

Contents

Foreword xi

I Introduction

Nature and Scope of Planetary Science 1
Guide to the Literature 3
Numbers in Science 4
Dimensions and Units 5
Exercises 6

II Astronomical Perspective

Introduction 7
Distance Scales in the Universe 7
The Big Bang 10
Limitations on Big Bang Nucleosynthesis 14
Galaxy and Star Formation 15
Structure and Classification of Galaxies 16
Classification of Stars 18
Stellar Evolution 25
Star Clusters 27
Stellar Origins 29

Outline of Star Formation 33
Stellar Explosions and Nucleosynthesis 34
Nuclear Cosmochronology 43
Exercises 47

III General Description of the Solar System

Introduction 50
The Sun 50
Orbits of the Planets 52
Changes in Orbital Motion 57
Properties of the Planets 58
Mass and Angular Momentum Distribution 59
Satellites 63
Asteroids 69
Comets 71
Meteoroids 72
Meteorites 72
Cosmic Dust 73
Cosmic Rays 73
Planetary Science in the Space Age 74

Summary	76
Exercises	76

IV The Sun and the Solar Nebula

Introduction	77
Energy Production in the Sun	77
Energy Transport in the Sun	79
Internal Structure of the Sun	83
Surface of the Sun	84
The Chromosphere	87
The Corona	88
Discovery of the Solar Wind	90
Radio Wave Propagation in Space Plasmas	91
The Solar Wind	92
Chemistry of Solar Material	96
Ionization	97
Dissociation and Molecule Formation	100
Hydrogen and the Rare Gases	101
Oxygen, Carbon, and Nitrogen	102
Magnesium and Silicon	105
Iron	106
Sulfur	107
Aluminum and Calcium	108
Sodium and Potassium	109
Nickel and Cobalt	110
Phosphorus and the Halogens	111
Geochemical Classification of the Elements	111
The Chemistry of Rapid Accretion	116
Kinetic Inhibition	117
Mass and Density of the Solar Nebula	118
Thermal Opacity in the Solar Nebula	121
Dust Opacity	129
Thermal Structure of the Nebula	131
Turbulence and Dust Sedimentation	134
Accretion of Rocks, Planetesimals, and Planets	136
Gas Capture from the Solar Nebula	138
The T Tauri Phase	141
Thermal History of the Early Solar System	143
Exercises	144

V The Major Planets

Introduction	147
Interiors of Jupiter and Saturn: Data	148
Isothermal Interior Models of Jupiter and Saturn	151
Thermal Models of Jupiter and Saturn	154
The Atmospheres of Jupiter and Saturn: Observed Composition	156

Tropospheric Composition and Structure: Theory	159
Cloud Condensation in the $\text{NH}_3\text{--H}_2\text{O--H}_2\text{S}$ System	165
Cloud Physics on the Jovian Planets	174
Galileo Perspectives on Jovian Clouds	179
Ion Production in the Jovian Atmosphere	180
Visible and Infrared Radiative Transfer	183
Horizontal Structure and Atmospheric Circulation	187
Photochemistry and Aeronomy	200
The Jovian Thermosphere	217
Radiophysics and Magnetospheres of Jupiter and Saturn	218
The Interiors of Uranus and Neptune	229
Atmospheres of Uranus and Neptune	238
Perspectives	247
Exercises	247

VI Pluto and the Icy Satellites of the Outer Planets

Introduction	252
Surfaces of Icy Satellites	253
Eclipse Radiometry	256
Surface Temperatures	257
Surface Morphology of the Galilean Satellites	258
Density and Composition of Icy Satellites	265
Internal Thermal Structure of Galilean Satellites	267
Dynamical Interactions of the Galilean Satellites	272
Thermal and Tectonic Evolution of Icy Satellites	275
Minor Satellites of Jupiter	278
Planetary Rings	280
Titan	289
The Intermediate-Sized Saturnian Satellites	293
Minor Satellites of Saturn	296
Satellites of Uranus	299
Satellites of Neptune	303
The Pluto–Charon System	308
The Neptune–Pluto Resonance	311
Spacecraft Exploration	311
Exercises	312

VII Comets and Meteors

Historical Perspectives	317
Nature and Nomenclature of Comets	319

Cometary Orbits	321
Heating by Passing Stars	325
Evaporation and Nongravitational Forces	326
The Nucleus and Coma of P/Halley	328
Chemistry and Photochemistry of Water	328
Further Chemical Processes in the Coma and Tail	332
Behavior of Small Particles	333
Dynamical Behavior of Dust in Space	334
Meteors	336
Cometary Fireballs	343
Cometary Impacts on Jupiter	344
Exercises	347

