

fluxes. Neutrinos cannot possibly be the dark matter—something more exotic is needed—but, surprisingly, in the framework of so-called leptogenesis scenarios they are intimately related to the cosmic matter–antimatter asymmetry.

Astroparticle physics, which covers the above and a diverse range of related topics, has begun to develop its identity as an independent research field with dedicated conferences, journals, university chairs, and even research centers and networks. Still, while excellent textbooks exist for cosmology, cosmic-ray physics, gravitational physics, and neutrino physics, few texts cover the full range of astroparticle physics. One notable exception is the excellent book *Cosmology and Particle Astrophysics* (Springer-Verlag, 2004) by Lars Bergström and Ariel Goobar, which has just appeared in its second edition.

Particle Astrophysics, by Donald Perkins, emeritus professor of physics at Oxford University, is another complete treatment, aimed at final-year undergraduate or beginning graduate students. It is largely based on the author's hugely successful *Introduction to High Energy Physics*, which has seen four editions since 1972. The latest one (Cambridge U. Press, 2000), now in its third printing, includes a single chapter on cosmology. In *Particle Astrophysics*, on the other hand, three chapters cover cosmology, two treat particle physics, and a chapter each is devoted to cosmic particles (including neutrinos and gravitational waves) and to stellar evolution. The text is interspersed with worked examples. Each chapter has a concise summary and an extensive set of problems ranging from the trivial to the challenging. Answers or detailed solutions are provided at the end of the book, along with a somewhat limited bibliography. *Particle Astrophysics* covers a lot of ground and touches on many topics. It will be a useful resource for professors and a helpful supplemental text for students.

In spite of its obvious virtues, however, I could not really warm to the book. The synergy between chapters is minimal, the choice and weight of different topics are often poorly adjusted to the main story line, and the perspective is often outdated. For example, the text uses about a page to swiftly dispose of the astrophysical evidence for dark matter and then gives five pages to gravitational microlensing. But it never says that the crucial microlensing experiments it describes have excluded compact stars as a dominant dark-matter com-

ponent and thus have strengthened the case for particle dark matter. Although neutrino oscillations are mentioned briefly in the cosmic-particles chapter, I find it bizarre that the particle-physics chapters are written as if the fantastic recent developments had never happened. Even Super-Kamiokande is introduced exclusively as a proton-decay detector.

That the universe may serve as a laboratory to test new particle-physics ideas is completely ignored. From this book, one would never guess that cosmology provides the most significant information on neutrino masses or that astrophysical arguments constrain numerous extensions of the standard model. I have complaints about many details and annoying errors, but what I am missing most is a coherent, contemporary presentation of astroparticle physics and a sense of real enthusiasm for this exciting field.

Georg Raffelt

*Max Planck Institute for Physics
Munich, Germany*

Rotational Spectroscopy of Diatomic Molecules

John M. Brown and Alan Carrington
Cambridge U. Press, New York, 2003. \$150.00, \$75.00 paper (1013 pp.). ISBN 0-521-81009-4, ISBN 0-521-53078-4 paper

John Brown and Alan Carrington, leading molecular spectroscopists, are well known for their work on high-resolution spectroscopy, mostly on short-lived molecules in the gas phase. In *Rotational Spectroscopy of Diatomic Molecules*, they have produced a survey of the various kinds of spectra that one can observe without changing the electronic or vibrational state of a molecule.

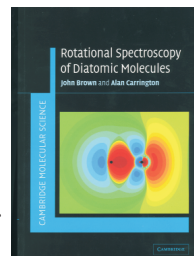
Scientists began to understand the spectra of diatomic molecules in the early 20th century and were given a great boost by the advent of quantum mechanics in the 1920s. Researchers such as John H. Van Vleck, Friedrich Hund, and Robert S. Mulliken developed the general principles of the interpretation of spectra of diatomic molecules. Those principles were summarized in Gerhard Herzberg's classic monograph, *Molecular Spectra and Molecular Structure. Volume 1: Spectra of Diatomic Molecules* (Prentice Hall, 1939). In 1989, Krieger Pub-

lishing revised and reprinted the second edition of the book. But Herzberg's 1939 book was rapidly overtaken during and after World War II by new developments in spectroscopy, including the introduction of molecular-beam techniques using electric and magnetic resonance and the wide availability of ex-radar microwave equipment. The most important factor in those developments was increased resolution, which the use of Fourier transform techniques and lasers has since extended to shorter wavelengths. With high resolution, the hyperfine structure due to nuclear spin—a structure rarely resolved in conventional spectroscopy—becomes accessible.

