Molecules in Space

Molecular Astrophysics. A Volume Honouring Alexander Dalgarno. T. W. HARTQUIST, Ed. Cambridge University Press, New York, 1990. xvi, 484 pp., illus. $79.50.

Despite centuries of observations of the night sky, it was not until early in this century that the existence of matter in the "empty space" between the stars was inferred from observations of atomic absorption lines in stellar spectra that had different Doppler shifts from the stars themselves, suggesting "clouds" of atomic gas along the line of sight. In the 1930s absorption lines of a few simple diatomic molecules were also observed in the interstellar gas, but until quite recently it was believed that most astrophysical environments, and certainly the interstellar medium, were too hostile for chemical (that is, molecular as opposed to atomic or nuclear) processes to be important. The introduction of radio astronomy in the 1950s proved an excellent means for studying the interstellar gas via observations of the 21-centimeter wavelength fine-structure transition of atomic hydrogen. Although many molecular species also have strong transitions at radio frequencies, they were not expected to be present in the interstellar gas and no one looked for them (with the exception of the simple hydroxyl radical, detected in 1963) until 1968 when ammonia was observed. This evidence prompted the search for other molecules in the interstellar gas, and within a few years dozens of additional species (including water, carbon monoxide, alcohols, aldehydes, and organic acids, nitriles, and amines) were identified, ushering in the whole new field of molecular astrophysics.

It is now apparent that the interstellar gas, although quite diffuse, contains an amount of matter comparable to that in the stars, divided approximately equally between atomic regions and molecular regions. Further, interstellar molecular clouds are intimately tied to stellar life cycles, being the material from which stars are created and the repository for various stellar ejecta. Studies of molecular clouds have therefore provided a better understanding of stellar evolution as well as the morphology, energetics, and kinematics of the interstellar gas itself. Because physical conditions in these objects (extremely high vacuum and low temperatures) are typically quite different from those obtainable in the terrestrial laboratory studies of interstellar molecules have also fostered new insights into molecular properties and processes.

During its short existence, molecular astrophysics has become an important subdiscipline of astronomy and is still growing rapidly, mostly through extending observations to higher frequencies that generally must be observed from above the atmosphere. *Molecular Astrophysics* is a collection of review articles covering most aspects of current research in this field. The first two chapters (part 1) provide an overview of molecular clouds (their distribution, physical properties, and chemical composition) in the Milky Way and in other galaxies, respectively. A chapter by Myers that gives a lucid general summary of cloud structure, motions, and evolution would appear to belong in part 1 also but is found much later in the book. Molecular clouds are generally classified as diffuse or dense: the former are translucent to visible and ultraviolet light so that photochemical processes are important, whereas the latter are opaque. (It should be noted that the extinction is due not to the gas itself but to the associate dust particles or "grains".) Diffuse clouds are considered in the next three chapters, which make up part 2. Van Dishoeck gives a good summary of the chemistry in these clouds. Early chemical studies, which assumed simple physical models for the clouds, predicted abundances in harmony with observations for many species, but a few discrepancies, notably excess abundances of CH^+, remained. It is now thought that shock waves passing through the clouds modify some of the abundances and explain these data. Langer discusses observational evidence for such velocity structure, and Hartquist, Flower, and Pineau des Forêts discuss the theory of shock waves and how they affect the chemistry. The next three chapters (part 3) discuss chemistry in dense clouds. One of the oustanding problems has been the nature of grains and their possible (catalytic) role in the chemistry. Whereas the line spectra of gas-phase molecules give unambiguous identifications, the broad spectral features attributed to the grains leave room for conjecture about their composition. Recently, new, if indirect, information has been obtained from exploration of Halley's comet and study of interplanetary dust particles collected in the stratosphere; the chapter by Buch gives a very good discussion of the grains and their chemistry in light of these new data. A related controversial area has been the existence of "large molecules" and whether they form a continuous bridge between the observed species (the largest of which have about a dozen atoms) and small grains; polyaromatic hydrocarbons, which are reminiscent of small bits of graphite, have been suggested. This topic is discussed by Lepp.

The first chapters in part 4 discuss basic molecular processes: molecular spectroscopy, photochemical rates, collisional excitation rates, and chemical reaction rates. Since these are fundamental to understanding some of the earlier chapters, it is not clear why they are placed here. In fact, it is suggested in the preface that the (excellent) paper on molecular spectroscopy by Kirby could profitably be read before part 2.

