

Contents

Preface	xi
1 Electrons, photons and atoms	1
1.1 The atomic nature of matter	1
1.2 The electron	3
1.3 Black body radiation	9
1.4 The photoelectric effect	15
1.5 X-rays and the Compton effect	18
1.6 The nuclear atom	23
1.7 Atomic spectra and the Bohr model of hydrogen	27
1.8 The Stern–Gerlach experiment – angular momentum and spin	40
1.9 De Broglie’s hypothesis and the genesis of wave mechanics	46
Problems	49
2 The elements of quantum mechanics	53
2.1 Waves and particles, wave packets and the uncertainty principle	53
2.2 The Schrödinger equation	61
2.3 Expansions, operators and observables	66
2.4 One-dimensional examples	73
2.5 Angular momentum	82
2.6 Central forces	96
2.7 Several-particle systems	101
2.8 Approximation methods	106
Problems	123
3 One-electron atoms	128
3.1 The Schrödinger equation for one-electron atoms	128
3.2 Energy levels	133
3.3 The eigenfunctions of the bound states	136
3.4 Expectation values. The virial theorem	145
3.5 Special hydrogenic systems: muonium; positronium; muonic and hadronic atoms; Rydberg atoms	148
Problems	153
4 Interaction of one-electron atoms with electromagnetic radiation	155
4.1 The electromagnetic field and its interaction with charged particles	156
4.2 Transition rates	160
4.3 The dipole approximation	166
4.4 The Einstein coefficients	168
4.5 Selection rules and the spectrum of one-electron atoms	170
4.6 Line intensities and the lifetimes of excited states	180

Contents

4.7	Line shapes and widths	183
4.8	The photoelectric effect	189
	Problems	193
5	One-electron atoms: fine structure, hyperfine structure and interaction with external electric and magnetic fields	195
5.1	Fine structure of hydrogenic atoms	195
5.2	The Zeeman effect	207
5.3	The Stark effect	219
5.4	The Lamb shift	229
5.5	Hyperfine structure and isotope shifts	232
	Problems	247
6	Two-electron atoms	249
6.1	The Schrödinger equation for two-electron atoms. Para and ortho states	249
6.2	Spin wave functions and the role of the Pauli exclusion principle	251
6.3	Level scheme of two-electron atoms	255
6.4	The independent particle model	258
6.5	The ground state of two-electron atoms	267
6.6	Excited states of two-electron atoms	278
6.7	Doubly excited states of two-electron atoms. Auger effect (autoionisation). Resonances	286
	Problems	288
7	Many-electron atoms	290
7.1	The central field approximation	290
7.2	The periodic system of the elements	300
7.3	The Thomas–Fermi model of the atom	308
7.4	The Hartree–Fock method and the self-consistent field	320
7.5	Corrections to the central field approximation. L–S coupling and j–j coupling.	339
	Problems	352
8	The interaction of many-electron atoms with electromagnetic fields	355
8.1	Selection rules	355
8.2	The spectra of the alkalis	359
8.3	Helium and the alkaline earths	364
8.4	Atoms with several optically active electrons. Multiplet structure	368
8.5	Interaction with magnetic fields. The Zeeman effect	374
8.6	The quadratic Stark effect	377
8.7	X-ray spectra	379
	Problems	382
9	Molecular structure	383
9.1	General nature of molecular structure	383
9.2	The Born–Oppenheimer separation for diatomic molecules	386
9.3	The rotation and vibration of diatomic molecules	389
9.4	Electronic structure of diatomic molecules	394
9.5	The structure of polyatomic molecules	420
	Problems	426
10	Molecular spectra	428
10.1	Rotational energy levels of diatomic molecules	428
10.2	Vibrational–rotational spectra of diatomic molecules	432

10.3	Electronic spectra of diatomic molecules	438
10.4	The electronic spin and Hund's cases	448
10.5	The nuclear spin	452
10.6	The inversion spectrum of ammonia	455
	Problems	459
11	Atomic collisions: basic concepts and potential scattering	461
11.1	Types of collisions, channels, thresholds and cross-sections	461
11.2	Potential scattering. General features	465
11.3	The method of partial waves	468
11.4	The integral equation of potential scattering	484
11.5	The Born approximation	488
11.6	Absorption processes and scattering by a complex potential	494
	Problems	496
12	Electron-atom collisions	499
12.1	Electron scattering: general principles	499
12.2	Elastic scattering	505
12.3	Excitation of atoms to discrete levels	513
12.4	Ionisation	519
12.5	Resonance phenomena	522
	Problems	525
13	Atom-atom collisions	527
13.1	Long-range interactions between atoms	528
13.2	The classical approximation	532
13.3	The elastic scattering of atoms at low velocities	534
13.4	Electronic excitation and charge exchange	540
	Problems	552
14	Some applications of atomic physics	554
14.1	Magnetic resonance and the measurement of gyromagnetic ratios	554
14.2	Masers and lasers	562
14.3	Controlled thermonuclear fusion	572
14.4	Astrophysics	583
	Problems	589
Appendices		592
1	Classical scattering by a central potential	593
2	The laboratory and centre of mass systems	600
3	Evaluation of integrals by using generating functions	608
4	Angular momentum – useful formulae and results	612
5	Hydrogenic wave functions in momentum space	621
6	The Hamiltonian for a charged particle in an electromagnetic field	629
7	The Dirac equation and relativistic corrections to the Schrödinger equation	631
8	Separation of the centre of mass coordinates for an N -electron atom	642
9	Evaluation of two-centre integrals	645
10	Solutions to selected problems	647
11	Fundamental constants, atomic units, and conversion factors	669
References		673
Index		675