

Contents

1	Introduction	1
1.1	The Cosmos as a Laboratory	1
1.2	Spectral Lines in Astronomy	1
1.3	The Bohr Atom	2
1.3.1	Bohr Lines at Radio Wavelengths	5
1.3.2	Other Line Series	6
1.4	Spectral Lines in Radio Astronomy	6
1.4.1	Theoretical Studies	6
1.4.2	Detection of Radio Recombination Lines	11
1.4.3	Other Searches and Detections	16
2	RRLs and Atomic Physics	21
2.1	The First Surprising Results: The Absence of Stark Broadening	21
2.2	The Broadening of Radio Recombination Lines	23
2.2.1	Natural Broadening	23
2.2.2	Doppler Broadening	26
2.2.3	Stark Broadening of RRLs	28
2.2.4	Elastic and Inelastic Impact Broadening	40
2.2.5	Combining Profiles: The Voigt Profile	43
2.2.6	Observational Test of the Revised Theory	45
2.3	Intensity of Radio Recombination Lines	52
2.3.1	Radiation Transfer	52
2.3.2	Continuum Emission	56
2.3.3	Transfer Equation for Continuum Radiation	60
2.3.4	Comparison with Continuum Observations	61
2.3.5	Line Absorption and Emission Coefficients	62
2.3.6	Transfer Equation for RRLs	66
2.3.7	The First Measurements of RRL Intensity	67
2.3.8	Departures from LTE	69
2.3.9	Non-LTE Line Intensities	71
2.3.10	Calculating Departure Coefficients	73

2.3.11	Line Intensities in Terms of Transfer Theory	80
2.3.12	Line Enhancement: A More General View	82
2.3.13	Classification of a Non-LTE Transition	85
2.4	The Range of RRL Studies	87
2.4.1	High-Frequency RRLs	87
2.4.2	Low-Frequency RRLs	92
2.5	How Many Atomic Levels Can Exist?	100
2.5.1	Radiation Broadening of RRLs	100
2.5.2	Existence as well as Detectability	105
2.6	Summary	106
3	RRLs: Tools for Astronomers	109
3.1	Physical Conditions in H II Regions	113
3.1.1	Electron Temperature of H II Regions	113
3.1.2	Electron Density of H II Regions	123
3.1.3	Velocities of Turbulent Motion	125
3.2	Ionized Hydrogen and Helium in the Galaxy	127
3.2.1	Distribution of H II Regions	127
3.2.2	Low-Density Ionized Hydrogen	132
3.2.3	Thickness of the Ionized Hydrogen Layer	143
3.2.4	Helium in the Galaxy	145
3.3	Exploration of the Cold ISM by RRLs	155
3.3.1	C II Regions at the Boundaries of ISM Clouds	155
3.3.2	C II Regions: Information from Carbon RRLs	160
3.3.3	The Relationship Between H II, H ⁰ , and Molecular Gas	165
3.3.4	C RRLs, IR Fine-Structure Lines of C ⁺ , and O I Lines	170
3.3.5	Carbon RRLs from Atomic and Molecular Clouds	176
3.3.6	Estimates of the Galactic Cosmic Ray Intensity	196
3.4	RRLs from Stars and Stellar Envelopes	200
3.4.1	Planetary Nebulae	200
3.4.2	The Sun	204
3.4.3	MWC349	207
3.5	RRLs from Extragalactic Objects	217
	Appendixes	225
	Appendix A Constants	227
A.1	Miscellaneous Constants	227
A.2	Rydberg Constants	227
A.2.1	Reduced Mass	227
A.2.2	Table of Rydberg Constants	228
	Appendix B Tables of Line Frequencies	229
B.1	Frequencies Below 100 GHz	229
B.2	Frequencies Above 100 GHz	242
B.3	FORTRAN Code for Fine-Structure Frequencies	258

Appendix C Supplemental Calculations	265
C.1 Early Estimates of Stark Broadening	265
C.2 Refinements to the Bohr Model	267
Appendix D Hydrogen Oscillator Strengths	269
D.1 Population of Atomic Sublevels	269
D.2 Calculation of Oscillator Strengths	270
D.3 Radial Matrix Integrals Code	272
D.3.1 Radial Matrix Integrals $\Re_H(n_2, \ell_1 - 1; n_1, \ell_1)$	272
D.3.2 Radial Matrix Integrals $\Re_H(n_2, \ell_1 + 1; n_1, \ell_1)$	275
Appendix E Departure Coefficients	281
E.1 FORTRAN Code for Calculating b_n Values	281
Appendix F Observational Units	313
F.1 What Radio Telescopes Measure	313
F.2 How Radio Telescopes Measure	314
F.2.1 Sources Smaller Than the Beam Size	314
F.2.2 Sources Larger Than the Beam Size	318
F.2.3 Antenna Temperature Scale	319
References	321
Author Index	333
Subject Index	341