

Contents

1	The Scientific Method	1
1.1	How Do We Know What Is True?	1
1.2	Induction and Deduction	4
1.3	Language and Certainty	7
1.4	<i>Math Focus.</i> Math Trick #1: Uncertainty and Significant Digits	10
1.5	<i>Bible Focus.</i> Are There Degrees of Faith?	12
1.6	The Scientific Method	14
1.7	Myths about the Scientific Method	16
1.8	Comparing Scientific Theories—Occam’s Razor	19
1.9	<i>Theology Focus.</i> Evidentialism and Presuppositionalism	21
1.10	A Hidden Assumption in the Scientific Method	25
1.11	<i>Personality Focus.</i> Roger Bacon	27
1.12	<i>Bible Focus.</i> Can We Learn Truth from Evil People?	30
1.13	<i>Personality Focus.</i> Francis Bacon	31
1.14	<i>Math Focus.</i> Math Trick #2: Functions	37
1.15	<i>Math Focus.</i> Making Plots of Theories and Data	39
1.16	<i>Math Focus.</i> Math Trick #3: Negligible Quantities	42
1.17	General Practicum. A Language Experiment	44
1.18	Vocabulary	46
2	Newton’s Laws of Motion	49
2.1	Newton’s Three Laws	49
2.2	How Do Rockets Move in Outer Space?	51
2.3	What Do We Mean by Scientific Laws?	52
2.4	<i>Personality Focus.</i> Isaac Newton	54
2.5	Why Are Mathematical Laws So Successful? Design and Intelligibility	56
2.6	General Practicum. Motion with a Constant Force	58
2.7	<i>Math Focus.</i> Math Trick #4: Derivatives	60
2.8	<i>Math Focus.</i> Math Trick #5: Units	62
2.9	<i>Math Focus.</i> Predicting Motion	63
2.10	<i>Math Focus.</i> Newton’s Laws in Mathematical Form	65
2.11	<i>Math Focus.</i> Math Trick #6: Units in Equations	67

2.12	<i>Math Focus.</i> Fitting Your Data	68
2.13	<i>Math Focus.</i> Math Trick #7: The Law of Conservation of Momentum	69
2.14	<i>Math Focus.</i> Math Trick #8: Vectors	71
2.15	<i>Math Focus.</i> Math Trick #9: Trigonometry	74
2.16	Advanced Practicum. How Does a Boat Sail into the Wind?	75
2.17	<i>Advanced Math Focus.</i> Math Trick #10: The Law of Conservation of Angular Momentum	78
2.18	Vocabulary	83
3	Newton's Law of Gravity	85
3.1	The Copernican Revolution	85
3.2	The Trial of Galileo. Appearances and Essences	88
3.3	<i>Theology Focus.</i> When Is It Proper to Change Our Interpretation of the Bible?	90
3.4	Why Did Science Arise Only in the West? The Problem of Multiculturalism	92
3.5	Newton's Law of Gravity	95
3.6	<i>Math Focus.</i> Math Trick #11: Scientific Notation	97
3.7	<i>Math Focus.</i> The Force of Gravity from the Planets. Could Astrology Be Right?	99
3.8	General Practicum. Galileo's Experiment and the Acceleration of Gravity	101
3.9	<i>Math Focus.</i> Data Fitting	102
3.10	<i>Math Focus.</i> Math Trick #12: Proportionalities	103
3.11	<i>Math Focus.</i> Orbits	105
3.12	<i>Math Focus.</i> Math Trick #13: The Law of Conservation of Energy	107
3.13	<i>Advanced Math Focus.</i> Math Trick #14: Integration	110
3.14	<i>Advanced Math Focus.</i> Escape Velocity	114
3.15	<i>Personality Focus.</i> Leibniz	116
3.16	<i>Advanced Math Focus.</i> Ballistics: Cannonballs and Bullets	118
3.17	Advanced Practicum. Firing Range	120
3.18	Measuring the Muzzle Velocity of a Gun	121
3.19	Vocabulary	122
4	Thermodynamics	123
4.1	Mach and the Positivists. Atoms as a Useful Fiction	123
4.2	The Question of Randomness and Probability	126
4.3	General Practicum. Average Behavior	128
4.4	The Problem of a Vacuum	130
4.5	The Laws of Thermodynamics	131
4.6	Friction and the Arrow of Time	134

