

Contents

Chapter 1

Basic Properties of Fusion Edge Plasmas and Role of Atomic and Molecular Processes

R. K. Janev

1. Introduction	1
2. Basic Plasma Edge Configurations	3
3. Parameters and Composition of Edge Plasmas	6
4. Atomic and Molecular Processes in the Plasma Edge	9
5. Role of Atomic and Molecular Processes in Plasma Edge Physics	10
6. Conclusion	12
References	13

Chapter 2

Spectroscopic Processes and Data for Fusion Edge Plasmas

W. L. Wiese

1. Introduction	15
2. Status of Research on Atomic Structure Data	17
3. Description of Principal Methods to Determine Transition Probabilities	18
3.1. Theoretical Methods	18

x	Contents	
	3.2. Experimental Methods	19
	4. Availability of Spectroscopic Data	21
	5. Numerical Spectroscopic Data Bases	22
	5.1. Wavelength Tables	22
	5.2. Energy Level Tables	23
	5.3. Transition Probability Tables	24
	5.4. Comprehensive Recent Determinations of Wavelength and Transition Probability Data of Interest for Fusion Edge Plasmas	25
	5.5. Spectroscopic Data for Molecules	25
	6. Summary	26
	References	28

Chapter 3

Elastic and Excitation Electron Collisions with Atoms

Sandor Trajmar and Isik Kanik

	1. Introduction	31
	2. Definition of Cross Sections	32
	3. Experimental Methods	33
	3.1. Differential Cross Sections	34
	3.2. Integral Cross Sections	36
	3.3. Total Scattering Cross Sections	37
	4. Review of Cross Section Data	37
	4.1. Primary Species: H, He	37
	4.2. Common Impurities: C, O	52
	4.3. Metallic Impurities: Be, Al, Ti, Cr, Fe, Ni, Cu, Ga, Mo, Ta, W, V, and Zr	53
	4.4. Diagnostic Species: Li, Ne, Ar, Kr, and Xe	54
	References	55

Chapter 4

Electron Impact Ionization of Plasma Edge Atoms

T. D. Märk

	1. Introduction	59
	2. Electron Impact Ionization: Mechanisms and Definitions	60
	3. Total Electron Impact Ionization Cross Sections of Atoms and Molecules	63
	3.1. Experimental Methods and Techniques	63
	3.2. Theoretical Considerations	65

Contents	xi
3.3. Consistency Checks	68
3.4. Recommended Total Ionization Cross Sections	69
4. Partial Electron Impact Ionization Cross Sections	74
4.1. Experimental Methods and Techniques	74
4.2. Theoretical Considerations	77
4.3. State-Selected Partial Ionization Cross Sections	79
4.4. Recommended Partial Cross Sections	81
References	86

Chapter 5

Electron–Ion Recombination Processes in Plasmas

Yukap Hahn

	1. Introduction	91
	2. Theory of Electron–Ion Recombination in Plasmas	94
	3. Radiative Recombination and Scaled Rates	97
	4. Dielectronic Recombination for the Ground States	101
	5. Plasma Field Effects and Rate Equations	110
	6. Summary and Conclusions	114
	References	116

Chapter 6

Excitation of Atomic Ions by Electron Impact

Swaraj S. Tayal, Anil K. Pradhan, and Michael S. Pindzola

	1. Introduction	119
	2. Carbon and Oxygen Ions	121
	2.1. General Considerations	121
	2.2. O ⁺ Cross Sections	129
	2.3. O ²⁺ Cross Sections	131
	2.4. C ⁺ and O ³⁺ Cross Sections	132
	2.5. C ²⁺ and O ⁴⁺ Cross Sections	132
	2.6. C ³⁺ and O ⁵⁺ Cross Sections	133
	2.7. C ⁴⁺ and O ⁶⁺ Cross Sections	134
	2.8. C ⁵⁺ and O ⁷⁺ Cross Sections	135
	3. Iron Ions	135
	3.1. General Considerations	135
	3.2. Fe ⁺ Cross Sections	136

