

# Brief Contents

## PART 1 THE COSMIC LANDSCAPE 1

- Unit 1 Our Planetary Neighborhood 1
- Unit 2 Beyond the Solar System 9
- Unit 3 Astronomical Numbers 17
- Unit 4 Scientific Foundations of Astronomy 25
- Unit 5 The Night Sky 33
- Unit 6 The Year 40
- Unit 7 The Time of Day 51
- Unit 8 Lunar Cycles 58
- Unit 9 Calendars 69
- Unit 10 Geometry of the Earth, Moon, and Sun 76
- Unit 11 Planets: The Wandering Stars 84
- Unit 12 The Beginnings of Modern Astronomy 93
- Unit 13 Observing the Sky 100

## PART 2 PROBING MATTER, LIGHT, AND THEIR INTERACTIONS 109

- Unit 14 Astronomical Motion: Inertia, Mass, and Force 109
- Unit 15 Force, Acceleration, and Interaction 114
- Unit 16 The Universal Law of Gravity 120
- Unit 17 Measuring a Body's Mass Using Orbital Motion 125
- Unit 18 Orbital and Escape Velocities 129
- Unit 19 Tides 135
- Unit 20 Conservation Laws 141
- Unit 21 The Dual Nature of Light and Matter 147
- Unit 22 The Electromagnetic Spectrum 155
- Unit 23 Thermal Radiation 162
- Unit 24 Identifying Atoms by Their Spectra 168
- Unit 25 The Doppler Shift 177
- Unit 26 Special Relativity 181
- Unit 27 General Relativity 189
- Unit 28 Detecting Light—An Overview 196
- Unit 29 Collecting Light 203
- Unit 30 Focusing Light 210
- Unit 31 Telescope Resolution 218
- Unit 32 Earth's Atmosphere and Space Observatories 224
- Unit 33 Amateur Astronomy 232

## PART 3 THE SOLAR SYSTEM 241

- Unit 34 The Structure of the Solar System 241
- Unit 35 The Origin of the Solar System 250
- Unit 36 Other Planetary Systems 261
- Unit 37 Earth as a Terrestrial Planet 272
- Unit 38 Earth's Atmosphere and Hydrosphere 283
- Unit 39 Our Moon 294
- Unit 40 Mercury 304
- Unit 41 Venus 311
- Unit 42 Mars 318
- Unit 43 Asteroids 330

- Unit 44 Comparative Planetology 340
- Unit 45 Jupiter and Saturn: Gas Giants 351
- Unit 46 Uranus and Neptune: Ice Giants 359
- Unit 47 Satellite Systems and Rings 365
- Unit 48 Ice Worlds, Pluto, and Beyond 375
- Unit 49 Comets 386
- Unit 50 Impacts on Earth 396

## PART 4 STARS AND STELLAR EVOLUTION 404

- Unit 51 The Sun, Our Star 404
- Unit 52 The Sun's Source of Power 414
- Unit 53 Solar Activity 422
- Unit 54 Surveying the Stars 431
- Unit 55 The Luminosities of Stars 442
- Unit 56 The Temperatures and Compositions of Stars 448
- Unit 57 The Masses of Orbiting Stars 456
- Unit 58 The Sizes of Stars 461
- Unit 59 The H-R Diagram 467
- Unit 60 Overview of Stellar Evolution 475
- Unit 61 Star Formation 483
- Unit 62 Main-Sequence Stars 491
- Unit 63 Giant Stars 498
- Unit 64 Variable Stars 505
- Unit 65 Mass Loss and Death of Low-Mass Stars 511
- Unit 66 Exploding White Dwarfs 518
- Unit 67 Old Age and Death of Massive Stars 524
- Unit 68 Neutron Stars 534
- Unit 69 Black Holes 541
- Unit 70 Star Clusters 550

## PART 5 GALAXIES AND THE UNIVERSE 559

- Unit 71 Discovering the Milky Way 559
- Unit 72 Stars of the Milky Way 566
- Unit 73 Gas and Dust in the Milky Way 574
- Unit 74 Mass and Motions in the Milky Way 582
- Unit 75 A Universe of Galaxies 592
- Unit 76 Types of Galaxies 600
- Unit 77 Galaxy Clustering 611
- Unit 78 Active Galactic Nuclei 620
- Unit 79 Dark Matter 629
- Unit 80 Cosmology 637
- Unit 81 The Edges of the Universe 646
- Unit 82 The Curvature and Expansion of Universes 654
- Unit 83 The Beginnings of the Universe 662
- Unit 84 Dark Energy and the Fate of the Universe 673
- Unit 85 Astrobiology 681
- Unit 86 The Search for Life Elsewhere 690

