of Education he was largely responsible for an excellent pre-war syllabus in school physics. He helped plan and supervise the construction of the present physics building which was completed in 1924—a testimony to his vision and foresight.

Vonwiller served in many organizations both within and outside the University. For example, he was at various times Secretary and President of the Royal Society of NSW, President of the Science Teachers' Association of NSW, Treasurer of the Australian Research Council—and many more. He became a Fellow of the Institute of Physics in 1927 and a Fellow of the Australian Institute of Physics in 1963. He was Vice President of the Australian Branch of the Institute of Physics in 1942.

Vonwiller had a strong interest in astronomy and was a member of the Board of Visitors of Sydney Observatory from 1930 until 1961 and Chairman of the Board of Visitors of the Commonwealth Observatory from 1944 until 1955. During World War II he was a member of the Commonwealth Optical Scientific Instruments Panel and he directed the Optical Munitions Annex to the School of Physics at the University of Sydney.

His research activities were mainly concerned with optics, especially spectroscopy, with papers on topics such as the spectrum of thallium, the production of interference fringes with a concave mirror, and the electro-optical properties of selenium. He also published papers in medical, educational and general topics.

Vonwiller was always courteous and pleasant, speaking carefully and correctly, and he was always correctly dressed—polished shoes, bowler hat and frequently a walking stick. He was greatly liked by all who came in contact with him.

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PHYSICS AND EDUCATION

J. A. McDonell
Monash University (and The Open University, Buckinghamshire, UK)

Physics at the Open University

The Open University has none of its Undergraduates on its campus. They are all part-timers, studying in their homes, and they are spread across the length and breadth of the UK. The material which they receive from the OU, in weekly or fortnightly instalments, is the most sophisticated integrated package of notes, study guides, assignments, tests, TV and radio broadcasts, cassette tapes, home experiment kits, etc., ever put into operation on a large scale. In 1973 the OU is teaching 38 courses, developing 23 more for next year, providing tutorial and counselling services in 261 regional study centres and has 44 000 students enrolled—and this is only its third teaching year! The minds of those of us who are familiar with the processes of course development and teaching in conventional universities tend to boggle at this information. But it is true; and the fact that this state of affairs has been achieved presents a new dimension to our thinking about the nature, purpose and organization of tertiary education.

The OU "... was set up to provide university and professional education to those with the keenness and ability to continue their education by study in their own time, and particularly to those who could not otherwise obtain education at a University. For these reasons, OU students need no ... formal academic qualification for entry. They are usually over twenty-one and the majority are in full-time employment or working at home." (BA Degree Handbook, 1973). It is important to note that the OU's interpretation of 'university and professional education' is not the conventional one. The OU does not set out to produce engineers, medics, lawyers or, indeed, professional physicists. It does, however, offer courses which, in the opinion of many observers, are as intellectually demanding as those of conventional universities. Its graduates should, by any of the traditional tests of clarity of thought, capacity for understanding and analysis and professionalism of attitude, match those of other institutions. In a sense the OU is strongly traditional—although it is seldom thought of in that light—since it leans towards the production of the highly educated 'all-rounder'. (This is surely to be applauded; other universities are producing a quite adequate supply of graduates who are skilled and competent specialists but otherwise poorly educated!)

The BA degree requirements are framed to allow the student great latitude in choosing the kind of degree which he wants. Although the academic structure is based on six Faculties—Arts, Social Sciences, Mathematics, Science, Technology and Education—the student is not tied to the course of any one. (Incidentally, an OU 'course' is roughly the equivalent of a 'subject' in our usual terminology.) Indeed, every degree must include foundation courses offered by two different Faculties. Since many second and third-level courses do not have one of these foundation courses as a pre-requisite, multi-faculty degrees are perfectly possible. Equally, fairly specialized programmes can be put together.

All courses have credit ratings, usually of I or ². The foundation courses are each full-credit courses. Two full-credit courses is the maximum for which a student can register in a year, and this is a really tough assignment for a part-timer, since the student is told to expect to spend, on one full-credit course, a minimum of 10 hours study per week over a 32–34 week period, plus attendance at a one-week residential summer school. Few full-time undergraduates would claim to spend as much time, in study, in an academic year, as the OU student doing two full-credit courses.

Let's see how this works in the area of physics. For the pass BA, the student must accumulate a total of six credits. Two credits come from foundation courses. The remaining four credits can then be made up from any of the second, third or fourth-level courses of all Faculties. Since the majority of these are half-credit courses, the average student will take six or eight of them to complete a degree. Production of new courses is a continuous process and, at the moment, there are five offered which directly involve physics. Let us look ahead to 1978. By then, at least the following 'mainstream' courses should be available to anyone wanting to take physics to third level.

