
Contents

1 Introduction

<i>T. Fujimoto</i>	1
1.1 What is Plasma Polarization Spectroscopy?	1
1.2 History of PPS	5
1.3 Classification of PPS Phenomena	7
1.4 Atomic Physics	8
References	10

2 Zeeman and Stark Effects

<i>M. Goto</i>	13
2.1 General Theory	13
2.2 Zeeman Effect	17
2.3 Stark Effect	20
2.4 Combination of Electric and Magnetic Fields	25
References	27

3 Plasma Spectroscopy

<i>T. Fujimoto</i>	29
3.1 Collisional-Radiative Model: Rate Equations for Population	29
3.2 Ionizing Plasma and Recombining Plasma	34
3.2.1 Ionizing Plasma Component	34
3.2.2 Recombining Plasma Component	39
3.2.3 Ionizing Plasma and Recombining Plasma	45
References	49

4 Population-Alignment Collisional-Radiative Model

<i>T. Fujimoto</i>	51
4.1 Population and Alignment	51
4.2 Excitation, Deexcitation and Elastic Collisions: Semiclassical Approach	55
4.2.1 Monoenergetic Beam Perturbors and Cross Sections	56
4.2.2 Axially Symmetric Distribution	58

VIII Contents

4.2.3	Rate Equation in the Irreducible-Component Representation	61
4.2.4	Rate Equation in the Conventional Representation	62
4.3	Ionization and Recombination	64
4.4	Rate Equations	66
4.4.1	Ionizing Plasma Component	66
4.4.2	Recombining Plasma Component	67
	References	68

5 Definition of Cross Sections for the Creation, Destruction, and Transfer of Atomic Multipole Moments by Electron Scattering: Quantum Mechanical Treatment

	<i>G. Csanak, D.P. Kilcrease, D.V. Fursa, and I. Bray.</i>	69
5.1	General Theory	69
5.2	Inelastic Scattering	76
5.3	Alignment Creation by Elastic Electron Scattering	81
5.3.1	Semi-Classical Background	82
5.3.2	Wave-Packet Formulation of Alignment Creation by Elastic Scattering	83
5.3.3	Discussion and Conclusions	87
	References	88

6 Collision Processes

	<i>T. Fujimoto</i>	91
6.1	Inelastic and Elastic Collisions	91
6.1.1	Excitation/Deexcitation and Ionization, $Q_0^{0,0}(r, p)$, and $Q_0^{0,0}(p, p)$	91
6.1.2	Alignment Creation, $Q_0^{0,2}(r, p)$, and Alignment-to-Population, $Q_0^{2,0}(r, p)$	93
6.1.3	Alignment Creation by “Elastic” Scattering, $Q_0^{0,2}(p, p)$	98
6.1.4	Alignment Transfer, $Q_q^{2,2}(r, p)$, and Alignment Destruction, $Q_q^{2,2}(p, p)$	101
6.2	Recombination	110
6.2.1	Radiative Recombination	110
6.2.2	Dielectronic Recombination: Satellite Lines	113
6.2.3	Ionization	116
6.3	Alignment Relaxation by Atom Collisions	117
6.3.1	LIFS Experiment: Depopulation and Disalignment	117
6.3.2	Alignment Relaxation Observed by the Self-Alignment Method	124
	References	125

7 Radiation Reabsorption

	<i>T. Fujimoto</i>	127
7.1	Alignment Creation by Radiation Reabsorption: Self-Alignment	127

7.1.1	Basic Principle	127
7.1.2	Latent Alignment	131
7.1.3	Self-Alignment	132
7.2	Alignment Relaxation: Alignment Destruction and Disalignment	136
	References	142
8 Experiments: Ionizing Plasma		
	<i>T. Fujimoto, E.O. Baronova, and A. Iwamae</i>	145
8.1	Gas Discharge Plasmas	145
8.1.1	Direct Current Discharge	146
8.1.2	High-Frequency Discharge	150
8.1.3	Neutral Gas Plasma Collision	152
8.2	Z-Pinch Plasmas	154
8.2.1	Vacuum Spark and X-Pinch	156
8.2.2	Plasma Focus and Gas Z-Pinch	159
8.3	Laser-Produced Plasmas	163
8.4	Magnetically Confined Plasmas	166
8.4.1	Tokamak Plasmas	166
8.4.2	Cusp Plasma	167
	References	176
9 Experiments: Recombining Plasma		
	<i>A. Iwamae</i>	179
9.1	Introduction	179
9.2	Laser-Produced Plasmas	179
	References	184
10 Various Plasmas		
	<i>Y.W. Kim, T. Kawachi, and P. Hakel</i>	185
10.1	Charge Separation in Neutral Gas-Confined Laser-Produced Plasmas	185
10.1.1	Nonideal Plasmas and Their 3D Plasma Structure Reconstruction	186
10.1.2	Polarization Spectroscopy of LPP Plumes Confined by Low-Density Gas	192
10.1.3	Analysis and Discussion	196
10.1.4	Polarization-Resolved Plasma Structure Imaging	197
10.1.5	Concluding Remarks	199
10.2	Polarization of X-Ray Laser	201
10.2.1	Introduction	201
10.2.2	Observation of the Polarization of QSS Collisional Excitation X-Ray Laser	202
10.3	Atomic Kinetics of Magnetic Sublevel Populations and Multipole Radiation Fields in Calculation of Polarization of Line Emissions	206

