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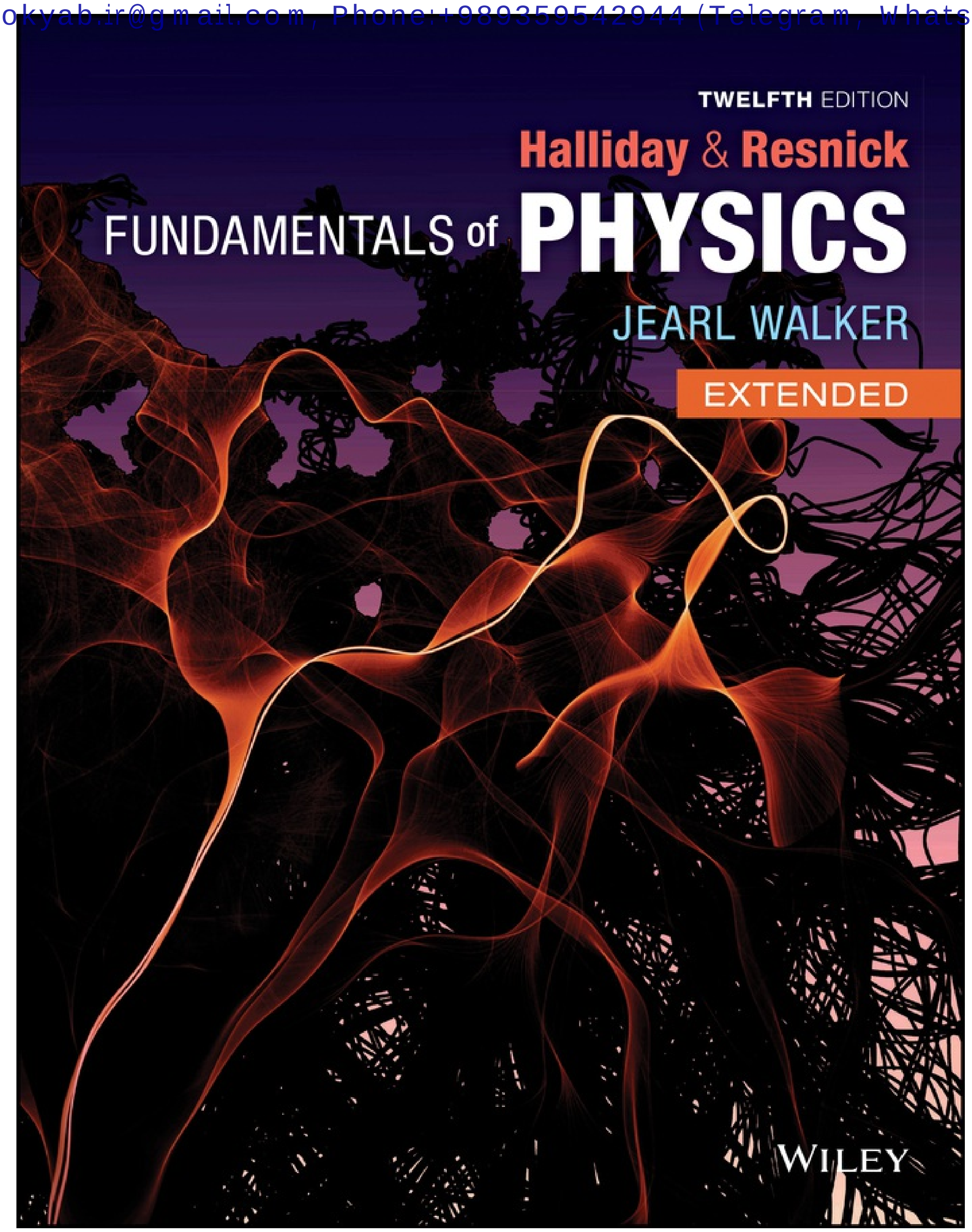

