

Astronomy: A Physical Perspective

Marc L. Kutner



CAMBRIDGE
UNIVERSITY PRESS

Contents

List of abbreviations used in the figure credits

Page xv

Preface

xvii

1 Introduction

1

1.1 An understandable universe

1

1.2 The scale of the universe

3

Part I | Properties of ordinary stars

7

2 Continuous radiation from stars

9

2.1 Brightness of starlight

9

2.2 The electromagnetic spectrum

10

2.3 Colors of stars

12

2.3.1 Quantifying color

12

2.3.2 Blackbodies

13

2.4 Planck's law and photons

15

2.4.1 Planck's law

15

2.4.2 Photons

16

2.5 Stellar colors

17

2.6 Stellar distances

18

2.7 Absolute magnitudes

20

Chapter summary

21

Questions

21

Problems

22

Computer problems

23

3 Spectral lines in stars

25

3.1 Spectral lines

25

3.2 Spectral types

26

3.3 The origin of spectral lines

27

3.3.1 The Bohr atom

28

3.3.2 Quantum mechanics

31

3.4 Formation of spectral lines

32

3.4.1 Excitation

32

3.4.2 Ionization

33

3.4.3 Intensities of spectral lines

34

3.5 The Hertzprung–Russell diagram

36

Chapter summary

38

Questions

39

Problems

39

Computer problems

40

4 Telescopes

41

4.1 What a telescope does

41

4.1.1 Light gathering

41

4.1.2 Angular resolution

42

4.1.3 Image formation in a camera

43

4.2 Refracting telescopes	45
4.3 Reflecting telescopes	46
4.4 Observatories	53
4.4.1 Ground-based observing	53
4.4.2 Observations from space	56
4.5 Data handling	58
4.5.1 Detection	58
4.5.2 Spectroscopy	60
4.6 Observing in the ultraviolet	62
4.7 Observing in the infrared	63
4.8 Radio astronomy	68
4.9 High energy astronomy	75
Chapter summary	78
Questions	78
Problems	79
Computer problems	81
5 Binary stars and stellar masses	83
5.1 Binary stars	83
5.2 Doppler shift	84
5.2.1 Moving sources and observers	84
5.2.2 Circular orbits	86
5.3 Binary stars and circular orbits	87
5.4 Elliptical orbits	91
5.4.1 Geometry of ellipses	91
5.4.2 Angular momentum in elliptical orbits	91
5.4.3 Energy in elliptical orbits	93
5.4.4 Observing elliptical orbits	93
5.5 Stellar masses	94
5.6 Stellar sizes	96
Chapter summary	97
Questions	98
Problems	99
Computer problems	100
6 The Sun: a typical star	101
6.1 Basic structure	101
6.2 Elements of radiation transport theory	101
6.3 The photosphere	105
6.3.1 Appearance of the photosphere	105
6.3.2 Temperature distribution	107
6.3.3 Doppler broadening of spectral lines	108
6.4 The chromosphere	109
6.5 The corona	110
6.5.1 Parts of the corona	110
6.5.2 Temperature of the corona	112
6.6 Solar activity	113
6.6.1 Sunspots	113
6.6.2 Other activity	116
Chapter summary	119
Questions	119

Problems	120
Computer problems	121
Part II Relativity	123
7 Special relativity	125
7.1 Foundations of special relativity	125
7.1.1 Problems with electromagnetic radiation	125
7.1.2 Problems with simultaneity	127
7.2 Time dilation	128
7.3 Length contraction	129
7.4 The Doppler shift	131
7.4.1 Moving source	131
7.4.2 Moving observer	131
7.4.3 General result	132
7.5 Space-time	132
7.5.1 Four-vectors and Lorentz transformation	132
7.5.2 Energy and momentum	135
Chapter summary	136
Questions	136
Problems	137
Computer problems	137
8 General relativity	139
8.1 Curved space-time	139
8.2 Principle of equivalence	141
8.3 Tests of general relativity	143
8.3.1 Orbiting bodies	143
8.3.2 Bending electromagnetic radiation	144
8.3.3 Gravitational redshift	145
8.3.4 Gravitational radiation	147
8.3.5 Competing theories	148
8.4 Black holes	148
8.4.1 The Schwarzschild radius	148
8.4.2 Approaching a black hole	149
8.4.3 Stellar black holes	150
8.4.4 Non-stellar black holes	151
Chapter summary	152
Questions	152
Problems	152
Computer problems	153
Part III Stellar evolution	155
9 The main sequence	157
9.1 Stellar energy sources	157
9.1.1 Gravitational potential energy of a sphere	157
9.1.2 Gravitational lifetime for a star	158
9.1.3 Other energy sources	158

9.2 Nuclear physics	159
9.2.1 Nuclear building blocks	159
9.2.2 Binding energy	160
9.2.3 Nuclear reactions	161
9.2.4 Overcoming the fusion barrier	162
9.3 Nuclear energy for stars	164
9.4 Stellar structure	168
9.4.1 Hydrostatic equilibrium	168
9.4.2 Energy transport	170
9.5 Stellar models	171
9.6 Solar neutrinos	172
Chapter summary	175
Questions	175
Problems	176
Chapter problems	176
10 Stellar old age	177
10.1 Evolution off the main sequence	177
10.1.1 Low mass stars	177
10.1.2 High mass stars	179
10.2 Cepheid variables	179
10.2.1 Variable stars	179
10.2.2 Cepheid mechanism	180
10.2.3 Period-luminosity relation	181
10.3 Planetary nebulae	183
10.4 White dwarfs	186
10.4.1 Electron degeneracy	186
10.4.2 Properties of white dwarfs	188
10.4.3 Relativistic effects	189
Chapter summary	190
Questions	190
Problems	190
Computer problems	191
11 The death of high mass stars	193
11.1 Supernovae	193
11.1.1 Core evolution of high mass stars	193
11.1.2 Supernova remnants	194
11.2 Neutron stars	197
11.2.1 Neutron degeneracy pressure	197
11.2.2 Rotation of neutron stars	198
11.2.3 Magnetic fields of neutron stars	199
11.3 Pulsars	199
11.3.1 Discovery	199
11.3.2 What are pulsars?	201
11.3.3 Period changes	203
11.4 Pulsars as probes of interstellar space	205
11.5 Stellar black holes	206
Chapter summary	206
Questions	206