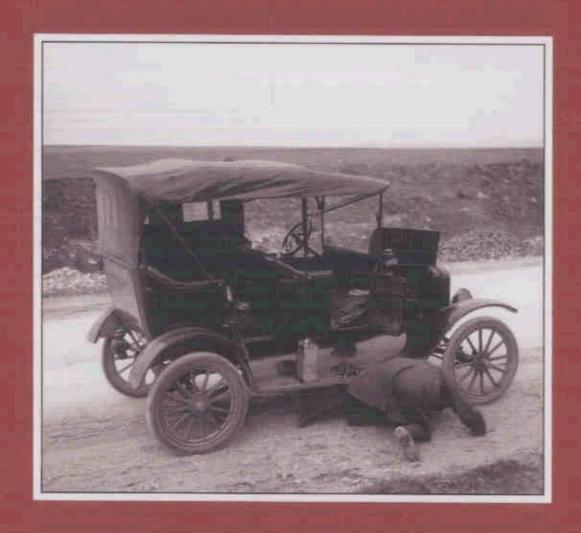
Classical Mechanics

John R. Taylor



Contents

Preface xi

CHAPTER 1 Newton's Laws of Motion 3

1.2 Space and Time 41.3 Mass and Force 9

1.1

Classical Mechanics 3

1.5	The Third Law and Conservation of Momentum	17
1.6	Newton's Second Law in Cartesian Coordinates	23
1.7	Two-Dimensional Polar Coordinates 26	
	Principal Definitions and Equations of Chapter 1	33
	Problems for Chapter 1 34	
CHAPTER 2	Projectiles and Charged Particles 43	
2.1	Air Resistance 43	
2.2	Linear Air Resistance 46	
2.3	Trajectory and Range in a Linear Medium 54	
2.4	Quadratic Air Resistance 57	
2.5	Motion of a Charge in a Uniform Magnetic Field	65
2.6	Complex Exponentials 68	
2.7	Solution for the Charge in a B Field 70	
	Principal Definitions and Equations of Chapter 2	71
	Problems for Chapter 2 72	

1.4 Newton's First and Second Laws; Inertial Frames 13

CHAPTER 3 Momentum and Angular Momentum 83

- 3.1 Conservation of Momentum 83
- 3.2 Rockets 85
- 3.3 The Center of Mass 87
- 3.4 Angular Momentum for a Single Particle 90
- 3.5 Angular Momentum for Several Particles 93
 Principal Definitions and Equations of Chapter 3 98
 Problems for Chapter 3 99

CHAPTER 4 Energy 105

- 4.1 Kinetic Energy and Work 105
- 4.2 Potential Energy and Conservative Forces 109
- 4.3 Force as the Gradient of Potential Energy 116
- 4.4 The Second Condition that F be Conservative 118
- 4.5 Time-Dependent Potential Energy 121
- 4.6 Energy for Linear One-Dimensional Systems 123
- 4.7 Curvilinear One-Dimensional Systems 129
- 4.8 Central Forces 133
- 4.9 Energy of Interaction of Two Particles 138
- 4.10 The Energy of a Multiparticle System 144
 Principal Definitions and Equations of Chapter 4 148
 Problems for Chapter 4 150

CHAPTER 5 Oscillations 161

- 5.1 Hooke's Law 161
- 5.2 Simple Harmonic Motion 163
- 5.3 Two-Dimensional Oscillators 170
- 5.4 Damped Oscillations 173
- 5.5 Driven Damped Oscillations 179
- 5.6 Resonance 187
- 5.7 Fourier Series * 192
- 5.8 Fourier Series Solution for the Driven Oscillator* 197
- 5.9 The RMS Displacement; Parseval's Theorem* 203
 Principal Definitions and Equations of Chapter 5 205
 Problems for Chapter 5 207

^{*} Sections marked with an asterisk could be omitted on a first reading.