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Table of Contents

- Cover
- Title Page
- Copyright Page
- PREFACE
- ACKNOWLEDGMENTS
- CHAPTER 1: Measurement
  - 1.1 MEASURING THINGS, INCLUDING LENGTHS
  - 1.2 TIME
  - 1.3 MASS
  - Chapter 1 Review & Summary
  - Chapter 1 Problems
- CHAPTER 2: Motion Along a Straight Line
  - 2.1 POSITION, DISPLACEMENT, AND AVERAGE VELOCITY
  - 2.2 INSTANTANEOUS VELOCITY AND SPEED
  - 2.3 ACCELERATION
  - 2.4 CONSTANT ACCELERATION
  - 2.5 FREE-FALL ACCELERATION
  - 2.6 GRAPHICAL INTEGRATION IN MOTION ANALYSIS
  - Chapter 2 Review & Summary
  - Chapter 2 Questions
  - Chapter 2 Problems
- CHAPTER 3: Vectors
  - 3.1 VECTORS AND THEIR COMPONENTS
  - 3.2 UNIT VECTORS, ADDING VECTORS BY COMPONENTS
  - 3.3 MULTIPLYING VECTORS
  - Chapter 3 Review & Summary
  - Chapter 3 Questions
  - Chapter 3 Problems
- CHAPTER 4: Motion in Two and Three Dimensions
  - 4.1 POSITION AND DISPLACEMENT
  - 4.2 AVERAGE VELOCITY AND INSTANTANEOUS VELOCITY
  - 4.3 AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION
  - 4.4 PROJECTILE MOTION
  - 4.5 UNIFORM CIRCULAR MOTION
  - 4.6 RELATIVE MOTION IN ONE DIMENSION
  - 4.7 RELATIVE MOTION IN TWO DIMENSIONS
  - Chapter 4 Review & Summary
  - Chapter 4 Questions
  - Chapter 4 Problems
- CHAPTER 5: Force and Motion—I
  - 5.1 NEWTON’S FIRST AND SECOND LAWS
  - 5.2 SOME PARTICULAR FORCES
  - 5.3 APPLYING NEWTON’S LAWS
  - Chapter 5 Review & Summary
  - Chapter 5 Questions
  - Chapter 5 Problems
- CHAPTER 6: Force and Motion—II
  - 6.1 FRICTION
  - 6.2 THE DRAG FORCE AND TERMINAL SPEED
  - 6.3 UNIFORM CIRCULAR MOTION
  - Chapter 6 Review & Summary
  - Chapter 6 Questions
  - Chapter 6 Problems

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CHAPTER 7: Kinetic Energy and Work
- 7.1 KINETIC ENERGY
- 7.2 WORK AND KINETIC ENERGY
- 7.3 WORK DONE BY THE GRAVITATIONAL FORCE
- 7.4 WORK DONE BY A SPRING FORCE
- 7.5 WORK DONE BY A GENERAL VARIABLE FORCE
- 7.6 POWER
- Chapter 7 Review & Summary
- Chapter 7 Questions
- Chapter 7 Problems

CHAPTER 8: Potential Energy and Conservation of Energy
- 8.1 POTENTIAL ENERGY
- 8.2 CONSERVATION OF MECHANICAL ENERGY
- 8.3 READING A POTENTIAL ENERGY CURVE
- 8.4 WORK DONE ON A SYSTEM BY AN EXTERNAL FORCE
- 8.5 CONSERVATION OF ENERGY
- Chapter 8 Review & Summary
- Chapter 8 Questions
- Chapter 8 Problems

CHAPTER 9: Center of Mass and Linear Momentum
- 9.1 CENTER OF MASS
- 9.2 NEWTON’S SECOND LAW FOR A SYSTEM OF PARTICLES
- 9.3 LINEAR MOMENTUM
- 9.4 COLLISION AND IMPULSE
- 9.5 CONSERVATION OF LINEAR MOMENTUM
- 9.6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS
- 9.7 ELASTIC COLLISIONS IN ONE DIMENSION
- 9.8 COLLISIONS IN TWO DIMENSIONS
- 9.9 SYSTEMS WITH VARYING MASS: A ROCKET
- Chapter 9 Review & Summary
- Chapter 9 Questions
- Chapter 9 Problems

CHAPTER 10: Rotational
- 10.1 ROTATIONAL VARIABLES
- 10.2 ROTATION WITH CONSTANT ANGULAR ACCELERATION
- 10.3 RELATING THE LINEAR AND ANGULAR VARIABLES
- 10.4 KINETIC ENERGY OF ROTATION
- 10.5 CALCULATING THE ROTATIONAL INERTIA
- 10.6 TORQUE
- 10.7 NEWTON’S SECOND LAW FOR ROTATION
- 10.8 WORK AND ROTATIONAL KINETIC ENERGY
- Chapter 10 Review & Summary
- Chapter 10 Questions
- Chapter 10 Problems