# Contents

## Looking Up Illustrations i

- #1 Northern Circumpolar Constellations ii
- #2 Ursa Major iii
- #3 M31 & Perseus iv
- #4 Summer Triangle v
- #5 Taurus vi
- #6 Orion vii
- #7 Sagittarius viii
- #8 Centaurus and Crux, The Southern Cross ix
- #9 Southern Circumpolar Constellations x

## About the Authors xiii

### Preface xv

- Approach xv
- New to the Fifth Edition xvi
- Features of this Book xix
- For the Instructor xxi
- Acknowledgements xxii

## PART 1 THE COSMIC LANDSCAPE 1

### Unit 1 Our Planetary Neighborhood 1

- 1.1 Earth 1
- 1.2 The Moon 2
- 1.3 The Planets 3
- 1.4 The Sun 4
- 1.5 The Solar System 5
- 1.6 The Astronomical Unit 6

### Unit 2 Beyond the Solar System 9

- 2.1 Stellar Evolution 9
- 2.2 The Light-Year 10
- 2.3 The Milky Way Galaxy 11
- 2.4 Galaxy Clusters and Beyond 12
- 2.5 The Still-Unknown Universe 14

### Unit 3 Astronomical Numbers 17

- 3.1 The Metric System 18
- 3.2 Scientific Notation 20
- 3.3 Special Units 21
- 3.4 Approximation 23

### Unit 4 Scientific Foundations of Astronomy 25

- 4.1 The Scientific Method 25
- 4.2 The Nature of Matter 27
- 4.3 The Four Fundamental Forces 29
- 4.4 The Elementary Particles 30

### Unit 5 The Night Sky 33

- 5.1 The Celestial Sphere 33
- 5.2 Constellations 34
- 5.3 Daily Motion 35
- 5.4 Latitude and Longitude 37
- 5.5 Celestial Coordinates 38

### Unit 6

#### The Year 40

- 6.1 Annual Motion of the Sun 41
- 6.2 The Ecliptic and the Zodiac 42
- 6.3 The Seasons 43
- 6.4 The Ecliptic's Tilt 45
- 6.5 Solstices and Equinoxes 46
- 6.6 Precession 49

### Unit 7

#### The Time of Day 51

- 7.1 The Day 51
- 7.2 Length of Daylight Hours 52
- 7.3 Time Zones 54
- 7.4 Daylight Saving Time 55
- 7.5 Leap Seconds 56

### Unit 8

#### Lunar Cycles 58

- 8.1 Phases of the Moon 58
- 8.2 Eclipses 61
- 8.3 Eclipse Seasons 65
- 8.4 Moon Lore 66

### Unit 9

#### Calendars 69

- 9.1 The Week 69
- 9.2 The Month 70
- 9.3 The Roman Calendar 71
- 9.4 The Leap Year 72
- 9.5 The Chronicling of Years 73

### Unit 10

#### Geometry of the Earth, Moon, and Sun 76

- 10.1 The Shape of Earth 76
- 10.2 Distance and Size of the Sun and Moon 77
- 10.3 The Size of Earth 79
- 10.4 Measuring the Diameter of Astronomical Objects 80
- 10.5 The Moon Illusion 82

### Unit 11

#### Planets: The Wandering Stars 84

- 11.1 Motions of the Planets 85
- 11.2 Early Ideas About Retrograde Motion 86
- 11.3 The Heliocentric Model 88
- 11.4 The Copernican Revolution 90

### Unit 12

#### The Beginnings of Modern Astronomy 93

- 12.1 Precision Astronomical Measurements 93
- 12.2 The Nature of Planetary Orbits 94
- 12.3 The First Telescopic Observations 97

### Unit 13

#### Observing the Sky 100

- 13.1 Learning the Constellations 100
- 13.2 Motions of the Stars 103
- 13.3 Motion of the Sun 104
- 13.4 Motions of the Moon and Planets 104
- 13.5 A Sundial: Orbital Effects on the Day 106

