Treatise on Heavy-Ion Science

Volume 6
Astrophysics, Chemistry,
and Condensed Matter

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EDITED BY D. ALLAN BROMLEY

Volume 1: Elastic and Quasi-Elastic Phenomena

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Volume 7: Instrumentation and Techniques

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For Pat, Lynn, and David

Preface to Treatise on Heavy-Ion Science

After a long gestation period, heavy-ion physics and chemistry is now, worldwide, the most rapidly growing area of nuclear science, and the concepts, techniques, and instrumentation of this heavy-ion work are finding ever-widening application in other areas of science and technology. Although there remain broad regions at higher energies, with heavier projectiles, and at higher excitations and angular momenta where heavy ions still provide gateways into the totally unknown, intensive studies over the past two decades have provided a sound framework of understanding of many of the salient features of interactions induced by these new heavier projectiles and a basis for coherent planning of future studies.

It thus seemed appropriate, at this point in the history of the field, to pull together in one place and in as coherent a fashion as possible, an overview of what has been accomplished and some enlightened speculation about where we go next. It is my hope that these volumes will provide a definitive reference for those working in this and neighboring fields—both students and professional scientists; beyond that I would also hope that they will make accessible to a much wider audience in other sciences and technologies some of the richness of heavy-ion research, and perhaps help to stimulate the transfer of techniques and concepts that I have already mentioned.

I have been singularly fortunate in planning these volumes in being able to persuade internationally recognized authorities to write in their areas of special expertise and interest, and also fortunate that I have not had to restrict them to any artificial or externally imposed procrustean restrictions on the scope or length of their chapters. I have asked each author to include sufficient background to make the chapter accessible to students and to the nonspecialist, to provide a broad selection of illustrations, and to feel free to extrapolate and to speculate about future directions.

In inviting contributions to these volumes I have made arbitrary decisions concerning both topics and contributors, and I make no claim to completeness. Indeed, a few chapters that I would have liked to include do not appear because of illness or other reasons which prevented their authors from completing them.

I should like to take this opportunity to thank all the authors represented for taking time in already full schedules to share with a wider audience their special experience and expertise in heavy-ion science. As was inevitable from the outset in a multiple-author venture of this scope—with over 65 different authors—my original scheduling and deadlines proved unrealistic. To all those authors who responded to them and produced manuscripts on or before the original deadline—in many cases, I am aware, at substantial personal cost—my most sincere thanks and appreciation. To them, too, however, go my apologies for the delay in bringing their work into print. I have delayed publication for over a year so that I might include a number of very important chapters without which the work would have been obviously incomplete.

Volumes 1–4 of the *Treatise on Heavy-Ion Science* are devoted to aspects of heavy-ion nuclear science, beginning with an overview of the historical development of the science and some of its simpler interactions—elastic and quasi-elastic, fusion and quasi-fusion phenomena—and moving from them to compound system phenomena and to much more complex and less well understood phenomena involving very heavy nuclear species and very high energies. Volume 5 is devoted to high-energy atomic physics, an entirely new field of science first made accessible by the availability of a broad range of heavy-ion beams, and one still very much in its infancy. Volume 6 considers the impact of heavy-ion studies on other sciences including astrophysics, chemistry, surface physics, condensed matter physics, materials science, and heavy-ion-induced fusion power. Volume 7, the concluding volume of this treatise, is devoted to some of the instrumentation peculiar to heavy-ion science and its applications.

Special thanks go to Ellis Rosenberg and Bennett K. Ragnauth of Plenum Press with whom it has been a pleasure to work on these volumes, and to Mary Anne Schulz for all her help in producing them. And I would also acknowledge my indebtedness to the Alexander von Humboldt Stiftung for a Humboldt Award that I was privileged to hold during part of the time these volumes were in preparation.

