

Atomic Physics

An Exploration through Problems and Solutions



CONTENTS

Preface to the Second Edition			XV
Pr	eface t	o the First Edition	xvii
Notation			xix
1	Aton	nic structure	1
	1.1	Ground state of phosphorus	1
	1.2	Exchange interaction	7
	1.3	Spin-orbit interaction	10
	1.4	Hyperfine structure and Zeeman effect in hydrogen	13
	1.5	Hydrogenic ions	18
	1.6	Geonium	21
	1.7	The Thomas-Fermi model (T)	30
	1.8	Electrons in a shell	33
	1.9	Isotope shifts and the King plot	37
	1.10	Crude model of a negative ion	41
	1.11	Hyperfine-interaction-induced mixing of states of different J	42
	1.12	Electron density inside the nucleus (T)	46
	1.13	Parity nonconservation in atoms	51
		Parity nonconservation in anti-atoms	61
	1.15	The anapole moment (T)	65
2	Aton	ns in external fields	75
	2.1	Electric polarizability of the hydrogen ground state	75
	2.2	Polarizabilities for highly excited atomic states	78
	2.3	Using Stark shifts to measure electric fields	79
	2.4	Larmor precession frequencies for alkali atoms	81
	2.5	Magnetic field inside a magnetized sphere	84
	2.6	Classical model of magnetic resonance	85
	2.7	Energy level shifts due to oscillating fields (T)	90
	2.8	Spin relaxation due to magnetic field inhomogeneity	102
	2.9	The $ec{E} imes ec{v}$ effect in vapor cells	107
		Field ionization of hydrogenic ions	110
	2.11	Electric-field shifts of magnetically split Zeeman sublevels	110

	2.12	Geometric (Berry's) phase	112
	2.13	Nuclear dipole-dipole relaxation	116
	2.14	Magnetic spin precession of a free magnet	118
3	Inte	raction of atoms with light	121
	3.1	Two-level system under periodic perturbation (T)	121
	3.2	Quantization of the electromagnetic field (T)	128
	3.3	Emission of light by atoms (T)	134
	3.4	Absorption of light by atoms	144
	3.5	Resonant absorption cross-section	147
	3.6	Absorption cross-section for a Doppler-broadened line	149
	3.7	Saturation parameters (T)	151
	3.8	Angular distribution and polarization of atomic fluorescence	158
	3.9	Change in absorption due to optical pumping	162
	3.10	Optical pumping and the density matrix	168
	3.11	Cascade decay	172
	3.12	Coherent laser excitation	175
	3.13	Transit-time broadening	176
		A quiz on fluorescence and light scattering	179
		Two-photon transition probability	183
		Vanishing Raman scattering	185
		Excitation of atoms by off-resonant laser pulses	187
	3.18	Hyperfine-interaction-induced magnetic dipole (M1) transi-	
		tions	190
		Transitions with unresolved hyperfine structure	193
		Optical pumping and quantum beats in Mercury	195
		Thomson scattering	199
		Classical model for a magnetic-dipole transition	201
		Nonlinear three-wave mixing in isotropic chiral media	204
		A negatively refracting atomic vapor?	207
		Light propagation in anisotropic crystals	212
	3.26	Electromagnetically induced transparency (EIT)	215
4	Inter	raction of light with atoms in external fields	223
	4.1	Resonant Faraday rotation	223
	4.2	Kerr effect in an atomic medium	227
	4.3	The Hanle effect	233
	4.4	Electric-field-induced decay of the hydrogen $2^2S_{1/2}$ state	236
	4.5	Stark-induced transitions (T)	238
	4.6	Magnetic deflection of light	244
	4.7	Classical model of an optical-pumping magnetometer	249

