Preface

The history of astrophysics has been a series of successful applications of modern physics to cosmic phenomena. In the 20th century, we saw the success of the application of nuclear physics to the understanding of the energy generation of the Sun and the stars, the synthesis of elements, and the change in nuclear processes as the driving force for stellar evolution. The application of atomic physics was instrumental in our understanding of the spectra of stars and gaseous nebulae. The measurements of the strengths of electronic transitions of elements allow us to determine the abundance of elements and to test the models of nucleosynthesis.

The discipline of astrochemistry began with the development of millimeter-wave astronomy in the early 1970s, leading to the detection of rotational transitions of over 120 molecules. The advent of infrared spectroscopy, in particular from space missions, has made possible the detection of complex organic molecules through their stretching and bending vibrational modes. Astrochemistry is not only interesting as part of the study of the interstellar medium, but also relevant to the question of the origin of life. Astrobiology is a rapidly growing field, and its importance is reflected in this book by the inclusion of organic chemistry relevant to astronomy.

The developments in space observations, in particular in the X-ray (*ROSAT, Chandra*), ultraviolet (*IUE, FUSE*), optical (*HST*), infrared (*IRAS, ISO, Spitzer*), and submillimeter (*SWAS, Odin*) regions, have revolutionarized our understanding of the interstellar medium. These new techniques have greatly expanded the range of physical processes that can be studied in the interstellar medium. Interstellar ions, atoms, molecules, and solid materials can now be studied in the UV, optical, infrared, and millimeter parts of the electromagnetic spectrum. These capabilities will be further developed with the launch of *Herschel* and *SOFIA*. Students will find the fundamental materials in this book useful in the interpretation of data from these missions.

Although this book is called the "Physics and Chemistry of the Interstellar Medium" and is primarily written for researchers and students involved in ISM research, many of the basic materials are applicable to problems in extragalactic astronomy. In the past, extragalactic astronomers derived most of their information from photometry and spectroscopy of a few emission lines, and it was thought that just some basic understanding of stellar colors and recombination line theory would be sufficient. After all, the spectra of normal galaxies are just the superposition of starlight and active galaxies and quasars are too far away to exhibit many emission lines. However, as the power of telescopes increases, physical processes that previously were observable only in our own galaxy will be observable in external galaxies. For example, with infrared and submm observations, dust continuum emissions are now commonly observed in galaxies. The lessons that we have learned in how to interpret spectra of dust clouds in the ISM are therefore extremely valuable. With modern large optical telescopes, many atomic lines in the ultraviolet can now be detected in distant galaxies as they are being redshifted into the visible region. The conditions under which intercombination lines and collisionally excited lines arise are now relevant. The construction of powerful mm arrays such as *ALMA* will make possible the detection of many molecular species in external galaxies. The greatly improved sensitivity of *Spitzer* over *ISO* means that many of the infrared lines previously seen only in the ISM are detectable in galaxies.

Goals and Philosophy

This book is based on class notes that I have developed over a period of 20 years teaching a two-semester course in advanced astrophysics for senior undergraduate and beginning graduate students at the University of Calgary. The intended readership is a physics student who is familiar with basic physics topics such as electromagnetism, atomic structures, and quantum mechanics, as well as a chemistry background at the first-year university level. The increasing availability of computer codes to treat various problems (e.g., *CLOUDY* for photoioinization, *Raymond-Smith* for X-ray spectra, *DUSTCD* for dust continuum transfer, etc.) has resulted in many students treating these tools as black boxes without understanding the underlying principles. The goal of the book is to prepare the readers with a fundamental background in physical and chemical processes and to allow them to properly interpret modern observations. In order to help achieve this goal, I have included many sample spectra and images from actual observations to illustrate the theoretical concepts.

By sticking with fundamental principles and avoiding phenomenological descriptions, I hope that the material in this book will stay relevant for a long time, and not be made obsolete by changing models and fashions.

In undergraduate studies, students try to solve problems whose solutions they know exist. In graduate studies, students are given a problem which has not been solved before and try to solve it. As research scientists, we identify a problem, formulate it in mathematical terms, and then solve them. When confronted with a physical problem, we have to isolate the critical variables, the physical processes involved, and the relevant equations to use. The key for a successful scientist is to think physically, and not to be bogged down by mathematical details. In this book, I try to emphasize these principles.

Instead of writing down the most general equations and seeking the most general solutions—the common approach taken by many physics textbooks—I deliberately limit all equations to the one-dimensional case to minimize mathematical complexity, and to obtain particular solutions for the simplest case. By this approach, I try to highlight the physical meanings of each term, which may otherwise be obscured by the mathematics. I hope this will prevent students from mechanically grinding through equations without realizing their meaning.

Some readers may notice that many topics are related to research that I have done over the years. Since I am obviously limited and biased by my own background, I apologize to readers who think some topics are neglected or not covered as extensively as they could be. For example, I have left out magnetic fields, turbulence, and high-energy phenomena such as relativity and cosmic rays.

Acknowledgments

I started drafting this book from my own teaching notes about ten years ago. Since administration, teaching and research activities take up most of my normal working hours, the writing of this book, unfortunately, has to be relegated to hobby status. Much of the material was written on airplanes, in airport lounges, hotel rooms, and at home during evenings and weekends. Many sections were written during early morning hours in foreign lands when I was up early suffering from the effects of jetlag. The task of writing this book was made easier by modern computer software. The manuscript was written in LaTeX, the calculations performed using MATHCAD, and many of the figures prepared using Adobe Illustrator and AXUM.

Over the course of writing this book, I have benefited from discussions and inputs from many friends and colleagues. Various versions of the draft have been in circulation in the astronomical community in the last five years and I would like to thank everyone who has commented on what they read. In particular, I thank Kevin Volk for many years of collaboration and for his ideas and contributions to various sections of the book. The expert knowledge of Peter Bernath in atomic and molecular physics has added greatly to the respective chapters. The pioneering work done by Renaud Papoular, Walt Duley and Alan Tokunaga on organic compounds in space has influenced my own thinking on this subject. I also benefited from the discussions with Lou Allamandolla, Huan-Cheng Chang, Dale Cruikshank, Olivier Guillois, Thomas Henning, Chun Ming Leung, Yvonne Pendleton, Scott Sandford, Farid Salama, Diane Wooden, Li-Hong Xu, and many others on different aspects of the ISM. Tatsuhiko Hasegawa contributed to the chapter on chemical reactions in the ISM. Comments, criticisms from several anonymous reviewers also helped improve the book. I want to thank the many authors who kindly allow their figures or other published materials to be used in the book. I also thank Orla Aaquist and Alexander Menshchikov for their careful readings of earlier drafts, and Emily Wei for her help in preparing some of the figures. The manuscript was proofread and checked by a number of students, including Joanna Wong, Nico Koning, Rong Ying Wu, and Jo Hsin Chen. The production of this book was professionally done by University Science Books, in particular Jane Ellis and Mark Ong who handled the manuscript and the graphics respectively. I thank Bruce Armbruster for his patience and continuous support. Especially, I want to thank my wife Emily who tolerated my long working hours and frequent trips away from home. Without her understanding and support, this work would not have been possible. Finally, I would like to pay tribute to Gerhard Herzberg, whose contribution to interstellar chemistry has been a great inspiration to me and many others who work in Canada.

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Hong Kong, March 2006