Foundation Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 100</td>
<td>Science foundation</td>
</tr>
<tr>
<td>M 100</td>
<td>Mathematics foundation</td>
</tr>
</tbody>
</table>

Second level

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MST 282</td>
<td>Mechanics and applied calculus</td>
</tr>
<tr>
<td>ST 285</td>
<td>Solids, Liquids and Gases</td>
</tr>
<tr>
<td>TS 251</td>
<td>Introduction to materials; the solid state</td>
</tr>
<tr>
<td>TS 282</td>
<td>Electromagnetics and electronics</td>
</tr>
</tbody>
</table>

Third level

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM 351</td>
<td>Quantum Theory and Atomic Structure</td>
</tr>
<tr>
<td>S 352</td>
<td>Solid State Physics</td>
</tr>
<tr>
<td>ST 291</td>
<td>Optics, Images and Information</td>
</tr>
<tr>
<td>S 354</td>
<td>Statistical Mechanics</td>
</tr>
</tbody>
</table>

At the same time there are plenty of second-level courses available in mathematics, related sciences and in technology. Thus, a range of specialist physics-oriented degrees will be available. But, as alternatives to specialization, other options are wide open. One can dream up all kinds of interesting and useful combinations.
For example:

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 100 Foundation Science</td>
<td>1</td>
</tr>
<tr>
<td>M 100 Foundation Mathematics</td>
<td>1</td>
</tr>
<tr>
<td>MST 282 Mechanics and Applied Calculus</td>
<td>½</td>
</tr>
<tr>
<td>TS 251 Introduction to materials—the solid state</td>
<td>½</td>
</tr>
<tr>
<td>S 233 Geology and the environment</td>
<td>1/3</td>
</tr>
<tr>
<td>SDT 286 Biological bases of behaviour</td>
<td>½</td>
</tr>
<tr>
<td>AST 281 Science and the rise of technology since 1800</td>
<td>½</td>
</tr>
<tr>
<td>DT 201 Urban development</td>
<td>½</td>
</tr>
<tr>
<td>SM 351 Quantum theory and atomic structure</td>
<td>½</td>
</tr>
<tr>
<td>ST 291 Optics, images and information</td>
<td>½</td>
</tr>
</tbody>
</table>

The items in the kits are by no means trivial. For example, the kit for the electronics course, ST 282, includes an oscilloscope, an oscillator, a stabilised power supply and a multimeter.

The OU points, with confidence, to the realization of that expectation.

One question that will be obvious is this—how can you hope to teach science without laboratories? The OU's answer is to use the student's home as his laboratory. Ingenious home kits have been devised; if the course calls for home experiments, every student gets a kit, for which he pays only a deposit. In some instances, major design breakthroughs, in terms of maintaining performance at a fraction of the cost of conventional designs, have been achieved.

Of course the home kits have limitations; large-scale and sophisticated items can't be included. This gap is, to some extent, covered by the summer schools, held in the laboratories of conventional universities, and by the TV programmes which are an integral part of every course. Nevertheless, it is true that OU graduates will have spent far less time in laboratories than science graduates from other universities. But will this matter? Will the lesser volume be compensated for by its being done in step with the course work, at the times when it should most effectively contribute to the student's learning, rather than being a parallel (and often seemingly unrelated) activity? Does laboratory work on the traditional pattern contribute to the student's education in proportion to the time spent on it—or is it something of a sacrificial cow? There is little hard evidence on which to base answers. But the OU Science Faculty has set up a research group which is seeking ways of evaluating the effectiveness of practical work in its courses. And a significant contribution to this controversy will surely come, in time, through feedback from OU graduates and their professional colleagues.

