

Astrochemistry

The Physical Chemistry of the Universe

SECOND EDITION

Andrew M. Shaw

*University of Exeter
Exeter, UK*

WILEY

Contents

Preface to the First Edition	ix
Preface to the Second Edition	xiii
About the Companion Website	xvii
1 The Molecular Universe	1
1.1 The Standard Model – Big Bang Theory	2
1.2 Galaxies, Stars, and Planets	5
1.3 Origins of Life	6
1.4 Other Intelligent Life	11
1.5 Theories of the Origin of Life	13
1.6 The Search for Extraterrestrial Intelligence (SETI)	15
Problems	16
References	16
2 Starlight, Galaxies, and Clusters	19
2.1 Simple Stellar Models – Black-Body Radiation	19
2.2 Cosmic Microwave Background Radiation: 2.725 K	25
2.3 Stellar Classification	27
2.4 Constellations	35
2.5 Galaxies	40
2.6 Cosmology	46
Problems	48
References	51
3 Atomic and Molecular Astronomy	53
3.1 Spectroscopy and the Structure of Matter	53
3.2 Line Shape	59
3.3 Telescopes	65
3.4 Atomic Spectroscopy	74
3.5 Molecular Astronomy	78
3.6 Molecular Masers	97
3.7 Detection of Hydrogen	99
3.8 Diffuse Interstellar Bands	100
3.9 Spectral Mapping	102
Problems	103
References	106

4	Stellar Chemistry	109
4.1	Classes of Stars	111
4.2	Herzprung–Russell Diagram	112
4.3	Stellar Evolution	113
4.4	Stellar Spectra	123
4.5	Exotic Stars	131
4.6	Cycle of Star Formation	138
	Problems	139
	References	142
5	The Interstellar Medium	145
5.1	Mapping Clouds of Molecules	146
5.2	Molecules in the Interstellar and Circumstellar Medium	152
5.3	Physical Conditions in the Interstellar Medium	156
5.4	Rates of Chemical Reactions	160
5.5	Chemical Reactions in the Interstellar Medium	170
5.6	Photochemistry	173
5.7	Charged Particle Chemistry	176
5.8	Polycyclic Aromatic Hydrocarbons	176
5.9	Dust Grains	180
5.10	Chemical Models of Molecular Clouds	185
5.11	Running the Models	192
5.12	Prebiotic Molecules in the Interstellar Medium	194
	Problems	199
	References	204
6	Meteorite and Comet Chemistry	207
6.1	Phases of Matter, Heat, and Change	208
6.2	Meteor Ablation	213
6.3	Enthalpy of Reaction	219
6.4	Formation of the Solar System	223
6.5	Classification of Meteorites	226
6.6	Geological Time	231
6.7	Chemical Analysis of Meteorites by $\mu\text{L}^2\text{MS}$	235
6.8	Comet Chemistry	247
6.9	Chemical Composition of Comets	252
6.10	Cometary Collisions with Planets	257
6.11	The Rosetta Mission	259
	Problems	263
	References	270
7	Planetary Chemistry	275
7.1	Structure of a Star–Planet System	276
7.2	Surface Gravity	278
7.3	Formation of the Earth	280
7.4	Earth–Moon System	283
7.5	Geological Periods	285
7.6	Radiative Heating	287
7.7	The Habitable Zone	289
7.8	Detecting Extrasolar Planets	291
7.9	Extrasolar Planets – The Current Inventory	293
7.10	Planetary Atmospheres	295
7.11	Atmospheric Photochemistry	304
7.12	Biomarkers in the Atmosphere	310

Problems	311
References	317
8 Prebiotic Chemistry	319
8.1 Carbon- and Water-Based Life Forms	319
8.2 Solvent Properties	320
8.3 Spontaneous Chemical Reactions	321
8.4 Acid-Base Buffers	332
8.5 Prebiotic Molecular Inventory	335
8.6 Exogenous Delivery of Organic Molecules	345
8.7 Homochirality	346
8.8 Surface Metabolism	350
8.9 Geothermal Vents	353
8.10 RNA World Hypothesis	356
Problems	358
References	362
9 Primitive Life Forms	365
9.1 Self-Assembly and Encapsulation	366
9.2 Protocells	370
9.3 Enzyme Catalysis	379
9.4 Universal Tree of Life	380
9.5 Astrobiology	383
9.6 Subsurface Antarctic Lakes – Astrobiological Time Capsules	390
Problems	391
References	396
10 Mars and Titan – Habitats for Life?	399
10.1 Solar System Habitats	399
10.2 Biosignatures	400
10.3 Contamination	404
10.4 Mars	405
10.5 Titan	408
10.6 Physical-Chemical Properties and the Radiation Budget	409
10.7 Temperature-Dependent Chemistry	414
10.8 The Atmospheres	416
10.9 Astrobiology on Mars and Titan	427
10.10 And Finally	430
Problems	430
References	437
Appendix A: Constants and Units	441
Appendix B: Astronomical Data	443
Appendix C: Thermodynamic Properties of Selected Compounds	445
Solutions to Problems	447
Index	475