4.7	The Heat Death of the Universe	136
4.8	<i>Bible Focus.</i> Is the Second Law of Thermodynamics Due to Sin?	138
4.9	States of Matter	141
4.10	Maxwell's Demon	143
4.11	<i>Personality Focus.</i> Lord Kelvin	145
4.12	<i>Math Focus.</i> Boltzmann's Constant and Absolute Zero Temperature	149
4.13	<i>Math Focus.</i> The Ideal Gas Law	151
4.14	<i>Math Focus.</i> Pressure	153
4.15	Convection. Why Do Boats Float?	154
4.16	<i>Math Focus.</i> Adiabatic Cooling	156
4.17	How Does a Refrigerator Work?	158
4.18	<i>Math Focus.</i> Friction Laws and Terminal Velocity	160
4.19	<i>Advanced Math Focus.</i> The Equilibrium Distribution	163
4.20	Advanced Practicum. Liquid Nitrogen	167
4.21	Vocabulary	169
5	Electricity and Coulomb's Law	171
5.1	A New Fundamental Force	171
5.2	<i>Bible Focus.</i> The "God of the Gaps" Argument. Does Understanding Physics Leave Less Room for God?	173
5.3	<i>Math Focus.</i> Coulomb's Law in Mathematical Form	176
5.4	Another Invisible Entity: the Field	178
5.5	General Practicum. Charge and Coulomb's Law	180
5.6	<i>Math Focus.</i> Why $1/r^2$? Gauss's Law	182
5.7	<i>Math Focus.</i> The Electric Field from a Wire	184
5.8	<i>Personality Focus.</i> Michael Faraday	186
5.9	Electronics Made Simple	189
5.10	<i>Math Focus.</i> Power Consumption	195
5.11	Shielding Electric Fields	197
5.12	<i>Advanced Math Focus.</i> Van der Waals Forces	199
5.13	<i>Advanced Math Focus.</i> Ohm's Law	201
5.14	Advanced Practicum. The Multimeter	204
5.15	How Does a Television Set Work?	207
5.16	How Do Computers Work? Transistor Logic	209
5.17	Vocabulary	213
6	Waves and Fields	215
6.1	Waves in the World Around Us	215
6.2	Electromagnetic Waves	217
6.3	<i>Personality Focus.</i> James Maxwell	220
6.4	The Field Is Real	223
6.5	<i>Math Focus.</i> Math Trick #15: Sine Waves	224
6.6	<i>Math Focus.</i> Plotting Sine Waves	226

6.7	Drawing Sine Waves	227
6.8	<i>Math Focus.</i> Superposition and Interference	229
6.9	General Practicum. Fun with a Slinky	231
6.10	The Electromagnetic Spectrum	233
6.11	What Is Waving in a Light Wave? The Question of the Medium	235
6.12	<i>Bible Focus.</i> Light and Darkness	236
6.13	The Greenhouse Effect and Energy Consumption	238
6.14	<i>Math Focus.</i> Math Trick #16: Spectral Analysis	241
6.15	<i>Math Focus.</i> Power in Waves	242
6.16	General Practicum. The Light Meter	244
6.17	Advanced Practicum. Seeing Waves with an Oscilloscope	245
6.18	<i>Math Focus.</i> Natural Oscillations	247
6.19	How Does a Microwave Oven Work?	251
6.20	How Do Radio, Television, and Cell Phones Work?	253
6.21	Vocabulary	257
7	Einstein's Theory of Special Relativity	259
7.1	Einstein's Theory of Absolutes	259
7.2	The Breakdown of Absolute Time and Space	262
7.3	General Practicum. A Trip in the Car	264
7.4	<i>Math Focus.</i> Time Dilation	265
7.5	<i>Math Focus.</i> Length Contraction	267
7.6	Paradoxes of Relativity	269
7.7	<i>Bible Focus.</i> Is Time Universal?	272
7.8	<i>Math Focus.</i> Math Trick #17: Approximations for Inverses	274
7.9	<i>Math Focus.</i> Mass-Energy Equivalence	276
7.10	Scientific Progress—Was Newton Wrong?	278
7.11	<i>Personality Focus.</i> Albert Einstein	279
7.12	The Usefulness of Answering Philosophical Questions	282
7.13	<i>Advanced Math Focus.</i> The Lorentz Transformations	284
7.14	<i>Math Focus.</i> Magnetic Fields and Relativity	287
7.15	Magnets and Current	290
7.16	Advanced Practicum. Making an Electromagnet	292
7.17	Electric Generators	293
7.18	How Does MRI Imaging Work? Can People Read Minds?	295
7.19	Vocabulary	298
8	Einstein's Theory of General Relativity	299
8.1	Einstein's Equivalence Principle	299
8.2	<i>Math Focus.</i> Geodesics	303
8.3	Our Perception of Gravity	306
8.4	Cosmology and the Big Bang	308

