HOW TO BREW THE ELEMENTS IN STARS, IN SUPERNOVAE AND IN THE BIG BANG

Cauldrons in the Cosmos: Nuclear Astrophysics

Claus E. Rolfs and William S. Rodney
U. of Chicago P., Chicago, 1988. 561 pp. $74.95 hc ISBN 0-226-72456-5; $34.95 pb ISBN 0-226-72457-3

Reviewed by Friedrich-Karl Thielemann

Progress in nuclear astrophysics, the topic of Claus Rolfs and William Rodney's *Cauldrons in the Cosmos*, has often been closely linked to progress in nuclear physics. Experiments on light targets in the early days of nuclear physics led Carl Friedrich von Weizsäcker, Hans Bethe and Charles L. Critchfield in the 1930s to the identification of the carbon–nitrogen and proton–proton cycles, which became the basis for the understanding of stellar energy generation. The wealth of neutron-capture cross sections that became available in the 1940s and 1950s, together with the elemental abundances collected by Hans Suess and Harold Urey in 1956, initiated the understanding of the formation of heavy nuclei beyond iron. These ideas were integrated into a coherent picture by Margaret Burbidge, Geoffrey Burbidge, William Fowler and Fred Hoyle as well as A. G. W. Cameron in 1957. Finally, high-energy heavy ion collisions can today probe aspects of the equation of state beyond nuclear matter densities so urgently needed to understand the collapse and explosion of type II supernovae.

In the meantime, a vast amount of nuclear data on light and intermediate nuclei was assembled in nuclear laboratories. This effort was spearheaded mainly by investigators at the Kellogg Radiation Laboratory at Caltech, working under Fowler's direction. Rolfs and Rodney met there in 1973. Since then they have pursued very active careers in nuclear astrophysics, and Rolfs's laboratory in Münster (FRG) has become one of the most important sources of data for low-energy nuclear astrophysics.

Among the many recent developments in nuclear astrophysics are the building of radioactive-ion-beam facilities for reactions on unstable nuclei (in Louvain-la-Neuve, Belgium; at RIKEN, Japan; at Lawrence Livermore National Laboratory; and possibly at TRIUMF, Canada) and the measurement of masses and halflives of very neutron-rich nuclei close to and in the r-process path (at CERN; Brookhaven National Laboratory; Studsvik, Sweden; GANIL, France; and GSI, FRG). It therefore now seems quite appropriate for a new textbook to present the developments since Donald D. Clayton's *Principles of Stellar Evolution and Nucleosynthesis* (McGraw–Hill, New York) appeared in 1968. *Cauldrons in the Cosmos* is not, however, intended as a replacement for Clayton's book. The latter mentioned the results of nuclear experiments where they seemed necessary, but it concentrated on stellar evolution. *Cauldrons* really focuses on experimental aspects.

The two introductory chapters about astronomy and astrophysics set the stage and give the motivation for research in nuclear astrophysics aimed at understanding stellar energy generation and the local Galactic abundances of nuclei. Here we find first a very general observational overview of astronomy from the solar system through stars, stellar clusters, galaxies and finally the universe. The chapter on astrophysics familiarizes the reader with theoretical aspects of the Big Bang, galaxy formation, stellar evolution, novae and supernovae. This chapter is, however, not as detailed as texts about these specific topics can be.

Then the book plunges into its real subject—nuclear reactions in stars—and makes the connection between the quantities needed in astrophysical applications and the nuclear quantities measured in the laboratory. This is probably the most complete presentation of the topic in an existing textbook. Here we get to know the main field of expertise of both authors when they describe laboratory equipment and techniques in nuclear astrophysics. This chapter could serve as a textbook by itself on experimental methods in nuclear physics; it gives a tremendous overview such as is hardly ever found even in standard nuclear physics textbooks. It discusses ion sources and methods of beam formation in all types of accelerators, from Van de Graaff machines to tandems, cyclotrons and linacs. The features and preparation of solid and gas targets, detectors, data reduction and future techniques (accelerator mass spectrometry, radioactive ion beams and storage rings) for dealing with unstable nuclei and targets are presented in excellent detail. This chapter could as well be part of an experimental nuclear physics textbook. But the emphasis throughout is on the techniques needed for astrophysical applications, specifically those for dealing with minuscule cross sections at energies below the Coulomb barrier. These are the energies of highest importance at the temperatures encountered in the hydrostatic burning stages of stellar evolution. This part of the book will be very helpful to graduate students getting into this field of experimental research, and it will amaze others with the complexity of the methods employed to provide them with data for their theoretical calculations.

After this impressive excursion, the book returns to astrophysics and goes in detail through all important reactions of hydrogen burning and helium

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burning. Advanced burning stages and explosive burning in supernovae are dealt with in a somewhat more cursory way, while nucleosynthesis beyond iron by the s-process and r-process is again discussed at great length. The concluding chapter is devoted to miscellaneous topics like the solar neutrino problem, isotopic anomalies in meteorites and the origin of the light elements lithium, beryllium and boron from spallation reactions.

