

Contents

<i>Preface</i>	v
1. Why Record Spectra of Astronomical Objects?	1
1.1 A Historical Introduction	1
1.2 What One Can Learn from Studying Spectra	3
2. The Nature of Spectra	7
2.1 Transitions	7
2.2 Absorption and Emission	8
2.3 Other Measures of Transition Probabilities	10
2.4 Stimulated Emission	10
2.5 Optical Depth	11
2.6 Critical Density	12
2.7 Wavelength or Frequency?	13
2.8 The Electromagnetic Spectrum	14
3. Atomic Hydrogen	17
3.1 Overview	17
3.2 The Schrödinger Equation of Hydrogen-Like Atoms	17
3.3 Reduced Mass	18
3.4 Atomic Units	19
3.5 Wavefunctions for Hydrogen	20
3.6 Energy Levels and Quantum Numbers	21
3.7 H-Atom Discrete Spectra	23
3.8 H-Atom Spectra in Different Locations	29
3.8.1 Balmer series	29

3.8.2	Lyman series	33
3.8.3	Infrared lines	35
3.9	H-Atom Continuum Spectra	35
3.9.1	Processes	35
3.9.2	H-atom emission in H II regions	36
3.10	Radio Recombination Lines	38
3.11	Radio Recombination Lines for Other Atoms	40
3.12	Angular Momentum Coupling in the Hydrogen Atom	43
3.13	The Fine Structure of Hydrogen	44
3.14	Hyperfine Structure in the H Atom	45
3.15	Allowed Transitions	46
3.16	Hydrogen in Nebulae	47
4.	Complex Atoms	51
4.1	General Considerations	51
4.2	Central Field Model	52
4.3	Indistinguishable Particles	54
4.4	Electron Configurations	55
4.5	The Periodic Table	56
4.6	Ions	58
4.7	Angular Momentum in Complex Atoms	59
4.7.1	L-S or Russell-Saunders coupling	59
4.7.2	j-j coupling	61
4.7.3	Why two coupling schemes?	61
4.8	Spectroscopic Notation	62
4.9	Parity of the Wavefunction	63
4.10	Terms and Levels in Complex Atoms	64
5.	Helium Spectra	69
5.1	He I and He II Spectra	69
5.2	Selection Rules for Complex Atoms	71
5.3	Observing Forbidden Lines	74
5.4	Grotrian Diagrams	75
5.5	Potential Felt by Electrons in Complex Atoms	77
5.6	Emissions of Helium-Like Ions	78
6.	Alkali Atoms	81
6.1	Sodium	81

6.2	Spin-Orbit Interactions	84
6.3	Fine Structure Transitions	88
6.4	Astronomical Sodium Spectra	89
6.5	Other Alkali Metal-Like Spectra	93
7.	Spectra of Nebulae	99
7.1	Nebulium	100
7.2	The Bowen Mechanism	104
7.3	Two Valence Electrons	107
7.4	Autoionisation and Recombination	109
8.	Spectra in Magnetic Fields	115
8.1	Uniform Magnetic Field	116
8.2	Strong Magnetic Field	117
8.3	Weak Magnetic Field	118
8.3.1	The normal Zeeman effect	118
8.3.2	The anomalous Zeeman effect	119
8.4	Spectra in Magnetic Field	120
9.	X-Ray Spectra	123
9.1	Inner Shell Processes	123
9.2	The Solar Corona	127
9.3	The Structure of Highly Ionised Atoms	127
9.4	Isotope Effects	131
10.	Molecular Structure	135
10.1	The Born–Oppenheimer Approximation	136
10.2	Electronic Structure of Diatomics	137
10.2.1	Labelling of electronic states	140
10.2.2	Symmetry	141
10.2.3	State labels	143
10.3	Schrödinger Equation	144
10.3.1	Nuclear motion in diatomic molecules	144
10.4	Fractionation	149
10.5	Vibration–Rotation Energy Levels	150
10.6	Temperature Effects	152
10.6.1	Rotational state populations	152
10.6.2	Vibrational state populations	154

10.6.3	Electronic state populations	155
11.	Rotational Spectra	157
11.1	Rotational Structure of Polyatomic Molecules	157
11.2	Selection Rules: Pure Rotational Transitions	160
11.3	Selection Rules	161
11.4	Isotope Effects	166
11.5	Rotational Spectra of Other Molecules	166
11.6	Rotational Spectra of Molecular Hydrogen	170
11.7	Maser Emissions	170
12.	Vibration-Rotation Spectra	175
12.1	Vibrations in Polyatomic Molecules	175
12.2	Vibrational Transitions	177
12.2.1	Structure of the spectrum	178
12.2.2	Isotope effects	181
12.2.3	Hydrogen molecule vibrational spectra	181
12.3	Astronomical Spectra	183
13.	Electronic Spectra of Diatomic Molecules	187
13.1	Electronic Transitions	187
13.2	Selection Rules	188
13.2.1	Vibrational selection rules	189
13.2.2	Rotational selection rules	190
13.3	Transition Frequencies	192
13.4	Astronomical Spectra	193
13.5	Non- $^1\Sigma$ Electronic States	195
	<i>Solutions to Model Problems</i>	199
	<i>Further Reading and Bibliography</i>	215
	<i>Index</i>	217