Lastly, it should be pointed out that the academic staff of the OU are by no means full-time pedagogues. In fact, few of them have had previous experience of experiment in educational techniques before joining the OU. The eight physicists in the Science Faculty come from traditional research-oriented backgrounds. They keep their research going—mostly in the laboratories of other universities at the moment, since the Science Faculty is still in temporary buildings on the OU campus. But their laboratories will come; and there is provision for post-graduate students—indeed there are already some in other departments. The distinguishing characteristics of these physicists—and, indeed, of academics and administrators of the OU, in general—is their enthusiasm for what they believe to be a social experiment of great significance and their commitment to giving it every chance of success. One soon realises that, had they not really been keen to be involved in this experiment, they would probably not be here; there is a healthy over-supply of good applicants for every advertised position.
NEUTRON DIFFRACTION CONFERENCE
A report on the Second AINSE Neutron Diffraction Conference held at Lucas Heights 16-17 October 1972

Programme
The programme for this two day meeting was a solid one, with the presentation of 31 papers and 2 abstracts followed by short reports from those conference participants who had just returned from the Ninth International Union of Crystallography Congress in Kyoto. The subject matter considered by the AINSE Conference was covered in ten sessions on Diffraction Physics, Data Analysis, Magnetism, Lattice Dynamics and Phase Transformations, Chemical Crystallography, Techniques and Instrumentation, Neutron Powder Studies, Discussion on aspects of Kyoto Conference Relating to Neutron Diffraction.

Impressions
This Conference was very much a working session at the business centre of Australia's neutron diffraction. The participants numbering 63, comprised most of the scientists in this country active in the field of neutron diffraction. Research students (with faces already very familiar at Lucas Heights) were strongly represented.

The papers were mostly reports of recent original work, and some had the tone of progress reports. The authors no doubt appreciated the opportunity to air their latest work in front of a crowd of diffractionists, and in their turn the audience appreciated hearing at first hand about the different projects going on around the country. The programme was full, so that anyone who attended throughout all the sessions had little time for either digestion or discussion. Fortunately (or by good management) all sessions ran to time.

For this reviewer, the highlight of the conference was the paper by Frank Moore with the mundane title 'Data Rejection Criteria and Estimates of Standard Deviations of Diffractometer Data'. This was a hard hitting criticism of the practices in which crystallographers reject weak data from diffractometer experiments or replace the weak data by an artificial data set. These practices have no foundation in statistics, and in fact contravene the usual rules of statistical analysis. Moore concluded by exhibiting an analysis of a restricted set of diffractometer data obtained from potassium hydrogen oxalate. The structure was obtained with good accuracy, while the data set used in the analysis was just that weak data which crystallographers commonly reject! For an outsider this expose added credence to the view that chemical crystallography is a black (but usually successful) art.

The notable achievements of chemical crystallographers were reported in Sessions II and V. Structures solved included $\theta$-diketones, amino acids and aquo (L-glutamato) cadmium (II) monohydrate. As always, neutron diffraction techniques were particularly useful in locating hydrogen atoms.

In the west Ted Maslen has continued his analyses of high precision X-ray and neutron diffraction data. He has extracted parameters that describe the electron charge distribution around each nucleus as far as the dipole and quadrupole moments. Although the evaluation of these moments seems somewhat ambitious, the results lead to fairly good estimates of the (measurable) electric field gradient. In New England the preparation of ice sounds disarmingly simple — large single crystals were grown in a freezing pond (modelled on those provided by nature) and then machined to size on a lathe. John Chamberlain reported that neutron diffraction data from this ice led to a successful elucidation of its structure.

Three sessions were devoted to neutron studies of magnetism. Powder measurements have been employed in the study of short range order in MnCu alloys, in the determination of Neel temperatures in the system UO$_2$-ThO$_2$, and in the examination of magnetic properties of face-centred cubic iron precipitated within a copper single crystal. These days the polarized neutron diffractometer and a long wavelength polarized beam instrument (LONGPOL) can also be deployed in the assault on magnetic problems.

Regrettably Colin Kennard was scheduled for 9.00 a.m. on the morning after the successful Conference Dinner so that the reviewer was unable to attend his 'Survey of Multi-Circle Computer Operated Diffractometers'. Other papers should have been valuable (particularly to visitors) as providing a description of facilities currently available at Lucas Heights. As well as the report on LONGPOL, we heard (from Margaret Elcombe) that the computer controlled Triple Axis Spectrometer was fully operational and comparable in performance with similar instruments overseas. David Wheeler (back from a trip) proved a mine of information on recent developments overseas in instrumentation for neutron diffraction. Perhaps Lucas Heights will acquire increasingly popular facilities such as a cold source (to provide higher intensity at long neutron wavelengths) and/or multi-counter diffractometers.

The Conference finished with some discussion of the Kyoto IUC Congress. The predominant current interest of crystallographers is the study of biological substances, and it is evident that neutron diffraction will play an important role in this work.

In all the Second AINSE Neutron Diffraction Conference was quite successful, and it is to be hoped that it will not be long before the Third.—C. J. Heward.

