

Contents

Editors' preface to the Manchester Physics Series	ix
Author's preface	xi
Author's preface to the second edition	xiii

1 BASIC CONCEPTS IN ASTROPHYSICS

1.1 Big Bang Nucleosynthesis	1
A brief history of the universe	1
The synthesis of helium	3
1.2 Gravitational Contraction	5
Free fall	6
Hydrostatic equilibrium	7
Equilibrium of a gas of non-relativistic particles	10
Equilibrium of a gas of ultra-relativistic particles	11
Equilibrium and the adiabatic index	12
1.3 Star Formation	13
Conditions for gravitational collapse	14
Contraction of a protostar	15
Conditions for stardom	17
1.4 The Sun	19
Pressure, density and temperature	19
Solar radiation	21
Thermonuclear fusion in the sun	23
1.5 Stellar Nucleosynthesis	25
Stellar mass and the extent of thermonuclear fusion	26
Neutron capture	28
1.6 Stellar Life Cycles	28
Rate of stellar evolution	29
The endpoints of stellar evolution	30
Abundances of the chemical elements	31
1.7 The Hertzsprung–Russell Diagram	33
Luminosity	33
Surface temperature	34

Luminosity and surface temperature	35
Star clusters	37
Summary	38
PROBLEMS 1	41

2 PROPERTIES OF MATTER AND RADIATION

2.1 The Ideal Gas	47
Density of states	47
Internal energy	49
Pressure in an ideal gas	50
The ideal classical gas	53
2.2 Electrons in Stars	55
The degenerate electron gas	56
A density–temperature diagram	58
Electrons in the sun	60
Electrons in massive stars	61
2.3 Photons in Stars	62
The photon gas	63
Radiation pressure in stars	65
2.4 The Saha Equation	66
2.5 Ionization in Stars	71
Stellar interiors	71
Stellar atmospheres	73
2.6 Reactions at High Temperature	78
Electron–positron pair production	78
Photodisintegration of nuclei	79
PROBLEMS 2	83

3 HEAT TRANSFER IN STARS

3.1 Heat Transfer by Random Motion	87
Random motion of electrons and ions	88
Random motion of photons	90
3.2 Heat Transfer by Convection	93
Critical condition for convection	93
3.3 Temperature Gradients in Stars	95
3.4 Cooling of White Dwarfs	98
Summary	102
PROBLEMS 3	103

4 THERMONUCLEAR FUSION IN STARS

4.1 The Physics of Nuclear Fusion	107
Barrier penetration	107
Fusion cross-sections	111
Thermonuclear reaction rates	112

4.2	Hydrogen Burning	117
	The proton–proton chain	118
	The carbon–nitrogen cycle	121
	Solar neutrinos	123
4.3	Helium Burning	127
	Production of ^8Be	129
	Production of $^{12}\text{C}^*$	131
	Carbon production	133
	Carbon consumption	134
	What if?	135
4.4	Advanced Burning	136
	Summary	139
	PROBLEMS 4	143

5 STELLAR STRUCTURE

5.1	Preamble	145
5.2	Simple Stellar Models	148
	Pressure inside a star	149
	Density and temperature inside a star	151
	A star with a high central density	152
5.3	Modelling the Sun	154
	Pressure, density and temperature	154
	The solar luminosity	155
5.4	Minimum and Maximum Masses for Stars	159
	Minimum mass of a main sequence star	159
	Maximum mass of a main sequence star	162
	A fundamental unit for stellar masses	164
	Summary	166
	PROBLEMS 5	167

6 THE ENDPOINTS OF STELLAR EVOLUTION

6.1	White Dwarfs	171
	Mass and central density	172
	Mass and radius	177
6.2	Collapse of a Stellar Core	180
	The onset of collapse	181
	Nuclear photodisintegration	181
	Electron capture	183
	The aftermath	185
6.3	Neutron Stars	189
	Matter inside neutron stars	190
	The size of neutron stars	192
	Gravitational binding energy of neutron stars	193

	Rotating neutron stars and pulsars	194
	The maximum mass of a neutron star	197
6.4	Black Holes	201
	Summary	204
	PROBLEMS 6	206
7	HELIOSISMOLOGY	
7.1	Introduction	211
7.2	Pressure and Gravity Waves	213
	Propagation of pressure waves	213
	Propagation of gravity waves	216
7.3	Waves Inside the Sun	217
7.4	Normal Modes of Oscillation	220
	Constant velocity approximation	223
	WKB approximation	224
	Concluding remarks	226
	Summary	227
	PROBLEMS 7	229
	HINTS TO SELECTED PROBLEMS	233
	Bibliography	241
	Index	243
	Physical constants and conversion factors	Inside Back Cover