CHAPTER 11: Rolling, Torque, and Angular Momentum
- 11.1 ROLLING AS TRANSLATION AND ROTATION COMBINED
- 11.2 FORCES AND KINETIC ENERGY OF ROLLING
- 11.3 THE YO-YO
- 11.4 TORQUE REVISITED
- 11.5 ANGULAR MOMENTUM
- 11.6 ROLLING AS TRANSLATION AND ROTATION COMBINED
- 11.7 ANGULAR MOMENTUM OF A RIGID BODY
- 11.8 CONSERVATION OF ANGULAR MOMENTUM
- 11.9 PRECESSION OF A GYROSCOPE

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  - Chapter 11 Review & Summary
  - Chapter 11 Questions
  - Chapter 11 Problems
- CHAPTER 12: Equilibrium and Elasticity
  - 12.1 EQUILIBRIUM
  - 12.2 SOME EXAMPLES OF STATIC EQUILIBRIUM
  - 12.3 ELASTICITY
  - Chapter 12 Review & Summary
  - Chapter 12 Questions
  - Chapter 12 Problems
- CHAPTER 13: Gravitation
  - 13.1 NEWTON'S LAW OF GRAVITATION
  - 13.2 GRAVITATION AND THE PRINCIPLE OF SUPERPOSITION
  - 13.3 GRAVITATION NEAR EARTH'S SURFACE
  - 13.4 GRAVITATION INSIDE EARTH
  - 13.5 GRAVITATIONAL POTENTIAL ENERGY
  - 13.6 PLANETS AND SATELLITES: KEPLER'S LAWS
  - 13.7 SATELLITES: ORBITS AND ENERGY
  - 13.8 EINSTEIN AND GRAVITATION
  - Chapter 13 Review & Summary
  - Chapter 13 Questions
  - Chapter 13 Problems
- CHAPTER 14: Fluids
  - 14.1 FLUIDS, DENSITY, AND PRESSURE
  - 14.2 FLUIDS AT REST
  - 14.3 MEASURING PRESSURE
  - 14.4 PASCAL'S PRINCIPLE
  - 14.5 ARCHIMEDES' PRINCIPLE
  - 14.6 THE EQUATION OF CONTINUITY
  - 14.7 BERNOULLI'S EQUATION
  - Chapter 14 Review & Summary
  - Chapter 14 Questions
  - Chapter 14 Problems
- CHAPTER 15: Oscillations
  - 15.1 SIMPLE HARMONIC MOTION
  - 15.2 ENERGY IN SIMPLE HARMONIC MOTION
  - 15.3 AN ANGULAR SIMPLE HARMONIC OSCILLATOR
  - 15.4 PENDULUMS, CIRCULAR MOTION
  - 15.5 DAMPED SIMPLE HARMONIC MOTION
  - 15.6 FORCED OSCILLATIONS AND RESONANCE
  - Chapter 15 Review & Summary
  - Chapter 15 Questions
  - Chapter 15 Problems
- CHAPTER 16: Waves—I
  - 16.1 TRANSVERSE WAVES
  - 16.2 WAVE SPEED ON A STRETCHED STRING
  - 16.3 ENERGY AND POWER OF A WAVE TRAVELING ALONG A STRING
  - 16.4 THE WAVE EQUATION
  - 16.5 INTERFERENCE OF WAVES
  - 16.6 PHASORS
  - 16.7 STANDING WAVES AND RESONANCE
  - Chapter 16 Review & Summary
  - Chapter 16 Questions
  - Chapter 16 Problems