NOTES ON THE SOLID STATE

Many investigations in solid state science are in those grey areas where physics, chemistry, mineralogy and metallurgy are overlapping the ceramic arts. It is thus not surprising to find that researchers working on
related problems in solid state claim allegiance to different disciplines, and accordingly pay their subscriptions to something other than the AIP. The following notes summarize various activities which may be of interest to physicists.

AIP

Although the AIP has no ‘Solid State Physics Group’ it has supported such activities in the field as the AIP Radiation Damage Conference (Sydney, 1972) and the AIP Summer School (Monash University, 1972). The Summer School themes were Magnetism, Phase Transitions and Advanced Materials.

The 1973 AIP Summer School (Brisbane) included a survey of Semiconductor Principles and Applications, and it is hoped that the AIP will channel further support in such directions in the future.

ROYAL AUSTRALIAN CHEMICAL INSTITUTE

The Solid State Division of the RACI seems set on an expansionist course with the circulation (commencing November 1972) of a newsletter to all who are interested in their activities. This Division delves into the science of surfaces, catalysis, molecular solids, electron microscopy, structural inorganic chemistry, and diffusion. This year the Division proposes to run a ‘Specialists’ Session on the ‘Physics and Chemistry of Surfaces’ and a ‘Research Symposium on the Electronic and Ionic Transport of Solids’. Both are expected in Melbourne in May. Any AIP reader who cares to add his name to the RACI-SSD mailing list should contact Dr N. J. Clark, School of Physical Sciences, The Flinders University of South Australia, Bedford Park, SA 5042.

AUSTRALIAN CERAMIC SOCIETY

This society has branches in Sydney, Melbourne and Adelaide, each of which holds regular evening meetings with invited technical speakers. The respective Branch Secretaries, from whom programmes can be obtained are Dr R. G. Anthony, c/- Department of Ceramic Engineering UNSW, Kensington, 2033; Mr S. Zsembery, Brick Development Research Institute, University of Melbourne, Parkville, Victoria, 3052; Mrs K. M. Pluck, Australian Mineral Development Laboratories, Osman Place, Thebarton, South Australia, 5031.

In addition, the Society holds biennial Ceramic Conferences of 3-4 days duration. The next Conference will be in Melbourne in August 1974.

The Society publishes a Journal, launched in 1965, which is devoted to publication of original papers, review papers and shorter notes on all aspects of ceramics, including solid state science.

AUSTRALIAN INSTITUTE OF METALS

This Institute has branches in all mainland capitals together with Newcastle and Port Kembla. All branch lecture programmes cater to some extent for those whose interests lie in the physical metallurgy and physics of metals areas although most emphasize industrial and engineering metallurgy. Solid state bias is strongest in Melbourne where the Physical Metallurgy Division of the Branch caters almost exclusively for the research-oriented physical metallurgist. In addition to its normal lecture programme, this Division sponsors conferences and symposia at regular intervals which attract international recognition. The Journal of the Australian Institute of Metals is also heavily oriented towards physical metallurgy interests.

Further enquiries are best directed, in the first instance, to the Hon. Federal Secretary, 191 Royal Parade, Parkville, Victoria 3052.

CRYSTALLOGRAPHERS

Solid state scientists should find something of interest to them in the ‘Meetings of Australian Crystallographers’. These are informal meetings held once every eighteen months. The 1973 meeting was held in February at Latrobe University. The next meeting is planned for Sydney, in February 1975.

NZ SCIENCE OF MATERIALS

Across the Tasman the Institute of Physics provides a ‘Science of Materials Conference’ once every two years. The Third Conference is to be held in Christchurch, 10–14 December 1973, and is expected to include papers on ionic crystals, metals, disordered solids, semiconductors, crystal growth, surface phenomena, strength of materials, polymers, fibres, and clays. The 1973 Conference Organiser is Dr J. Campbell, Physics Department, University of Canterbury, Christchurch, NZ.

NSW SOLID STATE GROUP

In 1964 scientists working in Sydney in the solid state field organised a monthly colloquium series on topics in metallurgy, solid state physics and solid state chemistry. These were found to fill a need and have continued ever since. The organization is completely informal and no financial arrangements of any kind are involved.

Meetings are held in Room G10, School of Metallurgy, University of New South Wales on the first Tuesday of each month, at 7.30 p.m. They are preceded by dinner at the Randwick Rugby Club, Coogee. The organising committee, which has never formally met, is Dr G. K. White, CSIRO, National Standards Laboratory; Professor M. Hatherly, School of Metallurgy, University of NSW; Professor N. Hush, School of Chemistry, University of Sydney; Dr T. M. Sabine, NSW Institute of Technology. Those who are interested in being informed of these meetings should contact one of the above.

