

Contents

Preface	xi
Acknowledgments	xiii
Chapter 1: Basic Concepts	1
1.1 Introduction	1
1.2 The Electromagnetic Spectrum	3
1.3 Blackbody Radiation	5
1.4 Luminosity, Effective Temperature, Flux and Magnitudes	8
1.5 Boltzmann and Saha Equations	13
1.6 Spectral Classification of Stars	21
1.7 The Hertzsprung–Russell Diagram	27
1.8 Summary	30
1.9 Exercises	31
Chapter 2: Stellar Formation	35
2.1 Introduction	35
2.2 Hydrostatic Equilibrium	36
2.3 The Virial Theorem	40
2.4 The Jeans Criterion	46
2.5 Free-Fall Times [†]	52
2.6 Pre-Main-Sequence Evolution [†]	54
2.7 Summary	57
2.8 Exercises	57
Chapter 3: Radiative Transfer in Stars	61
3.1 Introduction	61
3.2 Radiative Opacities	62
3.2.1 Matter–Radiation Interactions	62
3.2.2 Types of Radiative Opacities	64
3.3 Specific Intensity and Radiative Moments	69
3.4 Radiative Transfer Equation	77
3.5 Local Thermodynamic Equilibrium	81
3.6 Solution of the Radiative-Transfer Equation	82
3.7 Radiative Equilibrium	90
3.8 Radiative Transfer at Large Optical Depths	91
3.9 Rosseland and Other Mean Opacities	94

3.10	Schwarzschild–Milne Equations ^{††}	97
3.11	Demonstration of the Radiative-Transfer Equation [†]	99
3.12	Radiative Acceleration of Matter and Radiative Pressure [†]	100
3.12.1	Radiative Acceleration of Matter	100
3.12.2	Radiative Pressure	103
3.13	Summary	104
3.14	Exercises	105

Chapter 4: Stellar Atmospheres 109

4.1	Introduction	109
4.2	The Grey Atmosphere	110
4.2.1	The Temperature Profile in a Grey Atmosphere	111
4.2.2	Radiative Flux in a Grey Atmosphere ^{††}	117
4.3	Line Opacities and Broadening	119
4.3.1	Natural Broadening	120
4.3.2	Doppler Broadening	122
4.3.3	Pressure Broadening	130
4.3.4	Stimulated Emission and Masers	132
4.3.5	Einstein Coefficients ^{††}	134
4.4	Equivalent Width and Formation of Atomic Lines	137
4.4.1	Equivalent Width	137
4.4.2	Formation of Weak Atomic Lines	139
4.4.3	Curve of Growth [†]	142
4.5	Atmospheric Modelling	143
4.5.1	Input Data and Approximations	143
4.5.2	Algorithm for Atmospheric Modelling ^{††}	145
4.5.3	Example of a Stellar Atmosphere Model	148
4.5.4	Temperature-Correction Procedure ^{††}	150
4.6	Summary	151
4.7	Exercises	152

Chapter 5: Stellar Interiors 155

5.1	Introduction	155
5.2	Equations of Stellar Structure	156
5.2.1	Hydrostatic Equilibrium Equation	156
5.2.2	Equation of Mass Conservation	156
5.2.3	Energy-Transport Equation	159
5.2.4	Equation of Energy Conservation	160
5.2.5	Other Ingredients Needed	161
5.3	Energy Transport in Stars	163
5.3.1	Monochromatic Radiative Flux in Stellar Interiors	164
5.3.2	Conduction	166
5.3.3	Convection	167
5.3.3.1	General Description of Convection	167
5.3.3.2	The Schwarzschild Criterion for Convection [†]	168

5.3.3.3	The Mixing-Length Theory ^{††}	172
5.3.3.4	Convective Equilibrium [†]	176
5.4	Polytropic Models	176
5.5	Structure of the Sun	182
5.6	Equation of State	184
5.6.1	Introduction	184
5.6.2	The Ideal Gas	185
5.6.3	Degeneracy	189
5.6.4	Radiation Pressure	191
5.7	Variable Stars and Asteroseismology	191
5.7.1	Variable Stars	191
5.7.2	Asteroseismology [†]	197
5.7.3	Basic Physics Behind Period–Luminosity Relations [†]	200
5.8	Summary	202
5.9	Exercises	203
Chapter 6: Nucleosynthesis and Stellar Evolution		205
6.1	Introduction	205
6.2	Generalities Concerning Nuclear Fusion	206
6.3	Models of the Nucleus [†]	211
6.3.1	The Liquid-Drop Model	211
6.3.2	The Shell Model	214
6.4	Basic Physics of Nuclear Fusion	216
6.5	Main-Sequence Burning	218
6.5.1	Proton–Proton Chains	220
6.5.2	CNO Cycles	221
6.5.3	Lifetime of Stars on the Main Sequence	224
6.5.4	The Solar Neutrino Problem [†]	226
6.6	Helium-Burning Phase	230
6.7	Advanced Nuclear Burning	232
6.7.1	Carbon-Burning Phase	233
6.7.2	Neon-Burning Phase	234
6.7.3	Oxygen-Burning Phase	234
6.7.4	Silicon-Burning Phase	235
6.8	Evolutionary Tracks in the H–R Diagram	236
6.8.1	Generalities	236
6.8.2	Evolution of Low-Mass Stars ($M_* \leq 0.5 M_\odot$)	240
6.8.3	Evolution of a $1 M_\odot$ Star: Our Sun	241
6.8.4	Evolution of Massive Stars ($M_* \geq 10 M_\odot$)	245
6.9	Stellar Clusters	248
6.9.1	Stellar Populations, Galaxies and the Milky Way	248
6.9.2	Open Clusters	251
6.9.3	Globular Clusters	252
6.9.4	Age of Stellar Clusters	253
6.9.5	Distance to Stars and Stellar Clusters	255

6.10	Stellar Remnants	257
6.10.1	White Dwarfs	257
6.10.2	Neutron Stars, Pulsars and Magnetars	259
6.10.3	Black Holes	262
6.11	Novae and Supernovae [†]	268
6.12	Heavy Element Nucleosynthesis: s, r and p Processes [†]	273
6.12.1	The Slow and Rapid Processes	273
6.12.2	The p Process	276
6.13	Nuclear Reaction Cross Sections and Rates ^{††}	277
6.14	Summary	281
6.15	Exercises	281
Chapter 7: Chemically Peculiar Stars and Diffusion[†]		285
7.1	Introduction and Historical Background	285
7.2	Chemically Peculiar Stars	287
7.2.1	Am Stars	288
7.2.2	Ap Stars	288
7.2.3	HgMn Stars	289
7.2.4	He-Abnormal Stars	289
7.3	Atomic Diffusion Theory ^{††}	290
7.4	Radiative Accelerations ^{††}	297
7.5	Other Transport Mechanisms ^{††}	302
7.5.1	Light-Induced Drift	303
7.5.2	Ambipolar Diffusion of Hydrogen	304
7.6	Summary	305
7.7	Exercises	305
Answers to Selected Exercises		307
Appendix A: Physical Constants		309
Appendix B: Units in the cgs and SI Systems		311
Appendix C: Astronomical Constants		313
Appendix D: Ionisation Energies (in eV) for the First Five Stages of Ionisation for the Most Important Elements		315
Appendix E: Solar Abundances for the Most Important Elements		317
Appendix F: Atomic Masses		319
Appendix G: Physical Parameters for Main-Sequence Stars		321
Appendix H: Periodic Table of the Elements		323
References		325
Bibliography		327
Index		329