

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

Volume 2: Fusion and Quasi-Fusion Phenomena

Volume 3: Compound System Phenomena

Volume 4: Extreme Nuclear States

Volume 5: High-Energy Atomic Physics

Volume 6: Astrophysics, Chemistry, and Condensed Matter

Volume 7: Instrumentation and Techniques

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and Condensed Matter

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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, terrestrial and extraterrestrial, 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.

New Haven, Connecticut

D. Allan Bromley

Contents

1. Heavy-Ion Reactions in Nuclear Astrophysics

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

1. Introduction	3
2. Nuclear Astrophysics	4
2.1. The Primeval Big Bang	4
2.2. Some Mathematical Preliminaries	6
2.3. Stellar Burning Processes	7
2.4. Carbon, Neon, and Oxygen Burning	9
2.5. Silicon Burning and Supernovas	10
2.6. $^{12}\text{C} + ^{12}\text{C}$, $^{12}\text{C} + ^{16}\text{O}$, and $^{16}\text{O} + ^{16}\text{O}$ in Explosive Oxygen Burning	11
3. Measurement Techniques for Sub-Coulomb-Barrier Heavy-Ion Reactions	12
3.1. The Residual Radioactivity Method	15
3.2. Detection of Fusion Residues	16
3.3. Detection of the Emitted Particles	17
3.4. Gamma-Ray Measurements	17
3.5. The Elastic Scattering Method	20
3.6. The Effects of Resonances	21
4. Experimental Data	22
4.1. The $^{12}\text{C} + ^{12}\text{C}$ Reactions	23
4.2. The $^{12}\text{C} + ^{16}\text{O}$ Reactions	28
4.3. The $^{16}\text{O} + ^{16}\text{O}$ Reactions	31
5. Reaction Model Calculations	35
5.1. The Shapes of $S(E)$ Curves	35
5.2. Transfer Reactions	35
5.3. Optical Model Fits for Heavy-Ion Reactions	37
5.4. The Optical Model Fit of Michaud	43
5.5. The Equivalent Square-Well Optical Potential of Michaud and Fowler	44
5.6. A Simple Coulomb Barrier Penetration Model	48
5.7. The IWBC Model	49
5.8. Resonances in the Excitation Function	55
6. Concluding Remarks	56

Note Added in Proof	57
References	57

2. Heavy Ions in Hot Atom Chemistry

Fulvio Cacace

1. Introduction	63
2. Chemical Reactions Promoted by Accelerated Ions	64
2.1. Early Studies	64
2.2. Improved Bombardment Techniques	65
2.3. Results	66
3. Heavy Ions from the Spontaneous Decay of Radioactive Precursors	72
3.1. β Decay of Isolated Tritiated Species	73
3.2. Applications to Structural and Kinetic Studies	74
3.3. Multicharged Ions from Nuclear Transitions Leading to Inner-Shell Ionization	80
4. Collision-Induced Coulomb Explosion of Fast Molecular Ions as a Structural Probe	83
References	87

3. The Stopping and Range of Ions in Matter

James F. Ziegler and Jochen P. Biersack

Abstract	95
1. Introduction	96
2. Stopping Power Tables	97
2.1. 1958: The Whaling Table	97
2.2. 1970: The Northcliffe–Schilling Table	98
2.3. 1972: The Bichsel Table	100
2.4. 1974: Ziegler and Chu Tables	101
2.5. 1977: Andersen and Ziegler: H Tables	105
2.6. 1978: Ziegler: He Tables	107
2.7. 1980: Ziegler Energetic Ion Tables	108
2.8. The Current Accuracy of Stopping Tables	111
3. Range Tables	111
3.1. 1970: Northcliffe and Schilling, “Range and Stopping Power Tables”	115
3.2. 1970: Johnson and Gibbons LSS Range Tables	115
3.3. 1975: Gibbons, Johnson, and Mylroie Range Tables	118
3.4. 1975: Brice and Winterbon Range Tables	118
3.5. 1981: Littmark and Ziegler, Energetic Ion Range Tables	120
4. Electronic Stopping of Ions	120
5. Interaction of a Particle with a Free Electron Gas	121
6. Nuclear Stopping of Ions	124
7. Range Theory	125
References	128