VIII Meteorites and Asteroids

Introduction	350
Introduction to Meteorites	350
Meteorite Orbits	353
Phenomena of Fall	355
Physical Properties of Meteorites	358
Meteorite Minerals	362
Taxonomy and Composition of Chondrites	362
Metamorphic Grades of Chondrites	367
Taxonomy and Composition of Achondrites	369
Taxonomy and Composition of Stony-Irons	371
Taxonomy and Composition of Irons	372
Isotopic Composition of Meteorites	375
Genetic Relationships between Meteorite Classes	382
Introduction to Asteroids	384
Asteroid Orbits	386
Stability of Trojan and Plutino Orbits	389
Sizes, Shapes, and Albedos of Asteroids	391
Masses and Densities of Asteroids	393
Photometry and Spectroscopy of Asteroids	394
Thermal Evolution of Asteroids	401
Dynamical Evolution of the Asteroid Belt	406
Centaur and Trans-Neptunian Objects	409
Relationships among Asteroids, Meteorites, and Comets	412
Radar Observations of Near-Earth Asteroids	415
Asteroid Resources	416
Exercises	419

IX The Airless Rocky Bodies: Io, Phobos, Deimos, the Moon, and Mercury

Introduction	424
Orbits and Physical Structure of Phobos and Deimos	426

Io: General Properties	430
Io: Surface Processes	430
Io: Internal Energy Sources	432
Io: Geology	433
Io: Atmospheric and Volcanic Gases	435
Io: Escape and the Plasma Torus	437
Io: Genetic Relationships	438
Impact Cratering	438
Motions of the Moon	443
Physical Properties of the Moon	445
Elemental Composition of the Moon's Surface	445
Lunar Rock Types	447
Lunar Minerals	449
Lunar Elemental Abundance Patterns	451
Geology of the Moon	451
Geophysics of the Moon	452
History of the Earth-Moon System	456
Origin and Internal Evolution of the Moon	458
Solar Wind Interaction with the Moon and Mercury	460
The Planet Mercury	461
Motions of Mercury	461
Composition and Structure of Mercury	462
Noncrater Geology of Mercury	463
Geophysics of Mercury	463
Atmospheres of Mercury and the Moon	468
Polar Deposits on Mercury and the Moon	469
Unfinished Business	472
Exercises	474

X The Terrestrial Planets: Mars, Venus, and Earth

Introduction	477
Mars	478
Motions of Mars	479
Density and Figure of Mars	479
Geophysical Data on Mars	481
Gravity and Tectonics of Mars	483
Geology of Mars	483
Surface Composition	496
Viking Lander Investigations	503
The Shergottite, Nakhilite, and Chassignite Meteorites	505
Atmospheric Structure	508
Atmospheric Circulation	509
Atmospheric Composition	510
Photochemical Stability and Atmospheric Escape	513
Explosive Blowoff	519
Origin and Evolution of the Atmosphere	519

Organic Matter and the Origin of Life	522
Venus	524
Motions and Dynamics of Venus	526
Geophysical Data on Venus	526
Geology of Venus	528
Venus: Atmospheric Structure and Motions	534
Venus: Atmospheric Composition	537
Venus: Atmosphere–Lithosphere Interactions	539
Venus: Photochemistry and Aeronomy	543
Venus: Atmospheric Escape	547
Venus: Planetary Evolution	549
Earth	550
Earth: Motions	551
Earth: Internal Structure	552
Earth: Magnetic Field and Magnetosphere	554
Earth: Surface Geology	554
Earth: Early Geological History	557
Earth: Biological History	559
Earth: Geochemistry and Petrology	563
Weathering in the Rock Cycle	566
Earth: Atmospheric Composition and Cycles	568
Radiocarbon Dating	573
Stable Isotope Climate Records	574
Photochemistry and Aeronomy	575
Escape and Infall	575
Climate History, Polar Ice, and Ice Ages	579
Life: Origins	582
Life: Stability of the Biosphere	587
Exercises	588

XI Planets and Life around Other Stars

Chemical and Physical Prerequisites of Life	592
The Planetary Environment	595
The Stellar Environment	597
Brown Dwarfs	600
The Search for Planets of Other Stars	603
The Search for Extraterrestrial Intelligence	606
Exercises	608

XII Future Prospects

Mercury	611
Venus	612
Earth's Moon	612

Mars	613
Asteroids	614
Jupiter	615
Saturn, Uranus, and Neptune	615
Pluto	615
Comets	616
Beyond the Solar System	616

Appendix I: Equilibrium

Thermodynamics 621

Heat and Work	621
Adiabatic Processes and Entropy	622
Useful Work and the Gibbs Free Energy	623
Chemical Equilibrium	623
Exact and Complete Differentials	624
The Maxwell Relations	625

Appendix II: Absorption and

Emission of Radiation by Quantum Oscillators 626

Appendix III: Exploration of the Solar System 629

Appendix IV: Basic Physical Constants 634

Appendix V: Gravity Fields 635

Suggested Readings

Introduction	637
Chapter I–Introduction	637
Chapter II–Astronomical Perspective	637
Chapter III–General Description of the Solar System	638
Chapter IV–The Sun and the Solar Nebula	638
Chapter V–The Major Planets	638
Chapter VI–Pluto and the Icy Satellites of the Outer Planets	639
Chapter VII–Comets and Meteors	639
Chapter VIII–Meteorites and Asteroids	639
Chapter IX–The Airless Rocky Bodies: Io, Phobos, Deimos, the Moon, and Mercury	640
Chapter X–The Terrestrial Planets: Mars, Venus, and Earth	640
Chapter XI–Planets and Life around Other Stars	641
Chapter XII–Future Prospects	642

Index 643