



Contents

<i>Preface</i>	<i>page</i> xiii
Part I Kinematics and Dynamics	1
1 A Brief Review of Introductory Concepts	3
1.1 Kinematics	3
1.2 Newton's Second Law	5
1.3 Work and Energy	7
1.4 Momentum	8
1.5 Rotational Motion	9
1.6 Statics	11
1.7 Rotational Kinetic Energy	13
1.8 Angular Momentum	13
1.9 Rotational Equivalents	14
1.10 Summary	14
1.11 Problems	15
Computational Projects	17
2 Kinematics	19
2.1 Galileo Galilei (Historical Note)	19
2.2 The Principle of Inertia	20
2.3 Basic Concepts in Kinematics	21
2.4 The Position of a Particle on a Plane	29
2.5 Unit Vectors	30
2.6 Kinematics in Two Dimensions	32
2.7 Kinematics in Three Dimensions	35
2.8 Summary	43
2.9 Problems	43
Computational Projects	47
3 Newton's Laws: Determining the Motion	49
3.1 Isaac Newton (Historical Note)	49
3.2 The Law of Inertia	50
3.3 Newton's Second Law and the Equation of Motion	52
3.4 Newton's Third Law: Action Equals Reaction	55
3.5 Is Rotational Velocity Absolute or Relative?	57
3.6 Determining the Motion	58

vi	CONTENTS	
	3.7 Simple Harmonic Motion	65
	3.8 Closed-Form Solutions	67
	3.9 Numerical Solutions (Optional)	68
	3.10 Summary	70
	3.11 Problems	71
	Computational Projects	78
	4 Lagrangians and Hamiltonians	79
	4.1 Joseph Louis Lagrange (Historical Note)	79
	4.2 The Equation of Motion by Inspection	80
	4.3 The Lagrangian	81
	4.4 Lagrange's Equations	86
	4.5 Degrees of Freedom	89
	4.6 Generalized Momentum	90
	4.7 Generalized Force	93
	4.8 The Calculus of Variations	95
	4.9 The Hamiltonian and Hamilton's Equations	100
	4.10 Summary	104
	4.11 Problems	105
	Computational Projects	110
	Part II Conservation Laws	113
	5 Energy	115
	5.1 The Work–Energy Theorem	115
	5.2 Work Along a Path: The Line Integral	116
	5.3 Potential Energy	120
	5.4 Force, Work, and Potential Energy	130
	5.5 The Conservation of Energy	134
	5.6 Energy Diagrams	136
	5.7 The Energy Integral: Solving for the Motion	138
	5.8 The Kinetic Energy of a System of Particles	140
	5.9 Work on an Extended Body: Pseudowork	141
	5.10 Summary	142
	5.11 Problems	145
	Computational Projects	149
	6 Linear Momentum	150
	6.1 The Law of Conservation of Momentum	150
	6.2 The Motion of a Rocket	151
	6.3 Collisions	154
	6.4 Inelastic Collisions: The Coefficient of Restitution	161
	6.5 Impulse	162
	6.6 Momentum of a System of Particles	163
	6.7 Relative Motion and the Reduced Mass	164
	6.8 Collisions in Center of Mass Coordinates (Optional)	165
	6.9 Summary	170

CONTENTS	vii
6.10 Problems	171
Computational Projects	175
7 Angular Momentum	177
7.1 Definition of Angular Momentum	177
7.2 Conservation of Angular Momentum	178
7.3 Angular Momentum of a System of Particles	180
7.4 Rotation of a Rigid Body about a Fixed Axis	185
7.5 The Moment of Inertia	187
7.6 The Gyroscope	189
7.7 Angular Momentum is an Axial Vector	191
7.8 Summary	193
7.9 Problems	194
Computational Project	198
8 Conservation Laws and Symmetries	199
8.1 Emmy Noether (Historical Note)	199
8.2 Symmetry	200
8.3 Symmetry and the Laws of Physics	201
8.4 Symmetries and Conserved Physical Quantities	202
8.5 Are the Laws of Physics Symmetrical?	204
8.6 Strangeness (Optional)	205
8.7 Symmetry Breaking	206
8.8 Problems	206
Part III Gravity	209
9 The Gravitational Field	211
9.1 Newton's Law of Universal Gravitation	211
9.2 The Gravitational Field	213
9.3 The Gravitational Field of an Extended Body	216
9.4 The Gravitational Potential	219
9.5 Field Lines and Equipotential Surfaces	221
9.6 The Newtonian Gravitational Field Equations	222
9.7 The Equations of Poisson and Laplace	225
9.8 Einstein's Theory of Gravitation (Optional)	226
9.9 Summary	230
9.10 Problems	231
Computational Projects	234
10 Central Force Motion: The Kepler Problem	236
10.1 Johannes Kepler (Historical Note)	236
10.2 Kepler's Laws	238
10.3 Central Forces	238
10.4 The Equation of Motion	243
10.5 Energy and the Effective Potential Energy	246
10.6 Solving the Radial Equation of Motion	250

