

Contents

Part I Tools of the Astronomer

Introduction 1

1 A Review of Mathematical Concepts and Tools..... 3

A. Introduction 4

B. Scientific Notation 4

C. Significant Figures 6

D. Order of Magnitude Calculations 8

E. Conversion of Units..... 10

F. Calculation of Errors 10

 1. Percentage Errors..... 10

 2. Propagation of Errors..... 11

G. Mean and Standard Deviation 11

H. Angular Measurement..... 13

I. Scale Factors 15

J. Julian Dates 16

K. The Method of Least Squares..... 18

L. Galaxies Collide!: The Impact of the Milky Way
 and Andromeda Galaxies..... 19

M. Mathematical Concepts Experiment Exercises..... 24

2 A Review of Graphing Techniques..... 35

A. Introduction..... 35

B. Graphing Technique 36

C. Analysis of Graphs 40

 1. Slopes and Y-Intercepts of Straight-Line Graphs..... 40

 2. Interpolation 42

 3. Extrapolation 42

 4. Error Estimates from Graphical Representation of Data 43

D.	Examples of Well-Constructed Graphs	43
1.	Alien Beacons	43
2.	The Microwave Phase Effect of the Planet Mercury	45
E.	Graphing Techniques Experiment Exercises	47
3	The Optics of Telescopes: Part I. Image Size and Brightness.....	53
A.	Introduction	54
B.	Theory	54
1.	Telescope Characteristics	54
2.	Telescope Relationships.....	55
3.	Properties of an Image	56
4.	Ray Tracing	57
C.	Procedure and Observations.....	59
1.	Equipment	59
2.	Image Size: Effect of Objective Focal Length.....	60
3.	Image Brightness: Effect of Collecting Area and Focal Length.....	61
D.	Calculations and Analysis.....	61
1.	Image Size: Effect of Objective Focal Length.....	61
2.	Image Brightness: Effect of Collecting Area and Focal Length.....	62
E.	Telescope Optics Experiment I Data Sheets.....	63
1.	Image Size.....	63
2.	Image Brightness	66
F.	Telescope Optics Experiment I Discussion Questions.....	68
4	The Optics of Telescopes: Part II. Magnification and Chromatic Aberration.....	75
A.	Introduction.....	76
B.	Theory: Chromatic Aberration	76
C.	Procedure and Observations.....	76
1.	Magnification: Objective and Eyepiece Focal Lengths.....	76
2.	Chromatic Aberration	78
D.	Calculations and Analysis.....	78
1.	Magnification: Objective and Eyepiece Focal Lengths.....	78
2.	Chromatic Aberration	79
E.	Telescope Optics Experiment II Data Sheets	80
1.	Magnification.....	80
2.	Chromatic Aberration	82
F.	Telescope Optics Experiment II Discussion Questions.....	84
Part II	The Solar System	
Introduction.....		87
5	Earth: The Seasons and Local Latitude	89
A.	Introduction	90
B.	Theory: The Celestial Sphere and Zenith Angle Equation	91

C.	Procedure and Observations.....	96
D.	Calculations and Analysis.....	97
E.	Seasons and Local Latitude Experiment Data Sheets	99
F.	Seasons and Local Latitude Experiment Discussion Questions	102
6	The Surface Roughness of the Moon.	
	Reflection and Scattering from a Planetary Surface:	
	Part I. Surface Materials.....	105
A.	Introduction.....	106
B.	Theory	108
1.	Reflection.....	108
2.	Scattering.....	111
3.	Geometry of the Reflection	113
4.	The Polarization of Light	115
C.	Procedure and Observations.....	117
1.	Equipment	117
2.	Observations.....	119
D.	Calculations and Analysis.....	119
1.	Degree of Polarization	119
2.	Geometrical Correction Factor.....	120
3.	Analysis	123
E.	Surface Roughness Experiment I Data Sheets	124
F.	Surface Roughness Experiment Discussion Questions	126
7	The Surface Roughness of the Moon.	
	Reflection and Scattering from a Planetary Surface:	
	Part II. Beads and Surface Coverage	129
A.	Introduction.....	130
B.	Theory: Glass Beads on the Lunar Surface.....	130
C.	Procedure and Observations.....	131
1.	Particle Sizes	131
2.	Glass Bead Enhancement	131
D.	Calculations and Analysis.....	133
1.	Coefficients of Roughness.....	133
2.	Bead Reflection Enhancement	133
3.	Bead Surface Coverage on the Lunar Surface.....	134
E.	Surface Roughness Experiment II Data Sheets	138
F.	Surface Roughness Experiment Discussion Questions	151
8	The Formation of Impact Craters.....	155
A.	Introduction.....	156
B.	Theory	158
1.	Impact Energy	158
2.	Mathematical Model of Crater Formation	159
3.	Measurable Crater Parameters	161

