

Contents

Preface	ix
1 The molecular universe	1
Introduction	1
1.1 The Standard Model – Big Bang theory	1
1.2 Galaxies, stars and planets	3
1.3 Origins of life	4
1.4 Other intelligent life	9
1.5 Theories of the origin of life	10
Concepts and calculations	13
2 Starlight, galaxies and clusters	15
Introduction	15
2.1 Simple stellar models – black body radiation	15
2.2 2.725 K – cosmic microwave background radiation	20
2.3 Stellar classification	21
2.4 Constellations	26
2.5 Galaxies	31
2.6 Cosmology	36
Concepts and calculations	38
Problems	39
3 Atomic and molecular astronomy	41
Introduction	41
3.1 Spectroscopy and the structure of matter	41
3.2 Line shape	46
3.3 Telescopes	52
3.4 Atomic spectroscopy	56
3.5 Molecular astronomy	59
3.6 Molecular masers	77
3.7 Detection of hydrogen	79
3.8 Diffuse interstellar bands	80
3.9 Spectral mapping	81

Concepts and calculations	82
Problems	83
4 Stellar chemistry	85
Introduction	85
4.1 Classes of stars	86
4.2 Herzprung–Russell diagram	88
4.3 Stellar evolution	89
4.4 Stellar spectra	98
4.5 Exotic stars	102
4.6 Cycle of star formation	108
Concepts and calculations	110
Problems	111
5 The interstellar medium	113
Introduction	113
5.1 Mapping clouds of molecules	114
5.2 Molecules in the interstellar and circumstellar medium	117
5.3 Physical conditions in the interstellar medium	120
5.4 Rates of chemical reactions	123
5.5 Chemical reactions in the interstellar medium	130
5.6 Photochemistry	133
5.7 Charged particle chemistry	136
5.8 Polycyclic aromatic hydrocarbons	136
5.9 Dust grains	140
5.10 Chemical models of molecular clouds	145
5.11 Prebiotic molecules in the interstellar medium	151
Concepts and calculations	154
Problems	155
6 Meteorite and comet chemistry	157
Introduction	157
6.1 Formation of the solar system	158
6.2 Classification of meteorites	161
6.3 Meteorite mineralogy	162
6.4 Geological time	165
6.5 Chemical analysis of meteorites by $\mu\text{L}^2\text{MS}$	168
6.6 The Murchison meteorite – kerogen	171
6.7 Meteorite ALH84001	173
6.8 Comet chemistry	180
6.9 Structure of a comet	180
6.10 Physicochemical conditions in a cometary coma	181

6.11	Chemical composition of comets	183
6.12	Cometary collisions	185
6.13	The Rosetta mission – origin of the solar system	187
	Concepts and Calculations	190
	Problems	191
7	Planetary chemistry	193
	Introduction	193
7.1	Structure of a star–planet system	194
7.2	Surface gravity	195
7.3	Formation of the Earth	197
7.4	Earth–Moon system	199
7.5	Geological periods	200
7.6	Radiative heating	202
7.7	The habitable zone	204
7.8	Extrasolar planets	206
7.9	Planetary atmospheres	209
7.10	Atmospheric photochemistry	215
7.11	Biomarkers in the atmosphere	219
	Concepts and calculations	221
	Problems	222
8	Prebiotic chemistry	225
	Introduction	225
8.1	Carbon- and water-based life forms	225
8.2	Spontaneous chemical reactions	227
8.3	Rates of chemical reactions	236
8.4	Endogenous production of organic molecules	237
8.5	Exogenous delivery of organic molecules	245
8.6	Homochirality	246
8.7	Surface Metabolism – ‘clay organisms’	249
8.8	Geothermal Vents – ‘black smokers’	251
8.9	RNA World hypothesis	253
	Concepts and calculations	256
	Problems	257
9	Primitive life forms	259
	Introduction	259
9.1	Self-assembly and encapsulation	261
9.2	Protocells	264
9.3	Universal tree of life	273
9.4	Astrobiology	274
9.5	Microbial Mars	281
	Concepts and calculations	283
	Problems	284

10 Titan	287
Introduction	287
10.1 Physical properties	289
10.2 The atmosphere	291
10.3 Temperature-dependent chemistry	294
10.4 Energy balance and the greenhouse effect	296
10.5 Atmospheric chemistry	297
10.6 Astrobiology on Titan	302
Concepts and calculations	305
Problems	306
Glossary of terms and abbreviations	307
Appendix A – constants and units	319
Appendix B – astronomical data	321
Appendix C – thermodynamic properties of selected compounds	323
Answers to problems	325
Bibliography	329
Index	335