

# Contents

<b>Preface</b>	<b>XI</b>
<b>Guide for Users</b>	<b>XVII</b>
Bibliography . . . . .	XIX
<b>1 Introduction</b>	<b>1</b>
1.1 Overview . . . . .	1
1.2 Basic Algebra and Solving Equations . . . . .	10
1.3 Calculus . . . . .	14
1.4 Differential Equations . . . . .	17
1.4.1 Exact Solutions . . . . .	18
1.4.2 Special Functions . . . . .	19
1.4.3 Numerical Solutions . . . . .	21
1.5 Vectors and Matrices . . . . .	24
1.6 Summary . . . . .	36
<b>2 Oscillatory Motion</b>	<b>41</b>
2.1 Simple Harmonic Oscillator . . . . .	41
2.2 Damped Oscillation . . . . .	45
2.2.1 Overdamping . . . . .	46
2.2.2 Underdamping . . . . .	48
2.2.3 Critical Damping . . . . .	49
2.3 Sinusoidally Driven Oscillation . . . . .	50
2.4 Phase Space . . . . .	60
<b>3 Calculus of Variations</b>	<b>71</b>
3.1 Euler–Lagrange Equation . . . . .	71
3.2 Mathematical Examples . . . . .	72
3.3 Symmetry Properties . . . . .	80
3.4 Principle of Least Action . . . . .	82
3.5 Systems with Many Degrees of Freedom . . . . .	86
3.6 Force of Constraint . . . . .	89

<b>4</b>	<b>Integration of Equations of Motion</b>	<b>101</b>
4.1	Linearization of Equations . . . . .	101
4.2	Double Pendulum . . . . .	102
4.3	Central-force Problem . . . . .	108
4.3.1	Kepler Problem . . . . .	109
4.3.2	Correction Terms . . . . .	117
4.4	Motion of a Symmetric Top . . . . .	118
4.5	Nonlinear Oscillation and Chaos . . . . .	126
4.6	Summary of Lagrangian Mechanics . . . . .	134
<b>5</b>	<b>Orthogonal Functions and Expansions</b>	<b>139</b>
5.1	Fourier Series . . . . .	139
5.2	Fourier Integrals . . . . .	143
5.3	Orthogonal Functions in Complete Sets . . . . .	146
5.4	Legendre Polynomials . . . . .	147
5.4.1	Generating Function and Rodrigues Formula . . . . .	151
5.5	Bessel Functions . . . . .	152
5.6	Summary of Special Functions . . . . .	163
<b>6</b>	<b>Electrostatics</b>	<b>169</b>
6.1	Coulomb's Law . . . . .	169
6.2	Curvilinear Coordinates . . . . .	172
6.2.1	Spherical Coordinates . . . . .	174
6.2.2	Cylindrical Coordinates . . . . .	178
6.3	Differential Vector Calculus . . . . .	180
6.4	Electric Potential . . . . .	181
6.4.1	Cavendish's Apparatus for the Inverse Square Law . . . . .	186
6.4.2	Multipole Expansion . . . . .	190
6.5	Electric Field and Equipotential . . . . .	197
<b>7</b>	<b>Boundary-value Problems</b>	<b>205</b>
7.1	Theory of Potential . . . . .	205
7.2	Method of Images . . . . .	206
7.3	Complex-variable Techniques . . . . .	208
7.4	Laplace Equation in Cartesian Coordinates . . . . .	214
7.5	Laplace Equation in Spherical Coordinates . . . . .	218
7.6	Laplace Equation in Cylindrical Coordinates . . . . .	223
7.7	Summary . . . . .	231
<b>8</b>	<b>Magnetostatics</b>	<b>235</b>
8.1	Magnetic Forces . . . . .	235
8.2	Biot–Savart Law . . . . .	238
8.3	Vector Potential . . . . .	244
8.4	Force and Torque on Magnetic Dipoles . . . . .	250
8.5	Summary of Electromagnetism in Static Conditions . . . . .	253

<b>9</b>	<b>Electric Circuits</b>	<b>259</b>
9.1	Resistors in Series and in Parallel . . . . .	259
9.2	Kirchhoff's Rules . . . . .	261
9.3	Direct-current Circuits . . . . .	263
9.3.1	$RC$ Circuit . . . . .	264
9.3.2	$RL$ Circuit . . . . .	265
9.3.3	$RLC$ Circuit . . . . .	266
9.3.4	Lissajous Figures . . . . .	269
9.4	Alternating-current Circuits . . . . .	271
9.4.1	Impedance . . . . .	271
9.4.2	Bridges . . . . .	277
<b>10</b>	<b>Waves</b>	<b>283</b>
10.1	Wave Equation . . . . .	283
10.2	Vibrating String . . . . .	287
10.3	Sinusoidal Waves in Linear Combinations . . . . .	290
10.3.1	Complex Notation . . . . .	290
10.3.2	Fourier Integrals . . . . .	291
10.3.3	Uncertainty Principle . . . . .	292
10.4	Gaussian Wave Packet . . . . .	297
10.5	Two-dimensional Circular Membrane . . . . .	301
10.6	Electromagnetic Waves . . . . .	305
10.6.1	Electric-dipole Radiation . . . . .	306
10.6.2	Synchrotron Radiation . . . . .	312
<b>11</b>	<b>Physical Optics</b>	<b>321</b>
11.1	Light as an Electromagnetic Wave . . . . .	321
11.1.1	Polarization . . . . .	322
11.2	Mathematics of Interference . . . . .	325
11.3	Interference . . . . .	328
11.3.1	Double-slit Interference . . . . .	329
11.3.2	Multiple-slit Interference . . . . .	330
11.4	Diffraction . . . . .	334
11.4.1	Resolution of Single Slits and Circular Apertures . . . . .	336
11.5	Diffraction Grating . . . . .	340
11.6	Fourier Transform Spectrometry . . . . .	343
11.7	Fresnel Diffraction . . . . .	346
<b>12</b>	<b>Special Relativity</b>	<b>353</b>
12.1	Lorentz Transformation . . . . .	353
12.1.1	Length Contraction and Time Dilation . . . . .	357
12.1.2	Addition of Velocity . . . . .	361
12.1.3	Doppler Shift . . . . .	363
12.2	Relativistic Kinematics and Dynamics . . . . .	367
12.3	Transformations of Electromagnetic Fields . . . . .	373

