# REVIEWS

**Plasmas and Controlled Fusion.** By DAVID J. ROSE and MELVILLE CLARK. New York: M.I.T. Press and J. Wiley, 1961. 493 pp. £4. 6*s*.

It has seemed apparent for so long that there are only three states of matter that it perhaps comes as a surprise to find that most of the universe is essentially in a fourth state; a fully ionized gas or plasma. Although Tonks and Langmuir introduced the subject over thirty years ago, plasma physics has only been studied seriously in the past decade. By now it is not surprising that plasmas should be increasingly studied for their own sake just because they are all-pervading and plasma physics has penetrated into most branches of astronomy. Space research and the discovery of the Van Allen radiation belt has added another stimulus. However, the main impetus to work on plasma physics in the last few years has been the vision of limitless fuel supplies.

It has been known for nearly twenty-five years that stars obtain most of their energy from the fusion of light nuclei. It has been calculated that this process will occur at temperatures ranging from a few million degrees to hundreds of millions of degrees. The same source of energy has been used on the Earth in an uncontrolled fashion by the explosion of hydrogen bombs. One of the most tantalizing research problems today is whether fusion energy can be released in a controlled fashion in the laboratory. Although the only possible fuel appears to be the heavy isotopes of hydrogen, the supply would be virtually inexhaustible.

If temperatures of the order of a hundred million degrees are to be reached and held for long enough for a useful energy release, it is obvious that the plasma cannot be in contact with a solid wall. It is hoped, however, that strong magnetic fields can be used to confine a hot plasma of low density. Research has been in progress in many countries for a decade or more now. Although to many people progress has seemed disappointingly slow and a fusion reactor is certainly not in sight, there is a mood of cautious optimism among scientists working on the subject.

It does not take long now for a subject to pass from being front line research to being part of a university syllabus. In the case of plasma physics this is not too surprising. The subject was started rather late and, once interest in plasmas was aroused, there were many quite elementary properties to be discovered and explained. The present authors have in fact been teaching the subject of plasmas and controlled fusion to graduate classes at M.I.T. and have produced the first real text-book on the subject.

At first I was dubious whether it was yet time for such a text-book to be written, but, having read it, I feel the book will be a great success and I shall certainly recommed it to anyone wishing to find out what the subject is about. A big factor in its success is that the authors have been very wise in their choice of subject-matter. Although controlled thermonuclear research is the central theme of the book, most of it is devoted to the basic physical and technological ideas involved in the subject and only the last three chapters, representing a little over a quarter of the book, are concerned with descriptions of specific thermonuclear devices. At the present stage in development this balance seems correct; fusion devices come and go but the basic physical ideas change much more slowly. It is also unfortunately true that the pressure towards success has led to several over-exuberant claims regarding experimental results.

The book starts with a description of the world's energy needs and resources. If the consumption of energy continues to increase at the present rate, all non-nuclear fuels could be used up in a century. Although fissile fuels could last for several hundred years, only the controlled release of fusion energy seems capable of meeting really long-term needs. This naturally leads to a discussion of the possible fusion reactions; the calculations of fusion cross-section are described and it is shown that only reactions involving deuterium and tritium have large enough cross-sections to be of immediate experimental interest. In a successful reactor energy must be released more rapidly than it is lost. Later in the book radiation processes in a plasma are described and it is shown that energy losses in the form of Bremsstrahlung and electron cyclotron radiation place severe restrictions on the parameters of possible fusion reactors; in particular it might not be possible to build a pure deuterium reactor. A discussion is also given of basic processes in atomic physics. These are important in considering the interaction of plasma and radiation with the walls of the surrounding vessel and the behaviour of impurity atoms in the plasma.

There are two simple approximations to the theoretical description of a plasma. In the first the plasma is regarded as a highly conducting fluid containing a magnetic field. This is the hydromagnetic approach and it is quite a good approximation when the collision frequency is high. In the second approach the motion of individual particles in a given magnetic field is considered. Both these approaches are discussed by Rose and Clark. In fact a plasma is neither an ideal fluid nor a collection of free particles. The only complete description is that of all the particles interacting with one another through their Coulomb fields. Recently more adequate approximations to the complete behaviour have been found in the form of the so-called kinetic equations. The chief difficulty in the problem is the long-range nature of the Coulomb force. The authors discuss some of the consequences of the Coulomb law of force and also sketch how hydromagnetic equations can, under suitable conditions, be derived from the simplest kinetic equation, Boltzmann's equation.

If fusion reactors are to be built, plasmas must be confined by a magnetic field in a stable fashion. In fact, all the simple equilibrium configurations first suggested have proved to be seriously unstable. The authors describe the general characteristics of all confined equilibria, and they also discuss the techniques for studying the stability of these equilibria which have been developed in recent years. It is this stability problem which has absorbed most of the theoretical effort on thermonuclear research.

In the last part of the book three types of plasma devices are described; devices based on the pinch effect, mirror devices and the stellarator. Pinch devices are in essence very attractive. The self-magnetic field of a plasma current channel pulls it away from the wall of a containing vessel and the same field both confines and heats it. In practice, pinch devices are particularly prone to instabilities and attempts to stabilize them do make them appear much less promising. Mirror machines start from the idea of trapping individual particles in given magnetic fields; it is hoped to build up a high enough density for a release of fusion energy without the fundamental trapping concept becoming invalid. In some mirror devices very high energy particles are injected into magnetic fields, and inside the device the high energy must be converted into something which is effectively a high temperature. In a pinch device the heating of the plasma tends to destroy the confinement; in the stellarator different heating mechanisms will be used so that it can be a quasi-steady device. Rose and Clark discuss the fundamental ideas of these types of devices and also describe some specific experimental results.

I am impressed by the general standard of presentation in the book. I have found very few mistakes and misprints and many of these will, I am sure, be easily corrected in a subsequent edition. Some of the topics are of necessity dealt with rather sketchily, but I am sure that the book will be of great value not only to new graduate students but also to many who are working on a specific branch of the thermonuclear project and have never stopped to survey the whole field.

R. J. Tayler

**Hypersonic Flow Research.** Edited by Frederick R. Riddell. Academic Press, 1962. 758 pp. £4. 4*s*.

This is the seventh volume in the series 'Progress in Astronautics and Rocketry' sponsored by the American Rocket Society. It contains 22 papers on various aspects of hypersonics presented at a symposium of the American Rocket Society held at Cambridge, Massachusetts, in August 1961, together with a valuable summary report of the meeting and several short introductions to the subjects of the five sessions. The printed pages of the volume are photograpic reproductions of the texts of the various papers typed in a uniform style.