C.	Procedure and Observations.....	162
D.	Calculations and Analysis.....	165
E.	Formation of Impact Craters Experiment Data Sheet	168
F.	Formation of Impact Craters Experiment Discussion Questions ...	185
9	Determination of the Rotation Rate of Planets and Asteroids	
	by Radar: Part I. Observations of Mercury	193
A.	Introduction.....	194
B.	Theory	194
1.	Red Shifts and Blue Shifts	194
2.	Doppler Shifts for Rotating Objects	197
3.	Range-Doppler Radar Mapping.....	201
4.	Radar Systems.....	203
C.	Procedure and Observations: Radar Observations of Mercury.....	204
D.	Calculations and Analysis.....	206
E.	Rotation Rate by Radar Experiment I Data Sheets.....	207
F.	Rotation Rate by Radar Experiment I Discussion Questions	210
10	Determination of the Rotation Rate	
	of Planets and Asteroids by Radar: Part II. Observations	
	of Simulated Planets.....	215
A.	Introduction.....	216
B.	Theory	216
1.	Our Rotating Planets.....	216
2.	Radar System Conversion of Microwave to Audio Frequencies	218
C.	Procedure and Observations.....	218
1.	Simulated Planet Surface Material	218
2.	Record Player Turntable: The Planetary Rotation	219
3.	The Radar System	222
4.	Spectrum Analyzer Software	223
5.	Calibration of the Radar System and Background Noise	225
6.	Positioning the Radar System	226
7.	Observations of Simulated Planets	230
D.	Calculations and Analysis.....	231
1.	The Soil Samples	231
2.	System Calibration.....	231
3.	Echo Intensities	231
4.	Rotational Velocities	233
E.	Rotation Rate by Radar Experiment II Data Sheets.....	235
1.	Soil Material	235
2.	System Calibration.....	235
3.	Echo Intensities	237
4.	Rotational Velocities	247
F.	Rotation Rate by Radar Experiment II Discussion Questions.....	251

11 The Orbit of Venus	259
A. Introduction.....	260
B. Theory: Interpretations of the Orbit of Venus.....	260
1. The Ptolemaic System.....	260
2. The Simplicity of the Heliocentric Model.....	262
3. The Configurations of the Interior Planets.....	263
4. Determination of the Distance of Venus.....	264
5. Determination of the Orbital Period by Kepler's Second Law.....	267
C. Procedure and Observations.....	268
1. Observing Venus.....	268
2. Reticulated Eyepieces for Observations.....	269
3. Calibration of the Telescope Field of View.....	271
4. The Observations.....	273
D. Calculations and Analysis.....	275
1. Calibration of the Telescope Field of View.....	275
2. Telescope Magnification.....	275
3. The Orbit of Venus.....	275
4. The Orbital Period.....	277
E. Venus Experiment Data Sheets.....	280
1. Calibration of the Telescope Eyepiece.....	280
2. Telescope Magnification.....	280
F. Venus Experiment Discussion Questions.....	285
12 Kepler's Laws of Planetary Motion	291
A. Introduction.....	292
B. Theory.....	292
1. Kepler's Laws.....	292
2. Comets and Kepler's Second Law.....	294
C. Procedure and Observations.....	295
D. Calculations and Analysis.....	296
1. Kepler's First Law.....	296
2. Kepler's Second Law.....	296
3. Kepler's Third Law.....	297
E. Kepler's Laws Experiment Data Sheets.....	304
1. Kepler's First Law.....	304
2. Kepler's Second Law.....	306
3. Kepler's Third Law.....	309
F. Kepler's Laws Experiment Discussion Questions.....	311
13 The Galilean Satellites of Jupiter	319
A. Introduction.....	320
B. Theory: The General Form of Kepler's Third Law.....	320
C. Procedure and Observations.....	321