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CHAPTER 17: Waves—II
    17.1 SPEED OF SOUND
    17.2 TRAVELING SOUND WAVES
    17.3 INTERFERENCE
    17.4 INTENSITY AND SOUND LEVEL
    17.5 SOURCES OF MUSICAL SOUND
    17.6 BEATS
    17.7 THE DOPPLER EFFECT
    17.8 SUPERSONIC SPEEDS, SHOCK WAVES
    Chapter 17 Review & Summary
    Chapter 17 Questions
    Chapter 17 Problems
CHAPTER 18: Temperature, Heat, and the First Law of Thermodynamics
    18.1 TEMPERATURE
    18.2 THE CELSIUS AND FAHRENHEIT SCALES
    18.3 THERMAL EXPANSION
    18.4 ABSORPTION OF HEAT
    18.5 THE FIRST LAW OF THERMODYNAMICS
    18.6 HEAT TRANSFER MECHANISMS
    Chapter 18 Review & Summary
    Chapter 18 Questions
    Chapter 18 Problems
CHAPTER 19: The Kinetic Theory of Gases
    19.1 AVOGADRO'S NUMBER
    19.2 IDEAL GASES
    19.3 PRESSURE, TEMPERATURE, AND RMS SPEED
    19.4 TRANSLATIONAL KINETIC ENERGY
    19.5 MEAN FREE PATH
    19.6 THE DISTRIBUTION OF MOLECULAR SPEEDS
    19.7 THE MOLAR SPECIFIC HEATS OF AN IDEAL GAS
    19.8 DEGREES OF FREEDOM AND MOLAR SPECIFIC HEATS
    19.9 THE ADIABATIC EXPANSION OF AN IDEAL GAS
    Chapter 19 Review & Summary
    Chapter 19 Questions
    Chapter 19 Problems
CHAPTER 20: Entropy and the Second Law of Thermodynamics
    20.1 ENTROPY
    20.2 ENTROPY IN THE REAL WORLD: ENGINES
    20.3 REFRIGERATORS AND REAL ENGINES
    20.4 A STATISTICAL VIEW OF ENTROPY
    Chapter 20 Review & Summary
    Chapter 20 Questions
    Chapter 20 Problems
CHAPTER 21: Coulomb's Law
    21.1 COULOMB'S LAW
    21.2 CHARGE IS QUANTIZED
    21.3 CHARGE IS CONSERVED
    Chapter 21 Review & Summary
    Chapter 21 Questions
    Chapter 21 Problems
CHAPTER 22: Electric Fields
    22.1 THE ELECTRIC FIELD
    22.2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE
    22.3 THE ELECTRIC FIELD DUE TO A DIPOLE

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  - 22.4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE
  - 22.5 THE ELECTRIC FIELD DUE TO A CHARGED DISK
  - 22.6 A POINT CHARGE IN AN ELECTRIC FIELD
  - 22.7 A DIPOLE IN AN ELECTRIC FIELD
  - Chapter 22 Review & Summary
  - Chapter 22 Questions
  - Chapter 22 Problems
- CHAPTER 23: Gauss' Law
  - 23.1 ELECTRIC FLUX
  - 23.2 GAUSS' LAW
  - 23.3 A CHARGED ISOLATED CONDUCTOR
  - 23.4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY
  - 23.5 APPLYING GAUSS' LAW: PLANAR SYMMETRY
  - 23.6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY
  - Chapter 23 Review & Summary
  - Chapter 23 Questions
  - Chapter 23 Problems
- CHAPTER 24: Electric Potential
  - 24.1 ELECTRIC POTENTIAL
  - 24.2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD
  - 24.3 POTENTIAL DUE TO A CHARGED PARTICLE
  - 24.4 POTENTIAL DUE TO AN ELECTRIC DIPOLE
  - 24.5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION
  - 24.6 CALCULATING THE FIELD FROM THE POTENTIAL
  - 24.7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES
  - 24.8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR
  - Chapter 24 Review & Summary
  - Chapter 24 Questions
  - Chapter 24 Problems
- CHAPTER 25: Capacitance
  - 25.1 CAPACITANCE
  - 25.2 CALCULATING THE CAPACITANCE
  - 25.3 CAPACITORS IN PARALLEL AND IN SERIES
  - 25.4 ENERGY STORED IN AN ELECTRIC FIELD
  - 25.5 CAPACITOR WITH A DIELECTRIC
  - 25.6 DIELECTRICS AND GAUSS' LAW
  - Chapter 25 Review & Summary
  - Chapter 25 Questions
  - Chapter 25 Problems
- CHAPTER 26: Current and Resistance
  - 26.1 ELECTRIC CURRENT
  - 26.2 CURRENT DENSITY
  - 26.3 RESISTANCE AND RESISTIVITY
  - 26.4 OHM'S LAW
  - 26.5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS
  - Chapter 26 Review & Summary
  - Chapter 26 Questions
  - Chapter 26 Problems
- CHAPTER 27: Circuits
  - 27.1 SINGLE-LOOP CIRCUITS
  - 27.2 MULTILOOP CIRCUITS
  - 27.3 THE AMMETER AND THE VOLTMETER
  - 27.4 *RC* CIRCUITS
  - Chapter 27 Review & Summary

