

# Contents

## 1. INTRODUCTION TO MECHANICS

1-1 Introduction **1** 1-2 Definitions **1** 1-3 Experiment and Theory **2** 1-4 Error **2**  
 1-5 Scale **3** 1-6 Units **3** 1-7 Basic Definitions in Mechanics **3** 1-8 Conversion of  
 Units **5** 1-9 Summary **5** Problems **6**

## 2. DESCRIPTIVE MATHEMATICS IN PHYSICS

2-1 Introduction **7** 2-2 Coordinate Systems **7** 2-3 Trigonometry **9** 2-4 Relation-  
 ships Between Coordinate Systems **10** 2-5 Vectors **10** 2-6 Components of Vectors **12**  
 2-7 Vector Subtraction **14** 2-8 Addition (or Subtraction) of More Than Two Vectors **14**  
 2-9 Summary **14** Problems **15**

## 3. KINEMATICS OF POINT MASSES

3-1 Introduction **17** 3-2 The Position Vector and Displacement **17** 3-3 Composition  
 of Displacements (Moving Observers) **18** 3-4 Average Velocity **20** 3-5 Uniform  
 Velocity (Rectilinear Motion) **20** 3-6 Relative Velocities (Moving Reference Frames)  
**21** 3-7 Change in Velocity **23** 3-8 Summary **24** Problems **25**

## 4. INTERACTION OF PARTICLES (MASS, MOMENTUM, AND FORCE)

4-1 Introduction **27** 4-2 Mass **27** 4-3 Momentum **30** 4-4 Conservation of Mo-  
 mentum **30** 4-5 Average Force **31** 4-6 Newton's Second Law **32** 4-7 Newton's  
 First Law **33** 4-8 Newton's Third Law **33** 4-9 Gravitational Units **34** 4-10 Sum-  
 mary **34** Problems **35**

## 5. FORCES; EQUILIBRIUM

5-1 Introduction **38** 5-2 Forces Due to Elasticity (Calibration of a Spring) **39** 5-3  
 Gravitational Force at the Earth's Surface (Weight) **40** 5-4 Gravitational Force Be-  
 tween Point Masses **42** 5-5 Electric Force **43** 5-6 Contact Forces **43** 5-7 Friction  
**44** 5-8 Tension and Thrust (Strings and Rods) **45** 5-9 Systems **46** 5-10 Statics  
 of Point Masses **46** 5-11 Summary **50** Problems **51**

## 6. KINEMATICS (INSTANTANEOUS VELOCITY AND ACCELERATION)

6-1 Introduction **55** 6-2 Velocity **55** 6-3 Acceleration **58** 6-4 Instantaneous  
 Acceleration **59** 6-5 Integration Applied to Kinematics **59** 6-6 Motion in One Dimen-  
 sion (Rectilinear Motion) **61** 6-7 Two-Dimensional Motion (Cartesian Components **64**  
 6-8 Two-Dimensional Motion (Polar Coordinates) **65** 6-9 Noncircular Motion **69**  
 6-10 The Vector Product **72** 6-11 Summary **73** Problems **75**

**7. DYNAMICS (INSTANTANEOUS QUANTITIES)**

7-1 Introduction **79** 7-2 Conservation of Momentum While Velocity Is Changing **79**  
7-3 Instantaneous Force **80** 7-4 Newton's Laws of Motion **80** 7-5 Single Forces **81**  
7-6 Application of Newton's Laws **82** 7-7 Moving Coordinate Systems **85** 7-8 Two-  
and Three-Dimensional Motion **86** 7-9 The Third Law in Circular Motion **89** 7-10  
Forces by Streams of Material **90** 7-11 Summary **91** Problems **92**

**8. PERIODIC MOTION**

8-1 Introduction **99** 8-2 Periodic Motion Kinematics in General **99** 8-3 Circular  
Motion; Derivatives of the Sine and Cosine **100** 8-4 Kinematics of Simple Harmonic  
Motion **101** 8-5 Dynamics of a Free Simple-Harmonic Oscillator **104** 8-6 Linear  
Force Approximations **105** 8-7 Analysis of Complex Periodic Motion **106** 8-8 Har-  
monic Oscillator under External Forces **107** 8-9 Nonharmonic Driving Forces **108**  
8-10 Summary **109** Problems **110**