3.3. Fe ²⁺ Cross Sections	139
3.4. Fe ³⁺ Cross Sections	140
3.5. Fe ⁵⁺ Cross Sections	140
3.6. Fe ⁶⁺ Cross Sections	140
3.7. Fe ⁷⁺ Cross Sections	141
3.8. Further Considerations	141
4. Rare-Gas Ions	141
4.1. General Considerations	141
4.2. Ar ⁷⁺ Cross Sections	142
4.3. Ar ⁶⁺ Cross Sections	144
4.4. Kr ⁶⁺ Cross Sections	145
5. Conclusions	145
References	147

Chapter 7

Ionization of Atomic Ions by Electron Impact

P. Defrance, M. Duponchelle, and D. L. Moores

1. Introduction: Types of Ionization Processes	153
2. Electron Impact Ionization: Theoretical Methods	156
2.1. Direct, Single Ionization	156
2.2. Indirect Ionization	160
2.3. Multiple Ionization	164
3. Experimental Methods	166
3.1. Crossed Electron–Ion Beam Experiments	166
3.2. Electron Beam Ion Source and Trap	169
4. Cross Sections	170
4.1. Hydrogen Isoelectronic Sequence	170
4.2. Helium Isoelectronic Sequence	171
4.3. Lithium Isoelectronic Sequence	172
4.4. Be Sequence: B ⁺ , C ²⁺ , O ⁴⁺ , and Ne ⁶⁺	172
4.5. B Sequence: C ⁺ and O ³⁺	172
4.6. O ⁺ and O ²⁺	172
4.7. Rare Gases	172
4.8. Metallic Ions	177
5. Parametric Representation of the Cross Sections	182
6. Conclusions	191
References	191

Chapter 8

The Dependence of Electron Impact Excitation and Ionization Cross Sections of H₂ and D₂ Molecules on Vibrational Quantum Number

M. Capitelli and R. Celiberto

1. Introduction	195
2. Resonant Vibrational Excitation	197
3. Dissociative Attachment Cross Section	199
4. Electronic Excitation	200
5. Dissociation Processes	211
5.1. Allowed Transitions	211
5.2. Spin-Forbidden Transitions	213
6. Ionization	216
7. Electronic Excitation from Electronically Excited States	220
8. Conclusion	222
References	223

Chapter 9

Electron–Molecular Ion Collisions

J. B. A. Mitchell

1. Introduction	225
2. H ₂ ⁺	226
2.1. Dissociative Recombination	230
2.2. Dissociative Excitation	238
2.3. Dissociative Ionization	240
2.4. Ion–Pair Formation	241
3. H ₃ ⁺	243
3.1. Dissociative Recombination	245
3.2. Dissociative Excitation	251
3.3. Ion–Pair Formation	251
4. O ₂ ⁺	252
4.1. Dissociative Recombination	252
4.2. Dissociative Excitation	256
5. CO ⁺	256
5.1. Dissociative Recombination	256
5.2. Dissociative Excitation	258
6. CO ₂ ⁺	259

7. Summary	259
References	260

Chapter 10

Energy and Angular Distributions of Secondary Electrons Produced by Electron Impact Ionization

Yong-Ki Kim

1. Introduction	263
2. Qualitative Considerations	265
3. Analytical Model for Energy Distributions of Secondary Electrons	267
4. Analytical Model for Angular Distributions of Secondary Electrons	269
5. Comparisons with Experiment	271
6. Concluding Remarks	275
References	276

Chapter 11

Elastic and Related Cross Sections for Low-Energy Collisions among Hydrogen and Helium Ions, Neutrals, and Isotopes

D. R. Schultz, S. Yu. Ovchinnikov, and S. V. Passovets

1. Introduction	279
2. The Elastic and Related Cross Sections	281
2.1. Theoretical Approaches	282
2.2. Related Cross Sections	284
3. The Semiclassical Method	286
3.1. The Massey–Mohr Approximation	286
3.2. Practical Computational Schemes	289
3.3. Asymptotic Behavior	292
4. Specific Cross Sections	293
4.1. $H^+ + H$	293
4.2. $D^+ + D$	295
4.3. $H^+ + D$, $H^+ + T$, $D^+ + H$, $D^+ + T$, $T^+ + H$, $T^+ + D$, and $T^+ + T$	298
4.4. $H + H$	299
4.5. $H + He$ and $D + He$	301
4.6. H^+ , H_3^+ , H , H^- , and $H_2 + H_2$	303
4.7. $H^+ + He$, $H^+ + H_2$, $He^+ + He$, and $He^{2+} + He$	306
5. Conclusions	306
References	306