Twenty years ago, when it was first learned that molecules were abundant in the interstellar medium, it was difficult to understand how they could be formed from the atomic gas faster than they would be destroyed by photodissociation. It was eventually realized that once the density was great enough grain surfaces would efficiently catalyze the recombination of hydrogen atoms to H_2 and that this was sufficient to initiate chains of fast chemical reactions between ionic and neutral species. Quantitative models based on these ideas now give reasonable agreement with observed abundances as discussed in the chapter by Millar. More recently the problem has been turned around—understanding the significant atomic abundances that occur in dense molecular clouds. This topic is addressed in part 5. Melnick summarizes observations of the atomic species. Though ultraviolet light photodissociates molecules in diffuse clouds, it had been assumed that this was not important in dense clouds, because starlight does not penetrate. Roberge discusses the radiative transfer problem to assess photon flux inside dense clouds, considering sources embedded in the clouds as well as external flux from the background stars. A more general mechanism is discussed by Gredel: cosmic ray ionization of H_2 produces secondary electrons that collisionally excite electronic states of H_2, and these subsequently decay via ultraviolet fluorescence, producing a signficant source of photons in the interior of dense clouds.

Although H_2 is the dominant species in dense clouds, it has been difficult to observe directly. At the typical low temperatures in these objects H_2 is mostly in its lowest quantum level and so does not radiate, and even when it is excited its rotational and vibrational transitions have weak line strengths and are in difficult parts of the infrared. Nonetheless, as noted by Geballe, with improved telescopes and receivers such observations are becoming "commonplace" and indicate more H_2 in excited levels than had been expected. Mechanisms discussed in part 6 for exciting these levels higher include collisional excitation in high-temperature shocked regions and photon excitation.

The three chapters in part 7 discuss interesting observations of molecules associated with stars. Moran discusses the powerful masers that are often associated with regions

of star formation. Jura discusses the chemistry in circumstellar envelopes around mass-losing red giants; some of the more exotic molecular species, including polyacetylenes (essentially long linear carbon chains), are found in such regions. Observations of the recent Supernova 1987A are described in a very readable chapter by McCray.

The penultimate chapter, by Shields, considers moderately ionized regions, such as planetary nebulae. These are atomic rather than molecular regions, and one might wonder why they are included in this book. Perhaps it is because atom-atom charge transfer is important for the physics in these regions, and Dalgarno, to whom the book is dedicated, played a seminal and continuing role in calculating rate constants for such processes. The final chapter, by Black, considers the possibility of molecule formation in the early universe and the possibility of observing these molecules in objects with large red shifts.

Though *Molecular Astrophysics* provides rather comprehensive coverage of work in this field, a few topics have been slighted. There is essentially no discussion of experimental aspects: the telescopes, receivers, or methods of data analysis. Some interesting work—theoretical quantum chemical calculations and innovative laboratory spectroscopy—was needed to identify the "exotic" interstellar species, and this is not discussed. Also missing is discussion of possible mechanisms for pumping the interstellar masers.

A number of other collections of papers, generally proceedings of meetings, have been published on these same topics, but apart from some invited reviews these are just collections of primary research papers. *Molecular Astrophysics* is not just another such collection; a strong editorial intent is apparent. Most chapters present good overviews of their subjects, and for the most part the chapters are organized to present a coherent and reasonably complete picture of the field. A good index is provided. On the other hand, I do not believe that this volume is a "self-contained introduction to molecular astrophysics . . . suitable as a text for advanced postgraduate courses" as claimed. Because of the multiple authorship, many of the topics are not developed in as logical or coherent a manner as desired for a textbook. For example, discussions of the chemistry and of the theory of shock waves are fragmented among separate chapters, with attendant overlap in some areas and failure to note interrelationships in others.

Molecular Astrophysics would provide a good source of more recent and advanced material for an undergraduate course if used in conjunction with a text such as J. E. Dyson and D. A. Williams's *Physics of the Interstellar Medium* (Wiley, 1980) or W. W. Duley and D. A. Williams's *Interstellar Chemistry* (Academic Press, 1984). It is also an excellent book for researchers in related fields who would like an introduction to this fascinating subject.

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