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  - Chapter 27 Questions
  - Chapter 27 Problems
- CHAPTER 28: Magnetic Fields
  - 28.1 MAGNETIC FIELDS AND THE DEFINITION OF
  - 28.2 CROSSED FIELDS: DISCOVERY OF THE ELECTRON
  - 28.3 CROSSED FIELDS: THE HALL EFFECT
  - 28.4 A CIRCULATING CHARGED PARTICLE
  - 28.5 CYCLOTRONS AND SYNCHROTRONS
  - 28.6 MAGNETIC FORCE ON A CURRENT-CARRYING WIRE
  - 28.7 TORQUE ON A CURRENT LOOP
  - 28.8 THE MAGNETIC DIPOLE MOMENT
  - Chapter 28 Review & Summary
  - Chapter 28 Questions
  - Chapter 28 Problems
- CHAPTER 29: Magnetic Fields Due to Currents
  - 29.1 MAGNETIC FIELD DUE TO A CURRENT
  - 29.2 FORCE BETWEEN TWO PARALLEL CURRENTS
  - 29.3 AMPERE's LAW
  - 29.4 SOLENOIDS AND TOROIDS
  - 29.5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE
  - Chapter 29 Review & Summary
  - Chapter 29 Questions
  - Chapter 29 Problems
- CHAPTER 30: Induction and Inductance
  - 30.1 FARADAY'S LAW AND LENZ'S LAW
  - 30.2 INDUCTION AND ENERGY TRANSFERS
  - 30.3 INDUCED ELECTRIC FIELDS
  - 30.4 INDUCTORS AND INDUCTANCE
  - 30.5 SELF-INDUCTION
  - 30.6 RL CIRCUITS
  - 30.7 ENERGY STORED IN A MAGNETIC FIELD
  - 30.8 ENERGY DENSITY OF A MAGNETIC FIELD
  - 30.9 MUTUAL INDUCTION
  - Chapter 30 Review & Summary
  - Chapter 30 Questions
  - Chapter 30 Problems
- CHAPTER 31: Electromagnetic Oscillations and Alternating Current
  - 31.1 *LC* OSCILLATIONS
  - 31.2 DAMPED OSCILLATIONS IN AN RLC CIRCUIT
  - 31.3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS
  - 31.4 THE SERIES *RLC* CIRCUIT
  - 31.5 POWER IN ALTERNATING-CURRENT CIRCUITS
  - 31.6 TRANSFORMERS
  - Chapter 31 Review & Summary
  - Chapter 31 Questions
  - Chapter 31 Problems
- CHAPTER 32: Maxwell's Equations; Magnetism of Matter
  - 32.1 GAUSS' LAW FOR MAGNETIC FIELDS
  - 32.2 INDUCED MAGNETIC FIELDS
  - 32.3 DISPLACEMENT CURRENT
  - 32.4 MAGNETS
  - 32.5 MAGNETISM AND ELECTRONS
  - 32.6 DIAMAGNETISM
  - 32.7 PARAMAGNETISM

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- 32.8 FERROMAGNETISM
- Chapter 32 Review & Summary
- Chapter 32 Questions
- Chapter 32 Problems

CHAPTER 33: Electromagnetic Waves
- 33.1 ELECTROMAGNETIC WAVES
- 33.2 ENERGY TRANSPORT AND THE POYNTING VECTOR
- 33.3 RADIATION PRESSURE
- 33.4 POLARIZATION
- 33.5 REFLECTION AND REFRACTION
- 33.6 TOTAL INTERNAL REFLECTION
- 33.7 POLARIZATION BY REFLECTION
- Chapter 33 Review & Summary
- Chapter 33 Questions
- Chapter 33 Problems