CHAPTER 6	Calculus	of V	/ariations	215
-----------	----------	------	------------	-----

- 6.1 Two Examples 216
- 6.2 The Euler-Lagrange Equation 218
- 6.3 Applications of the Euler–Lagrange Equation 221
- 6.4 More than Two Variables 226Principal Definitions and Equations of Chapter 6 230Problems for Chapter 6 230

CHAPTER 7 Lagrange's Equations 237

- 7.1 Lagrange's Equations for Unconstrained Motion 238
- 7.2 Constrained Systems; an Example 245
- 7.3 Constrained Systems in General 247
- 7.4 Proof of Lagrange's Equations with Constraints 250
- 7.5 Examples of Lagrange's Equations 254
- 7.6 Generalized Momenta and Ignorable Coordinates 266
- 7.7 Conclusion 267
- 7.8 More about Conservation Laws * 268
- 7.9 Lagrange's Equations for Magnetic Forces * 272
- 7.10 Lagrange Multipliers and Constraint Forces* 275
 Principal Definitions and Equations of Chapter 7 280
 Problems for Chapter 7 281

CHAPTER 8 Two-Body Central-Force Problems 293

- 8.1 The Problem 293
- 8.2 CM and Relative Coordinates; Reduced Mass 295
- 8.3 The Equations of Motion 297
- 8.4 The Equivalent One-Dimensional Problem 300
- 8.5 The Equation of the Orbit 305
- 8.6 The Kepler Orbits 308
- 8.7 The Unbounded Kepler Orbits 313
- 8.8 Changes of Orbit 315
 Principal Definitions and Equations of Chapter 8 319
 Problems for Chapter 8 320

CHAPTER 9 Mechanics in Noninertial Frames 327

- 9.1 Acceleration without Rotation 327
- 9.2 The Tides 330
- 9.3 The Angular Velocity Vector 336
- 9.4 Time Derivatives in a Rotating Frame 339

10110	
9.5	Newton's Second Law in a Rotating Frame 342
9.6	The Centrifugal Force 344
9.7	The Coriolis Force 348
9.8	Free Fall and the Coriolis Force 351
9.9	The Foucault Pendulum 354
9.10	Coriolis Force and Coriolis Acceleration 358
	Principal Definitions and Equations of Chapter 9 359
	Problems for Chapter 9 360
CHAPTER 10	Rotational Motion of Rigid Bodies 367
10.1	Properties of the Center of Mass 367
10.2	Rotation about a Fixed Axis 372
10.3	Rotation about Any Axis; the Inertia Tensor 378
10.4	Principal Axes of Inertia 387
10.5	Finding the Principal Axes; Eigenvalue Equations 389
10.6	Precession of a Top due to a Weak Torque 392
10.7	Euler's Equations 394
10.8	Euler's Equations with Zero Torque 397
10.9	Euler Angles * 401
10.10	Motion of a Spinning Top* 403
	Principal Definitions and Equations of Chapter 10 407
	Problems for Chapter 10 408
CHAPTER 11	Coupled Oscillators and Normal Modes 417
11.1	Two Masses and Three Springs 417
11.2	Identical Springs and Equal Masses 421
11.3	Two Weakly Coupled Oscillators 426
11.4	Lagrangian Approach: The Double Pendulum 430
11.5	The General Case 436
11.6	Three Coupled Pendulums 441
11.7	Normal Coordinates * 444
	Principal Definitions and Equations of Chapter 11 447
	Problems for Chapter 11 448
PARTI	Further Topics 455
CHAPTER 12	Nonlinear Mechanics and Chaos 457
12.1	Linearity and Nonlinearity 458
12.2	The Driven Damped Pendulum DDP 462
12.3	Some Expected Features of the DDP 463

