

Contents

1 ■ Survey of the Elementary Principles	1
1.1 Mechanics of a Particle	1
1.2 Mechanics of a System of Particles	5
1.3 Constraints	12
1.4 D'Alembert's Principle and Lagrange's Equations	16
1.5 Velocity-Dependent Potentials and the Dissipation Function	22
1.6 Simple Applications of the Lagrangian Formulation	24
2 ■ Variational Principles and Lagrange's Equations	34
2.1 Hamilton's Principle	34
2.2 Some Techniques of the Calculus of Variations	36
2.3 Derivation of Lagrange's Equations from Hamilton's Principle	44
2.4 Extension of Hamilton's Principle to Nonholonomic Systems	45
2.5 Advantages of a Variational Principle Formulation	51
2.6 Conservation Theorems and Symmetry Properties	54
2.7 Energy Function and the Conservation of Energy	60
3 ■ The Central Force Problem	70
3.1 Reduction to the Equivalent One-Body Problem	70
3.2 The Equations of Motion and First Integrals	72
3.3 The Equivalent One-Dimensional Problem, and Classification of Orbits	76
3.4 The Virial Theorem	83
3.5 The Differential Equation for the Orbit, and Integrable Power-Law Potentials	86
3.6 Conditions for Closed Orbits (Bertrand's Theorem)	89
3.7 The Kepler Problem: Inverse-Square Law of Force	92
3.8 The Motion in Time in the Kepler Problem	96
3.9 The Laplace-Runge-Lenz Vector	103
3.10 Scattering in a Central Force Field	106
3.11 Transformation of the Scattering Problem to Laboratory Coordinates	115
3.12 The Three-Body Problem	121

4 ■ The Kinematics of Rigid Body Motion	134
4.1 The Independent Coordinates of a Rigid Body	134
4.2 Orthogonal Transformations	139
4.3 Formal Properties of the Transformation Matrix	144
4.4 The Euler Angles	150
4.5 The Cayley–Klein Parameters and Related Quantities	154
4.6 Euler’s Theorem on the Motion of a Rigid Body	155
4.7 Finite Rotations	161
4.8 Infinitesimal Rotations	163
4.9 Rate of Change of a Vector	171
4.10 The Coriolis Effect	174
5 ■ The Rigid Body Equations of Motion	184
5.1 Angular Momentum and Kinetic Energy of Motion about a Point	184
5.2 Tensors	188
5.3 The Inertia Tensor and the Moment of Inertia	191
5.4 The Eigenvalues of the Inertia Tensor and the Principal Axis Transformation	195
5.5 Solving Rigid Body Problems and the Euler Equations of Motion	198
5.6 Torque-free Motion of a Rigid Body	200
5.7 The Heavy Symmetrical Top with One Point Fixed	208
5.8 Precession of the Equinoxes and of Satellite Orbits	223
5.9 Precession of Systems of Charges in a Magnetic Field	230
6 ■ Oscillations	238
6.1 Formulation of the Problem	238
6.2 The Eigenvalue Equation and the Principal Axis Transformation	241
6.3 Frequencies of Free Vibration, and Normal Coordinates	250
6.4 Free Vibrations of a Linear Triatomic Molecule	253
6.5 Forced Vibrations and the Effect of Dissipative Forces	259
6.6 Beyond Small Oscillations: The Damped Driven Pendulum and the Josephson Junction	265
7 ■ The Classical Mechanics of the Special Theory of Relativity	276
7.1 Basic Postulates of the Special Theory	277
7.2 Lorentz Transformations	280
7.3 Velocity Addition and Thomas Precession	282
7.4 Vectors and the Metric Tensor	286

7.5	1-Forms and Tensors	289
7.6	Forces in the Special Theory; Electromagnetism	297
7.7	Relativistic Kinematics of Collisions and Many-Particle Systems	300
7.8	Relativistic Angular Momentum	309
7.9	The Lagrangian Formulation of Relativistic Mechanics	312
7.10	Covariant Lagrangian Formulations	318
7.11	Introduction to the General Theory of Relativity	324
8	■ The Hamilton Equations of Motion	334
8.1	Legendre Transformations and the Hamilton Equations of Motion	334
8.2	Cyclic Coordinates and Conservation Theorems	343
8.3	Routh's Procedure	347
8.4	The Hamiltonian Formulation of Relativistic Mechanics	349
8.5	Derivation of Hamilton's Equations from a Variational Principle	353
8.6	The Principle of Least Action	356
9	■ Canonical Transformations	368
9.1	The Equations of Canonical Transformation	368
9.2	Examples of Canonical Transformations	375
9.3	The Harmonic Oscillator	377
9.4	The Symplectic Approach to Canonical Transformations	381
9.5	Poisson Brackets and Other Canonical Invariants	388
9.6	Equations of Motion, Infinitesimal Canonical Transformations, and Conservation Theorems in the Poisson Bracket Formulation	396
9.7	The Angular Momentum Poisson Bracket Relations	408
9.8	Symmetry Groups of Mechanical Systems	412
9.9	Liouville's Theorem	419
10	■ Hamilton–Jacobi Theory and Action–Angle Variables	430
10.1	The Hamilton–Jacobi Equation for Hamilton's Principal Function	430
10.2	The Harmonic Oscillator Problem as an Example of the Hamilton–Jacobi Method	434
10.3	The Hamilton–Jacobi Equation for Hamilton's Characteristic Function	440
10.4	Separation of Variables in the Hamilton–Jacobi Equation	444
10.5	Ignorable Coordinates and the Kepler Problem	445
10.6	Action-angle Variables in Systems of One Degree of Freedom	452

10.7	Action-Angle Variables for Completely Separable Systems	457
10.8	The Kepler Problem in Action-angle Variables	466
11	■ Classical Chaos	483
11.1	Periodic Motion	484
11.2	Perturbations and the Kolmogorov–Arnold–Moser Theorem	487
11.3	Attractors	489
11.4	Chaotic Trajectories and Liapunov Exponents	491
11.5	Poincaré Maps	494
11.6	Hénon–Heiles Hamiltonian	496
11.7	Bifurcations, Driven-damped Harmonic Oscillator, and Parametric Resonance	505
11.8	The Logistic Equation	509
11.9	Fractals and Dimensionality	516
12	■ Canonical Perturbation Theory	526
12.1	Introduction	526
12.2	Time-dependent Perturbation Theory	527
12.3	Illustrations of Time-dependent Perturbation Theory	533
12.4	Time-independent Perturbation Theory	541
12.5	Adiabatic Invariants	549
13	■ Introduction to the Lagrangian and Hamiltonian Formulations for Continuous Systems and Fields	558
13.1	The Transition from a Discrete to a Continuous System	558
13.2	The Lagrangian Formulation for Continuous Systems	561
13.3	The Stress-energy Tensor and Conservation Theorems	566
13.4	Hamiltonian Formulation	572
13.5	Relativistic Field Theory	577
13.6	Examples of Relativistic Field Theories	583
13.7	Noether's Theorem	589
Appendix A	■ Euler Angles in Alternate Conventions and Cayley–Klein Parameters	601
Appendix B	■ Groups and Algebras	605
	Selected Bibliography	617
	Author Index	623
	Subject Index	625