10.3.1	Introduction	206
10.3.2	Development of a Magnetic-Sublevel Atomic Kinetics Model	207
10.3.3	Calculation of Polarization-Dependent Spectral Line Intensities	207
10.3.4	Results	210
	References	212

11 Polarized Atomic Radiative Emission in the Presence of Electric and Magnetic Fields

	<i>V.L. Jacobs</i>	215
11.1	Introduction	216
11.2	Polarization-Density-Matrix Description	218
11.2.1	Field-Free Atomic Eigenstate Representation	220
11.2.2	Multipole Expansion of the Electromagnetic Interaction	221
11.2.3	Photon-Polarization Density Matrix Allowing for Coherent Excitation Processes in a General Arrangement of Electric and Magnetic Fields	223
11.2.4	Irreducible Spherical-Tensor Representation of the Density Operators	226
11.2.5	Stokes-Parameter Representation of the Photon Density Operator	229
11.3	Polarization of Radiative Emission Along the Magnetic-Field Direction	230
11.3.1	Polarization of Radiative Emission in the Presence of Perpendicular (crossed) Electric and Magnetic Fields and Coherent Excitation Processes	230
11.3.2	Circular Polarization of Radiative Emission in the Absence of a Perpendicular Electric Field and a Coherent Excitation Process	231
11.3.3	Radiative Emission in the Absence of Electric and Magnetic Fields and Coherent Excitation Processes	232
11.3.4	Electric-Dipole Transitions	233
11.3.5	Directed Excitation Processes	233
11.3.6	Spectral Patterns Due to the Circularly Polarized Radiative Emissions	234
11.4	Reduced-Density-Matrix Formulation	236
11.4.1	Frequency-Domain (Resolvent-Operator) Formulation	239
11.4.2	Time-Domain (Equation-of-Motion) Formulation	241
	References	244

12 Astrophysical Plasmas	
<i>R. Casini and E. Landi Degl'Innocenti</i>	247
12.1 Introduction	247
12.2 Origin of Polarized Radiation	249
12.2.1 Description of Polarized Radiation	250
12.3 Quantum Theory of Photon–Atom Processes	252
12.4 The Hanle Effect in the Two-Level Atom	256
12.4.1 The 0–1 Atom in a Magnetic Field	258
12.4.2 The 1–0 Atom in a Magnetic Field	265
12.5 Scattering Polarization from Complex Atoms: The Role of Level-Crossing Physics	272
12.5.1 The Alignment-to-Orientation Conversion Mechanism	272
12.5.2 Hydrogen Polarization in the Presence of Magnetic and Electric Fields	280
References	286
13 Electromagnetic Waves	
<i>R.M. More, T. Kato, Y.S. Kim, and M.G. Baik</i>	289
13.1 Introduction	289
13.2 Effect of Environment on Atomic Dynamics	290
13.2.1 An Atomic Computer Code	290
13.2.2 Matrices for Quantum Operators	291
13.2.3 Density–Matrix Equation of Motion and Line Profile	292
13.2.4 Computer Time	293
13.2.5 Atomic Data for Hydrogen	293
13.2.6 Calculations	294
13.2.7 Limitations of the Calculations	299
References	300
14 Instrumentation I	
<i>A. Iwamae</i>	303
14.1 PPS Instrumentation in the UV–Visible Region	303
14.1.1 Sheet Polarizer and Narrow Bandpass Filters: Polarization Map	303
14.1.2 Birefringent Polarizers	307
14.2 Polarization Degree	315
14.2.1 Uncertainty of Polarization Degree for Low Signal Intensity	315
14.2.2 Signal Intensity and Photoelectron Number in CCD Detector	318
14.2.3 Experiments on the Uncertainty in Polarization Degree	319
14.2.4 Uncertainty with an Image Intensifier Coupled CCD	322
References	325

15 Instrumentation II

E.O. Baronova, M.M. Stepanenko, and L. Jakubowski 327

15.1 X-ray Polarization Measurements 327

15.2 Novel Polarimeter–Spectrometer for X-rays 334

 15.2.1 Principle of X-ray Polarimeter 334

 15.2.2 How to Cut a One-Crystal Polarimeter from a Crystal 335

 15.2.3 The Optics of Polarimeter 338

 15.2.4 Relationship between Bravais Indices of Polarizing
 and Mechanical Planes 339

 15.2.5 Characteristics of the Four-Facet Quartz
 X-ray Polarimeter 343

References 345

Appendix

Light Polarization and Stokes Parameters 347

A.1 Electric Dipole Radiation 347

A.2 Stokes Parameters 350

Angular Momentum and Rotation Matrix 351

B.1 Angular Momentum Coupling 351

 B.1.1 3-*j* Symbol 351

 B.1.2 6-*j* Symbol 352

B.2 Rotation Matrix 354

References 357

Density Matrix: Light Observation and Relaxation 359

C.1 Density Matrix 359

C.2 Temporal Development 361

C.3 Observation 362

C.4 Examples 363

 C.4.1 π -Light Excitation 363

 C.4.2 σ -Light Excitation 364

 C.4.3 Magic-Angle Excitation 365

 C.4.4 Isotropic Excitation 365

 C.4.5 Magnetic Field 366

C.5 Relaxation 368

References 369

Hanle Effect 371

D.1 Classical Picture 371

D.2 Quantum Picture 372

Method to Determine the Population 373

References 376

Index 377