BOOK REVIEWS

Controlled Thermonuclear Reactions. By L. A. Artsimovich. A. C. Kolb and K. S. Pease, eds. Transl. from Russian by P. Kelly and A. Peiperl. 405 pp. Gordon & Breach, New York, 1964. $19.50.
Reviewed by Harold P. Furth, Lawrence Radiation Laboratory.

A key sentence of Academician Artsimovich's thermonuclear survey is to be found in its Conclusion: "It is difficult to prophesy which of the various methods that have been developed for heating and confining plasmas will be the most successful; but this does not mean that all the methods must be regarded as being of equal worth." The vitality of Artsimovich's book springs precisely from his readiness to make value judgments on both the subject matter and the conduct of controlled-fusion research.

This attitude is new in the literature and may prove evolutionary. Ten years ago there was little basis in theory or practice for a critical comparison of the diverse approaches to thermonuclear power. It was natural and has meanwhile become traditional for reviews such as those of Project Sherwood in the United States to make a virtue of meticulous impartiality. Artsimovich's book reflects a newer ideal: that the accumulating wealth of experience should serve to define principles and directions of profitable research.

Artsimovich's credentials as a commentator are well supported. He is the leading figure in fusion research at the Kurchatov Institute in Moscow, widely regarded as the leading laboratory in world fusion research. The Moscow group has been noted from the outset for its conservative public-relations practices and its emphasis on plasma physics. These tendencies are generally ascribed to the influence of Artsimovich.

Artsimovich's concept of fusion research can be outlined as follows:

1. Controlled-fusion power should be regarded as achievable, but only after a research task of considerable and still uncertain magnitude.

2. The relevant principles of plasma stability are still largely obscure. When success is achieved, it will be as the result of the systematic elucidation of these principles, not as the result of engineering ventures undertaken in ignorance.

This point of view has its advocates also in the West, but is by no means universally respected there—or, for that matter, in the Soviet Union. In the United States, there has been an official reluctance to embrace the step-by-step evolution of plasma physics as the central process of controlled-fusion research. Intermediate goals of a different nature have in the past been taken more seriously: for example, empirical-technological achievements such as the realization of small neutron yields from "prototype thermonuclear reactors". For Artsimovich, this goal is not merely irrelevant but actively obstructive:

> . . . The artificial excitement created every time anyone announces the detection of an indication of 'real' thermonuclear neutrons introduces an unnecessary element of publicity into the work on one of the most arduous scientific and technical problems in existence today.

This and similar remarks, more of an anthropological than a plasma-physical flavor, remind the reviewer of Sir James Frazer's classic commentary on homeopathic magic. The analogy is sufficiently accurate that a few direct quotations from *The Golden Bough* may be of interest:

> The methods by which [the rain-makers] attempt to discharge the duties of their office are commonly, though not always, based on the principle of homeopathic or imitative magic. If they wish to make rain they simulate it by sprinkling or mimicking clouds. . . . [Practices based on homeopathic magic] derive in the final analysis from a false conception of natural law. The primitive magician, however, never analyzes the mental assumptions on which his performance is based, never reflects on the abstract principles involved. With him, as with the vast majority of men, logic is implicit, not explicit; he knows magic only as a practical thing, and to him it is always an art, never a science, the very idea of science being foreign to his thinking.

Artsimovich would presumably add that rain-makers must concentrate on researches in gas dynamics and the physical chemistry of the atmosphere.

Aside from a scientific outlook, *Controlled Thermonuclear Reactions* offers some elements of plasma physics, some ground rules of thermonuclear power production, some interesting but mildly chauvinistic historical material, and a "snapshot photograph" of experimental fusion research in early 1961. For the English version, prepared with the competent aid of Editors A. C. Kolb and R. S. Pease toward the end of 1962, the original Russian snapshot has been retouched extensively. Even so, it has already a slightly dated air—perhaps the best possible tribute to the current rate of progress in the field.

The experimentalist sympathies of *Controlled Thermonuclear Reactions* are revealed in the Foreword: "The choice and arrangement of the material have been governed by the belief that a clear understanding of the problems can be obtained without draping the meagre skeleton of experimental facts in a voluminous garment of mathematical elaboration. . . ." This metaphor, however, is a rather misleading one. High-energy nuclear physics may have an experimental skeleton on which theory is to be draped. In plasma physics the situation is precisely the reverse: a rigid theoretical skeleton grows out of the principles of classical mechanics and electrodynamics. The voluminous and largely amorphous experimental material is not needed to support the skeleton of theory, but serves rather to indicate the points at which today's primitive skeleton must grow.

Artsimovich's inversion of the normal anatomy of plasma physics tends to diminish the effectiveness of his book in several respects. As a primer for those entering the field, *Controlled Thermonuclear Reactions* will convey a vivid and intelligently drawn general picture, but is not as well suited to train an independent judgment. While the derivations given are always sound and physically illuminating, the linkage of the various theoretical bone-fragments is not consistently brought out. Many important results are merely stated, sometimes without mention of underlying assumptions or references conveniently accessible to the general public.

