EDDINGTON ON CONSTITUTION OF STARS

The Internal Constitution of the Stars. By A. S. Eddington. Cambridge University Press, 1926. viii+407 pp.

The author says that this book was written between May 1924 and November 1925 and that during this period theoretical papers in stellar constitution in the Monthly Notices alone amounted to more than 400 pages. He has tried to cover everything up to November 1925 and, in proof, some further material up to March 1926. Composition under such circumstances is difficult even for one who has contributed very actively to the subject for the previous decade, and particularly when he has been currently engaged in a running fight with his most eminent compatriot specializing in the same field. A popular account of the subject may be found in Science (May 6, 1927, pp. 431–438) by Menzel, and there is no need here to repeat it. Suffice it to remark that this book reads like a romance to those who are not deterred by the mathematics whether because they can follow it or because they ignore it; the difficulties of composition do not show in the style.

One may raise the question: Is it romance or science? We all recall the "Cosmic Crucibles" of G. E. Hale. We see only the thinnest fumes hovering over the crucibles; how much do we know about the conditions within them? Certainly very little. The highest steady temperatures with which we can work in the laboratory are only a few thousand degrees; by spectral observations on the exterior of stars we record spectra which by the law of Wien (or Planck) we estimate at most as toward a very few tens of thousands; just what the temperatures are, or even whether there is anything truly corresponding to temperature in the explosive discharges of Anderson we perhaps do not know. When therefore through a course of reasoning we set 40,000,000 degrees as the normal temperature of the center of a sun we are stretching our laboratory laws a great deal on the side of extrapolation toward infinity, we are dealing certainly not with scientific facts, in the sense of verifiable facts of observation, we are wholly in the realm of theory, in that of faith which has ever had a higher psychic appeal than fact.

True, we work in our vacuum tubes at high potentials with high speed electrons and observe their effects upon matter; true, too, that to produce free electrons of such speeds under conditions of thermal equilibrium would require intense temperatures; but how safe is the passage from an observed high tension electric dis-equilibrium with its multifarious manifestations to an inferential intense thermal equilibrium? And then there are the tremendous pressures; what are their effects on the imagined and inaccessible phenomena we are studying? Bridgman's highest laboratory pressures do not take us much if any below our lithosphere and yet they at least approach those that justify our speaking of the compressibility of the molecules and atoms. May it be that in the upper stellar atmospheres the luminous effects are chiefly electrical, as in our vacuum tubes or possibly in our aurora, rather than thermal as such, and that in the stellar interiors the physical state is one governed more by pressure than by temperature?

The author does not minimize the physical difficulties. What he does is to take our finite physical laws of observation as they are, add to them some inferential generalizations, assume both to hold everywhere even under conditions far more extreme than any realized in the laboratory, and upon this to build a mathematical physical theory of the internal constitution of the stars, which in turn he tries to justify, and with a large measure of success, upon the record of astronomical, chiefly astrophysical, classification of the stars. This is a perfectly sound procedure. The business of a scientific theory is to bind together the scientific observations. We have certain variables or parameters $a, b, c, \cdots$ which represent the facts observed; we desire to find rational relations between them; we introduce certain auxiliary unknown variables $x, y, z, \cdots$ with laws connecting them to $a, b, c, \cdots$ and among themselves; we ultimately eliminate the unknowns and come out with the desired relations between the knowns and verify those relations on the facts. In a field so actively worked as stellar physics is today, both observationally and theoretically, in a field in part so much in dispute as is this between Eddington and Jeans, changes may well come; such is science in the romantic, perhaps better in the heroic or epic phase when an Achilles fights his Hector for some lady who, forsooth, belongs to a third (or fourth) party.

There is something more involved than the rational correlation of the observed quantities $a, b, c, \cdots$, some constraints on the manner of that correlation; the real riddle is the permanence of this planet. Geology and paleontology need half a billion years, radioactive studies set the age of the earth's crust as around a billion years, we apparently must think of the luminous life of a star as measured in centuries of billions of years. Where does the energy come from? Evolution goes too slowly for the physics we know and can only be expounded on extensive extrapolations. Laplace, Helmholtz, Kelvin, all who have tried to set a time scale by old fashioned physics have fallen far short of the mark; our present hope seems to reside in the commutation of material mass into radiant energy through Einstein's equation $E=mc^2$, each disappearing gram of matter giving rise to 9×10^{20} ergs of radiation. The synthesis of hydrogen into helium, when, if, and as it takes place, would by this equation release a store of energy vast in comparison with ordinary chemical reactions, but apparently a bit too small in amount to maintain for its life the radiation of a star; we apparently have to fall back on some sort of super-radioactivity (Jeans) or on the coalescence of electron and proton into nothingness (Eddington).

After the immediate satisfaction of our needs for individual sustenance and for the continuation of the race, our most imperious demand seems to be to solve the infinite problems of our finite minds—a truly imperial ambition. It is right and proper that we should offer a crown to such a Caesar as our author. At the risk of marking ourselves as some miserable

Cinna we may make a few additional comments quoting from p. 163: "At the beginning of 1924 the giant and dwarf theory of Hertzsprung and Russell was almost universally accepted. . . . . I do not think it is too blunt an expression to say that this is now overthrown; at least it has been gutted, and it remains to be seen whether the empty shell is still standing." Note the great change in two years. Things are moving fast, not faster perhaps than a genius may develop new theory, but surely far faster than new facts of observation may be revealed and established. And herein lies a source of possible future overthrow for any present theory; we need more and better facts and they are slow to get. Moreover we need facts that are not colored or selected by our preconceived but not yet established theories. There is a marked tendency for an accepted, albeit perhaps not established, theory to bring to light those facts which may perchance support it and to obscure those which might contravert it. This is particularly true when the argument is statistical as is now common in astronomy. I do not say that the author is unfair; the question is one of judgment and his judgment should be as good as that of anybody and certainly incomparably better than mine; I merely cite his inevitable liabilities. In speaking of the synthesis of hydrogen into helium he says (p. 301): "We do not argue with the critic who urges that the stars are not hot enough for this process; we tell him to go and find *a hotter place*." I am not finding fault with the facts that we have but merely urging that we need better ones and more of them.

Although the chief interest of the author is in the deep interiors of the stars and in astronomical observations his text is full of developments of and suggestions for physics and of astronomical conditions on the surface of or exterior to the stars. A list of the chapter headings gives the best short summary of the content of the book. I. Survey of the Problem. II. Thermodynamics of Radiation. III. Quantum Theory. IV. Polytropic Gas Spheres. V. Radiative Equilibrium. VI. Solution of the Equations. VII. The Mass-Luminosity Relation. VIII. Variable Stars. IX. The Coefficient of Opacity. X. Ionization, Diffusion, Rotation. XI. The Source of Stellar Energy. XII. The Outside of a Star. XIII. Diffuse Matter in Space. There is a table of physical and astronomical constants, a long list of references with some brief summaries of their content, and a good index. If any reader thinks the author at times is too zealous, too dogmatic, let him persevere until he can distinguish brilliancy of style from fixation of mind, even unto these words from the final paragraph: "The history of scientific progress teaches us to keep an open mind. I do not think we need to feel greatly concerned as to whether these rude attempts to explore the interior of a star have brought us to anything like the final truth. We have learned something of the varied interests involved."

EDWIN B. WILSON