

Contents

Preface

xv

Biography

xvii

Chapter 1: Astronomy, an Observational Science

1

1.1	Introduction	1
1.2	Galileo Galilei's proof of the Copernican theory of the solar system	1
1.3	The celestial sphere and stellar magnitudes	4
1.3.1	The constellations	4
1.3.2	Stellar magnitudes	5
1.3.3	Apparent magnitudes	5
1.3.4	Magnitude calculations	6
1.4	The celestial coordinate system	7
1.5	Precession	9
1.6	Time	11
1.6.1	Local solar time	11
1.6.2	Greenwich mean time	11
1.6.3	The equation of time	12
1.6.4	Universal time	12
1.6.5	Sidereal time	13
1.6.6	An absolute time standard – cosmic time	14
1.7	A second major observational triumph: the laws of planetary motion	16
1.7.1	Tycho Brahe's observations of the heavens	17
1.7.2	Johannes Kepler joins Tycho Brahe	20
1.7.3	The laws of planetary motion	20
1.8	Measuring the astronomical unit	23
1.9	Isaac Newton and his Universal Law of Gravity	25
1.9.1	Derivation of Kepler's third law	30
1.10	Experimental measurements of G, the Universal constant of gravitation	32
1.11	Gravity today: Einstein's special and general theories of relativity	33
1.12	Conclusion	36
1.13	Questions	36

Chapter 2: Our Solar System 1 – The Sun	39
2.1 The formation of the solar system	39
2.2 The Sun	43
2.2.1 Overall properties of the Sun	43
2.2.2 The Sun’s total energy output	45
2.2.3 Black body radiation and the sun’s surface temperature	46
2.2.4 The Fraunhofer lines in the solar spectrum and the composition of the sun	49
2.3 Nuclear fusion	50
2.3.1 The proton–proton cycle	53
2.4 The solar neutrino problem	57
2.4.1 The solar neutrino problem is solved	58
2.5 The solar atmosphere: photosphere, chromosphere and corona	59
2.5.1 Coronium	61
2.6 The solar wind	61
2.7 The sun’s magnetic field and the sunspot cycle	62
2.7.1 Sunspots	62
2.7.2 The sunspot cycle	64
2.8 Prominences, flares and the interaction of the solar wind with the earth’s atmosphere	65
2.8.1 The aurora	66
2.9 Solar eclipses	67
2.9.1 Two significant solar eclipses	69
2.9.2 The Shapiro delay	71
2.10 Questions	72
Chapter 3: Our Solar System 2 – The Planets	75
3.1 What is a planet?	75
3.2 Planetary orbits	77
3.2.1 Orbital inclination	78
3.3 Planetary properties	79
3.3.1 Planetary masses	79
3.3.2 Planetary densities	80
3.3.3 Rotation periods	80
3.3.4 Planetary temperatures	81
3.3.5 Global warming	83
3.3.6 Albedo	83

3.4	Planetary atmospheres	84
3.4.1	Secondary atmospheres	86
3.4.2	The evolution of the earth's atmosphere	87
3.5	The planets of the solar system	87
3.5.1	Mercury	88
3.5.2	Venus	89
3.5.3	The Earth	92
3.5.4	The moon	94
3.5.5	Mars	102
3.5.6	Ceres and the minor planets	106
3.5.7	Jupiter	108
3.5.8	Saturn	113
3.5.9	Uranus	117
3.5.10	Neptune	120
3.5.11	Pluto	124
3.5.12	Eris	128
3.6	Comets	129
3.6.1	Halley's comet	130
3.6.2	Cometary nuclei	131
3.7	Questions	132

Chapter 4: Extra-solar Planets **135**

4.1	The radial velocity (Doppler wobble) method of planetary detection	135
4.1.1	Pulsar planets	138
4.1.2	The discovery of the first planet around a sun-like star	139
4.2	Planetary transits	142
4.3	Gravitational microlensing	145
4.4	Astrometry	148
4.5	Discovery space	149
4.6	Selection effects and the likelihood of finding solar systems like ours	151
4.7	Questions	151

Chapter 5: Observing the Universe **153**

5.1	Thinking about optics in terms of waves rather than rays	153
5.1.1	The parabolic mirror	153
5.1.2	Imaging with a thin lens	156
5.1.3	The achromatic doublet	159

5.2	The human eye	161
5.3	The use of a telescope or pair of binoculars to see fainter objects	163
5.4	Using a telescope to see more detail in an image	164
5.4.1	An interesting worked example of the effects of diffraction	166
5.4.2	The effect of diffraction on the resolution of a telescope	167
5.5	The magnification of a telescope	168
5.6	Image contrast	170
5.7	The classic Newtonian telescope	170
5.8	The Cassegrain telescope	172
5.9	Catadioptric telescopes	172
5.9.1	The Schmidt camera	172
5.9.2	The Schmidt–Cassegrain telescope	173
5.9.3	The Maksutov–Cassegrain telescope	174
5.10	Active and adaptive optics	174
5.10.1	Active optics	175
5.10.2	Adaptive optics	175
5.11	Some significant optical telescopes	176
5.11.1	Gemini North and South telescopes	176
5.11.2	The Keck telescopes	177
5.11.3	The South Africa Large Telescope (SALT)	177
5.11.4	The Very Large Telescope (VLT)	178
5.11.5	The Hubble Space Telescope (HST)	179
5.11.6	The future of optical astronomy	180
5.12	Radio telescopes	181
5.12.1	The feed and low noise amplifier system	182
5.12.2	Radio receivers	183
5.12.3	Telescope designs	184
5.12.4	Large fixed dishes	186
5.12.5	Telescope arrays	188
5.12.6	Very Long Baseline Interferometry (VLBI)	189
5.12.7	The future of radio astronomy	191
5.13	Observing in other wavebands	193
5.13.1	Infrared	193
5.13.2	Submillimetre wavelengths	193
5.13.3	The Spitzer space telescope	195
5.13.4	Ultraviolet, X-ray and gamma-ray observatories	195