Parallel to the experimental developments, new methods of fitting the data were introduced. Rather than use explicit formulas for the energy levels, researchers treated them as the eigenvalues of a (hopefully small) matrix representation of the effective Hamiltonian. For example, for a state with electron spin S but no orbital degeneracy, the effective Hamiltonian would be a matrix of dimension $2S+1$, which can usually be factorized into two submatrices because of parity symmetry. For a doubly degenerate orbital state, the matrices would be twice as large. A nuclear spin I would increase the matrix size by a factor $2I+1$, and so on. Extra symmetry exists for molecules containing two identical nuclei.

Brown and Carrington's weighty volume is a paean to the effective Hamiltonian, which is developed in considerable detail from fairly basic principles. The essential technique is to transform the Hamiltonian to remove terms whose matrix elements connect states that are well separated in energy. For instance, different electronic states tend to be well separated in energy, and the interactions between them can be simulated by terms in the effective Hamiltonians of the two states, with coefficients that reflect the size of the interaction. A good example is the so-called Λ -type doubling of Π electronic states, produced by interactions with Σ states. The procedure is relatively simple for the purely electronic and rotational degrees of freedom but becomes quite involved when nuclear spin and electromagnetic fields have to be considered.

The treatment of the subject in Brown and Carrington's book is exhaustive. For example, the formula for the full electronic Hamiltonian be-



fore transformation, including electric and magnetic fields but not nuclear spins, covers two full pages with 32 distinct terms identified. The systematic evaluation of the matrix elements of such terms requires spherical-tensor techniques, which the authors develop from scratch and use extensively. By way of contrast, I searched in vain in Herzberg's book for the matrix elements of J_+ and J_- , which are fundamental operators in the spherical-tensor algebra.

After the authors develop the theoretical tools, much of the second half of the book is devoted to case studies of spectra of particular molecules. The studies are often described in terms of classic experiments that introduced some of the observational techniques. These case studies often show the authors' bias toward electric- and magnetic-field effects and hyperfine structure; not until chapter 10 (more than two-thirds of the way through the book) do readers finally reach the subject of pure rotational spectroscopy in a book on rotational spectroscopy!

Rotational Spectroscopy of Diatomic Molecules is carefully written and well produced. But a curious characteristic, partly responsible for the book's great size, is its repetitiveness. For example, the authors introduce the Euler angles twice, in chapter 2 and again in chapter 5, using exactly the same diagram. Spherical harmonics are defined in table 5.1 with standard phases, but they reappear for no apparent reason in table 6.1, with different phases. In the case studies, the matrix elements of terms often duplicate previous equations. The authors sometimes repeat steps in the algebra as though their treatment of each molecule had to be self-contained. The formulas are useful for their intended purpose, but to the uninitiated they look like opaque jumbles of Wigner $3j$, $6j$, and occasionally $9j$ symbols, with strange sign factors that only a devotee could love; it is difficult to see why they should be repeated.

A significant error in the book is in the authors' calculation of transition probabilities in chapter 6. The radiation density should be twice that given in the equation. As a result, the whole calculation is off by a factor of 2. In addition, the important statistical-weight factors are omitted from the calculation, but they appear later in chapter 10. The authors have the annoying habit of referring to some topic "as described elsewhere in this book," but with more than 1000 pages to choose from, such things are not easy to find.