For those already familiar with the fusion field, the most interesting elements of Artsimovich's book are the oracular passages and the general surveys. In particular, the broad juxtaposition of experiment and theory is a much-needed contribution to the technical literature. In the area of gross hydromagnetic phenomena, one can see that positive experimental-theoretical correlations are almost universally obtained; elsewhere, noncorrelation is still the rule rather than the exception. Here again the moral drawn by Artsimovich (i.e., theorists busy making voluminous garments instead of fitting the experimental skeleton) seems curiously inverted. Few large-scale fusion experiments anywhere in the world today are designed primarily to shed the clearest possible light on theoretical questions—for example, on the nature of the breakdown of the infinite-conductivity hydromagnetic approximation in various plasma regimes. As Artsimovich's book serves to illustrate, fusion experimenters tend to look to stability theory for helpful hints on "how to improve things" rather than for the definition of critical experiments requiring special apparatus. To draw an analogy with ordinary fluid dynamics one should try to imagine the development of its theory on the strength of reports from science-minded sailors and flyers.

Fortunately, the weakness of detailed stability theory does not leave fusion research in a state of total disorientation. Thermodynamic arguments can be used to identify the energy sources on which various classes of instability feed. Even in an infinite plasma volume, free energy for microinstabilities is made available by certain departures from the thermal velocity distribution, and particularly by directed particle streams. In finite plasma configurations, energy to drive instabilities can be provided also by perturbations of the confining magnetic field. Especially where a current in the plasma makes an important contribution to the confining field, a wide range of instability modes is energetically accessible; but in any case energy can be realized by displacement of the "diamagnetic" plasma in directions of diminishing magnetic field strength. The thermodynamic argument, of course, merely sets limits on the existence and growth rate of instabilities, and does not prove that thermodynamically "worse" configurations will actually be more unstable. From the experiments, however, one can see that hot, dense plasmas are extremely inventive in finding detailed modes to exploit what is thermodynamically permissible.

This is the background for Artsimovich's fatalistic dismissal of certain approaches to plasma confinement—for example, conventional mirror machines and all species of pinch. The fatalistic thermodynamic point of view is also somewhat popular in the West, particularly among theorists, but thus far has largely failed to convince those experimentalists with whose technological orientation it is incompatible. The stand *against* the thermodynamic argument, after all, is inherently a durable one: no finite amount of detailed theoretical analysis or experimentation could furnish a rigorous proof of nonfeasibility in any broad category of plasma confinement or heating.

Meanwhile those enterprises that respect the thermodynamic argument as the principal signpost of fusion research are enjoying a rather marked prosperity. The most important development of the past few years has been the investigation of so-called "minimum-B" configurations. These are magnetic traps based on special systems of external conductors such that the strength of the confining field increases in every direction away from the plasma. The existence of such configurations had been known almost since the beginning of fusion research, but their uniquely favorable thermodynamic position had never been taken seriously on the level of experimental policy. At the 1961 international controlled-fusion conference held in Salzburg, the first dramatic success with a minimum-B machine was announced by M.S. Ioffe, an experimentalist working under Artsimovich. Simply by turning the minimum-B property on and off, he was able to switch his plasma from classically stable confinement to instability and rapid escape—one of those rare experiments that rank at the same time as direct "accomplishments" in fusion research and as clear-cut demonstrations in physics. The last section of *Controlled Thermonuclear Reactions* gives a brief account of Ioffe's work and its significance. More recently, in the United States, in the United Kingdom, and in France, as well as in Moscow, numerous variants of the Ioffe experiment have confirmed and extended the initial results.

At the present time, the minimum-B experiments seem to be headed for conditions of long-time stable confinement at levels of plasma density and temperature that are nontrivial on the thermonuclear scale. More importantly, these new experiments can hope to come to grips in a clear-cut fashion with the intrinsic stability problem of controlled-fusion research: whether the mere localization in space of a hot, dense plasma provides an energy reservoir sufficient to set up unacceptably high levels of "universal" instability. The existence of potentially dangerous "universal" modes has been demonstrated during the last two years by Soviet theorists. (Artsimovich's discussion is restricted to the earliest work along this line.) Forthcoming minimum-B experiments will shed light on the theoretically as yet uncertain finite-amplitude effects of the "universal" instabilities, and on the efficacy of various configurational remedies that would suppress the currently known modes.

On the question of success, the last paragraph of *Controlled Thermonuclear Reactions* states:

> It is hardly to be doubted that ultimately the problem of controlled thermonuclear fusion will be solved. Nature can put only a finite number of difficulties on the road to the solution; and when man has overcome

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MATHEMATICS • PHYSICS • CHEMISTRY • BIOLOGICAL SCIENCES • MEDICAL RESEARCH • SPACE SCIENCES • ENGINEERING • PSYCHOLOGY them by unremitting creative activity, nature will not be able to invent new obstacles. All that is uncertain is how long the process will last.