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Preface to Volume 6

Although still a very young field, the techniques, instrumentation, and concepts of heavy-ion science are finding broad application in other areas of science. In this sixth volume of this treatise on heavy-ion science, I include representative examples of such application to ten different areas of science. Barnes *et al.* discuss the role of heavy-ion reactions in nuclear astrophysics and in nucleogenesis and stellar energy generation in particular. Cacace considers their role in hot atom chemistry—so-called because the reactant species are not in their normal atomic or molecular ground states but rather in excited configurations reflecting the passage of energetic ions. Ziegler and Biersack review the essential data on the stopping range of heavy ions in matter—information of critical importance in the understanding of heavy-ion phenomena in almost all fields. Poate discusses ion implantation, a technique of burgeoning importance in the fabrication of ultra large-scale integrated electronic circuits, in ion–beam mixing to produce entirely new alloys and products and in ionic treatment of surfaces to obtain new wear, corrosion and other resistance, often in relatively inexpensive substrates. The fact that rapidly moving ions, when properly oriented and directed, can pass directly through lattice channels in crystalline targets with anomalously low energy loss has been recognized as providing a powerful probe for study of the interatomic forces and potentials in solids. Reflecting the very large local electrostatic and magnetic fields encountered by the ions within such a lattice, there may well be substantial practical applications. Datz and Moak review these questions in detail. During their passage through matter, highly charged ionic species have been shown to have dramatic effects on the electron gas in that matter; such phenomena as wakes and Mach shock waves have been clearly identified as have the Coulomb explosions that occur when a molecular ionic bond is broken and the fragments separate under their mutual electrostatic repulsion. Gemmell and Vager, pioneers in this work, review its present status. Haff reports on the modification of surfaces, terrestial and extraterrestial, under ionic bombardment and sputtering. This is yet another process that although very poorly understood,

as yet, from any fundamental viewpoint, has already found widespread technological application. English and Jenkins consider heavy-ion-induced damage in solids; this is of major importance in the mechanical hardening of materials through the introduction of dislocations, in the simulation of long term damage under neutron bombardment in both fission and fusion reactors, and as a further probe for the structure of solids. There is already a growing history of utilization of heavy ions as analytic probes in Rutherford backscattering, induced X radiation, and the like; Lanford considers all these analytic techniques including those in which he has done major work e.g., the use of ^{15}N beams in quantitative, nondestructive hydrogen profiling in solids. Finally, Arnold considers one of the possible longer range applications of heavy-ion beams in the induction of inertial confinement fusion. Here the heavy ions have the great advantages of tight coupling to the fuel pellet, hence efficient energy delivery, and well understood beam production and handling techniques. And as emphasized above, this volume represents only a sampling of the application of heavy ions to other sciences and to technology. I regret, for example, that it was not possible to include a chapter here on the medical and clinical uses of heavy-ion beams. Successful use of GeV/A beams of silicon, from the Berkeley Bevalac, in the treatment of otherwise intractable pancreatic cancer is only a single example of such use.

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Contents

1. Heavy-Ion Reactions in Nuclear Astrophysics

Charles A. Barnes, Stephen Trentalange, and Shiu-Chin Wu

2. Heavy Ions in Hot Atom Chemistry

Fulvio Cacace

3. The Stopping and Range of Ions in Matter

James F. Ziegler and Jochen P. Biersack

4. Ion Implantation

John M. Poate

5. Heavy-Ion Channeling

Sheldon Datz and Charles D. Moak

6. The Electronic Polarization Induced in Solids Traversed by Fast Ions

Donald S. Gemmell and Zeev Vager

7. Erosion of Surfaces by Fast Heavy Ions

Peter K. Haff

8. Heavy-Ion Damage in Solids

Colin A. English and Michael L. Jenkins

9. Analysis with Heavy Ions

William A. Lanford

10. Heavy-Ion-Induced Fusion Power

Richard C. Arnold

Contents of Volumes 1–5, 7

Volume 1: Elastic and Quasi-Elastic Phenomena

Volume 2: Fusion and Quasi-Fusion Phenomena

Volume 3: Compound System Phenomena

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