VICTORIA

There are strong groups of solid state physicists working at such places as Aeronautical Research Laboratories, Defence Standard Laboratories, and Monash University. Each group conducts its own colloquia, but at the moment there seem to be no regular meetings involving workers from several or all of the groups around Melbourne.—C. J. Howard.
THE APPLICATION OF THE TECHNIQUE OF OPTICAL PUMPING FOR THE PRECISE MEASUREMENT OF WEAK MAGNETIC FIELDS

Ronald Green and J. M. Stanley
Department of Geophysics, University of New England, Armidale, NSW

Introduction
A couple of decades ago, magnetic flux was measured by means of the flux changes through coils feeding a ballistic galvanometer. Considerable improvement was effected with the development of Hall-material devices and flux-gate magnetometers which had an analogue output. Subsequently, essentially digital devices such as the proton-precession magnetometer and more recently the optical pumped magnetometer have been developed which are accurate to 0.01 nT. The caesium vapour optically pumped magnetometer gives out a frequency of 3.49869 GHz per tesla. It is a true digital device measuring the magnetic field in terms of the energy difference between the Zeeman levels.

The Principle of Optical Pumping

The expression 'optical pumping' was first used by Kastler [1951] to describe the assembling of atomic spin orientations into a non-equilibrium distribution in which the majority of spins were orientated in a particular direction.

Alkali atoms have a single valence electron, located in the $^2S_1/2$ ground-state. Transitions between this and the first excited level, involve energies corresponding to optical wavelengths. Since the first excited level is a $P$-level with orbital angular momentum vector $L = 1$, and the total electron spin vector $S$ can only be $\pm 1/2$, there are in this level two possible values of the total electronic angular momentum $J$, ($J = L + S$), and hence $J = 3/2$ and 1/2. These two states of the $P$-level differ slightly in energy, and give rise to the familiar doublet observed in the spectra of the alkali metals. The two components of this doublet are designated $D_1$ and $D_2$, corresponding to $J = 1/2$ and 3/2 (figure 1). The existence of nuclear spin further divides this doublet into a number of substates known as the 'hyperfine' states (figure 1, 2nd column). Each of these hyperfine states has slightly different energy arising from the interactions of the electron with the nuclear magnetic dipole moment and the electric quadrupole moment. The different energies of this hyperfine structure arise from the discrete number of quantization-mechanically allowed orientations of the nuclear angular momentum $I$ relative to the total electronic angular momentum $J$. As dictated by the rules of quantisation, the allowed orientations are such that the total angular momentum $F$ is restricted to only the values $I + J > F > |I - J|$. Of particular relevance to the optically pumped magnetometer is a still further splitting of these hyperfine states when a weak external field is applied to the system (figure 1, 3rd column). This phenomenon is the well

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known Zeeman effect and is valid for external fields of up to about one gauss. (10⁻⁴T) The splitting arises from the different energies associated with allowed orientations of a given \( F \) with the external field \( H \). The only allowed orientations of \( F \) are those which give projections \( m_F \) along the \( H \) direction, where \( m_F = F, F - 1, \ldots, -F \). Conveniently, the energy difference between the Zeeman levels is directly proportional to the magnitude of \( H \) in the weak field limit. Figure 1 depicts the ground and first excited state electron energy levels of an alkali atom with nuclear angular momentum \( I = 7/2 \), and their subdivision in the presence of a weak magnetic field. Caesium 133, for example, has a nuclear angular momentum of \( 7/2 \).

Hyperfine transitions (between substates of different \( F \)) involve the absorption or emission of magnetic dipole radiation with the selection rule that \( \Delta F = 0, \pm 1 \) only. Zeeman transitions (between different \( m_F \) levels) are similarly constrained by the rule \( \Delta m_F = 0, \pm 1 \). Consider what happens to such an electron when illuminated with a beam of circularly polarized \( D_1 \) light. (See figure 1).

When left circularly polarized light interacts with an electron, \( m_F \) is forced to change by \( +1 \). (Similarly, for right circular polarization, \( \Delta m_F = -1 \)). Hence, if only left circular polarized \( D_1 \) radiation is present, its absorption can lead only to a \( F \) excited substate with increased \( m_F \). When the electron relaxes to the ground state, the normal selection rule \( \Delta m_F = 0, \pm 1 \) applies, as the relaxation is independent of the means of excitation. Because these three transitions are equally likely, (table 1) there is a probability of \( 2/3 \) that the electron will return to the ground state with a greater value of \( m_F \), i.e., a greater component of spin along the reference axis than it had previously.