This is not so much an oracle as an expression of official Soviet policy. Inquiries of Soviet scientists in the field have always received more or less the same reply: the Soviet Union is aiming at excellence in high-temperature plasma physics and is content to let the physics show what time scale is natural to the harvesting of economic benefits.

Course 28: Star Evolution (Proceedings of the International School of Physics "Enrico Fermi," Varenna, Italy). L. Gratton, ed. 488 pp. Academic Press, New York, 1963. $18.50.
Reviewed by J. Allen Hynek, Dearborn Observatory.

Stellar evolution is a broad domain into which virtually all phases of astrophysics and observational astronomy enter, and to which they all contribute, in greater or lesser degree. No one volume, or a series for that matter, can essay to cover the field adequately. The rapid evolution our ideas of stellar evolution themselves have undergone, even in the time since the volume under review was in preparation, emphasizes this point. Quasistellar sources and recent advances in our knowledge of radio galaxies and in relativistic astrophysics were not yet a part of the working data of the contributors when they met on the shores of Lake Como in Varenna, Italy, to deliver Course 28 in the *International School of Physics "Enrico Fermi"*, on the subject of star evolution. Thus, even though sixteen specialists presented eighteen excellent and thorough lectures on specific problems in stellar evolution, this volume, edited competently by L. Gratton, himself one of the contributors, is not a comprehensive survey of the field of stellar evolution. Rather, many contributors dealt with those ideas which were frontier aspects of the field when the symposium was held in 1962.

Despite these limitations, an understandable price of progress, the volume contains much fundamental material basic to an understanding of the central ideas of stellar evolution. There are areas in the field which are well established even though progress has been rapid, and many of the contributors have given an excellent résumé of these.

For this reason the book can be fully recommended to serious readers wishing an authoritative discussion of integral aspects of the problem of stellar evolution. These cover a wide spectrum, ranging from the observational approach to stellar evolution, to nuclear astrophysics and the construction of stellar models. Schatzman treats the early stages of stellar evolution in one chapter, and in another he deals with the very late stages of stellar evolution in his discussion of white dwarfs and Type I supernovae. Gratton follows this with a discussion of stellar association and very young clusters, while much older stars, Cepheids, white dwarfs, and stars with helium-rich cores are treated by Baker and Schatzman. Ledoux contributes a fine chapter on stellar stability and stellar evolution. The Burbidges give a comprehensive treatment of nuclear astrophysics and nucleosynthesis, covering in detail the synthesis of elements and the related topic of supernova explosion; then following this, they discuss the observed chemical composition of the stars. G. Burbidge includes a very excellent bibliography.

No detailed chapter-by-chapter discussion can be given in this review, but the survey of the observational approach to stellar evolution given by Sandage and Gratton should be especially noted as it will appeal to a much wider audience than some of the more specialized chapters. Following a résumé of the theory of the Hertzsprung-Russell diagram and the closely related color-magnitude diagrams, they present the observational evidences for stellar evolution as shown particularly by diagrams for open and globular star clusters, interpreted as envelopes of stellar evolutionary tracks.

The mathematics of stellar structure cannot be encompassed in a few chapters, and Wrubel devotes his chapter on construction of stellar models to a few selected aspects, particularly calculation of opacities for use in model integrations. Another special aspect, "stellar evolution as a problem for an electronic computer", will be found timely.

The closing chapter of the symposium by M. Hack deals with the evolution of close binary systems. This is one of the most exciting and potentially productive phases of the problem of stellar evolution. When the components of a close binary (separation of the order of diameter of the stars) are not of equal mass, the more massive will evolve from the main sequence first, expanding in size and transferring part of its mass to the companion through the first Lagrangian point of the system. This, in turn, upsets the normal course of stellar evolution, leading to a variety of consequences.

The task of editing a symposium in so rapidly evolving a field is a harassing one, and Gratton has handled this well although an excessive number of typographical errors have been left unattended.

The Equilibrium Theory of Classical Fluids. A Lecture Note and Reprint Volume. By Harry L. Frisch and Joel L. Lebowitz. 3 Chapters. Benjamin, New York, 1964. Cloth $10.00; paper $5.95.
Reviewed by Stuart A. Rice, University of Chicago.

The Equilibrium Theory of Classical Fluids is a reprint volume which departs somewhat from the pattern established in the past. In addition to useful comments in a number of places provided by both editors and authors, there are several good new articles with the nature of critical reviews. The purpose of these articles is to provide new and clearer derivations of well-known results and, hopefully, thereby new insights. Thus, instead of making a compendium of reprints, the editors have constructed something intermediate between an original monograph and a collection, and should be commended for this. I believe the book to be useful to all interested in statistical mechanics and the classical many-body problem.

As minor demurrers, let me remark that in my copy pages II-258 and II-259 are identical. I also believe that it would have been better to cut open the journals before photographing the articles, since the