body by abrasion or compression, owed nothing to Newton, but it provided an entirely satisfactory explanation of virtually all observed phenomena. It was not until a full 50 years after Count Rumford's cannon-boring demonstrations that the dynamical aspects of heat began to be explainable. More seriously misleading to the student, however, was Tait's distortion of the important insights of Clausius regarding entropy. Many of us who grew up in the textbook tradition will learn for the first time that Clausius had a much clearer conception of entropy than Tait and his copiers have led us to believe. Except in esoteric studies, nobody until Cardwell has taken the trouble to pass on to readers what Clausius thought he was doing. He did not invent the index of unavailability, nor did he invent a pure mathematical function, unexplainable except symbolically. His explanation of entropy is not reducible to a phrase, but it can provide a classroom teacher or a student with more than the conventional and unsatisfactory bare-bones definition.

Cardwell shows clearly that the steam engine had to exist, and that it had to be in the form given to it by James Watt, before a satisfactory doctrine of thermodynamics could develop. It would be unthinkable, for example, for Sadi Carnot to have devised in 1824 a cycle that required a high-temperature source and a low-temperature sink if the Watt engine, with a separate condenser, had not provided the underlying pattern, if not the immediate model. Neither the Newcomen steam engine, in which condensation occurred in the steam cylinder, nor the high pressure noncondensing engine, whose condenser was the atmosphere, could reasonably have suggested the Carnot cycle. Of course, those who view science as merely the discovery of a preexisting coherent and logical system of relationships will disagree, but the evidence adduced by Cardwell is convincing to me.

On the other hand, the development of a theory of heat transfer, which was largely the work of French graduates of École Polytechnique, had no corresponding model in practice—for example, there was no developed technology of heat exchangers to suggest to Fourier that the mechanisms of heat transfer could be separately analyzed as conduction, convection, and radiation. Yet the definitive theory appeared, nevertheless, in Fourier's book of 1822. Neither is there a clear connection between practice and science during the period of intense activity in thermodynamics from 1845 to 1865. The work of Mayer, Joule, Kelvin, and Clausius all appears to have been impelled by intellectual, not practical, interests.

The narrative supports the idea that direct cause-effect contacts of science and technology occur sometimes but not always. To be convinced that technology must always "be there" in order for a science to develop still requires a leap of faith, but the leap is made a little shorter, I think, by this book.

Some readers may be irritated, as I was, by the author's occasional impatience with a scientist who "failed" to draw a nearly obvious conclusion or with one who "might have been successful if" he had just been a bit more perceptive. It is difficult to avoid the superior wisdom of hindsight, of course, but it should be more carefully guarded against. I disagree also on a few matters of fact, but no change that I should want to make would damage Cardwell's arguments. The text references to plates are hopelessly confused; otherwise, the publisher has produced a well-made book.

The *Bicentenary of the James Watt Patent* records the proceedings of a two-day symposium, in which a knowledgeable historian gave a lecture on Watt's genius, the James Watt Professor of Mechanical Engineering in Glasgow University traced the engineering development of the separate condenser from 1769 to the present and supplied a useful bibliography, and four technical papers were presented on current aspects of condensers. Two of the papers review recent research in film condensation and "dropwise" condensation, respectively. Because the book is such a mixed bag, the contributions will be effectively lost to readers who might in the future be interested. Better, it seems to me, to issue a commemorative brochure for ceremonial purposes, then publish the substantial contributions in the journals where they belong.

The symposium may have made a long-term contribution, however, by placing a large rock to mark approximately the spot on the "Green of Glasgow" where James Watt was walking on "a fine Sabbath afternoon" in 1765 when the idea struck him of the separate condenser.

EUGENE S. FERGUSON
University of Delaware, Newark, and
Hagley Museum, Greenville

Cosmology

Relativistic Astrophysics. Vol. 1, Stars and Relativity. YA. B. ZELDOVICH and I. D. NOVIKOV. Translated from the Russian edition (Moscow, 1967; revised by the authors) by Eli Arlock. Kip S. Thorne and W. David Arnett, Eds. University of Chicago Press, Chicago, 1971. xviii, 522 pp., illus. $24.

Relativistic astrophysics was born prematurely in December 1963 at the first of the well-known Texas conferences of that name. The purpose of that conference was to explore the idea of Fowler and Hoyle that radio galaxies arise from an explosion associated with the gravitational collapse of super-massive stars. Such collapsing stars would rapidly enter the regime where general relativity is important. The discovery of quasars in 1963 suggested a further field of application of this idea. The birth was premature, however, because even today we do not know whether radio galaxies or quasars have anything to do with super-massive stars. The real beginning of relativistic astrophysics was in 1968 when Hewish and his colleagues discovered pulsars and Gold suggested that they are rotating neutron stars, a suggestion that is now generally accepted. The gravitational potential at the surface of a neutron star is as large as about one-tenth in units of the square of the velocity of light, which means that general relativity has important effects on its structure and stability. A dramatic example of a relativistic effect would be the behavior of a Foucault pendulum placed at one of the poles of the neutron star in the Crab nebula. Such a pendulum would define a local inertial frame, but in that frame the system of stars would be seen to rotate about three times per second.

The book under review is the first comprehensive discussion of relativistic astrophysics as it stood in late 1969. It is based on a Russian original completed in 1967 by the distinguished physicists Zeldovich and Novikov, revised by them in 1969, and further edited by the American astrophysicists Thorne and Arnett on the basis of an excellent translation by Arlock. Despite the complexities of this collaboration the book maintains a unified tone, the one we have come to associate over the years with the senior author. That means emphasis on the physics rather than on the formal mathematical structure of general relativity. In that spirit the book contains an interesting account of gravitational radiation, of the prototype black holes associated with the Schwarzschild and Kerr metrics, of the equilibrium, stability, and evolution of ordinary and super-massive stars, of relativistic star clusters, and of accretion processes in the vicinity of highly condensed objects.