One minor criticism I have is that the subtitle *Nuclear Astrophysics* is probably too general. Electron captures on nuclei in late burning stages under partially degenerate conditions define the size of the iron core before a type II supernova collapse and have a decisive influence on the collapse. The equation of state at nuclear densities and beyond plays a significant role in type II supernovae. These important topics are not covered in detail in *Cauldrons in the Cosmos*. Some of these subjects can be found, for example, in Stuart Shapiro and Saul Teukolsky's *Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects* (Wiley, New York, 1983; reviewed in PHYSICS TODAY, October 1983, page 89). *Cauldrons* is a bit short on these points, and it is not a replacement for a textbook on all aspects of stellar evolution such as Clayton's. The authors rather purposely restrict themselves to *experimental* nuclear astrophysics, where they do an excellent job.

Cauldrons in the Cosmos is a book from which every astrophysicist can gain insight into present-day laboratory efforts, and it gives up-to-date treatments of many of the topics in a standard course on stellar evolution. For nuclear physicists it presents the motivation and the astrophysical background for laboratory experiments as well as the methods needed for this field of application. For everybody else it will give an excellent overview of the state of the art in nuclear astrophysics.

Handbook on Synchrotron Radiation, Volume 2

Edited by Geoffrey V. Marr
North-Holland,
New York, 1987. 846 pp.
Dfl 450.00 ($219.50) hc
ISBN 0-444-87046-6

There has been rapid development in the use of synchrotron radiation sources for research in physics, chemistry, biology, medicine and materials science during the last 10–15 years. Therefore, it is laudable that North-Holland has undertaken the task of issuing a series of handbooks on synchrotron radiation research with the objective of providing as complete a coverage as possible. Four years elapsed between the first volume of *Handbook on Synchrotron Radiation* and volume 2. Less time between the remaining volumes in this series would be desirable.

In handbooks of this kind there is frequently little or no connection and correlation among the chapters: They comprise entities of their own within the research specialties of the authors. Thus there are obvious overlaps and serious omissions in the material covered. This limits the usefulness of such a handbook, the main asset being that good review articles with some common themes are bound together in one volume and in this way provide a convenient introduction to the field. *Handbook on Synchrotron Radiation, Volume 2,* certainly belongs to this category. In general, the chapters are well written and informative, and the collective knowledge and experience of the authors are impressive. I can certainly recommend this handbook as an excellent starting point for researchers entering the synchrotron radiation field. The price will deter most individuals and research groups from buying it, but it is mandatory for a well-equipped reference library.

The first three chapters deal with synchrotron radiation properties in general and instrumental aspects. Three chapters (4, 5 and 6) are devoted to atomic and molecular physics, three (7, 8 and 10) to surface and interface science, and one (chapter 9) to theoretical aspects of core-level photoelectron spectroscopy. Chapter 11 is concerned with optical constants.

In chapter 1, though it is by necessity short and fragmented, the volume editor, G. V. Marr, in collaboration with I. H. Munro, gives an introduction to synchrotron radiation sources: where their development stands and what their prospects are.

Chapter 2, by J. B. West and H. A. Padmore, is entitled "Optical Engineering" and covers a broad range of topics related to source properties, mirrors, diffraction-grating optics, beam-line layout and beam-line instrumentation. I think that this chapter is the best available introduction to the general considerations that must go into the design and construction of a synchrotron radiation beam-line. I strongly recommend it for those entering the field who need to get an understanding and appreciation of the instrumental requirements and limitations.

Chapter 3, by P. A. Ridley, is entitled "Data Acquisition and Analysis Systems" but addresses more specifically the requirements for experiments in the vacuum ultraviolet and soft-x-ray spectral regions. Ridley covers data acquisition electronics, motor driving and digital interfacing, local computer systems and data processing facilities.

Chapter 4, entitled "High Resolution Spectroscopy of Atoms and Molecules Including Faraday Rotation Effects," is by J. P. Connerade and M. A. Baig. It covers only a small fraction of the work of the authors and others on spectroscopic investigations of atoms and molecules, and the discussion is restricted to wavelengths longer than 100 Å. This shortcoming is partially compensated for by extensive references to the literature.

Chapter 5, by J. L. Dehmer, A. C. Parr and S. H. Southworth, is a very clear exposition on "Resonances in Molecular Photoionization." It reviews the elementary aspects of shape resonances and autoionization, with a good balance between theory and experiment, and provides the reader with an excellent understanding of where the field stood in early 1986. The authors draw heavily from their own published research in a major fraction of the chapter that is devoted to case studies.

The topic of chapter 6 is "Molecular Photodissociation and Photoionization." The authors I. Nenner and J. A. Beswick describe the basic mechanism of dissociation and ionization in isolated small molecules. A large body of work has been done in these fields using lasers and conventional sources, but synchrotron radiation has undoubtedly caused a rapid development during the last few years and has steered the fields in new directions.

Synchrotron radiation has probably had a greater impact on surface science than on any other field. In chapter 7, I. T. McGovern, D. Norman and R. H. Williams have taken on the unenviable task of giving a broad overview of "Surface Science with Synchrotron Radiation." They have been largely successful in providing a good introduction for the nonspecialist. The reader is served a few tidbits, which should increase the appetite for further reading.

In chapter 8, L. J. Brillson focuses the discussion on "Metal–Semiconductor Interface Studies." The coverage is fairly traditional: chemical bonding at metal–semiconductor interfaces, metal–semiconductor interdiffusion and so on. The review may