D.	Calculations and Analysis.....	326
1.	The Complications.....	326
2.	Date of the Observation	330
3.	Determination of the Orbit	330
4.	Error Analysis.....	333
E.	Galilean Satellites Experiment Data Sheet	336
F.	Galilean Satellites Experiment Discussion Questions	348
14	Thermal Radiation from a Planetary	
	Subsurface: Part I. Calibration and Initial Measurements	355
A.	Introduction.....	356
B.	Theory	356
1.	Planetary Heat Balance	356
2.	Insolation.....	358
3.	Radio Telescopes: Beam Patterns	358
4.	Radio Telescopes: Bandwidths	362
5.	Radio Telescopes: Radio Astronomy Targets.....	363
C.	Procedure and Observations.....	364
1.	The Soil Samples	364
2.	The Incandescent Light Bulbs and Sand Boxes.....	365
3.	The Radiometer.....	367
4.	Sand Box Dimensions	371
5.	Radiometer Calibration: Use of Water Baths	372
6.	Radiometer Calibration: The Procedure.....	374
7.	“Nighttime” Soil Sample Measurements.....	375
8.	“Nighttime” Temperature Measurements	376
D.	Calculations and Analysis.....	376
1.	The Soil Sample	376
2.	Radiometer Calibration	376
3.	Soil Sample Observations and Gain Variations.....	377
4.	“Nighttime” Temperature Measurements	378
E.	Planetary Subsurface Experiment I Data Sheet	380
1.	Soil Samples	380
2.	Calibration Data	381
3.	“Nighttime” Soil Sample Observations	382
4.	“Nighttime” Temperature Measurements	386
F.	Planetary Subsurface Experiment I Discussion Questions	390
15	Thermal Radiation from a Planetary	
	Subsurface: Part II. Soil Sample Measurements.....	393
A.	Introduction.....	394
B.	Theory	394
C.	Procedure and Observations.....	399
1.	The Incandescent Light Bulbs.....	399
2.	Radiometer Calibration	400
3.	Heated Soil Sample Measurements.....	402

D.	Calculations and Analysis.....	404
1.	Calibration and Gain Variation.....	404
2.	Heat Penetration Graphs.....	405
3.	Temperature Profile Graphs	406
4.	Effective Depth Graphs.....	408
5.	Diffusion Depths.....	409
E.	Planetary Subsurface Experiment II Data Sheets	410
F.	Planetary Subsurface Experiment II Discussion Questions	422
16	The Microwave Phase Effect of the Moon.....	427
A.	Introduction.....	428
B.	Theory	428
1.	Thermal Diffusivity of the Lunar Subsurface Material	428
2.	Microwave Phase Effect of the Moon.....	429
3.	Lunar Eclipses	430
4.	Measuring the Temperature of a Celestial Source	432
5.	The Brightness of the Sky at 11 GHZ.....	434
6.	Measuring the Sky Brightness.....	437
C.	Procedure and Observations.....	437
1.	The Telescope	437
2.	The Optical Guide	438
3.	Avoiding Interfering Signals	440
4.	Microwave Phase Effect: Calibration	440
5.	Microwave Phase Effect: Observations of the Moon	442
6.	Lunar Eclipses	444
D.	Data Reduction and Analysis	445
1.	Radiometer Calibration.....	445
2.	Graph of the Microwave Phase Effect	447
3.	Graph of the Lunar Eclipse.....	448
E.	Data Sheet	449
1.	Microwave Phase Effect.....	449
2.	LUNAR ECLIPSE.....	460
F.	Discussion Questions for Microwave Phase Effect of the Moon...	466
Part III	Measuring the Stars and Beyond	
	Introduction.....	471
17	Blackbody Radiation	473
A.	Introduction.....	474
B.	Theory	475
1.	Blackbody Relationships	475
2.	Ohm's Law	478
3.	Color Filters.....	478
4.	The Effective Temperature of the Sun	481