## PART 2 PROBING MATTER, LIGHT, AND THEIR INTERACTIONS 109

<b>Unit 14</b>	Astronomical Motion: Inertia, Mass, and Force 109
14.1	Inertia and Mass 109
14.2	The Law of Inertia 111
14.3	Forces and Weights 111
14.4	The Force in an Orbit 112
<b>Unit 15</b>	Force, Acceleration, and Interaction 114
15.1	Acceleration 114
15.2	Newton's Second Law of Motion 116
15.3	Action and Reaction: Newton's Third Law of Motion 117
<b>Unit 16</b>	The Universal Law of Gravity 120
16.1	Orbital Motion and Gravity 120
16.2	Newton's Universal Law of Gravity 121
16.3	Surface Gravity and Weight 122
<b>Unit 17</b>	Measuring a Body's Mass Using Orbital Motion 125
17.1	Masses from Orbital Speeds 125
17.2	Kepler's Third Law Revisited 127
<b>Unit 18</b>	Orbital and Escape Velocities 129
18.1	Circular Orbits 129
18.2	Escape Velocity 130
18.3	The Shapes of Orbits 132
<b>Unit 19</b>	Tides 135
19.1	Cause of Tides 135
19.2	The Size of the Tidal Force 136
19.3	Solar Tides 138
19.4	Tidal Braking 139
<b>Unit 20</b>	Conservation Laws 141
20.1	Conservation of Energy 141
20.2	Conservation of Mass (Almost) 144
20.3	Conservation of Angular Momentum 145
<b>Unit 21</b>	The Dual Nature of Light and Matter 147
21.1	The Nature of Light 147
21.2	The Effect of Distance on Light 149
21.3	The Nature of Matter 150
21.4	The Interaction of Light and Matter 152
<b>Unit 22</b>	The Electromagnetic Spectrum 155
22.1	Wavelengths and Frequencies 155
22.2	Energy Carried by Photons 157
22.3	White Light and the Color Spectrum 157
22.4	The Electromagnetic Spectrum 159
<b>Unit 23</b>	Thermal Radiation 162
23.1	Blackbodies 162
23.2	Color, Luminosity, and Temperature 163
23.3	Measuring Temperature 164
23.4	Taking the Temperature of Astronomical Objects 165
23.5	The Stefan-Boltzmann Law 166

<b>Unit 24</b>	Identifying Atoms by Their Spectra 168
24.1	The Spectrum of Hydrogen 169
24.2	Identifying Atoms by Their Light 170
24.3	Types of Spectra 173
24.4	Astronomical Spectra 174
<b>Unit 25</b>	The Doppler Shift 177
25.1	Calculating the Doppler Shift 177
25.2	Astronomical Motions 179
<b>Unit 26</b>	Special Relativity 181
26.1	Light from Moving Bodies 181
26.2	The Michelson-Morley Experiment 183
26.3	Einstein's Theory of Special Relativity 184
26.4	Special Relativity and Space Travel 186
26.5	The Twin Paradox 187
<b>Unit 27</b>	General Relativity 189
27.1	The Principle of Equivalence 189
27.2	Gravity and the Curvature of Space 191
27.3	Gravitational Time Dilation 192
27.4	Gravitational Waves 194
<b>Unit 28</b>	Detecting Light—An Overview 196
28.1	Technological Frontiers 196
28.2	Detecting Visible Light 197
28.3	Observing at Nonvisible Wavelengths 198
28.4	The Crab Nebula: A Case History 200
<b>Unit 29</b>	Collecting Light 203
29.1	Modern Observatories 203
29.2	Collecting Power 206
29.3	Filtering Light 207
29.4	Surface Brightness 208
<b>Unit 30</b>	Focusing Light 210
30.1	Refracting Telescopes 210
30.2	Reflecting Telescopes 212
30.3	Development of Larger Apertures 214
30.4	Color Dispersion 216
<b>Unit 31</b>	Telescope Resolution 218
31.1	Resolution and Diffraction 218
31.2	Calculating the Resolution of a Telescope 220
31.3	Interferometers 220
<b>Unit 32</b>	Earth's Atmosphere and Space Observatories 224
32.1	Atmospheric Absorption 224
32.2	Atmospheric Scintillation 226
32.3	Atmospheric Refraction 228
32.4	Observatories in Space 229
<b>Unit 33</b>	Amateur Astronomy 232
33.1	The Human Eye 232
33.2	Your Eyes at Night 233
33.3	Choosing a Telescope 234
33.4	Completing the Telescope 235
33.5	Astronomical Photography 237