5.14	Observing the universe without using electromagnetic radiation	197
5.14.1	Cosmic rays	197
5.14.2	Gravitational waves	199
5.15	Questions	202

Chapter 6: The Properties of Stars **205**

6.1	Stellar luminosity	205
6.2	Stellar distances	205
6.2.1	The parsec	207
6.3	Proper motion	208
6.3.1	Hipparcos and GAIA	208
6.4	The absolute magnitude scale	209
6.4.1	The standard formula to derive absolute magnitudes	210
6.5	Colour and surface temperature	212
6.6	Stellar photometry	214
6.7	Stellar spectra	214
6.7.1	The hydrogen spectrum	215
6.7.2	Spectral types	216
6.8	Spectroscopic parallax	217
6.9	The Hertzsprung–Russell Diagram	219
6.9.1	The main sequence	220
6.9.2	The giant region	220
6.9.3	The white dwarf region	222
6.9.4	Pressure broadening	222
6.10	The size of stars	223
6.10.1	Direct measurement	223
6.10.2	Using binary star systems to calculate stellar sizes	225
6.10.3	Using the Stephan–Boltzman law to estimate stellar sizes	226
6.11	The masses and densities of stars	227
6.12	The stellar mass–luminosity relationship	228
6.13	Stellar lifetimes	229
6.14	Questions	230

Chapter 7: Stellar Evolution – The Life and Death of Stars	231
7.1 Low mass stars: 0.05–0.5 solar masses	231
7.2 Mid mass stars: 0.5–~8 solar masses	232
7.2.1 Moving up the main sequence	233
7.2.2 The triple alpha process	234
7.2.3 The helium flash	236
7.3 Variable stars	237
7.4 Planetary nebula	239
7.5 White dwarfs	240
7.5.1 The discovery of white dwarfs	240
7.5.2 The future of white dwarfs	241
7.5.3 Black dwarfs	241
7.6 The evolution of a sun-like star	241
7.7 Evolution in close binary systems – the Algol paradox	243
7.8 High mass stars in the range >8 solar masses	243
7.9 Type II supernova	246
7.9.1 The Crab Nebula	247
7.9.2 Supernova 1987A	248
7.10 Neutron stars and black holes	250
7.11 The discovery of pulsars	252
7.11.1 What can pulsars tell us about the universe?	255
7.12 Pulsars as tests for general relativity	257
7.13 Black holes	259
7.13.1 The detection of stellar mass black holes	260
7.13.2 Black holes are not entirely black	262
7.14 Questions	262
Chapter 8: Galaxies and the Large Scale Structure of the Universe	265
8.1 The Milky Way	265
8.1.1 Open star clusters	266
8.1.2 Globular clusters	267
8.1.3 The interstellar medium and emission nebulae	268
8.1.4 Size, shape and structure of the Milky Way	269
8.1.5 Observations of the hydrogen line	271
8.1.6 A super-massive black hole at the heart of our galaxy	275

8.2	Other galaxies	275
8.2.1	Elliptical galaxies	275
8.2.2	Spiral galaxies	277
8.2.3	Evidence for an unseen component in spiral galaxies – dark matter	279
8.2.4	Weighing a galaxy	280
8.2.5	Irregular galaxies	283
8.2.6	The Hubble classification of galaxies	284
8.3	The universe	285
8.3.1	The cosmic distance scale	285
8.3.2	Using Supernova 1987A to measure the distance of the Large Magellanic Cloud	285
8.3.3	The Cepheid variable distance scale	287
8.3.4	Starburst galaxies	289
8.3.5	Active galaxies	291
8.3.6	Groups and clusters of galaxies	295
8.3.7	Superclusters	297
8.3.8	The structure of the universe	297
8.4	Questions	298

Chapter 9: Cosmology – the Origin and Evolution of the Universe 301

9.1	Einstein's blunder?	301
9.2	Big Bang models of the universe	301
9.3	The blueshifts and redshifts observed in the spectra of galaxies	303
9.4	The expansion of the universe	304
9.4.1	A problem with age	306
9.5	The steady state model of the universe	308
9.6	Big Bang or Steady State?	309
9.7	The cosmic microwave background	309
9.7.1	The discovery of the cosmic microwave background	310
9.8	Inflation	312
9.9	The Big Bang and the formation of the primeval elements	313
9.10	The 'ripples' in the Cosmic Microwave Background	313
9.11	How dark matter affects the cosmic microwave background	314
9.12	The hidden universe: dark matter and dark energy	316
9.12.1	Evidence for dark matter	317
9.12.2	How much non-baryonic dark matter is there?	319
9.12.3	What is dark matter?	319

9.12.4	Dark energy	322
9.12.5	Evidence for dark energy	322
9.12.6	The nature of dark energy	324
9.13	The makeup of the universe	325
9.14	A universe fit for intelligent life	326
9.14.1	A ‘multiverse’	328
9.14.2	String theory: another approach to a multiverse	328
9.15	Intelligent life in the universe	329
9.15.1	The Drake equation	329
9.15.2	The Search for Extra Terrestrial Intelligence (SETI)	331
9.16	The future of the universe	332
	Index	335