8.5	Measuring Distances to the Stars. Can We Look Back in Time?	310
8.6	<i>Math Focus.</i> Newton's Estimation of the Distance to the Stars	312
8.7	<i>Theology Focus.</i> Is the Big Bang Theory Heresy?	314
8.8	<i>Math Focus.</i> Olber's Paradox	316
8.9	<i>Theology Focus.</i> Eternity	318
8.10	<i>Bible Focus.</i> The Young-Earth versus the Old-Earth View	320
8.11	<i>Math Focus.</i> Parallax	324
8.12	<i>Math Focus.</i> The Doppler Effect	326
8.13	<i>Math Focus.</i> The Color-Brightness Relation and the Hubble Red Shift	329
8.14	General Practicum. Measuring Distances with Parallax	331
8.15	Advanced Practicum. Measuring the Doppler Effect	334
8.16	Black Holes	335
8.17	<i>Math Focus.</i> Why Do Black Holes Suck Light In?	338
8.18	<i>Math Focus.</i> Tidal Forces	340
8.19	<i>Personality Focus.</i> Hawking and the Problem of the Beginning of Time	342
8.20	Vocabulary	346
9	Quantum Mechanics I. Matter Waves	347
9.1	<i>Bible Focus.</i> When Should We Believe an Outlandish Story?	347
9.2	Quantum Mechanics = Wave Mechanics	350
9.3	General Practicum. Newton's Rings	352
9.4	<i>Math Focus.</i> The DeBroglie Relations	355
9.5	<i>Personality focus.</i> Paul Dirac	358
9.6	Why "Quantum"?	361
9.7	General Practicum. Resonances and Music	364
9.8	<i>Math Focus.</i> Standing Waves	367
9.9	The Paradox of the Stability of the Atom	369
9.10	Advanced Practicum. Spectroscopy	370
9.11	<i>Advanced Math Focus.</i> Interference and Diffraction Gratings	372
9.12	<i>Math Focus.</i> The Uncertainty Principle	375
9.13	<i>Advanced Math Focus.</i> The Uncertainty Principle and Energy Conservation	377
9.14	<i>Math Focus.</i> Energies of Wave Resonances	378
9.15	Why Are There Particles? Field Theory	381
9.16	<i>Bible Focus.</i> What Holds the Universe Together?	383
9.17	Why Don't Nuclei Fly Apart? The Last Fundamental Force	385
9.18	Is There a Smallest Particle? Neutrinos, Quarks, and Other Particles	387

9.19 Vocabulary	390
10 Quantum Mechanics II. Particle Statistics	391
10.1 Wave-Particle Duality	391
10.2 <i>Math Focus.</i> The Amplitude-Squared Rule	394
10.3 The Question of Randomness in Quantum Mechanics	395
10.4 <i>Math Focus.</i> Polarization	402
10.5 General Practicum. Polarizers	404
10.6 <i>Math Focus.</i> The EPR Paradox	407
10.7 Dealing with Apparent Contradictions	411
10.8 <i>Personality Focus.</i> Postmodernism and the Mysticism of Niels Bohr	415
10.9 <i>Bible Focus.</i> Can Anything Happen Outside God's Will?	417
10.10 Quantum Tunneling and Radioactivity	418
10.11 <i>Math Focus.</i> Particle Transition Rates. Superfluids, Superconductors and Pauli Exclusion	420
10.12 <i>Math Focus.</i> Thermal Radiation	423
10.13 Advanced Practicum. The Infrared Camera and Night Vision	425
10.14 How Does a Laser Work?	426
10.15 Antimatter	428
10.16 Spontaneous Symmetry Breaking	432
10.17 The Semiconductor Revolution	435
10.18 <i>Advanced Math Focus.</i> Why Are Solids Solid?	437
10.19 <i>Advanced Math Focus.</i> Why Are Things Springy?	439
10.20 Vocabulary	441
11 Biophysics and Complex Systems	443
11.1 Life as a Physical System	443
11.2 Measuring Design	444
11.3 DNA, Evolution and the Design of Life	448
11.4 Spontaneous Pattern Formation	452
11.5 <i>Theology Focus.</i> Models of the Origin of Life	454
11.6 Large-Numbers Coincidences and the Many-Universes Hypothesis	456
11.7 <i>Personality Focus.</i> The Cosmologists	460
11.8 Mocking Evolution	464
11.9 <i>Bible Focus.</i> Should We Fear Similarities with the Animals?	468
11.10 Design as Science	469
11.11 <i>Math Focus.</i> Optics	471
11.12 General Practicum. Optical Design	477
11.13 <i>Advanced Math Focus.</i> Lens Optics	480
11.14 CCD Cameras and Optical Information	483
11.15 Reductionism and Free Will	485

11.16 Artificial Intelligence, Gödel's Theorem, and Conscious Thought	487
11.17 Unpredictability in a Deterministic World. Chaos Theory	490
11.18 <i>Math Focus</i> . A Simple Chaotic System	491
11.19 <i>Bible Focus</i> . Should We Fear Causes of Our Behavior?	493
11.20 Vocabulary	496
A Constants of Nature and Unit Conversions	499
B Resources	503