4. Ion Implantation

John M. Poate

1. Introduction	133
2. Dynamics	135
2.1. Energy Loss, Range, and Damage	135
2.2. Replacement Collisions	136
2.3. Collision Cascades	137
2.4. Sputtering	141
3. Metals	144
3.1. Dilute Alloys	144
3.2. Concentrated Alloys	151
4. Semiconductors (Si)	155
4.1. Amorphous Silicon and Epitaxy	155
4.2. Supersaturation	157
5. Ion Beam Mixing	160
References	165

5. Heavy-Ion Channeling

Sheldon Datz and Charles D. Moak

1. Introduction	169
2. Trajectories and Interaction Potentials	174
2.1. Planar Channeling	175
2.2. Hyperchanneling	191
3. Energy Loss in Channels	198
3.1. Screening Effects on Energy Loss	203
3.2. Higher-Order Corrections for Electronic Stopping of Heavy Ions	206
4. Charge Changing Collisions	213
4.1. Capture and Loss under Channeling Conditions	213
4.2. Radiative Electron Capture	216
4.3. Electron Capture and Loss to Continuum States (Convey Electron Production)	221
5. Resonant Coherent Excitation	225
References	237

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

Donald S. Gemmell and Zeev Vager

1. Introduction	243
2. The Wake	244
2.1. Bohr's Model	245

2.2. The Electron-Gas Model	246
2.3. Fluctuations in the Wake	254
3. Experiments with Fast Molecular-Ion Beams	254
3.1. Stopping-Power Effects	254
3.2. High-Resolution Measurements of Fragment Momenta	256
3.3. Understanding the Ring Patterns	269
Acknowledgments	282
<i>References</i>	282

7. Erosion of Surfaces by Fast Heavy Ions

Peter K. Haff

1. Introduction	287
2. Sputtering at Low Energies	289
3. Sputtering at High Energies	291
3.1. General Remarks	291
3.2. Possible Connections with Track Formation	291
3.3. Role of Target Strength	294
3.4. Role of Electrical Conductivity	295
3.5. Experiments with UF ₄ Targets	296
3.6. Thermal Model of High-Energy Sputtering	300
3.7. Alternative Mechanisms	311
3.8. Elaboration of the Zeroth-Order Thermal Model	313
4. Applications	317
5. Summary and Conclusions	318
Acknowledgments	319
<i>References</i>	320

8. Heavy-Ion Damage in Solids

Colin A. English and Michael L. Jenkins

1. Introduction	325
2. Low-Energy Irradiations ($E < 5$ keV)	328
3. Medium-Energy Irradiations (5–200 keV)	331
3.1. Models of Displacement Cascades	332
3.2. Direct Observation of Individual Displacement Cascades	334
3.3. Point Defect Clustering in Individual Cascades	338
3.4. Studies of Cascades in Nonmetals	345
3.5. High-Dose Irradiations	346
3.6. Radiation-Enhanced Diffusion and Solute Redistribution	347
4. High-Energy Irradiation ($E > 200$ keV)	349
4.1. Study of the Primary Damage	350
4.2. Use of High-Energy Damage to Produce High Levels of Displacement Damage	351
<i>References</i>	356

9. Analysis with Heavy Ions

William A. Lanford

1. Introduction 363

2. Nuclear Reaction Analysis of Hydrogen in Solids 364

 2.1. Hydrogen Profiles of Lunar Material and the History of the Solar Wind . . . 370

 2.2. Hydrogen Surface Contaminations and the Containment of Ultracold Neutrons 371

 2.3. Hydrogen in Thin Film High Technology Materials 372

3. Rutherford Backscattering Spectrometry 376

 3.1. Principles and Applications of Rutherford Backscattering Spectrometry . . . 377

 3.2. Analysis of Ion Implanted Samples 381

 3.3. Thin Film Analysis: Ion-Beam-Mixing Induced Silicide Formation 381

 3.4. Analysis of Surfaces with Heavy-Ion Beams 383

4. Nuclear Recoil Analysis 386

Acknowledgments 389

References 389

10. Heavy-Ion-Induced Fusion Power

Richard C. Arnold

1. Introduction 395

 1.1. Inertial Confinement Fusion 395

 1.2. Driver Technologies 397

 1.3. Power Production Requirements 398

2. Heavy-Ion Drivers 399

 2.1. Basic Concepts 399

 2.2. Reference Designs 401

 2.3. Feasibility Constraints 403

 2.4. Costs 406

3. Targets 408

 3.1. Principles 408

 3.2. Designs 409

4. Reactors 412

 4.1. General Considerations 412

 4.2. Examples 413

5. Prospects 414

 5.1. Secrecy Problems 414

 5.2. Development Programs 416

 5.3. Overview 419

Appendix A: Statement of USDOE on Declassification Actions Issued on September 4, 1980 419

