

Contents

1 Mathematical Preliminaries	1
1.1 Vectors	2
1.2 Calculus	7
1.3 Problems	21
2 Kinematics	23
2.1 Position, Velocity and Acceleration	24
2.2 Ballistic Motion	25
2.3 Relative Motion	29
2.4 Angular Motion	32
2.5 Problems	39
3 Forces and Dynamics	43
3.1 Newton's Laws	44
3.2 Momentum and Newton's Laws	45
3.3 Motion under Forces	46
3.4 Newton's Laws in Non-Linear Motion	57
3.5 Problems	62
4 Energy and its Conservation	67
4.1 The Work-Energy Theorem	68
4.2 Conservation of Energy	72
4.3 Forces and Potential Energy	77
4.4 Power	81
4.5 Energy and Oscillation	83

4.6	Harmonic Motion in Equilibrium	85
4.7	Problems	87
5	Momentum and its Conservation	91
5.1	The Center of Mass	92
5.2	Impulse	95
5.3	Conservation of Momentum in Collisions	97
5.4	Center of Mass Coordinates	101
5.5	Mass Flow and Momentum Transport	105
5.6	Problems	111
6	Rotational Dynamics	117
6.1	Torque	118
6.2	Moment of Inertia	118
6.3	Newton's Second Law for Rotation	123
6.4	Rigid Body Equilibrium	124
6.5	Rolling without Slipping	125
6.6	Rolling with Slipping	129
6.7	Rotational Kinetic Energy	132
6.8	Physical Pendulums	134
6.9	Examples in Rotational Dynamics	135
6.10	Problems	138
7	Angular Momentum	143
7.1	The Definition of Angular Momentum	144
7.2	Kinetic Energy of General Motion	145
7.3	The Inertia Matrix	147
7.4	Angular Impulse	152
7.5	Conservation of Angular Momentum	155
7.6	Non-Constant Angular Momentum	158
7.7	Euler's Rigid Body Equations	162

7.8	Infinitesimal Rotations	166
7.9	Euler Angles	171
7.10	Problems	175
8	Gravitation and Central Forces	179
8.1	Properties of Central Forces	180
8.2	Gravity as a Central Force	180
8.3	Gravity of Large Bodies	183
8.4	Kepler's Laws	192
8.5	Central Force Scattering	203
8.6	Systems of Many Bodies	209
8.7	Binary Systems	212
8.8	Problems	221
9	Oscillations	227
9.1	Damped Oscillations	228
9.2	Driven Oscillations	230
9.3	Nonlinear Oscillators	236
9.4	Coupled Oscillators	247
9.5	Many Oscillators	251
9.6	The Continuous Limit: Wave Equation	261
9.7	Problems	263
10	The Wave Equation	267
10.1	Solutions to the Wave Equation	268
10.2	Wave Phenomena	270
10.3	Dispersion Relations	277
10.4	Energy and Waves	281
10.5	Attenuation and Impedance	283
10.6	The Wave Equation in Many Dimensions	289
10.7	Problems	296

11 Diffraction and Geometric Optics	301
11.1 Diffraction	302
11.2 The Fresnel-Kirchhoff Theorem	311
11.3 Fermat's Principle of Least Time	318
11.4 Transfer Matrices	325
11.5 Further Applications in Optics	331
11.6 Problems	340
12 Non-inertial Reference Frames	347
12.1 The Galilean Transformation	348
12.2 Uniform Acceleration	348
12.3 Uniform Rotation	351
12.4 d'Alembert's Principle	359
12.5 Problems	364
13 Relativistic Kinematics	369
13.1 The Acoustic Doppler Effect	370
13.2 The Lorentz Transformation	372
13.3 Basic Relativistic Effects	375
13.4 Spacetime Diagrams	387
13.5 Proper Time	397
13.6 Problems	400
14 Relativistic Dynamics	405
14.1 Four-Vectors	406
14.2 Proper Velocity	409
14.3 Momentum and Energy	410
14.4 Conservation of Four-Momentum	411
14.5 Consequences of Four-Momentum Conservation	414
14.6 Relativistic Force	424
14.7 Relativistic Harmonic Oscillator	433

14.8 Central Forces in Relativity	436
14.9 Problems	439
A Multivariable Calculus	445
A.1 Vector Functions of Time	445
A.2 Scalar Functions of Space	450
A.3 Vector Functions of Space	465
A.4 Curvilinear Coordinates	476
A.5 Problems	480
B Linear Algebra	483
B.1 Vector Spaces	484
B.2 Matrices and Linear Maps	490
B.3 Eigenvalues and Eigenvectors	496
B.4 Inner Product Spaces	502
B.5 Determinants	508
B.6 Problems	513
C Differential Equations	515
C.1 First Order Equations	516
C.2 Higher Order Equations	520
C.3 Integral Transforms	534
C.4 Green's Functions	544
C.5 Problems	548
D Conic Sections	551
D.1 Circles and Ellipses	552
D.2 Parabolas	553
D.3 Hyperbolas	554
D.4 Polar Coordinates	555
D.5 General Conic Sections	557
D.6 Problems	559