4.8	Searches for permanent electric dipole moments (T)	253
4.9	Sensitivity to electric dipole moments	264
4.10	Absorption, dispersion, optical rotation, and induced elliptic-	
		267
4.11		270
Aton	nic collisions	273
5.1	Collisions in a buffer gas	273
5.2	Spectral line broadening due to phase diffusion	274
5.3	Dicke narrowing	277
5.4	Basic concepts in spin exchange	281
5.5	The spin-temperature limit	285
5.6	Electron-randomization collisions	287
5.7	Larmor precession under conditions of rapid spin exchange	288
5.8	Penning ionization of metastable helium atoms	290
Cold	l atoms	295
6.1	Laser cooling: basic ideas (T)	295
6.2	Magneto-optical traps	302
6.3	Zeeman slower	306
6.4	Bose-Einstein condensation (T)	311
6.5	Bose-Einstein condensation from an optical lattice	322
6.6	Cavity cooling	324
6.7	Cavity cooling for many particles: stochastic cooling	329
6.8	Fermi energy for a harmonic trap	331
Mol	ecules	335
7.1	Amplitude of molecular vibrations	335
7.2	Vibrational constants for the Morse potential	336
7.3	Centrifugal distortion	338
7.4	Relative densities of atoms and molecules in a vapor	341
7.5	Isotope shifts in molecular transitions	346
7.6	Electric dipole moments of polar molecules	351
7.7	Scalar coupling of nuclear spins in molecules	355
7.8	Zeeman effect in diatomic molecules	359
7.9	Omega-type doubling	363
Exp	erimental methods	367
8.1		367
8.2	Laser heating of a small particle	369
	4.9 4.10 4.11 Atom 5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 Cold 6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 Mol 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 Exp 8.1	4.9 Sensitivity to electric dipole moments 4.10 Absorption, dispersion, optical rotation, and induced ellipticity 4.11 Optical rotation in a gas of polarized neutrons Atomic collisions 5.1 Collisions in a buffer gas 5.2 Spectral line broadening due to phase diffusion 5.3 Dicke narrowing 5.4 Basic concepts in spin exchange 5.5 The spin-temperature limit 5.6 Electron-randomization collisions 5.7 Larmor precession under conditions of rapid spin exchange 7.8 Penning ionization of metastable helium atoms Cold atoms 6.1 Laser cooling: basic ideas (T) 6.2 Magneto-optical traps 6.3 Zeeman slower 6.4 Bose-Einstein condensation (T) 6.5 Bose-Einstein condensation from an optical lattice 6.6 Cavity cooling 6.7 Cavity cooling for many particles: stochastic cooling 6.8 Fermi energy for a harmonic trap Molecules 7.1 Amplitude of molecular vibrations 7.2 Vibrational constants for the Morse potential 7.3 Centrifugal distortion 7.4 Relative densities of atoms and molecules in a vapor 7.5 Isotope shifts in molecular transitions 7.6 Electric dipole moments of polar molecules 7.7 Scalar coupling of nuclear spins in molecules 7.8 Zeeman effect in diatomic molecules 7.9 Omega-type doubling Experimental methods 8.1 Reflection of light from a moving mirror

	8.3	Spectrum of frequency-modulated light	372
	8.4	Frequency doubling of modulated light	374
	8.5	Ring-down of a detuned cavity	376
	8.6	Transmission through a light guide	377
	8.7	Quantum fluctuations in light fields	378
	8.8	Noise of a beamsplitter	382
	8.9	Photon shot noise in polarimetry	384
		Light-polarization control with a variable retarder	386
		Pile-up in photon counting	390
		Photons per mode in a laser beam	391
	8.13	Tuning dye lasers	392
	8.14	Matter-wave vs. optical Sagnac gyroscopes	395
	8.15	Femtosecond laser pulses and frequency combs	398
	8.16	Magnetic field fluctuations due to random thermal currents	403
	8.17	Photodiodes and circuits (T)	406
9	Miso	cellaneous topics	415
	9.1	Precession of a compass needle?	415
	9.2	Ultracold neutron polarizer	417
	9.3	Exponentially growing/decaying harmonic field	418
	9.4	The magic angle	420
	9.5	Understanding a Clebsch-Gordan coefficient selection rule	426
	9.6	The Kapitsa pendulum	428
	9.7	Visualization of atomic polarization	431
	9.8	Estimate of elasticity and tensile strength of materials	438
	9.9	The Casimir force	440
A	Unit	s, conversion factors, and typical values	443
В	Refe	rence data for hydrogen and alkali atoms	449
C	Spec	troscopic notation for atoms and diatomic molecules	451
D	Desc	ription of polarization states of light	455
	D.1	The Stokes parameters	455
	D.2	The Jones calculus	456
E	Eule	r angles and rotation matrices	459

F	The Wigner-Eckart theorem and irreducible tensors F.1 Wigner-Eckart theorem F.2 Irreducible tensors	461 461 467
G	The density matrix G.1 Connection between the density matrix and the wavefunction G.2 Ensemble-averaged density matrix G.3 Time evolution of the density matrix: the Liouville equation G.4 Atomic polarization moments	469 469 472 474 476
Н	Elements of the Feynman diagram technique	481
I	The 3-J and 6-J symbols I.1 3-J symbols I.2 6-J symbols	485 485 488
Bibliography Index		