Much of this material is not particularly relativistic, and when relativistic effects do come in they are usually treated as perturbations, although occasionally they are also qualitatively important. It is my impression that future developments in this subject will require a more mathematically sophisticated technique than is used by Zeldovich and Novikov. The truth of this has already been foreshadowed by the singularity theorems of Penrose and Hawking, and it seems to be substantiated in the recent work of Carter and Hawking on the final asymptotic state exterior to a collapsing system and on the efficiency with which rest-mass is converted into gravitational radiation when black holes combine. Thus although this book will remain valuable for some time to come for the physical insights it provides, the future research worker in relativistic astrophysics will probably need to supplement it with a more profound treatment of general relativity.

D. W. SCIAMA
Department of Astrophysics, University Observatory, Oxford, England

Separation Technology

Synthetic Polymeric Membranes. Robert E. KESTING. McGraw-Hill, New York, 1971. xii, 308 pp., illus. $18.75.

In 1855, Adolf Fick reported the first experiments on osmosis and diffusion through artificial membranes. The membranes were cast collodion (nitrocellulose) films that separated pure water from a saturated solution of common salt. Fick observed the selectivity that is the basis of all membrane separation processes in noting that whereas appreciable osmotic transport of water occurred there was very little transport of salt. Fick's main purpose in performing this experiment was to check the theory that separation occurred by motion of the solution through fine pores —pores small enough that the salt concentration was very small within them. He concluded, on grounds that seem quite incorrect today, that this pore theory was untenable, both for these artificial and for natural membranes.

Strangely enough, the question of the existence and importance of pores in membrane transport processes is still unresolved and is one that excites violent emotions, a major reason for the controversy being that the detailed structure of membranes, both artificial and biological, is not well known by direct measurements. The past decade has seen a dramatic increase in the study of membrane transport and, most particularly, in the synthesis of new membranes for specific separatory processes. Indeed, more new types of membranes have been introduced in this time than in all of previous technology. For instance, the differential transport of salt and water studied by Fick is the basis of a process for making fresh water out of salt or brackish water. The process, reverse osmosis, is simply the forcing of salt water through a suitably selective membrane. A key technical event in its development was the discovery—by S. Loeb and S. Sourirajan—of a cellulose acetate membrane structure that gave both efficient separation and large flow. This discovery coupled with a far-reaching program of support by the Office of Saline Water of the U.S. Department of the Interior has led to an extremely broad search for new membranes and increased investigation of the relationship between structure and properties. The volume under review is the first to take full advantage of this increased effort. (A complementary encyclopedic and authoritative account of the present understanding of membrane transport is found in *Transport Phenomena in Membranes* by N. Lakshminarayanaiah, Academic Press, 1969.)

The emphasis of the present work is on the structural aspects of synthetic polymeric membranes as they relate to the properties and modes of fabrication. In order, the author treats dense membranes (films), porous membranes, phase inversion membranes, membranes formed in situ, and ion exchange membranes. The chapter on porous phase inversion membranes is the first extended account in English of this commercially important and complex technology. If the process is not rendered completely clear by this treatment, the reason lies in the fact that four volatile components concomitantly evaporate into a controlled atmosphere to leave the porous cellulose ester behind.

Another feature of the book is a large collection of scanning electron photomicrographs of various structures. Unfortunately, those that are original to the author are uniformly given with no indication of magnification.

A chapter that deals with the microscopic aspects of membrane processes is less successful than the rest of the book. Kesting emphasizes those studies that indicate a structuring of water at interfaces. Unfortunately, the collection of work cited is somewhat careless and the results are ill digested. For example, some early work by Schwan on the high-frequency dielectric properties of hemoglobin solutions is presented to demonstrate the existence and indicate the importance of bound or structured water but later work from Schwan's laboratory (*J. Phys. Chem.* **73**, 2600 [1969]) that significantly modifies his earlier conclusions is neglected. Indeed, the bound water is now thought to amount to less than a monolayer on the protein molecule.

With some reservations concerning the theoretical explanations of transport processes, this book can be recommended to those engaged in membrane research and development as well as those who wish to apply membranes with a better knowledge of their structure.

CHARLES P. BEAN
General Electric Research and Development Center, Schenectady, New York

Books Received

Advances in Pharmacology and Chemotherapy. Vol. 9. Silvio Garattini, A. Goldin, F. Hawking, I. J. Kopin, and R. J. Schnitzer, Eds. Academic Press, New York, 1971. x, 358 pp., illus. $19.

Advances in Veterinary Science and Comparative Medicine. Vol. 15. C. A. Brandly and Charles E. Cornelius, Eds. Academic Press, New York, 1971. xviii, 326 pp., illus. $19.

Aerial Photo-Ecology. John A. Howard. Elsevier, New York, 1970. xviii, 326 pp. + plates. $18.

Algebraic Spaces. Michael Artin. Yale University Press, New Haven, Conn., 1971. viii, 40 pp., illus. $2.95. Yale Mathematical Monographs, 3.

The Alkaloids. Chemistry and Physiology. Vol. 13. R. H. F. Manske, Ed. Academic Press, New York, 1971. xviii, 458 pp., illus. $24.

American City Planning Since 1890. A History Commemorating the Fiftieth Anniversary of the American Institute of

(Continued on page 810)