NUCLEAR MOLECULES

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Dedicated to

D. Allen Bromley,
distinguished colleague and friend

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PREFACE

The field of nuclear molecular physics is a very extensive and expanding one and a great deal of research work has been done in this area since the historic and pioneering discovery of resonances in the excitation functions of the $^{12}\text{C} + ^{12}\text{C}$ system by D. A. Bromley and coworkers over thirty years ago. The concept of nuclear molecules played a significant role in our efforts to understand many features of heavy-ion collisions. We have attempted to provide a well balanced and not too specialized review of the field, focussing on underlying concepts and ideas and essential results rather than a collection of all the published works. It is hoped, therefore, that this book will be of value not only to the practitioner in this exciting field but also to the initiate as a helpful, comprehensive and up-to-date introduction to the enchanting field of heavy ion nuclear physics.

The number of topics and the length of the discussion of each topic is necessarily restricted. At the beginning of many sections which discuss mostly works by others, we have listed the main references we have consulted and/or review articles which discuss the subject of the section more in detail. The references cited are as of March 1994 and are only meant to provide some representative works and not a complete bibliography. Our apologies go in advance to those authors whose work have not been discussed or quoted adequately. It is not possible to be complete or up to date.

The reader is referred to several excellent review articles by Bromley (Br 75b, Br 78d, Br 82, Br 84a, Br 87), Cindro (Ci 76, Ci 81, Ci 88), Cormier (Co 82), Feshbach (Fe 76), Erb et al. (Er 78, Er 79, Er 85), Braun-Munzinger (Br 84b), and others (St 73, Ri 79, La 86, Im 87b), and books on heavy ion reactions by Hodgson (Ha 78), and Bass (Ba 80a) and by others (Nö 80, Br 84a, Br 85) and the eight volume treatise on heavy-ion science edited by Bromley (Br 84a) and three volume treatise edited by Bock (Bo 80). For the latest developments in the field the reader is urged to consult review journals and the proceedings of recent conferences (See Selected List of Conference Proceedings).

The book is organized in fifteen chapters. First, a brief review of selected experiments which give evidences for nuclear molecular phenomena is given (chapter 2). Theoretical bases for nuclear molecular configurations are discussed in chapter 3. The two-center shell model which provides a theoretical basis of nuclear molecules is surveyed (Section 3.1), followed by simple potential model interpretations of the experimental data (Section 3.2). Nucleus-nucleus interaction potentials, including optical model potentials, interaction potentials under two extreme approximations, namely adiabatic and sudden, and various phenomenological and microscopic models for elastic potentials are discussed next in Chapter 4. Two equivalent models which have played important roles in our understanding of heavy-ion resonances in terms of nuclear molecular concepts, namely the double resonance model (or mechanism) and the band crossing model, are discussed in Sections 5.1 and 5.2 respectively. Other models used in the calculation of structure for cluster or molecular configurations are briefly summarized also in Chapter 5. Molecular resonance states are classified according to their widths, or equivalently lifetimes, and the concept of molecular window and its role for the existence of quasimolecular resonances are covered in Chapter 6. Starting with a general formulation several methods employed in theoretical treatments of the scattering of light heavy-ions, namely the Feshbach formalism, the optical model and generator coordinate and equivalent resonating group methods, are discussed in Chapter 7. Various approximation methods used for heavy-ion collisions, such as the semiclassical method, the DWBA method, and the time-dependent Hartree-Fock method are treated in Chapter 8, including a discussion of deep inelastic collisions. Collective molecular states and coupled channel calculations of heavy-ion scattering which have been performed by several groups are treated in Chapter 9. The elements of the molecular particle-core model with applications are presented in Chapter 10. The single particle aspects of molecular configurations are the subject of Chapter 11, focussing on the

two-center level diagram and level crossing. The Landau-Zener mechanism in the excitation of molecular single-particle states and a general theory based on the particle-core model are considered here with illustrative applications to several systems. A microscopic molecular reaction theory in the framework of the particle-hole formalism and the two-center shell model is developed in Chapter 12. The transfer of clusters in heavy-ion reactions is considered in Chapter 13. The fragmentation theory in heavy ion collisions and its applications including cluster radioactivity are presented in Chapter 14. Some new speculative molecular effects which are being investigated in recent years are briefly discussed in Chapter 15.

It is our pleasure to acknowledge many colleagues for collaborations and discussions, in particular, Professor D. A. Bromley, Professor N. Cindro, Dr. K. A. Erb, Professor R. K. Gupta, Dr. D. Hahn, Professor J. A. Maruhn, Professor A. Sandulescu, Professor G. Terlecki, and Dr. A. Thiel. One of us (J. Y. P.) would like to thank also Professors Y. Abe, M. H. Cha, B. Imanishi and T. Tazawa for discussions. We would like to acknowledge gratefully Professor U. Abbondano for sending us his reference list on resonances in heavy-ion reactions. Our thanks go to Mrs. Jennifer Tuten for performing an excellent job in typing the manuscript, including numerous additions and corrections, and to Miss Astrid Steidl for preparing figures.

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