The atom may absorb and re-radiate repeatedly resulting in a net migration of valence electrons to the ground state having greatest value of \( m_F \). In the case of Caesium 133, this is \( F = 4, m_F = 4 \) substate.

It can be noted from figure 1 that in the \( 2p_1 \) level, there does not exist a substate having \( m_F = 5 \). Hence, if only left circular polarized \( D_1 \) radiation is present to energize these optical transitions, then electrons in the \( m_F = 4 \) level of the ground state cannot be excited further by absorbing the \( D_1 \) photon. The electrons have been 'pumped' into an unnatural condition of maximum spin alignment. Provided there is no mechanism enabling relaxation from \( m_F = 4 \) to a lower value, photons from the 'pumping' light beam can no longer be absorbed, and the alkali vapour becomes transparent.

Nevertheless, depumping from the ordered substate can be brought about by a quantum of radiation energy equal to the energy between the Zeeman levels [Deymelt, 1957]. The frequency of this radiation is directly proportional to the separation energy of the Zeeman levels, and is hence also directly proportional to the external magnetic field. Thus the magnetic field can be measured in terms of the depumping frequency.

If the intensity of the pumping light beam passing through the absorption cell is monitored while an electromagnetic field is swept through the depumping frequency, a minimum will be observed. This corresponds to the reabsorption of photons from the beam after the cell has been depumped on every cycle of the electromagnetic field at the depumping frequency. In principle this is one method to measure the magnetic field. The particular requirement of an alkali vapour magnetometer is that a high degree of orientation be obtained quickly and that spontaneous relaxation be slow when considered relative to the depumping frequency. The relaxation times are given in table 1.

<table>
<thead>
<tr>
<th>Atom</th>
<th>n.a./%</th>
<th>( \lambda_1 )</th>
<th>( \lambda_2 )</th>
<th>( \tau_1 )</th>
<th>( \tau_2 )</th>
<th>( \mu_\perp )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs</td>
<td>100</td>
<td>7/2</td>
<td>994.4 nm</td>
<td>892.1 nm</td>
<td>34</td>
<td>33</td>
</tr>
</tbody>
</table>

**The Self Oscillating Type Caesium Vapour Magnetometer**

Various approaches may be taken to utilize optical pumping for a magnetometer system. A simple self-oscillating type has been built in the Department of Geophysics at the University of New England, Armidale, NSW for mineral exploration purposes and for installation in the Cooney Underground Geophysical Observatory [Green and Sydenham, 1971]. Figure 2 represents basically, the components of the completed instrument.

**Applications**

New applications for precise magnetic field measurements have been found in a wide diversity of fields since the development of optically pumped alkali vapour magnetometers. An indication of the scope of these instruments can be gauged from the examples considered below.

Perhaps one of the most striking successes of the alkali vapour magnetometer has been in the field of archaeological mapping. [Ralph, 1968]. Where the alkali vapour instrument has excelled, is in the detection of items of pottery, stone walls and humus deposits buried to depths of many feet in sediment [Scollar, 1972]. In archaeological work a pair of magnetometers placed 2 m apart can be used to measure the magnetic field gradient directly, rather than the total field. This arrangement is adopted because secular change in the field will cause no change in the gradient. However, human activities such as constructions, or a fire place, hundreds of years old, causes changes in the magnetization of the rocks which can be detected with a gradient instrument.

Nevertheless, the most common application of magnetometers has been in the field of geological prospecting. Total field and vertical field gradient measurements made from the air [Steensland, 1970] or from the ground can be interpreted in terms of size, shape, orientation, depth and magnetic susceptibility of mineral bearing formations. The high quality of surface magnetic data obtainable with alkali vapour magnetometers has been particularly suited to digital analysis with computers.
and many advances have recently been made in this regard [Giret, 1965, Talwani, 1965]. When applied in oceanographic work, the mapping of remanent magnetic anomalies occurring in stripes across the ocean floors, has proved positive evidence of sea floor spreading and continental drift [Heintzler, et al., 1968].

