

changes have been made in the text, they are obviously not numerous; in fact, I have not been able to discover any of them. The notes have been altered significantly, even though the changes (once again) are not numerous. Most alterations represent minor corrections or additional bibliographical information, though on a few occasions Drake has changed his mind about an earlier interpretation of Galileo.

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Particles in the belts

RADIATION TRAPPED IN THE EARTH'S MAGNETIC FIELD. (Advanced Study Institute, Bergen, Norway, 1965) B. M. McCormac, ed. 908 pp. Gordon and Breach, New York, 1966. \$45.00

by S. Fred Singer

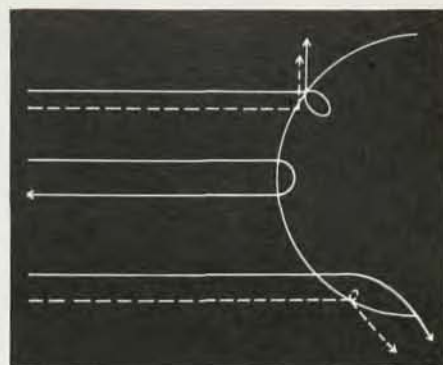
One of the dramatic findings of the initial satellite experiments was the discovery of charged particles trapped in the earth's magnetic field. The possibility of trapping and even the probability of the existence of particles had been discussed; yet the actual measurement came as a surprise to many and stimulated a vast amount of work, both experimental and theoretical. Thus, within a few weeks following the discovery and before the radiation could even be identified, one could predict with some degree of certainty the existence of high-energy protons of several hundred MeV as part of the radiation. They would necessarily be produced by cosmic rays through the intermediary of secondary (albedo) neutrons that are ejected out of the earth's atmosphere and occasionally decay in the magnetosphere, the region above the ionosphere where the geomagnetic field plays a predominant role. Even though injection rates are very low, of the order of 1 per cm^3 per million years, when multiplied by lifetime, approximately 100 years, and by velocity, about 10^9 cm/sec, one obtains the rather impressive fluxes that are measured.

One of the central problems of work on trapped radiations has been to determine whether the neutron albedo

source is indeed the major source for high-energy protons. The other central problem has been to account for the low-energy components of electrons and protons, establish their sources, their energy mechanisms (acceleration mechanisms), and their connection with the variations of the earth's magnetic field and with the aurora.

In this volume, which is based on papers presented at a NATO Advanced Study Institute, these two major problems are extensively discussed, but no completely satisfactory conclusions are reached. While the neutron albedo theory appears well established, the essential input to the theory, namely, the specification of the neutron albedo flux, its energy spectrum, angular distribution, latitude distribution, etc., is not sufficiently well known to allow a final definitive conclusion. If neutron albedo is the major source, then, for example, protons of 500 MeV energy would have to have lifetimes of several hundred years in the earth's magnetosphere. This lifetime is completely permissible from the point of view of ionization loss: But is the magnetic field steady enough to permit this excellent degree of trapping, about 10^{13} gyrations?

On the second problem, there are a great many measurements presented but, again, no final conclusion. In the organization of the institute, the related geomagnetic and auroral problems were not brought in, so the discussion could deal only with a portion of the problem. The dynamics of the magnetic field, the existence of electric fields in the magnetosphere owing to convection and similar topics were not specifically discussed. Of course these subjects are immensely complicated, and some major physical factors have not been taken into account. For example, rotation of the earth and corotation of the magnetosphere must play a role. Some slipping must take place between the corotating magnetosphere and the noncorotating interplanetary magnetic field. It appears intuitively possible to me that the rotation will result in a winding up of the lines of force until their energy density reaches some limiting value and that then a release of energy can take place through merging of the lines of force, perhaps with the solar wind acting as a triggering device. Clearly this is not an easy concept to deal with



CHARGED-PARTICLE TRAJECTORIES. This simplified model shows trajectories (solid lines positive ions, dashed lines electrons) incident perpendicular to a magnetic dipole that is projected along the equatorial plane.

analytically. On the other hand, the static models of the magnetosphere, on which a great deal of detailed discussion is here lavished, do not appear to me to be capable of explaining trapped-particle and auroral phenomena. The volume contains a good many of what I would call classical papers. Of the nearly 60 papers, many have a review character and should be useful to anyone who wishes to understand the status of the field. The rest are useful mostly for specialists in the subject.

The institute was divided into five sessions. The first dealt with B-L space, basically a description of the earth's magnetic field and the coordinate system which is useful in describing trapped-particle phenomena. The next two sessions dealt with observed particle distributions, both in the inner and outer zones, describing measurements on trapped protons and trapped electrons. Session 4 was theoretically oriented, and the participants tried to describe sources and sinks of natural trapped radiation. The neutron albedo source, the atmospheric sink and diffusion of protons of low energy appear to be the best understood phenomena. Session 5 presented a number of papers on the outer magnetosphere, including magnetospheric models and motions of charged particles in unusual magnetic environments. Session 6 described the results of measurements from artificially injected radiation during high-altitude nuclear tests. Session 7 dealt quite briefly with synchrotron radiation. Sessions 8 and 9 described effects of trapped radiation on electronic devices and on manned flight.

In reviewing the book, generally,



The Lincoln Laboratory of the Massachusetts Institute of Technology conducts research in selected areas of advanced electronics with emphasis on applications to national defense and space exploration. *Radio Physics* is a field of major interest. The program includes radio propagation studies leading to systems for satellite and deep-space communications, as well as investigations of the sun and the planets, utilizing new techniques of radar astronomy. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 15, Lexington, Mass. 02173.

