

THE
PLANETARY
SCIENTIST'S
COMPANION

Katharina Lodders
Bruce Fegley, Jr.

New York Oxford
Oxford University Press

1998

Contents

1 Technical data

- Table 1.1 The Greek alphabet 1
- Table 1.2 Prefixes used with the SI system 1
- Table 1.3 Basic SI and cgs units 2
- Table 1.4 Derived SI units 2
- Table 1.5 Frequently used constants 4
- 1.1 Conversion factors 7
 - Table 1.6 Length 7
 - Table 1.7 Area 8
 - Table 1.8 Volume 8
 - Table 1.9 Pressure 9
 - Table 1.10 Energy 9
 - Temperature conversions 10
 - Table 1.11 Time 10
 - Table 1.12 Concentration (by mass) 10
 - Density conversions 10
- 1.2 Mathematical formulae 11
 - Solution of quadratic equations 11
 - Solution of cubic equations 11
 - Some statistical formulae 12
 - Error propagation 13
 - Simple geometric formulae 14
 - Coordinate transformations 14
 - The conic functions 15
 - The celestial sphere 16
 - Astronomical coordinate transformations 17
 - Horizontal and celestial (equatorial) systems 17
 - Ecliptic and celestial (equatorial) systems 17
 - Galactic and celestial (equatorial) systems 17
 - Some formulae related to orbital descriptions 18
 - Formulae useful for atmospheric modeling 19
- 1.3 Elemental data 20
 - Table 1.13 Periodic table of the elements 20
 - Table 1.14 Atomic weights and isotopic composition of the elements 21

xii. Contents

| | | |
|------------|--|---|
| Table 1.15 | Metallic, covalent, and ionic radii, and coordination numbers (CN) of the elements | 30 |
| Table 1.16 | Some radioactive nuclides, their stable daughter, and half-lives | 35 |
| | Stable isotopes: Notation and reference standards | 36 |
| | Table 1.17 | Stable isotope reference standards 36 |
| 1.4 | Minerals and compounds | 37 |
| | Table 1.18 | Physical properties of some minerals and compounds 37 |
| | Table 1.19 | Melting and boiling points of some icy substances 40 |
| | Table 1.20 | Vapor pressure over low-temperature solids and liquids 41 |
| | Table 1.21 | Thermodynamic properties of some substances at 298.15 K 43 |
| | Oxygen fugacity buffers as a function of temperature | 60 |
| 1.5 | Partition coefficients | 61 |
| | Table 1.22 | Some partition coefficients between minerals and silicate melt (weight ratios) 63 |
| | Table 1.23 | Some experimental metal/silicate and sulfide/silicate partition coefficients (weight ratios) 70 |
| | Table 1.24 | Isothermal metal/silicate partition coefficients as a function of oxygen fugacity 74 |
| | Table 1.25 | Metal/silicate partition coefficients as a function of oxygen fugacity and temperature 75 |
| | Table 1.26 | Isothermal sulfide/silicate partition coefficients as a function of oxygen fugacity 75 |

2 The solar system

| | | |
|-----|--|---|
| 2.1 | Solar system elemental abundances | 76 |
| | Table 2.1 | Solar system abundances on the atomic astronomical scale 76 |
| | Table 2.2 | Solar system abundances on the cosmochemical scale 80 |
| 2.2 | Condensation chemistry of the elements in the solar nebula | 83 |
| | Table 2.3 | Equilibrium condensation chemistry of the elements in the solar nebula 83 |
| 2.3 | The sun, the planets, and planetary satellites | 87 |
| | Table 2.4 | The sun, the planets, and planetary satellites: Comparison of orbital and some physical data 87 |
| | Table 2.5 | Comparison of some planetary properties 91 |
| | Table 2.6 | Comparison of the terrestrial planets and the moon 92 |
| | Table 2.7 | Some physical properties of planetary atmospheres 92 |

3 The sun

| | | |
|-----------|---|----|
| Table 3.1 | Physical parameters of the sun | 95 |
| Table 3.2 | Solar interior structure standard model | 96 |
| Table 3.3 | Solar model atmosphere | 97 |

| | |
|---|----|
| Table 3.4 Solar luminosity through time standard model | 98 |
| Table 3.5 Elemental abundances in the sun's photosphere | 99 |
| Table 3.6 Elemental abundances in the sun's corona | 99 |

4 Mercury

| | |
|---|-----|
| Table 4.1 Some physical properties of Mercury | 104 |
| Table 4.2 Composition of Mercury's atmosphere | 104 |
| Table 4.3 Model mass distribution within Mercury | 105 |
| Table 4.4 Model compositions of Mercury | 106 |
| Table 4.5 Locations and sizes of craters on Mercury | 107 |

5 Venus

| | |
|---|-----|
| Table 5.1 Spacecraft missions to Venus | 116 |
| Table 5.2 Some physical properties of Venus | 118 |
| Table 5.3 Temperature, pressure, and density in Venus' atmosphere | 119 |
| Table 5.4 Chemical composition of the atmosphere of Venus | 120 |
| Table 5.5 Isotopic composition of the atmosphere of Venus | 121 |
| Table 5.6 XRF elemental analyses of Venus' surface | 122 |
| Table 5.7 Gamma ray analyses of Venus' surface | 122 |
| Table 5.8 Model elemental abundance in Venus | 123 |
| Table 5.9 Model compositions of Venus | 124 |