<b>13 Quantum Phenomena</b>	<b>379</b>
13.1 Blackbody Radiation . . . . .	379
13.2 Photoelectric and Compton Effects . . . . .	383
13.3 Wave–Particle Duality . . . . .	385
13.4 Bohr Model of the Hydrogen Atom . . . . .	387
13.5 Dielectrics and Paramagnetism . . . . .	390
<b>14 Schrödinger Equation in One Dimension (I): Unbound States</b>	<b>401</b>
14.1 Formulation of Quantum Mechanics . . . . .	401
14.2 Zero Potential and Plane Waves . . . . .	403
14.3 Step Potential . . . . .	404
14.3.1 Step Potential ( $E > V_0$ ) . . . . .	404
14.3.2 Step Potential ( $E < V_0$ ) . . . . .	407
14.4 Barrier Potential . . . . .	408
14.4.1 Barrier Potential ( $E > V_0$ ) . . . . .	409
14.4.2 Barrier Potential ( $E < V_0$ ) . . . . .	410
14.5 Summary of Stationary States . . . . .	411
14.6 Wave Packet . . . . .	414
14.6.1 Reflection of Wave Packet . . . . .	417
<b>15 Schrödinger Equation in One Dimension (II): Bound States</b>	<b>425</b>
15.1 Discrete Spectrum . . . . .	425
15.2 Infinite Potential Well . . . . .	426
15.3 Finite Potential Well . . . . .	428
15.4 Series Solution and Hermite Equation . . . . .	436
15.5 Linear Harmonic Oscillator . . . . .	438
15.6 Homogeneous Field . . . . .	441
15.7 Morse Potential . . . . .	445
15.8 Bound Nonstationary States . . . . .	449
15.9 Two-state System . . . . .	450
<b>16 Schrödinger Equation in Three Dimensions</b>	<b>465</b>
16.1 Central-force Problem . . . . .	465
16.2 Spherical Harmonics . . . . .	466
16.3 Angular Momentum . . . . .	470
16.4 Coulomb Potential . . . . .	472
16.5 Hydrogen Atom . . . . .	474
16.5.1 Electric Potential Due to the Electron . . . . .	492
16.5.2 Hybrid Bond Orbitals . . . . .	494
16.6 Infinite Spherical Well . . . . .	497
<b>17 Quantum Statistics</b>	<b>509</b>
17.1 Statistical Distributions . . . . .	509
17.2 Maxwell–Boltzmann Statistics . . . . .	512

17.3	Ideal Bose Gas . . . . .	515
17.3.1	Low Density and Virial Expansion . . . . .	518
17.3.2	Bose–Einstein Condensation at Low Temperature . . . . .	522
17.4	Ideal Fermi Gas . . . . .	528
17.4.1	Low Density and Virial Expansion . . . . .	530
17.4.2	Specific Heat of a Metal at Low Temperature . . . . .	531
17.5	Relativistic Gases . . . . .	538
<b>18</b>	<b>General Relativity</b>	<b>545</b>
18.1	Basic Formulation . . . . .	545
18.2	Newtonian Limit . . . . .	549
18.2.1	Gravitational Redshift . . . . .	551
18.3	Schwarzschild Solution . . . . .	553
18.4	Robertson–Walker Metric . . . . .	563
18.4.1	Evolution of the Universe . . . . .	565
 <b>Appendix</b>		
<b>A</b>	<b>Physical and Astrophysical Constants</b>	<b>577</b>
<b>B</b>	<b>Mathematical Notes</b>	<b>579</b>
B.1	Legendre Equation and Series Solutions . . . . .	579
B.2	Whittaker Function and Hypergeometric Series . . . . .	583
B.2.1	Harmonic Oscillator . . . . .	584
B.2.2	Morse Potential . . . . .	586
B.2.3	Coulomb Potential . . . . .	587
B.3	Clausius–Mossotti Equation . . . . .	589
B.4	Bose–Einstein Integral Function . . . . .	592
B.5	Embedding Formula . . . . .	596
<b>Index</b>		<b>599</b>