Solid State Physics
Information Processing
Radio Physics and Astronomy
Radar
Computer Applications
Space Surveillance Techniques
Re-entry Physics
Space Communications
A description of the Laboratory's work will be sent upon request.



Cosmic Radio Source

several things stand out: very excellent production and careful copy editing, including discussions following papers; about 70 lecturers from the US, one Canadian, two from the United Kingdom, and two Scandinavians—with the two-week meeting held in Bergen, Norway; and the very high price.

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Light at the junctions

THE PHYSICS OF ELECTROLUMINESCENT DEVICES. By P. R. Thornton. 382 pp. Barnes & Noble, New York, 1967. \$14.50

by D. G. Thomas

This book begins with the brave statement that the study of electroluminescence is not one for faint hearts. One wonders sometimes whether there is a branch of physics, and particularly one that aspires to be useful, that can be tackled by faint hearts. But it is probably true that the subject of electroluminescence, that is, the direct conversion of electrical energy into visible or near-visible light by exciting a solid without significantly heating it, is one that had better be approached with a certain ebullience of spirit. The trouble is not the magnitude of the intellectual challenge, but rather the demands that are made on patience and imagination. There is great variety to the field, which spreads over the physics and chemistry of semiconductors. This book deals chiefly with the physics of the subject to omit any discussion of materials preparation. The author points out that materials preparation is extremely important, but a proper discussion would occupy too much space.

Generally speaking, a straightforward, elementary and reasonably critical account is given. The author presents an outline of the theory, such as it is, of the various subjects. The treatments are brief and not very deep; thus the theory of p-n junctions under forward and reverse bias are given, but for an appreciation of the problems that remain and of the approximations that have been made it would be necessary to refer to the original literature to which adequate references are supplied. Nevertheless the

summaries are a useful introduction to the main subject of the book, which consists of an account of various specific electroluminescent processes. The immensely detailed work on the "classical" electroluminescent system of zinc sulfide embedded in a plastic dielectric is summarized, and the author gives an appropriate critique. More attention is given to electroluminescence generated by the dc forward biasing of well defined p-n junctions, and this reflects the direction the field is taking today. Spontaneous emission from gallium arsenide, gallium phosphide, silicon carbide and various semiconductor alloys is dealt with quite competently as far as the subject allows it. There is a quite lengthy account of injection lasers, which, as the author writes, is a more satisfying subject as one can say a good deal about it that is both clear and relevant. It is unfortunate that at present these devices do not work continuously at room temperature, and only exceptional ones generate visible light. These limitations are pointed out in the book and comments are made upon their possible solutions. The book concludes with a reasonable discussion of the applications of electroluminescent devices and touches on the dismal subject of their possible failure.

There are a few 1966 references, but most of the work pertains to 1965 or earlier. Inevitably, therefore, in places the book is out of date. Thus the author states that efficiencies of electroluminescence from gallium phosphide are in the range 0.01–0.04% at room temperature, whereas in fact today they are roughly 100 times these values.

The field of electroluminescence is one of growing importance and almost certainly will have an impact on electronics technology because it can play a part at that point at which a man confronts his machine. The convenient visual display of information will clearly be valuable.

P. R. Thornton, who has spent three years in England at the Services Electronics Research Laboratory, an institution active in this field, and who now teaches material sciences at the University College of North Wales has given us a useful, critical and well written account of the physics of the subject. It is likely that it will find use for several years among those who are working in the field of electroluminescence and among those, pre-

sumably of stout heart, who propose to take it up.

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The reviewer has worked for several years at Bell Telephone Labs with emission of light from semiconductors.

Spinors and spaces

THE THEORY OF SPINORS. (Trans. from 1937 French edition) By Elie Cartan. 157 pp. MIT Press, Cambridge, Mass., 1966. \$8.00

by Lawrence C. Biedenharn

Elie Cartan was one of the great mathematicians of this century; for physicists he is probably best known for his fundamental work on Lie groups. It is probably not well known that Cartan developed the *general* theory of spinors in 1913, a dozen years before Wolfgang Pauli made the spin- $1/2$ system a commonplace in physics (the name "spinor" stems from this latter application).

The present book is a translation (the first in English) of Cartan's lectures on spinors in 1937—a classic of the mathematical literature. Cartan's purpose in these lectures is to develop the theory of spinors from a purely *geometrical* point of view, in contrast to earlier treatments, such as that of Weyl and Brauer. (A second motivation, for Cartan, was the desire to extend Paul Dirac's equations to general relativity; on this particular subject the present book is now somewhat out of date; the recent literature is cited in B. S. Dewitt, *Relativity, Groups and Topology*, Gordon and Breach, New York, 1965.)

The lectures were aimed at a general audience and develop the necessary techniques for linear representations of groups from the beginning by employing the (now familiar) method of infinitesimal generators. The work divides into two main parts: The first treats generalities on rotations and reflections in n-space, linear representations and the theory of spinors in 3-space; the second treats the theory of spinors in n-space including Minkowski space and Riemannian geometry.

Cartan's geometrical view of spinors can be best illustrated, for physicists nowadays, by reversing his order of presentation. Consider an arbitrary vector V in ordinary 3-space and the Pauli matrix vector σ . If we define a