viii	CONTENTS	
10.7	The Equation of the Orbit	251
10.8	The Equation of an Ellipse	255
10.9	Kepler's Laws Revisited	261
10.10	Orbital Mechanics	265
10.11	A Perturbed Circular Orbit	267
10.12	Resonances	272
10.13	Summary	273
10.14	Problems	273
	Computational Projects	278
Part IV	Oscillations and Waves	281
11	Harmonic Motion	283
11.1	Springs and Pendulums	283
11.2	Solving the Differential Equation	286
11.3	The Damped Harmonic Oscillator	291
11.4	The Forced Harmonic Oscillator	297
11.5	Coupled Oscillators	309
11.6	Summary	315
11.7	Problems	316
	Computational Projects	319
12	The Pendulum	320
12.1	A Simple Pendulum with Arbitrary Amplitude	320
12.2	The Physical Pendulum	326
12.3	The Center of Percussion	329
12.4	The Spherical Pendulum	333
12.5	Summary	342
12.6	Problems	343
	Computational Projects	347
13	Waves	348
13.1	A Wave in a Stretched String	348
13.2	Direct Solution of the Wave Equation	351
13.3	Standing Waves	355
13.4	Traveling Waves	357
13.5	Standing Waves as a Special Case of Traveling Waves	359
13.6	Energy	360
13.7	Momentum (Optional)	364
13.8	Summary	366
13.9	Problems	367
	Computational Projects	370
14	Small Oscillations (Optional)	371
14.1	Introduction	371
14.2	Statement of the Problem	371
14.3	Normal Modes	376
14.4	Matrix Formulation	383

CONTENTS	ix
14.5 Normal Coordinates	385
14.6 Coupled Pendulums: An Example	387
14.7 Many Degrees of Freedom	391
14.8 Transition to Continuous Systems	394
14.9 Summary	399
14.10 Problems	401
Computational Projects	402
Part V Rotation	403
15 Accelerated Reference Frames	405
15.1 A Linearly Accelerating Reference Frame	405
15.2 A Rotating Coordinate Frame	406
15.3 Fictitious Forces	408
15.4 Centrifugal Force and the Plumb Bob	410
15.5 The Coriolis Force	412
15.6 The Foucault Pendulum	417
15.7 Application: The Tidal Force (Optional)	422
15.8 Summary	426
15.9 Problems	426
Computational Projects	429
16 Rotational Kinematics	430
16.1 Orientation of a Rigid Body	430
16.2 Orthogonal Transformations	432
16.3 The Euler Angles	439
16.4 Euler's Theorem	442
16.5 Infinitesimal Rotations	451
16.6 Summary	452
16.7 Problems	454
Computational Projects	455
17 Rotational Dynamics	456
17.1 Angular Momentum	456
17.2 Kinetic Energy	460
17.3 Properties of the Inertia Tensor	461
17.4 The Euler Equations of Motion	472
17.5 Torque-Free Motion	473
17.6 The Spinning Top (Gyroscope)	475
17.7 Summary	483
17.8 Problems	484
Computational Projects	487
Part VI Special Topics	489
18 Statics	491
18.1 Basic Concepts	491

x	CONTENTS	
18.2	Couples, Resultants, and Equilibrants	494
18.3	Reduction to the Simplest Set of Forces	495
18.4	The Hanging Cable	495
18.5	Stress and Strain	500
18.6	The Centroid (Optional)	501
18.7	The Center of Gravity (Optional)	503
18.8	D'Alembert's Principle and Virtual Work	504
18.9	Summary	508
18.10	Problems	509
	Computational Projects	512
19	Fluid Dynamics and Sound Waves (Optional)	513
19.1	Introduction	513
19.2	Equilibrium of Fluids (Hydrostatics)	513
19.3	Fluid Kinematics	518
19.4	Equation of Motion: Euler's Equation	526
19.5	Conservation of Mass, Momentum, and Energy	529
19.6	Sound Waves	533
19.7	Solving the Wave Equation by Separation of Variables	539
19.8	Summary	543
19.9	Problems	544
20	The Special Theory of Relativity	546
20.1	Albert Einstein (Historical Note)	546
20.2	Experimental Background	547
20.3	The Postulates of Special Relativity	549
20.4	The Lorentz Transformations	549
20.5	The Addition of Velocities	555
20.6	Simultaneity and Causality	557
20.7	The Twin Paradox	559
20.8	Minkowski Space-Time Diagrams	561
20.9	4-Vectors	564
20.10	Relativistic Dynamics	568
20.11	Summary	571
20.12	Problems	572
21	Classical Chaos (Optional)	575
21.1	Configuration Space and Phase Space	576
21.2	Periodic Motion	577
21.3	Attractors	579
21.4	Chaotic Trajectories and Liapunov Exponents	580
21.5	Poincaré Maps	580
21.6	The Henon–Heiles Hamiltonian	582
21.7	Summary	584
21.8	Problem	585
	Computational Projects	585

CONTENTS

xi

<i>Appendix A</i>	<i>Formulas and Constants</i>	587
<i>Appendix B</i>	<i>Answers to Selected Problems</i>	589
<i>Bibliography</i>		596
<i>Index</i>		597