Contents

Lis	st of acronyms	xi
	PART I INTRODUCTION TO LIGHT-ATOM INTERACTIONS	
1	Introduction	3
	1.1 Why was this book written?	3
	1.2 How to use this book	3
	1.3 Relation to other texts	4
	1.4 Formalism of quantum mechanics	5
2	Atomic states	8
	2.1 Energy states of the hydrogen atom	8
	2.2 Angular momentum of the electron in the hydrogen atom	9
	2.3 Multi-electron atoms	19
	2.4 Hyperfine interactions and hyperfine structure of atomic states	26
	2.5 Parity of atomic states	27
3	A bit of angular-momentum theory	30
	3.1 Classical rotations	30
	3.2 Quantum-mechanical rotations	36
	3.3 The angular-momentum operator	39
	3.4 Rotations in the Zeeman basis	43
	3.5 Addition of angular momenta; Clebsch–Gordan coefficients	45
	3.6 $3j$ and $6j$ symbols	46
	3.7 Irreducible tensors and tensor products	49
	3.8 The Wigner–Eckart theorem	51
4	Atoms in external electric and magnetic fields	55
	4.1 Linear Zeeman effect	55
	4.2 Zeeman effect in the manifold of hyperfine levels, Breit–Rabi diagrams	58
	4.3 Atoms in an electric field: the Stark effect	62
	4.4 Combined effect of electric and magnetic fields	72
	4.5 Atoms in oscillating fields	75
5	Polarized atoms	82
	5.1 The density matrix	82
	5.2 Rotation of density matrices	88

Angular-momentum probability surfaces	89
Angular-momentum probability surfaces and the density matrix: equivalence	00
and symmetries Temporal evolution of the density matrix: the Liouville equations	92
Example: alignment-to-orientation conversion	94
Multipole moments	96
	100
rized light	110
Partially polarized light and uppolarized light	114
Spin angular momentum of polarized light	116
Spherical basis for light polarization	118
The polarization density matrix	121
Angular-momentum probability surfaces for light	122
Stokes parameters for partially polarized light	123
nic transitions	126
Two-level system under the action of a periodic perturbation	126
Selection rules for electric-dipole transitions	129
Probability calculation for electric-dipole transitions	133
Line strength	141
Higher-multipole radiative transitions	144
Multipole expansion	148
Two-photon and multi-photon transitions	152
Visualization of atomic transitions	155
erence in atomic systems	159
Dark and bright states	159
Quantum beats	164
The Hanle effect	100
ical pumping	169
Linear and nonlinear processes; saturation parameters	169
Optical pumping on closed transitions	1/3
Optical pumping on open transitions	183
nt-atom interaction observed in transmitted light	186
Effect of atoms on transmitted light	186
Magneto-optical effects with linearly polarized light	190
Perturbative approach	213
Perturbative approach TII ADVANCED TOPICS	213
Perturbative approach RT II ADVANCED TOPICS linear magneto-optical rotation	213
Perturbative approach T II ADVANCED TOPICS linear magneto-optical rotation Nested nonlinear magneto-optical rotation features	213 219 219
Perturbative approach CT II ADVANCED TOPICS dinear magneto-optical rotation Nested nonlinear magneto-optical rotation features Bennett-structure effects	213 219 219 220
Perturbative approach RT II ADVANCED TOPICS linear magneto-optical rotation Nested nonlinear magneto-optical rotation features Bennett-structure effects The role of alignment-to-orientation conversion in nonlinear magneto-optical	213 219 219 220
i	Angular-momentum probability surfaces Angular-momentum probability surfaces and the density matrix: equivalence and symmetries Temporal evolution of the density matrix: the Liouville equations Example: alignment-to-orientation conversion Multipole moments rized light The light polarization ellipse Partially polarized light and unpolarized light Spin angular momentum of polarized light Spherical basis for light polarization The polarization density matrix Angular-momentum probability surfaces for light Stokes parameters for partially polarized light mic transitions Two-level system under the action of a periodic perturbation Selection rules for electric-dipole transitions Probability calculation for electric-dipole transitions Line strength Higher-multipole radiative transitions Multipole expansion Two-photon and multi-photon transitions Visualization of atomic transitions erence in atomic systems Dark and bright states Quantum beats The Hanle effect ical pumping Linear and nonlinear processes; saturation parameters Optical pumping on closed transitions nt-atom interaction observed in transmitted light Effect of atoms on transmitted light Effect of atoms on transmitted light

	11.4 Buffer-gas vapor cells11.5 Antirelaxation-coated cells11.6 Optically thick media11.7 Nonlinear magneto-optical rotation with modulated light	224 225 228 234
12	 Perturbative and approximate methods for light-atom interactions 12.1 Polarization transfer in spontaneous decay 12.2 Perturbative solution of the steady-state density matrix 12.3 The optical-field case 12.4 Repopulation and depopulation 12.5 Optical excitation 12.6 Absorption and optical rotation signals 12.7 What kind of atomic polarization can influence the absorption and emission of light? 12.8 The broad-line approximation 	 239 239 243 244 246 248 248 248 252 252
13	Polarization effects in transitions with partially resolved hyperfine structure13.1Depopulation pumping13.2Excited state and repopulation pumping13.3Absorption13.4Fluorescence13.5Comparison of different cases	257 259 263 266 269 269
14	 The effect of hyperfine splitting on nonlinear magneto-optical rotation 14.1 Doppler-free transit effect 14.2 Doppler-broadened transit effect 14.3 Wall effect 14.4 Higher nuclear spin and the <i>D</i>2 line 14.5 Comparison of quantitative results for different cases 	271 272 277 280 283 287
15	Coherence effects revisited15.1Dark and bright states15.2Quantum beats15.3The Hanle effect	289 289 292 296
16	Collapse and revival in quantum beats	303
17	Nuclear quadrupole resonance and alignment-to-orientation conversion	309
18	 Selective addressing of high-rank polarization moments 18.1 General technique and production and detection of the κ = 2 and κ = 4 moments 18.2 Production and observation of the κ = 6 hexacontatetrapole moment 18.3 Production and detection of the hexadecapole moment in the Earth's magnetic field 	314314319322
19	Tensor structure of the DC- and AC-Stark polarizabilities	329
20	Photoionization of polarized atoms with polarized light 20.1 Photoionization cross-section	333 334

x Contents

20.2 Formulas for $\sigma_{0,1,2}$	336
Appendix A Constants, units, and notations	339
Appendix B Units of energy, frequency, and wavelength	342
Appendix C Reference data for hydrogen and the alkali atoms	343
Appendix D Classical rotations	344
D.1 Rotations in the Cartesian basis	344
D.2 The spherical basis	347
Appendix E Nonlinear magneto-optical rotation with hyperfine structure	352
E.1 Perturbation theory with polarization moments	352
E.2 Doppler-free transit effect	354
E.3 Doppler-broadened transit effect	356
E.4 Wall effect	357
Appendix F The Atomic Density Matrix software package	358
Bibliography	360
Index	367