Chapter 12

Rearrangement Processes Involving Hydrogen and Helium Atoms and Ions

F. Brouillard and X. Urbain

1. Introduction	309
2. Experimental Methods	310
2.1. The Interaction of Two Beams	310
2.2. Control of the Reactants	312
2.3. Specification of the Process	313
2.4. Detection of Reaction Products	314
3. Cross Sections	314
3.1. Collisions of H —Production of H^-	314
3.2. Collisions of H —Production of H^+	316
3.3. Collisions of H^+ —Production of H	318
3.4. Collisions of H^+ —Production of H^-	319
3.5. Collisions of He^{2+}	319
3.6. Collisions of He^+	322
3.7. Collisions of He	323
3.8. Collisions of H^-	326
3.9. Collisions of H_2 —Ionization and Dissociation	328
3.10. Collisions of H_2^+ —Ionization, Dissociation, and Charge Exchange	330
3.11. Associative and Penning Ionization	332
References	334

Chapter 13

Electron Capture Processes in Slow Collisions of Plasma Impurity Ions with H , H_2 , and He

R. K. Janev, HP. Winter, and W. Fritsch

1. Introduction	341
2. Methods in Studies of Low-Energy Electron Capture Processes	344
2.1. Experimental Methods	344
2.2. Theoretical Methods	351
3. Total Electron Capture	356
3.1. Collisions with Atomic Hydrogen	357
3.2. Collisions with Helium Atoms	367
3.3. Collisions with Molecular Hydrogen	376
4. State-Selective Electron Capture	382
4.1. General Considerations: n -Distributions and l -Distributions	382
4.2. Collisions with Hydrogen Atoms	384

4.3. Collisions with He Atoms	387
4.4. Collisions with H ₂ Molecules	389
5. Conclusion	390
References	391

Chapter 14

Reactive Ion–Molecule Collisions Involving Hydrogen and Helium

F. Linder, R. K. Janev, and J. Botero

1. Introduction	397
2. Experimental Methods	399
3. Total Cross Sections for Particle Rearrangement Collisions	403
3.1. Electron Transfer Reactions	404
3.2. Particle Interchange Reactions	409
4. State-Selective Cross Section Measurements	423
4.1. Reactions in Hydrogen Ion–Molecule Systems	424
4.2. Reactions in Hydrogen–Helium Ion-Molecule Systems	426
4.3. Energy and Angular Distribution of Reaction Products	428
5. Summary and Conclusions	429
References	430

Chapter 15

Particle Interchange Reactions Involving Plasma Impurity Ions and H₂, D₂, and HD

P. B. Armentrout and J. Botero

1. Introduction	433
2. Experimental Description	434
2.1. General Considerations	434
2.2. The Octopole Ion-Beam Guide	435
2.3. Kinetic Energy Scale and Doppler Broadening	436
2.4. Ion Sources	436
3. Theoretical Considerations	437
4. Results	440
4.1. Carbon, Oxygen, and Silicon	440
4.2. Metals	445
5. Analytic Representation	453
6. Discussion	457
References	459

Chapter 16

Electron Collision Processes Involving Hydrocarbons

Hiroyuki Tawara

1. Introduction	461
1.1. Physical Sputtering	462
1.2. Chemical Sputtering	464
2. Important Collision Processes Involving Hydrocarbon Molecules	466
3. Experimental Techniques and Their Features	468
4. Present Status of Electron Collision Data for Hydrocarbon Molecules	470
4.1. Dissociation and Ionization or Ion and Neutral Particle Production	472
4.2. Energy Distributions of Product Ion and Neutral Species	481
4.3. Dissociative Recombination and Dissociation/Ionization of Hydrocarbon Molecular Ions	484
4.4. Photon Emission	485
5. Summary, Further Data Needs, and Recommended Work	493
References	495

<i>Index</i>	497
-------------------------------	------------