## PART 5 GALAXIES AND THE UNIVERSE 559

<b>Unit 71</b>	Discovering the Milky Way 559
71.1	The Shape of the Milky Way 560
71.2	Star Counts and the Size of the Galaxy 561
71.3	Globular Clusters and the Size of the Galaxy 562
71.4	Galactic Structure and Contents 564
<b>Unit 72</b>	Stars of the Milky Way 566
72.1	Stellar Populations 566
72.2	Formation of Our Galaxy 568
72.3	Evolution Through Mergers 570
72.4	The Future of the Milky Way 572
<b>Unit 73</b>	Gas and Dust in the Milky Way 574
73.1	The Interstellar Medium 574
73.2	Interstellar Dust: Dimming and Reddening 576
73.3	Radio Waves from Cold Interstellar Gas 578
73.4	Heating and Cooling in the ISM 579
<b>Unit 74</b>	Mass and Motions in the Milky Way 582
74.1	The Mass of the Milky Way and the Number of Its Stars 582
74.2	The Galactic Center and Edge 585
74.3	Density Waves and Spiral Arms 587
<b>Unit 75</b>	A Universe of Galaxies 591
75.1	Early Observations of Galaxies 591
75.2	The Distances of Galaxies 594
75.3	The Redshift and Hubble's Law 596
<b>Unit 76</b>	Types of Galaxies 600
76.1	Galaxy Classification 600
76.2	Differences in Star and Gas Content 604
76.3	The Evolution of Galaxies 605
76.4	Galaxy Mergers and Changing Types 608
<b>Unit 77</b>	Galaxy Clustering 611
77.1	The Local Group 612
77.2	Rich and Poor Galaxy Clusters 613
77.3	Superclusters 615
77.4	Large-Scale Structure 616
77.5	Probing Intergalactic Space 618
<b>Unit 78</b>	Active Galactic Nuclei 620
78.1	Active Galaxies 620
78.2	Quasars 622
78.3	Cause of Activity in Galaxies 624
78.4	Black Hole/Galaxy Interactions 626
<b>Unit 79</b>	Dark Matter 629
79.1	Measuring the Mass of a Galaxy 629
79.2	Dark Matter in Clusters of Galaxies 631
79.3	Gravitational Lenses 632
79.4	What Is Dark Matter? 634
<b>Unit 80</b>	Cosmology 637
80.1	Evolving Concepts of the Universe 637
80.2	The Recession of Galaxies 638
80.3	The Meaning of Redshift 641
80.4	The Age of the Universe 643

<b>Unit 81</b>	The Edges of the Universe 646
81.1	Olbers' Paradox 646
81.2	The Cosmic Microwave Background 649
81.3	The Era of Galaxy Formation 651
<b>Unit 82</b>	The Curvature and Expansion of Universes 654
82.1	Quantifying Curvature 654
82.2	Curvature and Expansion 656
82.3	The Density of the Universe 657
82.4	A Cosmological Constant 659
<b>Unit 83</b>	The Beginnings of the Universe 662
83.1	The Eras of the Universe 662
83.2	The Origin of Helium 663
83.3	Radiation, Matter, and Antimatter 666
83.4	The Epoch of Inflation 667
83.5	Cosmological Problems Solved by Inflation 670
<b>Unit 84</b>	Dark Energy and the Fate of the Universe 673
84.1	The Type Ia Supernova Test 673
84.2	An Accelerating Universe 674
84.3	Dark Matter, Dark Energy, and the Cosmic Microwave Background 676
84.4	A Runaway Universe? 677
84.5	Other Universes? 678
<b>Unit 85</b>	Astrobiology 681
85.1	The History of Life on Earth 681
85.2	The Chemistry of Life 683
85.3	The Origin of Life 685
85.4	Life, Planets, and the Universe 688
<b>Unit 86</b>	The Search for Life Elsewhere 690
86.1	The Search for Life on Mars 690
86.2	Life on Other Planets? 692
86.3	Are We Alone? 693
86.4	SETI 696

## Appendix

Scientific Notation	A-1
Solving Distance, Velocity, Time ( $d, V, t$ ) Problems	A-1
Table 1	Physical and Astronomical Constants A-2
Table 2	Metric Prefixes A-2
Table 3	Conversion Between English and Metric Units A-2
Table 4	Some Useful Formulas A-2
Table 5	Physical Properties of the Planets A-3
Table 6	Orbital Properties of the Planets A-3
Table 7	Larger Satellites of the Planets A-4
Table 8	Properties of Main-Sequence Stars A-6
Table 9	The Brightest Stars A-6
Table 10	The Nearest Stars A-7
Table 11	Known and Suspected Members of the Local Group of Galaxies A-8
Table 12	The Brightest Galaxies Beyond the Local Group A-9
Table 13	The Messier Catalog A-9
Table 14	A Cosmic Periodic Table of the Elements A-12

## Answers to Test Yourself Questions AQ-1

### Glossary G-1

### Credits C-1

### Index I-1

### 编辑手记 E-1

### 图片声明 P-1