CHAPTER 34: Images
- 34.1 IMAGES AND PLANE MIRRORS
- 34.2 SPHERICAL MIRRORS
- 34.3 SPHERICAL REFRACTING SURFACES
- 34.4 THIN LENSES
- 34.5 OPTICAL INSTRUMENTS
- 34.6 THREE PROOFS
- Chapter 34 Review & Summary
- Chapter 34 Questions
- Chapter 34 Problems

CHAPTER 35 Interference
- 35.1 LIGHT AS A WAVE
- 35.2 YOUNG'S INTERFERENCE EXPERIMENT
- 35.3 INTERFERENCE AND DOUBLE-SLIT INTENSITY
- 35.4 INTERFERENCE FROM THIN FILMS
- 35.5 MICHELSON'S INTERFEROMETER
- Chapter 35 Review & Summary
- Chapter 35 Questions
- Chapter 35 Problems

CHAPTER 36: Diffraction
- 36.1 SINGLE-SLIT DIFFRACTION
- 36.2 INTENSITY IN SINGLE-SLIT DIFFRACTION
- 36.3 DIFFRACTION BY A CIRCULAR APERTURE
- 36.4 DIFFRACTION BY A DOUBLE SLIT
- 36.5 DIFFRACTION GRATINGS
- 36.6 GRATINGS: DISPERSION AND RESOLVING POWER
- 36.7 X-RAY DIFFRACTION
- Chapter 36 Review & Summary
- Chapter 36 Questions
- Chapter 36 Problems

CHAPTER 37: Relativity
- 37.1 SIMULTANEITY AND TIME DILATION
- 37.2 THE RELATIVITY OF LENGTH
- 37.3 THE LORENTZ TRANSFORMATION
- 37.4 THE RELATIVITY OF VELOCITIES
- 37.5 DOPPLER EFFECT FOR LIGHT
- 37.6 MOMENTUM AND ENERGY
- Chapter 37 Review & Summary
- Chapter 37 Questions

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  - Chapter 37 Problems
- CHAPTER 38: Photons and Matter Waves
  - 38.1 THE PHOTON, THE QUANTUM OF LIGHT
  - 38.2 THE PHOTOELECTRIC EFFECT
  - 38.3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE
  - 38.4 THE BIRTH OF QUANTUM PHYSICS
  - 38.5 ELECTRONS AND MATTER WAVES
  - 38.6 SCHRÖDINGER’S EQUATION
  - 38.7 HEISENBERG’S UNCERTAINTY PRINCIPLE
  - 38.8 REFLECTION FROM A POTENTIAL STEP
  - 38.9 TUNNELING THROUGH A POTENTIAL BARRIER
  - Chapter 38 Review & Summary
  - Chapter 38 Questions
  - Chapter 38 Problems
- CHAPTER 39: More About Matter Waves
  - 39.1 ENERGIES OF A TRAPPED ELECTRON
  - 39.2 WAVE FUNCTIONS OF A TRAPPED ELECTRON
  - 39.3 AN ELECTRON IN A FINITE WELL
  - 39.4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS
  - 39.5 THE HYDROGEN ATOM
  - Chapter 39 Review & Summary
  - Chapter 39 Questions
  - Chapter 39 Problems
- CHAPTER 40: All About Atoms
  - 40.1 PROPERTIES OF ATOMS
  - 40.2 THE STERN–GERLACH EXPERIMENT
  - 40.3 MAGNETIC RESONANCE
  - 40.4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP
  - 40.5 BUILDING THE PERIODIC TABLE
  - 40.6 X RAYS AND THE ORDERING OF THE ELEMENTS
  - 40.7 LASERS
  - Chapter 40 Review & Summary
  - Chapter 40 Questions
  - Chapter 40 Problems
- CHAPTER 41: Conduction of Electricity in Solids
  - 41.1 THE ELECTRICAL PROPERTIES OF METALS
  - 41.2 SEMICONDUCTORS AND DOPING
  - 41.3 THE p-n JUNCTION AND THE TRANSISTOR
  - Chapter 41 Review & Summary
  - Chapter 41 Questions
  - Chapter 41 Problems
- CHAPTER 42: Nuclear Physics
  - 42.1 DISCOVERING THE NUCLEUS
  - 42.2 SOME NUCLEAR PROPERTIES
  - 42.3 RADIOACTIVE DECAY
  - 42.4 ALPHA DECAY
  - 42.5 BETA DECAY
  - 42.6 RADIOACTIVE DATING
  - 42.7 MEASURING RADIATION DOSAGE
  - 42.8 NUCLEAR MODELS
  - Chapter 42 Review & Summary
  - Chapter 42 Questions
  - Chapter 42 Problems
- CHAPTER 43: Energy from the Nucleus

