

Contents

Part I Elementary Information on Atomic Spectra

Chapter 1

The Hydrogen Spectrum

1.1 Schrödinger's Equation for the Hydrogen Atom	3
1.1.1 Energy Levels	3
1.1.2 Wave Functions	5
1.2 Series Regularities	7
1.2.1 Radiative Transition Selection Rules	7
1.2.2 Spectral Series of the Hydrogen Atom	8
1.2.3 Hydrogenlike Ions	9
1.3 Fine Structure	10
1.3.1 Velocity Dependence of Electron Mass	10
1.3.2 Spin-Orbit Interaction	11
1.3.3 Fine Structure. Selection Rules	12
1.3.4 Lamb Shift	15

Chapter 2

Systematics of the Spectra of Multielectron Atoms

2.1 Central Field	16
2.1.1 Central Field Approximation	16
2.1.2 Parity of States	18
2.1.3 Systematics of Electron States in a Central Field	19
2.2 Electrostatic and Spin-Orbit Splitting in the <i>LS</i> Coupling Approximation	20
2.2.1 Spectral Terms. <i>LS</i> Quantum Numbers	20
2.2.2 Fine Structure of Terms	21
2.2.3 Finding the Terms of Multielectron Configurations	23
2.2.4 Radiative Transitions	26
2.3 <i>jj</i> Coupling Approximation	27
2.3.1 Various Coupling Schemes	27
2.3.2 Systematics of Electron States with <i>jj</i> Coupling	29

Chapter 3

Spectra of Multielectron Atoms

3.1 Periodic System of Elements	32
3.2 Spectra of the Alkali Elements.....	34
3.2.1 Term Scheme	34
3.2.2 Series Regularities	37
3.2.3 Fine Structure	37
3.2.4 Copper, Silver, and Gold Spectra.....	38
3.3 Spectra of the Alkaline Earth Elements	39
3.3.1 He Spectrum	39
3.3.2 Spectra of the Alkaline Earth Elements.....	40
3.3.3 Zinc, Cadmium, and Mercury Spectra	42
3.4 Spectra of Elements with <i>p</i> Valence Electrons	42
3.4.1 One <i>p</i> Electron Outside Filled Shells	42
3.4.2 Configuration <i>p</i> ²	43
3.4.3 Configuration <i>p</i> ³	44
3.4.4 Configuration <i>p</i> ⁴	45
3.4.5 Configuration <i>p</i> ⁵	46
3.4.6 Configuration <i>p</i> ⁶	46
3.5 Spectra of Elements with Unfilled <i>d</i> and <i>f</i> Shells	48
3.5.1 Elements with Unfilled <i>d</i> Shells.....	48
3.5.2 Elements with Unfilled <i>f</i> Shells	49

Part II

Theory of Atomic Spectra

Chapter 4

Angular Momenta

4.1 Angular Momentum Operator. Addition of Angular Momenta	53
4.1.1 Angular Momentum Operator	53
4.1.2 Orbital Angular Momentum	54
4.1.3 Electron Spin	54
4.1.4 Addition of Two Angular Momenta	55
4.1.5 Addition of Three or More Angular Momenta	57
4.2 Angular Momentum Vector Addition Coefficients	60
4.2.1 Clebsch-Gordan and Associated Coefficients	60
4.2.2 Summary of Formulas for <i>3j</i> Symbols	62
4.2.3 Racah <i>W</i> Coefficients and <i>6j</i> Symbols	66
4.2.4 Summary of Formulas for <i>6j</i> Symbols	70
4.2.5 <i>9j</i> Symbols	72
4.3 Irreducible Tensor Operators	74

4.3.1 Spherical Tensors	74
4.3.2 Matrix Elements	76
4.3.3 Some Examples of Calculation of Reduced Matrix Elements	78
4.3.4 Tensor Product of Operators	80
4.3.5 Matrix Elements with Coupled Angular Momenta	84
4.3.6 Direct Product of Operators	86