6 The earth and the moon

| | |
|---|-----|
| 6.1 Earth | 125 |
| The solid earth | 125 |
| Table 6.1 Some physical properties of the earth | 128 |
| Table 6.2 Mass distribution within the earth | 129 |
| Table 6.3 Some properties of the Earth's crust | 129 |
| Table 6.4 Some properties of the Earth's silicate mantle | 130 |
| Table 6.5 Some properties of the Earth' core | 130 |
| Table 6.6 Interior structure of the Earth | 131 |
| Table 6.7 Geologic time scale | 132 |
| Table 6.8 Elemental abundances in the whole earth | 133 |
| Table 6.9 Elemental abundances in the bulk silicate earth and present depleted mantle | 135 |
| Table 6.10 Elemental abundances in the Earth's crust | 140 |
| Table 6.11 Elemental abundances in the Earth's present continental crust | 143 |
| Table 6.12 Elemental abundances in some terrestrial rocks | 145 |
| Table 6.13 Selected volcanic gas analyses | 148 |
| Table 6.14 Terrestrial impact craters | 151 |
| Earth's atmosphere | 156 |

xiv. Contents

| | | |
|--------------------------------|---|-----|
| Table 6.15 | Temperature, pressure, and density in the Earth's atmosphere | 160 |
| Table 6.16 | Chemical composition of the terrestrial troposphere | 161 |
| Table 6.17 | Isotopic composition of noble gases in the terrestrial atmosphere | 163 |
| Earth's hydrosphere and oceans | | 164 |
| Table 6.18 | Major elements in river water | 168 |
| Table 6.19 | Mean chemical composition of terrestrial oceans | 169 |
| 6.2 | The moon | 170 |
| Table 6.20 | Spacecraft missions to the moon | 172 |
| Table 6.21 | Some physical parameters of the moon | 176 |
| Table 6.22 | Composition of the lunar atmosphere | 176 |
| Table 6.23 | Composition of the moon, lunar bulk silicates, and the lunar highland crust | 177 |
| Table 6.24 | Compositions of some typical lunar rocks | 180 |
| Table 6.25 | Geologic time scale for the moon | 182 |
| Table 6.26 | Locations, sizes, and ages of lunar maria | 182 |
| Table 6.27 | Ages and diameters of lunar impact basins | 182 |
| Table 6.28 | Locations and sizes of lunar impact craters | 183 |

7 Mars and satellites

| | | |
|-----------|--|-----|
| 7.1 | Mars | 185 |
| Table 7.1 | Spacecraft missions to Mars | 189 |
| Table 7.2 | Some physical properties of Mars | 190 |
| Table 7.3 | Temperature, pressure, and density in Mars' atmosphere | 192 |
| Table 7.4 | Chemical composition of the atmosphere of Mars | 193 |
| Table 7.5 | Isotopic composition of the atmosphere of Mars | 194 |
| Table 7.6 | Elemental analyses of the Martian surface | 195 |
| Table 7.7 | Model mantle and core composition of Mars | 196 |
| Table 7.8 | Model elemental abundances in Mars (mantle, crust, and core) | 197 |
| 7.2 | Phobos and Deimos | 198 |
| Table 7.9 | Some physical properties of Mars' moons Phobos and Deimos | 198 |

8 Jupiter, rings, and satellites

| | | |
|-----------|---|-----|
| Table 8.1 | Some physical properties of Jupiter | 202 |
| Table 8.2 | Temperature, pressure and density in Jupiter's atmosphere | 203 |
| Table 8.3 | Chemical composition of the atmosphere of Jupiter | 204 |
| Table 8.4 | Jupiter's rings | 206 |
| Table 8.5 | Some physical properties of the Galilean satellites | 207 |

9 Saturn, rings and satellites

- 9.1 Saturn 209
 - Table 9.1 Some physical properties of Saturn 211
 - Table 9.2 Temperature, pressure, and density in Saturn's atmosphere 212
 - Table 9.3 Chemical composition of the atmosphere of Saturn 213
 - Table 9.4 Saturn's rings 215
- 9.2 Titan 216
 - Table 9.5 Some physical parameters of Saturn's moon Titan 216
 - Table 9.6 Temperature, pressure, and density of Titan's atmosphere 217
 - Table 9.7 Chemical composition of the atmosphere of Titan 218

10 Uranus, rings, and satellites

- Table 10.1 Some physical properties of Uranus 223
- Table 10.2 Temperature, pressure and density in Uranus' atmosphere 224
- Table 10.3 Chemical composition of the atmosphere of Uranus 225
- Table 10.4 Uranus' rings 227

11 Neptune, rings, and satellites

- 11.1 Neptune 228
 - Table 11.1 Some physical properties of Neptune 230
 - Table 11.2 Temperature, pressure and density in Neptune's atmosphere 231
 - Table 11.3 Chemical composition of the atmosphere of Neptune 232
 - Table 11.4 Neptune's rings 234
- 11.2 Triton 235
 - Table 11.5 Some physical properties of Neptune's moon Triton 236