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- 43.1 NUCLEAR FISSION
- 43.2 THE NUCLEAR REACTOR
- 43.3 A NATURAL NUCLEAR REACTOR
- 43.4 THERMONUCLEAR FUSION: THE BASIC PROCESS
- 43.5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS
- 43.6 CONTROLLED THERMONUCLEAR FUSION
- Chapter 43 Review & Summary
- Chapter 43 Questions
- Chapter 43 Problems

CHAPTER 44: Quarks, Leptons, and the Big Bang
- 44.1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES
- 44.2 LEPTONS, HADRONS, AND STRANGENESS
- 44.3 QUARKS AND MESSENGER PARTICLES
- 44.4 COSMOLOGY
- Chapter 44 Review & Summary
- Chapter 44 Questions
- Chapter 44 Problems

APPENDICES
- APPENDIX A: THE INTERNATIONAL SYSTEM OF UNITS (SI)
- APPENDIX B: SOME FUNDAMENTAL CONSTANTS OF PHYSICS
- APPENDIX C: SOME ASTRONOMICAL DATA
- APPENDIX D: CONVERSION FACTORS
- APPENDIX E: MATHEMATICAL FORMULAS
- APPENDIX F: PROPERTIES OF THE ELEMENTS
- APPENDIX G: PERIODIC TABLE OF THE ELEMENTS

ANSWERS: To Checkpoints and Odd-Numbered Questions and Problems

INDEX

End User License Agreement

List of Tables

CHAPTER 1
- **Table 1.1.1** Units for Three SI Base Quantities
- **Table 1.1.2** Prefixes for SI Units
- **Table 1.1.3** Some Approximate Lengths
- **Table 1.2.1** Some Approximate Time Intervals
- **Table 1.3.1** Some Approximate Masses
- **Table 1.1** Problem 6
- **Table 1.2** Problem 36

CHAPTER 2
- **Table 2.4.1** Equations for Motion with Constant Acceleration

CHAPTER 4
- **Table 4.4.1** Two Fly Balls[a]

CHAPTER 5
- **Table 5.1.1** Units in Newton’s Second Law (Eqs. 5.1.1 and 5.1.2)

CHAPTER 6
- **Table 6.2.1** Some Terminal Speeds in Air

CHAPTER 10
- **Table 10.2.1** Equations of Motion for Constant Linear Acceleration and for Constant Angular Ac...
- **Table 10.5.1** Some Rotational Inertias
- **Table 10.8.1** Some Corresponding Relations for Translational and Rotational Motion

CHAPTER 11

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Table 11.7.1 More Corresponding Variables and Relations for Translational and Rotational Moti...

CHAPTER 12

Table 12.3.1 Some Elastic Properties of Selected Materials of Engineering Interest

CHAPTER 13

Table 13.3.1 Variation of a_g with Altitude

Table 13.5.1 Some Escape Speeds

Table 13.6.1 Kepler's Law of Periods for the Solar System

CHAPTER 14

Table 14.1.1 Some Densities

Table 14.1.2 Some Pressures

CHAPTER 16

Table 16.5.1 Phase Difference and Resulting Interference Types^a

CHAPTER 17

Table 17.1.1 The Speed of Sound^a

Table 17.4.1 Some Sound Levels (dB)

Table 17.7.1

CHAPTER 18

Table 18.2.1 Some Corresponding Temperatures

Table 18.3.1 Some Coefficients of Linear Expansion^a

Table 18.4.1 Some Specific Heats and Molar Specific Heats at Room Temperature

Table 18.4.2 Some Heats of Transformation

Table 18.5.1 The First Law of Thermodynamics: Four Special Cases

Table 18.6.1 Some Thermal Conductivities

CHAPTER 19

Table 19.3.1 Some RMS Speeds at Room Temperature (T = 300 K)^a

Table 19.7.1 Molar Specific Heats at Constant Volume

Table 19.8.1 Degrees of Freedom for Various Molecules

Table 19.9.1 Four Special Processes

CHAPTER 20

Table 20.4.1 Six Molecules in a Box

CHAPTER 21

Table 21.2.1 The Charges of Three Particles and Their Antiparticles

Table 21.2.2 The Charges of Two Quarks and Their Antiparticles

CHAPTER 22

Table 22.4.1 Some Measures of Electric Charge

CHAPTER 25

Table 25.5.1 Some Properties of Dielectrics

CHAPTER 26

Table 26.3.1 Resistivities of Some Materials at Room Temperature (20°C)