**9. IMPULSE, WORK, AND ENERGY**

9-1 Introduction **114** 9-2 Impulse and Momentum **114** 9-3 Work **116** 9-4 Recti-  
linear Motion with Constant Force (Direction and Magnitude) **117** 9-5 Rectilinear  
Motion with Uniform Friction Force **118** 9-6 Rectilinear Motion with a Position-  
Dependent Force **118** 9-7 Work Expressed as an Ordinary Integral: Power **119** 9-8  
Work and Energy **119** 9-9 Potential Energy in Rectilinear Motion **120** 9-10 Work  
by Friction: Heat Energy **121** 9-11 Kinetic Energy in Rectilinear Motion **121** 9-12  
Conservation of Energy **122** 9-13 Two-Dimensional Motion **123** 9-14 Kinetic Energy  
in Two-Dimensional Motion **125** 9-15 Forces of Constraint **126** 9-16 Two-Dimen-  
sional Motion near the Earth **126** 9-17 Energy in Central Force Problems **128** 9-18  
Systems with Two or More Conservative Forces **130** 9-19 Collisions and Explosions  
**130** 9-20 Summary **132** Problems **134**

**10. GRAVITATION, ANGULAR MOMENTUM, AND SATELLITES**

10-1 Introduction **141** 10-2 The Universality of Gravitation **141** 10-3 Effect of  
Finite Size **142** 10-4 Conservation of Angular Momentum **146** 10-5 Angular Mo-  
mentum as a Vector **149** 10-6 Satellite Motion **149** 10-7 Summary **150** Problems  
**151**

**11. CENTER OF MASS; NONINERTIAL REFERENCE FRAMES**

11-1 Introduction **155** 11-2 Center of Mass **155** 11-3 Interaction of Two Point  
Masses **156** 11-4 Systems of More Than Two Bodies **157** 11-5 Noninertial Reference  
Frames **157** 11-6 Linearly Accelerated Reference Frames **158** 11-7 Coordinate  
Frames Rotating at Uniform Angular Velocity **160** 11-8 Summary **162** Problems **163**

**12. SUMMARY IN DEDUCTIVE FORM**

12-1 Introduction **166** 12-2 Development of Mechanics in This Text **166** 12-3  
Development of Mechanics in Deductive Form **167** 12-4 Force Laws **169** 12-5  
Summary **170**

**13. SPECIAL RELATIVITY**

13-1 Introduction **171** 13-2 Newtonian Relativity in Space **171** 13-3 Galilean Transformation **172** 13-4 Newtonian Time **172** 13-5 Velocity of Light **173** 13-6 The Nature of Light **173** 13-7 The Ether as a Medium for Light Propagation **174** 13-8 The Postulates of Special Relativity **178** 13-9 Dilation of Time Intervals **178** 13-10 Length Contraction **183** 13-11 Point Transformation **185** 13-12 Simultaneity **187** 13-13 Velocity Transformation **191** 13-14 Relativistic Mass Increase **192** 13-15 Mass and Energy **193** 13-16 Summary **195** Problems **197**

**14. RIGID BODIES**

14-1 Introduction **200** 14-2 Description of a Rigid Body **200** 14-3 Translation of a Rigid Body **201** 14-4 Rotation of a Rigid Body **201** 14-5 Mixed Displacements **201** 14-6 Kinematics of Rotation **201** 14-7 Moments **203** 14-8 Dynamics of Translation **208** 14-9 Dynamics of Rotation **210** 14-10 Equilibrium Conditions for a Rigid Body **214** 14-11 Center of Gravity **215** 14-12 Applications of Rigid-Body Mechanics **216** 14-13 Work and Energy **218** 14-14 Conservation of Angular Momentum **220** 14-15 Rotation in Three Dimensions **222** 14-16 Precession **224** 14-17 Conservation of Angular Momentum of Systems of Rigid Bodies **225** 14-18 Summary **227** Problems **229**

**15. TEMPERATURE, THE GAS LAWS, AND HEAT**

15-1 The Nature of Thermodynamics **233** 15-2 Temperature **233** 15-3 The Law of Gay-Lussac; The Centigrade and Kelvin Scales **235** 15-4 Boyle's Law; The Ideal Gas **237** 15-5 Equation of State **237** 15-6 Avogadro's Law **239** 15-7 Temperature of a Substance **239** 15-8 Heat and Calorimeters **240** 15-9 Change of State; Latent Heat **242** 15-10 Heat Transfer **243** 15-11 Summary **245** Problems **246**

**16. THE FIRST LAW OF THERMODYNAMICS**

16-1 Introduction **249** 16-2 The Mechanical Equivalent of Heat **250** 16-3 Mechanical Work **251** 16-4 Internal Energy **253** 16-5 Statement of the First Law of Thermodynamics **253** 16-6 Specific Heat of an Ideal Gas at Constant Volume; Internal Energy **253** 16-7 Specific Heat of an Ideal Gas at Constant Pressure **255** 16-8 Compression and Expansion of Gases **256** 16-9 The Carnot Heat Engine **258** 16-10 Summary **264** Problems **266**