12.4	The DDP: Approach to Chaos 467
12.5	Chaos and Sensitivity to Initial Conditions 476
12.6	Bifurcation Diagrams 483
12.7	State-Space Orbits 487
12.8	Poincaré Sections 495
12.9	The Logistic Map 498
	Principal Definitions and Equations of Chapter 12 513
	Problems for Chapter 12 514
CHAPTER 13	Hamiltonian Mechanics 521
13.1	The Basic Variables 522
13.2	Hamilton's Equations for One-Dimensional Systems 524
13.3	Hamilton's Equations in Several Dimensions 528
13.4	Ignorable Coordinates 535
13.5	Lagrange's Equations vs. Hamilton's Equations 536
13.6	Phase-Space Orbits 538
13.7	Liouville's Theorem * 543
	Principal Definitions and Equations of Chapter 13 550
	Problems for Chapter 13 550
CHAPTER 14	Collision Theory 557
CHAPTER 14 14.1	Collision Theory 557 The Scattering Angle and Impact Parameter 558
14.1	The Scattering Angle and Impact Parameter 558
14.1 14.2	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560
14.1 14.2 14.3	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563
14.1 14.2 14.3 14.4	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568
14.1 14.2 14.3 14.4 14.5	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572
14.1 14.2 14.3 14.4 14.5	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574
14.1 14.2 14.3 14.4 14.5 14.6 14.7	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames* 579
14.1 14.2 14.3 14.4 14.5 14.6 14.7	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames * 579 Relation of the CM and Lab Scattering Angles * 582
14.1 14.2 14.3 14.4 14.5 14.6 14.7	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames* 579 Relation of the CM and Lab Scattering Angles* 582 Principal Definitions and Equations of Chapter 14 586
14.1 14.2 14.3 14.4 14.5 14.6 14.7	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames* 579 Relation of the CM and Lab Scattering Angles* 582 Principal Definitions and Equations of Chapter 14 586 Problems for Chapter 14 587
14.1 14.2 14.3 14.4 14.5 14.6 14.7 14.8	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames* 579 Relation of the CM and Lab Scattering Angles* 582 Principal Definitions and Equations of Chapter 14 586 Problems for Chapter 14 587 Special Relativity 595
14.1 14.2 14.3 14.4 14.5 14.6 14.7 14.8	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames * 579 Relation of the CM and Lab Scattering Angles * 582 Principal Definitions and Equations of Chapter 14 586 Problems for Chapter 14 587 Special Relativity 595 Relativity 596
14.1 14.2 14.3 14.4 14.5 14.6 14.7 14.8 CHAPTER 15 15.1 15.2	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames* 579 Relation of the CM and Lab Scattering Angles* 582 Principal Definitions and Equations of Chapter 14 586 Problems for Chapter 14 587 Special Relativity 596 Galilean Relativity 596
14.1 14.2 14.3 14.4 14.5 14.6 14.7 14.8 CHAPTER 15 15.1 15.2 15.3	The Scattering Angle and Impact Parameter 558 The Collision Cross Section 560 Generalizations of the Cross Section 563 The Differential Scattering Cross Section 568 Calculating the Differential Cross Section 572 Rutherford Scattering 574 Cross Sections in Various Frames * 579 Relation of the CM and Lab Scattering Angles * 582 Principal Definitions and Equations of Chapter 14 586 Problems for Chapter 14 587 Special Relativity 595 Relativity 596 Galilean Relativity 596 The Postulates of Special Relativity 601

The Relativistic Velocity-Addition Formula 615

15.7

15.8	Four-Dimensional Space-Time; Four-Vectors 617
15.9	The Invariant Scalar Product 623
15.10	The Light Cone 625
15.11	The Quotient Rule and Doppler Effect 630
15.12	Mass, Four-Velocity, and Four-Momentum 633
15.13	Energy, the Fourth Component of Momentum 638
15.14	Collisions 644
15.15	Force in Relativity 649
15.16	Massless Particles; the Photon 652
15.17	Tensors* 656
15.18	Electrodynamics and Relativity 660
	Principal Definitions and Equations of Chapter 15 664
	Problems for Chapter 15 666
CHAPTER 16	Continuum Mechanics 681
16.1	Transverse Motion of a Taut String 682
16.2	The Wave Equation 685
16.3	Boundary Conditions; Waves on a Finite String* 688
16.4	The Three-Dimensional Wave Equation 694
16.5	Volume and Surface Forces 697
16.6	Stress and Strain: The Elastic Moduli 701
16.7	The Stress Tensor 704
16.8	The Strain Tensor for a Solid 709
16.9	Relation between Stress and Strain: Hooke's Law 715
16.10	The Equation of Motion for an Elastic Solid 718
16.11	Longitudinal and Transverse Waves in a Solid 721
16.12	Fluids: Description of the Motion* 723
16.13	Waves in a Fluid * 727
	Principal Definitions and Equations of Chapter 16 730
	Problems for Chapter 16 732
	Diamandining Deal Comments Matrices 700
APPENDIX	0 0 ,
A.1	Diagonalizing a Single Matrix 739
A.2	Simultaneous Diagonalization of Two Matrices 743
	Further Reading 747
	Answers for Odd-Numbered Problems 749
	Index 777