Among other books covering similar subject material, the closest to

Brown and Carrington's book is possibly *The Theory of Rotating Diatomic Molecules* (Wiley, 1975) by Masataka Mizushima, which is less useful for the working spectroscopist and may be difficult to find in print. *Perturbations in the Spectra of Diatomic Molecules* (Academic Press, 1986) by Hélène Lefebvre-Brion and Robert W. Field—or its revised version, *The Spectra and Dynamics of Diatomic Molecules* (Elsevier, 2004), by the same authors—is more concerned with excited electronic states that are nearly degenerate with each other. Walter Gordy and Robert L. Cook's *Microwave Molecular Spectra* (Wiley, 1984) and Eiji Hirota's *High-Resolution Spectroscopy of Transient Molecules* (Springer-Verlag, 1985) contain chapters on similar subjects, but those books are not restricted to diatomic molecules.

Rotational Spectroscopy of Diatomic Molecules is a detailed, wide-ranging presentation of all kinds of spectra within a given electronic-vibrational state of a diatomic molecule. All serious spectroscopists should have a copy, and the book's price is reasonable. Besides, its sheer mass could be used to deter intruders.

James K. G. Watson

*Steacie Institute for Molecular Sciences
Ottawa, Canada*

Stellar Alchemy: The Celestial Origin of Atoms

Michel Cassé (translated from French by Stephen Lyle)
Cambridge U. Press, New York,
2003. \$30.00 (242 pp.).
ISBN 0-521-82182-7

Many of us like to reflect on our childhood and family history. The search for origins covers not only human sensibility but also astronomical pursuits. In fact, "origins" is one of NASA's main themes and the title of one of its programs. In *Stellar Alchemy: The Celestial Origin of Atoms*, French astronomer Michel Cassé tells in his native language (translated by Stephen Lyle) some of the fascinating stories about how the elements in each of us came to be.

The lightest elements—including hydrogen (and its deuterium isotope), helium, lithium, beryllium, and boron—were formed in the first few hundred seconds or so after the Big Bang, an interval immortalized in Steven

Weinberg's book *The First Three Minutes: A Modern View of the Origin of the Universe* (Basic Books, 1977). Heavier elements, up to and including iron, were synthesized in stars. Elements heavier than iron come from fusion processes, called nucleosynthesis, that take place in supernovae, exceedingly violent events in our universe's history.

Cassé tells how the ideas of nuclear origins were put together. He even tells a personal story about his asking William Fowler, who shared in a Nobel Prize for his work on the origin of the elements, how he had linked up with Fred Hoyle to figure out basic paths for nucleosynthesis. Hoyle had found the fundamental idea of how to bridge an instability gap with beryllium to form carbon. Cassé describes how the work wound up in the fundamental paper B²FH, which stands for Margaret Burbidge, Geoffrey Burbidge, Fowler, and Hoyle. The paper, which shows the variety of paths needed for the formation of elements, appeared in *Reviews of Modern Physics* in 1957.

Deuterium is the only isotope that is uniquely formed in the period just after the Big Bang. Thus deuterium abundance reveals initial conditions because, unlike helium, for example, which is a common product of stars, it is not created in the subsequent eons. Cassé acknowledges the importance of determining the deuterium abundance, but he relegates it to his first lengthy, discursive appendix in the book. He writes that "deuterium holds the key to the mystery, but it is difficult to measure." My own work in the field deals with cosmic deuterium. Most recently, Jayaram Changelur, Donald Lubowich, and I tried again, without immediate success, to detect deuterium's fundamental spin-flip line at a 92-cm wavelength using the new Giant Meterwave Radio Telescope outside Pune, India. But values of the deuterium abundance from UV spectra and from radio observations of deuterated molecules, which need chemical interpretation, have elucidated light-element formation from this primordial nucleosynthesis.

Stellar Alchemy is for the general reader, although some parts of the text and some diagrams are complex. The author does not hesitate to give equations for fusion and decay processes. I think it is strange and rather off-putting to begin each chapter with a boldfaced set of vocabulary words and definitions. Chapter 1 begins with