12 Pluto and Charon

- Table 12.1 Some physical properties of the Pluto-Charon system 239

13 The asteroids

- 13.1 Introduction 241
 - Table 13.1 Asteroids and possibly related meteorite groups 243
 - Table 13.2 Asteroid taxonomic classes and compositional interpretations 244
 - Table 13.3 Asteroid zone, groups, and some asteroid families 245
- 13.2 Gaspra 247
 - Table 13.4 Some physical properties of Gaspra 247
- 13.3 Ida and Dactyl 248
 - Table 13.5 Some physical properties of 243 Ida and (243)1 Dactyl 248
- 13.4 Mathilde 249
 - Table 13.6 Some physical properties of 253 Mathilde 249

| | |
|--|-----|
| 13.5 Asteroid data | 250 |
| Table 13.7 Asteroid data | 251 |
| 14 Centaur objects and Kuiper belt objects | |
| 14.1 Centaur objects | 264 |
| Table 14.1 Centaur objects | 264 |
| Table 14.2 Centaur objects: Colors | 265 |
| 14.2 Kuiper belt objects | 266 |
| Table 14.3 Properties of some Kuiper belt objects | 267 |
| Table 14.4 Kuiper belt objects: Colors | 269 |
| 15 Comets | |
| Table 15.1 Space missions to comets | 273 |
| Table 15.2 Species observed in comets | 274 |
| Table 15.3 Elemental abundances in comet Halley, CI-chondrites, and the solar photosphere | 277 |
| Table 15.4 Relative abundances in P/Halley | 277 |
| Table 15.5 Orbital elements of some short-period comets | 278 |
| Table 15.6 Orbital elements of some long-period comets | 283 |
| Table 15.7 Some meteor streams | 288 |
| Table 15.8 Some meteor streams: Orbital elements | 289 |
| 16 Meteorites | |
| 16.1 Introduction to meteorites | 290 |
| Table 16.1 Meteorite collections | 291 |
| 16.2 Antarctic meteorites | 292 |
| Table 16.2 Find locations of Antarctic meteorites | 292 |
| 16.3 Meteorites recovered from deserts | 293 |
| Table 16.3 Meteorite find locations in the Sahara | 294 |
| 16.4 Meteorite literature | 294 |
| 16.5 Meteorite classification and composition tables | 295 |
| Table 16.4 Meteorite classes | 296 |
| Table 16.5 Petrological classification of chondrites | 298 |
| Table 16.6 Shock classification of chondrites | 299 |
| Table 16.7 Minerals in meteorites | 300 |
| Table 16.8 Comparison of some meteorite ages | 309 |
| Table 16.9 Elemental abundances in CI-chondrites | 311 |
| Table 16.10 Elemental abundances in carbonaceous chondrites | 314 |
| Table 16.11 Elemental abundances in ordinary and enstatite chondrites | 317 |
| Table 16.12 Structural classification of iron meteorites | 320 |
| Table 16.13 Chemical trends in iron meteorites | 320 |
| Table 16.14 Chemical classification of iron meteorites | 321 |
| Table 16.15 Lunar meteorites | 322 |

| | |
|--|-----|
| Table 16.16 SNC meteorites | 323 |
| Table 16.17 Composition of shergottites, nakhlites, and chassignites | 324 |
| Table 16.18 Compositions of eucrites, howardites, and diogenites | 326 |
| Table 16.19 Model elemental abundances in the silicate portion of the eucrite parent body | 328 |
| Table 16.20 Model compositions of the eucrite parent body | 329 |
| Table 16.21 Approximate mean oxygen, nitrogen, carbon, and hydrogen isotopic compositions of meteorites and of the earth | 330 |

17 Beyond the solar system

| | |
|--|-----|
| Table 17.1 Constellations | 332 |
| 17.1 Some definitions and practical equations for stellar parameters | 335 |
| Stellar classifications | 335 |
| Table 17.2 Stellar spectral classes | 335 |
| Table 17.3 Stellar luminosity classes | 335 |
| Table 17.4 Other notations associated with spectral classifications | 335 |
| Effective temperature | 336 |
| Magnitude | 336 |
| Table 17.5 Wavelength band systems | 336 |
| Apparent magnitude | 336 |
| Absolute magnitude | 336 |
| Color index | 337 |
| Bolometric flux and bolometric magnitude | 337 |
| Luminosity | 337 |
| Stellar distances | 338 |
| Stellar radii | 338 |
| Surface gravity | 338 |
| Table 17.6 Stars within 5 parsecs of the sun | 339 |
| Table 17.7 Properties of low-mass substellar objects (extrasolar planets and brown dwarfs) and comparison to Jupiter | 342 |
| Table 17.8 Properties of some primary stars with low-mass companions and comparison to the sun | 344 |
| Table 17.9 Other primary star designations | 346 |
| Table 17.10 Some properties of interstellar molecular clouds | 347 |
| Table 17.11 Some observed interstellar molecules | 348 |

Glossary 349

Index 363