

Contents

1	Some Basic Physics	1
1.1	Basic Structure of Matter	2
1.1.1	Elementary Particles and Fundamental Forces	2
1.1.2	Atoms	4
1.1.3	Units of Measurement and Exponential Notation	6
1.1.4	Elements	7
1.1.5	Molecules	9
1.1.6	Gases	9
1.2	Thermodynamic Equilibrium	12
1.2.1	The Energy Distribution of Gas Particles	12
1.2.2	Maxwell Distribution	14
1.2.3	Boltzmann Distribution	21
1.2.4	Saha Distribution	24
1.2.5	The Indefinite Integral	32
1.2.6	The Definite Integral	32
1.3	The Nature of Light	35
1.3.1	Waves, Photons and the Electromagnetic Spectrum	35
1.3.2	The Black Body	38
1.4	The Nuclear Energy	45
1.4.1	The Missing Mass	45
1.4.2	The Mass–Energy Relation	46
1.4.3	The Nuclear Fission	47
1.4.4	Nuclear Power Stations	49
1.4.5	Radioactivity	49
1.4.6	The Nuclear Fusion in the Sun	50
1.4.7	Further Exercises	52
2	Introduction to the Sun	55
2.1	Our Approach	55
2.1.1	Motivation	55

2.1.2	The Steady Sun	57
2.1.3	Methods	57
2.2	The Characteristic Data	58
2.2.1	The Distance from Earth	59
2.2.2	The Radius	60
2.2.3	The Mass.	64
2.2.4	The Luminosity	66
2.2.5	The Temperature	68
2.2.6	Further Exercises	70
3	The Photosphere	71
3.1	The Physical Parameters	72
3.1.1	Physical Constrains	72
3.1.2	Hydrostatic Equilibrium	73
3.1.3	Scale Height	74
3.1.4	Pressure Stratification	75
3.1.5	Plane Parallel Model	77
3.1.6	Optical Thickness	79
3.1.7	Flux Formation Depth	82
3.1.8	Photospheric Opacity	84
3.1.9	Hydrogen Ionization Equilibrium	84
3.1.10	Electric Charge and Mass Conservation	86
3.1.11	Evaluating Density and Pressure	88
3.2	A Model of the Photosphere	90
3.2.1	Radiation Intensity and Flux	90
3.2.2	The Spectrum	92
3.2.3	The Origin of Continua and Lines	93
3.2.4	Equation of Radiation Transfer	95
3.2.5	Solution of the Transfer Equation	97
3.2.6	The Eddington-Barbier Approximation	99
3.2.7	LTE	99
3.2.8	Center to Limb Intensity	101
3.2.9	The Temperature Variation	102
3.2.10	Temperature as Function of Height	106
3.2.11	Complete Model Photosphere	109
3.2.12	Accurate Models of Photosphere	115
3.2.13	The Chemical Composition	120
3.2.14	Differences Between Photosphere and the Earth's Atmosphere	124
3.2.15	Further Exercises	125
4	The Convection Zone	127
4.1	Glimpses of the Solar Interior	128

4.1.1	Pressure	129
4.1.2	Temperature	130
4.1.3	Opacity	130
4.2	The Radiative Temperature Gradient	132
4.2.1	The Diffusion Approximation	132
4.3	The Convective Temperature Gradient	136
4.3.1	Convection	136
4.3.2	The Convective Temperature Gradient	138
4.4	The Convection Zone Model	144
4.4.1	Convective Stability Criterion	144
4.4.2	A Model of Convection Zone	151
4.4.3	The Extension of the Convection Zone	163
4.4.4	Checking the Hydrostatic Equilibrium	165
4.4.5	Further Exercises	168
5	The Radiation Zone	171
5.1	The Physical Conditions	171
5.1.1	Temperature	172
5.1.2	The Opacity Power Laws	172
5.1.3	Pressure	176
5.1.4	State Equation	177
5.1.5	Mass Conservation	177
5.2	The Radiation Zone Model	178
5.2.1	Further Exercises	188
6	The Core	189
6.1	Cross Sections	189
6.1.1	Solar Nuclear Reactions	189
6.1.2	The First Reaction of the ppI Chain	192
6.1.3	De Broglie Wavelength	195
6.1.4	Wave Function	197
6.1.5	The Uncertainty Principle	199
6.1.6	Tunnel Effect	200
6.1.7	Cross Section	201
6.2	Reaction Rates	202
6.2.1	The Average over the Maxwell Distribution	204
6.2.2	The Gamow Peak	206
6.2.3	Lifetime	208
6.2.4	Energy Production Rate	209
6.3	The Core Model	211
6.3.1	Luminosity	211
6.3.2	Energy Conservation	211
6.3.3	Model	212

6.3.4	Boundary Conditions	213
6.3.5	Further Exercises	222
7	Evolution	227
7.1	Pre-main Sequence Evolution	227
7.1.1	Onset of Gravitational Collapse	227
7.1.2	The Contribution of Core-Collapse Supernovae	229
7.1.3	Jeans Criterion	229
7.1.4	Isothermal Collapse and Fragmentation	233
7.1.5	Adiabatic Collapse	233
7.1.6	ProtoSun	235
7.1.7	Sizes	235
7.1.8	Temperature	236
7.1.9	Contraction Times	237
7.1.10	The Hayashi Track	239
7.1.11	Virial Theorem	242
7.2	Main Sequence Phase	244
7.2.1	Stability of the Solar Equilibrium	245
7.2.2	Equations of Evolution	246
7.2.3	Evolution Sequence	249
7.2.4	Main Sequence Evolution	250
7.2.5	MS Evolution and Life on the Earth	252
7.3	Post-main Sequence Evolution	256
7.3.1	Hydrogen Shell Fusion and Red Giant Phase	256
7.3.2	Mass Loss	257
7.3.3	Degenerate Gas	258
7.3.4	Helium Fusion	259
7.3.5	Thermal Instability and Helium Flash	260
7.3.6	Horizontal Branch and Asymptotic Giant Branch	261
7.3.7	Planetary Nebula	262
7.3.8	White Dwarf and Evolution Last Phases	262
7.3.9	Further Exercises	264
	List of Exercises and Answers	267
	References	275

<http://www.springer.com/978-3-319-64960-3>

The Structure and Evolution of the Sun

Severino, G.

2017, XIV, 275 p. 78 illus., 51 illus. in color., Softcover

ISBN: 978-3-319-64960-3