Micropulsations [Davidson and Heintzler, 1968] in the earth’s magneto-sphere which are caused by solar bursts can be monitored from ground station geomagnetic observatories, with a high degree of fidelity using alkali vapour magnetometers. Another application is in the measurement of magnetic micro-pulsations and correlating them with telluric currents within the earth’s crust. This correlation provides a means of calculating a resistivity profile of the crust to a depth of several hundred kilometers [Cagniard, 1953].

In zoological field research, some small mammals with restricted home ranges have had magnets attached to them and they have been relocated with magnetometers.

The origin of planetary magnetic fields is a topic about which little is known [Dyad and Parkin, 1971] and where accuracy and a wide dynamic range is required the alkali vapour magnetometer is ideal. For this reason, one has been placed in the Mariner spacecraft to Mars.

The scope for industrial use of magnetometers as metal detectors is varied. Magnetometers also have numerous military uses, e.g. locating submerged submarines or detecting munition dumps either hidden underground or in jungle. Given the extreme accuracy of the alkali vapour magnetometer (0.01 nT) unexpected observations can be made. The authors recently recorded the buildup of charge for five hours before an electrical storm broke out.

References
NOTES AND NEWS

AGENTS AND DISTRIBUTORS
Tecnico Electronics have been appointed exclusive representatives of: Analog Digital Research (Canada), manufacturers of frequency measurement equipment; Ohmic (France), makers of resistors and power supplies; and RCL Electronics (USA), makers of resistors, delay lines and switches.

NEWS
Centenary of J.E.T.P.
The Russian Journal of Experimental & Theoretical Physics recently celebrated the centenary of its establishment as the Journal of the Russian Physical Society.

Resignation of Prof. R. May
Robert May has resigned his personal chair in Physics at Sydney University, to accept an invitation to become a Professor of Biology at Princeton University. Beginning in an accidental and amateur way early in 1971, May's interests over the past two years have turned increasingly to theoretical aspects of the structure and function of communities of interacting species. This will now become a full-time commitment as he moves to the senior position in the population ecology group at Princeton.

Metric Conversion News
The January issue of MCB Newsletter deplores the use of exact conversions in such cases as distance markers, and discourages the use of conversion tables. In particular, a warning is given that Lefax conversion tables are based on US customary units, not imperial units.

Group Membership—A Reminder
Some members appear to have overlooked the new requirements for membership of a Group. The 1973 subscription form asked for an indication of the Groups which a member wished to join, and pointed out that a fee of $2 per Group was payable (except by Students) to the Treasurer, AIP. Please notify the Treasurer if you wish to amend your original subscription.

CONFERENCES
Symposium on Solar Power
The International Solar Energy Society will hold a symposium on 'Large Scale Solar Power for Australia' on Friday, 1 June 1973, at the University of Queensland. For details, contact Dr N. R. Sheridan, Department of Mechanical Engineering, U. of Queensland, St. Lucia, Q 4067.

The Sun in the Service of Mankind
An International Congress will be held in Paris, 2-6 July 1973. The topics listed cover biological effects of solar radiation, measurements, energy conversion, and applications to the design of housing. Further details from Congrès-Services, 1, rée Jules-Lefebvre, 75009 Paris, France.

ANZAAS Congress, Perth 1973
The 45th Congress will be held from 13-17 August. The theme will be 'Science, Development, and the Environment'. Following the Congress, there may be a Symposium in Singapore. All enquiries to Mrs Dulcie Streton, ANZAAS Congress Executive Officer, U. of Western Australia, Nedlands, WA 6009.

SCHOOL OF NUCLEAR TECHNOLOGY
Radio-nuclides in Medicine and Biology
A course for medical and science graduates will be held at Lucas Heights from 25 June to 20 July 1973. Applications should reach The Principal, Australian School of Nuclear Technology, Private Mail Bag, Sutherland, NSW 2232, by 21 May.

Radio-isotope Course for Non-graduates
This course will be given from 20 August to 7 September 1973. Applications should reach the Principal (see address above) by 16 July.

BOOK REVIEWS

Reviewed by D. C. Wallace, National Standards Laboratory, Sydney.
The purpose of this monograph, to paraphrase the authors, is to help fill the gap between the necessarily abbreviated accounts of solid state textbooks, and the papers and advanced books intended primarily for the already initiated specialist. Whether or not such a gap indeed exists, the book is a good intermediate level text; it is clear, concise, and accurate. Topics treated include Born's theory of lattice dynamics in the harmonic approximation, the adiabatic approximation, and the following applications for non-metallic crystals: thermodynamic functions, dielectric properties, elastic and inelastic scattering of neutrons, x-rays, and light, and vibrations of impurities. While these topics are adequately illustrated by force constant models and shell models, the underlying correlation between the band structure theory of crystals and the lattice dynamical properties, which unifies these two areas of solid state theory and gives a deeper physical significance to the simple lattice dynamics models, is not discussed.