C.	Procedure and Observations.....	481
1.	The Sun	481
2.	Incandescent Light Bulb.....	482
D.	Analysis and Calculations.....	483
1.	The Sun	483
2.	Incandescent Light Bulb.....	485
E.	Blackbody Radiation Experiment Data Sheet	486
1.	The Sun	486
2.	Incandescent Light Bulb.....	490
F.	Blackbody Radiation Experiment Discussion Questions	493
18	The Surface Temperature and Energy	
	Output of the Sun	499
A.	Introduction.....	500
B.	Theory	501
1.	Solar Energy Output and Lifetime	501
2.	Relationship Between Surface Temperature and Luminosity of a Star	502
3.	Specific Heat Capacity.....	503
4.	Sun Elevation Correction	504
C.	Procedure and Observations.....	507
1.	Measurement by Heating of Water.....	507
2.	Measurement by Solar Cells.....	508
D.	Calculations and Analysis.....	508
1.	Measurement by Heating of Water.....	508
2.	Measurement by Solar Cells.....	508
3.	Experimental Errors	509
E.	Energy Output of the Sun Experiment Data Sheets	510
1.	Water Heating	510
2.	Solar Cell	512
3.	Experimental Errors	512
F.	Energy Output of the Sun Experiment Discussion Questions.....	513
19	The Theory of Atomic Spectra	517
A.	Introduction.....	518
B.	Theory	518
1.	Atomic Spectra	518
2.	The Bohr Atom	519
3.	Hydrogen Energy-Level Diagram	521
C.	Procedure and Observations.....	522
1.	Equipment	522
2.	Observations	524
D.	Calculations and Analysis.....	526
1.	Determination of the Wavelength from the Angular Displacements	526
2.	The Value of the Rydberg Constant.....	526

E.	Atomic Spectra Experiment Data Sheets.....	527
F.	Atomic Spectrum Experiment Discussion Questions.....	529
20	Discovering the Nature of Objects in Space:	
	Kirchhoff's Laws of Radiation	533
A.	Introduction.....	534
B.	Theory.....	534
C.	Procedure and Observations.....	536
	1. Continuous Blackbody Spectrum: Kirchhoff's First Law.....	537
	2. Emission Line Spectrum: Kirchhoff's Second Law.....	538
	3. Absorption Line Spectrum: Kirchhoff's Third Law	538
D.	Calculations and Analysis.....	539
	1. Continuous Blackbody Spectrum: Kirchhoff's First Law.....	539
	2. Emission Line Spectrum: Kirchhoff's Second Law.....	539
	3. Absorption Line Spectrum: Kirchhoff's Third Law	540
E.	Kirchhoff's Law Experiment Data Sheets.....	541
	1. Continuous Blackbody Spectrum: Kirchhoff's First Law.....	541
	2. Emission Line Spectrum: Kirchhoff's Second Law.....	542
	3. Absorption Line Spectrum: Kirchhoff's Third Law	543
F.	Kirchhoff's Law Experiment Discussion Questions.....	545
Appendix I	Physical Constants and Astronomical Measurements	551
Appendix II	Julian Dates.....	553
Appendix III	Day-of-the-Year Tables.....	555
Appendix IV	Fast Fourier Transform Spectrum Analyzer Software.....	557
About the Author		561
Index		563