**17. THE SECOND LAW OF THERMODYNAMICS**

17-1 Introduction **268** 17-2 Statements of the Second Law **268** 17-3 The Carnot Refrigerator **268** 17-4 Extensions of the Carnot Theorem **270** 17-5 The Thermodynamic Temperature Scale **272** 17-6 Entropy **273** 17-7 Perpetual Motion **276** 17-8 Summary **276** Problems **278**

**18. KINETIC THEORY OF HEAT**

18-1 Introduction **279** 18-2 The Pressure of an Ideal Gas **279** 18-3 Temperature and Specific Heat **282** 18-4 Direct Measurement of Velocities **282** 18-5 Brownian

**x CONTENTS**

Motion **283** 18-6 Real Gases (Molecular Model) **283** 18-7 Liquids and Solids **284**  
18-8 Molecular Gases; Equipartition of Energy **285** 18-9 Thermal Conduction; Trans-  
port Phenomena **286** 18-10 Molecular Theory Interpretation of the First Law **287**  
18-11 Molecular Theory and the Second Law **287** 18-12 Molecular Theory and Entropy  
**288** 18-13 Summary **289** Problems **290**

**19. THE ELECTROSTATIC FORCE**

19-1 Introduction **292** 19-2 Some Properties of the Electric Charge **293** 19-3 The  
Coulomb Law for Point Charges **294** 19-4 Units **295** 19-5 Superposition. Charge  
Dispositions **296** 19-6 Summary **297** Problems **298**

**20. THE ELECTROSTATIC FIELD**

20-1 Introduction **300** 20-2 Definition of the Electric Field **300** 20-3 Electric Field  
Due to Arbitrary Charge Distributions **301** 20-4 Electric Lines of Force **304** 20-5  
The Gauss Theorem **306** 20-6 Metals in Electrostatics **313** 20-7 Induced Charges  
on Conductors **314** 20-8 Surface and Volume Integrals **316** 20-9 Summary **317**  
Problems **318**

**21. THE ELECTROSTATIC POTENTIAL AND ENERGY**

21-1 Introduction and Definitions **323** 21-2 Electrostatic Potential **323** 21-3 Poten-  
tial Due to a Point Charge **325** 21-4 Potential Due to a Charge Distribution **326**  
21-5 Equipotentials and Lines of Force **327** 21-6 Conductors and Potential **329** 21-7  
Electric Capacitors **330** 21-8 Energy in Systems of Charged Conductors **332** 21-9  
The Energy of an Arbitrary Distribution of Electric Charge **334** 21-10 Production of  
Electrostatic Potential Differences Directly by Mechanical Work **337** 21-11 Summary  
**339** Problems **340**

**22. ELECTRIC CURRENT**

22-1 Introduction **345** 22-2 Measurement of Electric Current **346** 22-3 An Ele-  
mentary Electric Circuit **347** 22-4 Ohm's Law **348** 22-5 Production of Potential  
Differences **350** 22-6 Potential Differences in Electric Circuits **351** 22-7 Kirchhoff's  
Laws **355** 22-8 Graphical Representation **357** 22-9 Energy and Power in Electrical  
Circuits **360** 22-10 Summary **361** Problems **363**

**23. THE MAGNETIC FIELD**

23-1 Introduction **368** 23-2 The Magnetic Field Defined **369** 23-3 Magnetic Flux  
**372** 23-4 Motion of a Particle in a Constant Magnetic Field **372** 23-5 Motion in  
Magnetic and Electric Fields (Measurement of  $q/m$ ) **376** 23-6 Force on a Current-  
Carrying Wire **378** 23-7 Energy Interchanges **379** 23-8 Force and Torque on a Cur-  
rent Loop **380** 23-9 Motion of a Current Loop (Meters and Motors) **382** 23-10 Sum-  
mary **383** Problems **385**

**24. PRODUCTION OF MAGNETIC FIELDS**

24-1 Introduction **388** 24-2 The Law of Biot and Savart **389** 24-3 Definition of the  
Ampere of Current **390** 24-4 Force Between Currents in General **392** 24-5 Wires of

Finite Cross Section **392** 24-6 Fields and Forces for Individual Moving Charges **392**  
 24-7 Ampere's Law for the Magnetic Field **395** 24-8 Magnetism Due to Atoms **398**  
 24-9 Magnetic Field Maps **399** 24-10 Summary **400** Problems **401**

## 25. ELECTROMAGNETIC INDUCTION

25-1 Introduction **405** 25-2 The Inductive Approach **405** 25-3 The Deductive Approach to Electromagnetic Induction **407** 25-4 Mechanical-Electrical Energy Interchange **411** 25-5 Time-Varying Source of Field **413** 25-6 Self-Inductance **416** 25-7 Circuits with Self-Inductance **418** 25-8 Energy in the Magnetic Field **418** 25-9 Mutual Inductance **419** 25-10 Circuits with Self-Inductance and Capacitance **419** 25-11 Maxwell's Equations **420** 25-12 Summary **423** Problems **424**