Chapter 5 Systematics of the States of Multielectron Atoms

5.1 Wave Functions	89
5.1.1 Central Field Approximation	89
5.1.2 Two-Electron Wave Functions in $LSM_L M_S$ Representation	90
5.1.3 Two-Electron Wave Functions in $mm' SM_S$ Representation	93
5.1.4 Multielectron Wave Functions in a Parentage Scheme Approximation	96
5.1.5 Fractional Parentage Coefficients	96
5.1.6 Classification of Identical Terms of l^n Configuration According to Seniority (Seniority Number)	98
5.2 Matrix Elements of Symmetric Operators	106
5.2.1 Statement of the Problem	106
5.2.2 F Matrix Elements. Parentage Scheme Approximation	108
5.2.3 F Matrix Elements. Equivalent Electrons	109
5.2.4 Q Matrix Elements. Parentage Scheme Approximation	111
5.2.5 Q Matrix Elements. Equivalent Electrons	113
5.2.6 Summary of Results	115
5.3 Electrostatic Interaction in LS Coupling. Two-Electron Configuration	115
5.3.1 Coulomb and Exchange Integrals	115
5.3.2 Configuration Mixing	118
5.4 Electrostatic Interaction in LS Coupling. Multielectron Configuration	120
5.4.1 Configurations l^n and $l^n l'$	120
5.4.2 More Than Half Filled Shells	123
5.4.3 Filled (Closed) Shells	123
5.4.4 Applicability of the Single-Configuration Approximation	124
5.5 Multiplet Splitting in LS Coupling	126
5.5.1 Preliminary Remarks	126
5.5.2 Landé Interval Rule	126
5.5.3 One Electron Outside Closed Shells	128
5.5.4 Configuration l''	130
5.5.5 Parentage Scheme Approximation	132
5.5.6 Fine-Structure Splitting of Levels of He	133
5.5.7 Spin-Spin and Spin-Other Orbit Interactions	139
5.6 jj Coupling	141
5.6.1 Wave Functions	141
5.6.2 Spin-Orbit and Electrostatic Interactions	143

5.7 Intermediate Coupling and Other Types of Coupling	144
5.7.1 Transformations Between LS and jj Coupling Schemes	144
5.7.2 Intermediate Coupling	147
5.7.3 jl Coupling	152
5.7.4 Experimental Date	153
5.7.5 Other Types of Coupling	154

Chapter 6**Hyperfine Structure of Spectral Lines**

6.1 Nuclear Magnetic Dipole and Electric Quadrupole Moments	156
6.1.1 Magnetic Moments	156
6.1.2 Quadrupole Moments	157
6.2 Hyperfine Splitting	159
6.2.1 General Character of the Splitting	159
6.2.2 Calculation of the Hyperfine Splitting Constant A	162
6.2.3 Calculation of the Hyperfine Splitting Constant B	168
6.2.4 Radiative Transitions Between Hyperfine-Structure Components ..	170
6.2.5 Isotope Shift of the Atomic Levels	170

Chapter 7**The Atom in an External Electric Field**

7.1 Quadratic Stark Effect	173
7.2 Hydrogenlike Levels. Linear Stark Effect	177
7.3 Inhomogeneous Field. Quadrupole Splitting	181
7.4 Time-Dependent Field	183
7.4.1 Amplitude Modulation	183
7.4.2 The Hydrogen Atom in a Rotating Electric Field	187

Chapter 8**The Atom in an External Magnetic Field**

8.1 Zeeman Effect	189
8.2 Paschen-Back Effect	194
8.2.1 Strong Field	194
8.2.2 Splitting of Hyperfine Structure Components in a Magnetic Field	198

Chapter 9**Radiative Transitions**

9.1 Electromagnetic Radiation	200
9.1.1 Quantization of the Radiation Field	200
9.1.2 Radiative Transition Probabilities	201
9.1.3 Correspondence Principle for Spontaneous Emission	202
9.1.4 Dipole Radiation	203