Appendix B: Excerpts from the Public Transcript of the May 3, 1979 Meeting of the USDOE Energy Research Advisory Board; Testimony of Dr. John Foster, Reporting on the Conclusions of the ICF Review he Chaired in 1979 420

References 421

Index 423

Contents of Volumes 1–5, 7

Volume 1: Elastic and Quasi-Elastic Phenomena

1. The Development of Heavy-Ion Nuclear Physics
D. Allan Bromley
2. Elastic Scattering
Wilhelm E. Frahn
3. Inelastic Scattering—Coulomb Excitation
Jorrit de Boer
4. Inelastic Scattering—Nuclear
Stephen Landowne and Andrea Vitturi
5. One- and Two-Nucleon Transfer Reactions Induced by Heavy Ions—Interplay of Nuclear Structure and Reaction Mechanisms
Robert J. Ascutto and Ernest A. Seglie
6. Cluster Transfer Reactions Induced by Heavy Ions
Akito Arima and Shigeru Kubono

Volume 2: Fusion and Quasi-Fusion Phenomena

1. Heavy-Ion Fusion Reactions
Ulrich Mosel

2. Heavy-Ion Radiative Capture
Andrew M. Sandorfi
3. Damped Nuclear Reactions
Wolfgang U. Schröder and John. R. Huizenga

Volume 3: Compound System Phenomena

1. TDHF Calculations of Heavy-Ion Collisions
K. T. R. Davies, K. R. S. Devi, S. E. Koonin, and M. R. Strayer
2. The Use of Statistical Models in Heavy-Ion Reaction Studies
Robert G. Stokstad
3. Heavy-Ion Resonances
Karl A. Erb and D. Allan Bromley
4. High Angular Momentum Phenomena
Ikuko Hamamoto
5. Polarization Phenomena in Heavy-Ion Reactions
Kenzo Sugimoto, Masayasu Ishihara, and Noriaki Takahashi
6. Magnetic Moments of Short-Lived Nuclear Levels
Gvirol Goldring and Michael Hass

Volume 4: Extreme Nuclear States

1. Heavy Ions and Nuclear Fission
Yuri Ts. Oganessian and Yuri A. Lazarev
2. Transuranium Nuclei
Glenn T. Seaborg and Walter D. Loveland
3. Superheavy Elements
Georgy N. Flerov and Gurgun M. Ter-Akopian

4. Relativistic Heavy-Ion Collisions: Experiment
Erwin M. Friedlander and Harry H. Heckman
5. Relativistic Heavy-Ion Reactions: Theoretical Models
Joachim A. Maruhn and Walter Greiner

Volume 5: High-Energy Atomic Physics

1. Heavy-Ion Atomic Physics—Theoretical
Joachim Reinhardt and Walter Greiner
2. High-Energy Atomic Physics—Experimental
Jack S. Greenberg and Paul Vincent
3. Beam-Foil Spectroscopy
Indrek Martinson

Volume 7: Instrumentation and Techniques

1. Positive Heavy-Ion Sources
David J. Clark
2. A Review of Negative Heavy-Ion Sources
Roy Middleton
3. Stripping Foils for Heavy-Ion Beams
Joseph L. Gallant
4. Heavy-Ion Targets
Harold L. Adair and Edward H. Kobisk
5. Focal Plane Detectors for Magnetic Spectrometers
Harry W. Fulbright
6. Heavy-Ion Identification Using Detector Telescopes
Frederick S. Goulding

7. Time-of-Flight Systems for Heavy Ions
Jean-Pierre Coffin and Pierre Engelstein
8. Streamer Chambers for Heavy Ions
Karl Van Bibber and Andres Sandoval
9. Electromagnetic Separators for Recoiling Reaction Products
Harald A. Enge
10. Accelerator-Based Ultrasensitive Mass Spectrometry
Harry E. Gove