## 26. ONE-DIMENSIONAL WAVE PROPAGATION

26-1 Introduction **428** 26-2 Wave Velocity in a String **428** 26-3 Wave Equation for Transverse Waves in a String **430** 26-4 Wave Velocity **432** 26-5 Other Types of Waves **433** 26-6 Wave Form; Monochromatic Waves **434** 26-7 The Superposition of Waves of the Same Frequency **438** 26-8 The Superposition of Waves of Different Frequencies **440** 26-9 Complex Waves **441** 26-10 Dispersion and Group Velocity **443** 26-11 Polarization **445** 26-12 Reflection and Transmission **446** 26-13 Energy Flow in Wave Motion **447** 26-14 Summary **448** Problems **450**

## 27. ELECTROMAGNETIC WAVES (LIGHT)

27-1 Introduction **453** 27-2 Electromagnetic Radiation: Classical Theory and Experiments **453** 27-3 Propagation of Waves in Three Dimensions **463** 27-4 Huygens' Principle **465** 27-5 Reflection **467** 27-6 Refraction **468** 27-7 Velocity of Light **471** 27-8 Geometrical Optics **472** 27-9 Interference **479** 27-10 Diffraction **481** 27-11 Detailed Analysis of Single-Slit Diffraction **488** 27-12 Double-Slit Diffraction **491** 27-13 Diffraction by Circular Apertures: Images **492** 27-14 Summary **493** Problems **496**

## 28. OPTICAL INSTRUMENTS

28-1 Introduction **500** 28-2 The Single Lens; Real Image **500** 28-3 The Single Lens; Virtual Images **501** 28-4 The Telescope **503** 28-5 The Microscope **505** 28-6 Resolving Power of a Telescope **505** 28-7 Resolving Power of a Microscope **507** 28-8 Useful Magnification **508** 28-9 Summary **509** Problems **509**

## 29. CONSTITUENTS OF THE ATOM

29-1 Introduction **511** 29-2 The Structure of Matter **511** 29-3 The Electron **512** 29-4 The Ionic Charge **514** 29-5 Atomic Mass **515** 29-6 Isotopes **516** 29-7 The Wave Nature of Cathode Rays **517** 29-8 Birth of the Quantum Theory: Electromagnetic Radiation from Hot Solids or Liquids **521** 29-9 The Photoelectric Effect **522** 29-10 The Compton Effect **524** 29-11 Atomic Constitution and Dimensions **526** 29-12 The Neutron **529** 29-13 Summary **530** Problems **531**

**30. ATOMIC PHYSICS: THE STRUCTURE OF THE ATOM (QUANTUM MECHANICS)**

30-1 Introduction **534** 30-2 Atomic Spectra **534** 30-3 The Bohr Model of Hydrogen **537** 30-4 Energy-Level Diagram **542** 30-5 The Correspondence Principle **544** 30-6 Franck and Hertz Experiment **545** 30-7 Failure of the Bohr Model **545** 30-8 Magnetic Properties of Atoms; Electron Spin **546** 30-9 Stern-Gerlach Experiment **548** 30-10 Summary **550** Problems **551**

**31. WAVE MECHANICS**

31-1 Introduction **553** 31-2 Wave-Photon Duality; Probability **553** 31-3 Particle-Wave Duality; Probability **555** 31-4 The Uncertainty Principle **555** 31-5 The Schrödinger Wave Equation **558** 31-6 Stationary Energy States; Particle in a Box **562** 31-7 Penetration of Barriers **563** 31-8 One-Dimensional Harmonic Oscillator **565** 31-9 Atomic Hydrogen **566** 31-10 Multielectron Atoms; The Pauli Exclusion Principle **570** 31-11 The Periodic Table **570** 31-12 Summary **571** Problems **573**

**32. THE NUCLEUS**

32-1 Introduction **575** 32-2 General Properties of the Nucleus **579** 32-3 Spin **580** 32-4 Magnetic Moment **580** 32-5 Electron-Binding Energy **580** 32-6 Discovery of the Neutron **582** 32-7 The Nuclear Radius **583** 32-8 Nuclear Radiation **584** 32-9 Nuclear Binding Energy **588** 32-10 Stability of the Isotopes **590** 32-11 Structure of the Deuteron **593** 32-12 Elementary Particles **596** 32-13 Summary **599** Problems **601**

**APPENDIX**

Trigonometry **603** Greek Alphabet **603** Periodic Table of the Elements **604** Natural Trigonometric Functions **605** Conversion Factors **606** Fundamental Constants **607** Common Logarithms **608** Isotopes **610**

**ANSWERS TO ODD-NUMBERED PROBLEMS 613**

**INDEX 622**