9.1.5 Stimulated Emission and Absorption	203
9.1.6 Effective Cross Sections of Absorption and Stimulated Emission	205
9.2 Electric Dipole Radiation	205
9.2.1 Selection Rules, Polarization and Angular Distribution	205
9.2.2 Oscillator Strengths and Line Strengths	208
9.2.3 <i>LS</i> Coupling Approximation. Relative Intensities of Multiplet Components	211
9.2.4 One Electron Outside Closed Shell	213
9.2.5 Multielectron Configurations. Different Coupling Schemes	214
9.2.6 Relative Intensities of Zeeman and Stark Components of Lines	215
9.3 Multipole Radiation	216
9.3.1 Fields of Electric and Magnetic Multipole Moments	216
9.3.2 Intensity of Multipole Radiation	220
9.3.3 Selection Rules	222
9.3.4 Electric Multipole Radiation	223
9.3.5 Magnetic Dipole Radiation	225
9.3.6 Transitions Between Hyperfine Structure Components. Radio Emission from Hydrogen	227
9.4 Calculation of Radiative Transition Probabilities	229
9.4.1 Approximate Methods	229
9.4.2 Three Ways of Writing Formulas for Transition Probabilities	230
9.4.3 Theorems for Sums of Oscillator Strengths	232
9.4.4 Semiempirical Methods of Calculating Oscillator Strengths	235
9.4.5 Electric Dipole Transition Probabilities in the Coulomb Approximation	236
9.4.6 Intercombination Transitions	237
9.5 Continuous Spectrum	239
9.5.1 Classification of Processes	239
9.5.2 Photorecombination and Photoionization: General Expressions for Effective Cross Sections	239
9.5.3 Bremsstrahlung: General Expressions for Effective Cross Sections	245
9.5.4 Radiation and Absorption Coefficients	248
9.5.5 Photorecombination and Photoionization: Hydrogenlike Atoms	251
9.5.6 Photorecombination and Photoionization: Nonhydrogenlike Atoms	255
9.5.7 Bremsstrahlung in a Coulomb Field	257
9.6 Formulas for <i>Q</i> Factors	274
9.6.1 Symmetry and Sum Rules	274
9.6.2 <i>LS</i> Coupling. Allowed Transitions	275
9.6.3 <i>jl</i> Coupling	279
9.7 Tables of Oscillator Strengths and Radiative Transition Probabilities	281
9.7.1 Transition Probabilities for the Hydrogen Atom	281
9.7.2 Radiative Transition Probabilities in the Bates-Damgaard Approximation	283

9.7.3 Oscillator Strengths and Probabilities of Some Selected Transitions.....	284
9.7.4 Effective Cross Sections and Rates of Photorecombination	284
 Chapter 10	
Relativistic Corrections in the Spectroscopy of Multicharged Ions	
10.1 Dirac Equation. Pauli Equation	303
10.1.1 Dirac Equation.....	303
10.1.2 Electron Spin	305
10.1.3 Non-Relativistic Approximation. Pauli Equation.....	308
10.2 Central Field	310
10.2.1 Non-Relativistic Approximation	310
10.2.2 Second Approximation with Respect to v/c . Fine Splitting.....	313
10.2.3 Dirac Equation for a Central Field	316
10.2.4 Coulomb Field. Energy Levels, Fine Splitting	319
10.2.5 Coulomb Field. Radial Functions	322
10.3 Relativistic Corrections	325
10.3.1 Calculation of Some Radial Integrals.....	325
10.3.2 Hyperfine Splitting Constant A	326
10.3.3 Hyperfine Splitting Constant B	330
10.3.4 Nucleus Finite-Size Correction.....	331
10.3.5 Radiative Corrections. Lamb Shift.....	333
 Chapter 11	
Spectra of Multicharged Ions	
11.1 Energy Levels	339
11.2 Forbidden Transitions	341
11.2.1 H-like Ions	342
11.2.2 He-like Ions	342
11.3 Satellite Structure	346
 References	351
List of Symbols	353
Subject Index	355