The Australian Physicist, March 1973 55

Reviewed by M. I. Large, School of Physics, University of Sydney.

This book, which is reproduced directly from typescript, is based on a series of lectures given at the University of Maryland in late 1969, with additional material contributed up to October 1970. The 14 American authors are all well known for the original work they have done on the observation or theory of pulsars. Their chapters are written in the style of review lectures (with verbatim questions and answers). Topics include pulsar search techniques, details of radio, optical and X-ray observations, physics of the interstellar material and discussion of the properties of neutron stars and possible emission mechanisms.

The air of excitement of the first three years of pulsar work is captured in the informal style. An unforgettable sequence of strobled photographs of the Crab Nebula shows the time resolution of the optical pulsation. Of course, this book is out of date; for the pulsar research worker, hopefully so. For the physicist wishing to study pulsars seriously, it provides a good introduction to the extensive journal literature of the last two years. For the general reader with a curiosity about pulsars it contains most of the leading ideas. Indeed, we still think pulsars are rotating neutron stars, and don’t understand how they radiate. There is still only one optical pulsar known, and only a handful more radio pulsars have been discovered in the last two years.


Reviewed by J. G. Collins, National Standards Laboratory, Sydney.

‘Kittel’ has dominated the solid-state textbook market for nearly twenty years, and this new edition will continue to do so. Nearly half of the material in the third edition (1966) has been rewritten, either as a pedagogical improvement (e.g. the basic chapters on crystal diffraction and energy bands), to include new topics (Josephson junctions, the Kondo effect), or to emphasize fields in which there has been renewed research interest in recent years (Zener tunnelling, the metal-insulator transition).

The new edition is longer and more profusely illustrated than its predecessor, and it includes thirteen appendices on advanced topics, treated with more mathematical sophistication than is the main text. The now fashionable SI units are used throughout, but most results are also given in the esu system. References are included up to 1970, and the value of the book in the research laboratory has been increased by the inclusion of forty comprehensive and largely up-to-date tables of physical properties of solids.

Inevitably an author is selective in his choice of topics and in the degree of emphasis he places on them; just as inevitably a reviewer will disagree. Thus:

thermal expansion receives the same cursory treatment as in the first (1953) edition; the Gruneisen relation and the equation of state have been omitted entirely; the Mossbauer effect rates a single sentence; and electronic transport properties are dealt with briefly in simple kinetic terms with no mention of the Boltzmann equation, electron-phonon Umklapp processes or the magneto-electric power. On the other hand dielectric, optical and transport properties of insulators are well covered, three chapters and an appendix are devoted to magnetic properties and various magnetic resonances, and two chapters cover defects in solids. There is also some unevenness in the reference tables: the 1969 compilation of fundamental constants is in, whereas the 1966 and 1969 Landolt-Börnstein compilations of elastic moduli are not mentioned, the values and references given dating back to the early 1960’s.

Despite these criticisms, which are mainly matters of personal bias, this remains far and away the best general text on introductory solid-state physics. It is reasonably priced: I urge all students taking a solid-state course to buy their own copy, and all research workers in the field to update their earlier editions.


Operational amplifiers are now abundantly available in economic integrated circuit form and are finding a wide range of applications in the fields of instrumentation, control and use by research workers in their day to day measurement problems. Because of this proliferation in applications the book is timely and fills a definite need in that it presents a good introduction to operational amplifiers for non-specialists in electronics together with a good collection of the types of circuits in which operational amplifiers can be used. The book should be useful to the science student, who is interested in applications of operational amplifiers rather than an in-depth physical understanding of the devices and their limitations, and also to a lesser extent to the research worker who needs solutions to his day to day measurement problems.

In the latter respect it is in general a catalogue of circuit ideas rather than of fully detailed practical circuits; however, the author goes to considerable length in stressing the pitfalls which beset the novice in the practical utilisation of operational amplifiers and such topics as specification, selection, drift, noise and stability are adequately covered.

In some of the applications quoted more might have been said about the relative merits of alternative devices, for example, multivibrators, which are now available in integrated circuit form.

The book is not an exhaustive treatment of the subject, only twenty-one references are given; however, it should find reasonable acceptance as an introductory text combining sufficient depth for the non-electronics specialist with numerous examples of the applications of operational amplifiers.

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