

## Contents

<b>Preface</b>	<i>IX</i>
<b>Index to Codes</b>	<i>XI</i>
<b>1</b>	<b>Introduction</b> 1
<b>2</b>	<b>Alkali-Metal Atoms</b> 15
2.1	Electronic Energies 15
2.2	Valence-Electron Wave Functions 18
2.3	Hyperfine Structure 20
<b>3</b>	<b>Wave Functions and Schrödinger Space</b> 25
3.1	Uncoupled States 25
3.1.1	Kronecker Products 25
3.1.2	Angular Momentum Matrices 27
3.2	Energy States 28
3.3	Zero-Field States 30
<b>4</b>	<b>Density Matrix and Liouville Space</b> 33
4.1	Purity and Entropy 35
4.2	Ground State, Excited State, and Optical Coherence 35
4.3	Column-Vector and Row-Vector Transforms 36
4.3.1	Column-Vector Transforms 36
4.3.2	Row-Vector Transforms 37
4.3.3	Expectation Values 38
4.4	Superoperators 39
4.4.1	Transposition Matrix 39
4.4.2	Evolution Matrices 40
4.5	Eigendecomposition of $G$ 41
4.5.1	Nullspace 42
4.5.2	Critical Damping 43
4.6	Matrix Transformations from Schrödinger Space to Liouville Space 44
4.6.1	Flat and Sharp Superoperators 44
4.6.2	Square Matrices 46
4.6.3	Commutator Superoperators 47

4.6.4	O-Dot Superoperators	47
<b>5</b>	<b>Optical Pumping of Atoms</b>	<b>49</b>
5.1	The Electric Field of Light	49
5.2	The Electric Dipole Moment of Atoms	50
5.2.1	Spherical Tensors	50
5.2.2	Hermitian Conjugates	51
5.2.3	Addition of Angular Momentum	52
5.2.4	Spherical Basis Tensors	53
5.2.5	Identities for $\mathbf{A}$ and $\mathbf{A}^\dagger$	53
5.2.6	Amplitude $\mathcal{D}$	56
5.2.7	Energy Basis	56
5.3	Spontaneous Emission	57
5.4	Electric Dipole Interaction	58
5.5	Rotating Coordinate System	59
5.6	Net Evolution	62
5.6.1	The Amagat Unit of Density	64
5.6.2	Normalization	64
5.6.3	Notation and Coding	65
5.7	Optical Bloch Equations	65
5.8	Liouville Space	66
5.8.1	Transients	68
5.8.2	Steady State	69
5.8.3	Steady State Versus Detuning	70
<b>6</b>	<b>Quasi-Steady-State Optical Pumping</b>	<b>73</b>
6.1	Ground-State Evolution	74
6.2	Excited-State Evolution	76
6.3	Collisions	77
6.4	Saturation	78
6.5	Identities	78
6.6	Net Evolution	80
6.7	Negligible Stimulated Emission	81
6.8	High-Pressure Pumping	82
6.8.1	Liouville Space	84
6.9	Spectral Width of Pumping Light	87
6.9.1	Gaussian Spectral Profiles	88
6.9.2	Plasma Dispersion Function	89
6.10	Doppler Broadening	90
<b>7</b>	<b>Modulation</b>	<b>93</b>
7.1	Magnetic Resonance	94
7.2	Modulated Light	94
7.2.1	High Pressure	95
7.2.2	Lower Pressure	95
7.2.3	Modulated Optical Pumping Matrices	96

7.3	Secular Approximation	97
7.4	Attenuation of Modulated Coherence in Passing through the Excited State	100
7.5	Examples	102
7.5.1	Isolated Magnetic Resonances	102
7.5.2	Zeeman Magnetic Resonances	103
7.5.3	Push–Pull Pumping	106
<b>8</b>	<b>Light Propagation</b>	<b>109</b>
8.1	Induced Electric Dipole Moment	109
8.2	Absorption Cross Section	111
8.3	Small Magnetic Fields	112
8.4	Evolution of a Beam in Space and Time	114
8.5	First-Order Propagation Equation	115
8.6	Propagation of Weak Probe Light	116
8.7	Faraday Rotation	117
8.8	Specific Absorption	118
8.9	Fluorescent Light	119
<b>9</b>	<b>Radiation Forces</b>	<b>121</b>
9.1	Mean Force	121
9.2	Forces from Monochromatic Light	123
9.3	Forces in Magneto-Optical Traps	124
9.3.1	Repump Lasers	130
9.4	Pointing Probability	132
9.5	Momentum Space	135
9.6	Evolution in Spin-Momentum Space	138
9.7	Liouville Space	140
9.8	Compactification	140
9.8.1	Compactified $p q$ Space	141
9.8.2	Compactification within a Tile	143
9.9	Displays	147
9.9.1	Momentum-Space Displays	147
9.9.2	Position-Space Displays	149
9.10	Momentum Diffusion	151
9.11	Momentum Diffusion Due to Spontaneous Emission	152
9.12	Momentum Diffusion from Pumping	153
<b>10</b>	<b>Relaxation of Polarized Atoms</b>	<b>159</b>
10.1	S-Matrix	160
10.2	Collisions in the Gas	163
10.3	Weak Collisions	164
10.4	Relative Power Spectrum	166
10.5	Sudden Collisions	167
10.6	Strong Collisions	168
10.7	Hyperfine-Shift Interaction	171

10.8	Spin–Rotation Interaction	175
10.8.1	Binary Collisions	176
10.8.2	Experimental Measurements	178
10.9	Spin Exchange between Alkali-Metal Atoms and Noble Gas Atoms	178
10.9.1	Binary Collisions	181
10.9.2	Spin Temperature	184
10.9.3	Experimental Measurements	186
10.10	Spatial Diffusion	189
10.11	Adsorption on the Walls	194
10.12	Spin Exchange between Pairs of Alkali-Metal Atoms	198
10.12.1	Partial-Wave Analysis	198
10.12.2	Semiclassical Calculation of Partial-Wave Cross Sections	207
10.13	Pressure Dependence of Relaxation in the Dark	208
10.14	Collisions of Excited Atoms	212
<b>11</b>	<b>Mathematical Appendix</b>	<b>219</b>
11.1	Electronic Multipoles	219
11.2	Projection Operators in Terms of $S$ or $J$	221
11.3	Recoupling Example	223
	<b>References</b>	<b>225</b>
	<b>Index</b>	<b>231</b>