Table 26.5.1 Some Electrical Properties of Copper and Silicon

CHAPTER 27

Table 27.2.1 Series and Parallel Resistors and Capacitors

CHAPTER 28

Table 28.1.1 Some Approximate Magnetic Fields

Table 28.8.1 Some Magnetic Dipole Moments

Table 28.1 Question 6

Table 28.2 Question 12

CHAPTER 31

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Table 31.1.1 Comparison of the Energy in Two Oscillating Systems

Table 31.3.1 Phase and Amplitude Relations for Alternating Currents and Voltages

CHAPTER 32

Table 32.3.1 Maxwell's Equations[a]

CHAPTER 33

Table 33.5.1 Some Indexes of Refraction[a]

CHAPTER 34

Table 34.2.1 Your Organizing Table for Mirrors

Table 34.4.1 Your Organizing Table for Thin Lenses

Table 34.1 problems 9 through 16: Spherical Mirrors, See the setup for thesee problems.

Table 34.2 Problems 17 through 29: More Mirros. See the setup for these problems

Table 34.3 Problems 32 through 38:Spherical Refracting Surfaces. See the setup for these pr...

Table 34.4 Problems 50 through 57: Thin Lenses. See the setup for these problems

Table 34.5 Problems 58 through 67: lenses with Given Radii. See the setup for these problem...

Table 34.6 Problems 69 through 79: More Lenses. See the setup for these problems.

Table 34.7 Problems 80 through 87: Two-Lens Systems. See the setup for these problems

CHAPTER 35

Table 35.4.1 An Organizing Table for Thin-Film Interference in Air (Fig. 35.4.3)[a]

Table 35.1 Problems 41 through 52: Reflection by Thin Layers. See the setup for these probl...

Table 35.2 Problems 57 through 68: Transmission Through Thin Layers. See the setup for thes...

Table 35.3 Problem 102: Parts (d) through (o)

CHAPTER 36

Table 36.6.1 Three Gratings[a]

CHAPTER 37

Table 37.1.1 Record of Event *A*

Table 37.3.1 The Lorentz Transformation Equations for Pairs of Events

Table 37.6.1 The Energy Equivalents of a Few Objects

CHAPTER 39

Table 39.4.1 Energy Levels

Table 39.5.1 Quantum Numbers for the Hydrogen Atom

Table 39.5.2 Quantum Numbers for Hydrogen Atom States with $n = 2$

Table 39.1

CHAPTER 40

Table 40.1.1 Electron States for an Atom

Table 40.4.1 Ground-State Configuration and Energies

CHAPTER 41

Table 41.1.1 Some Electrical Properties of Two Materials[a]

Table 41.2.1 Properties of Two Doped Semiconductors

CHAPTER 42

Table 42.2.1 Some Properties of Selected Nuclides

Table 42.4.1 Two Alpha Emitters Compared

CHAPTER 43

Table 43.1.1 Energy Released by 1 kg of Matter

Table 43.2.1 Test of the Fissionability of Four Nuclides

CHAPTER 44

Table 44.1.1 The Particles or Antiparticles Involved in the Event of Fig. 44.1.3

Table 44.2.1 The Leptons[a]

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Table 44.2.2 Eight Spin-1/2 Baryons

Table 44.2.3 Nine Spin-Zero Mesons[a]

Table 44.3.1 The Quarks[a]

Table 44.1 Problem 48

List of Illustrations

CHAPTER 1

Figure 1.2.1 When the metric system was proposed in 1792, the hour was redefined to provide a...

Figure 1.2.2 Variations in the length of the day over a 4-year period. Note that the entire v...

Figure 1.3.1 The international 1 kg standard of mass, a platinum–iridium cylinder 3.9 cm in h...

Figure 1.1 Problem 8.

Figure 1.2 Problem 9.

Figure 1.3 Problem 13.

Figure 1.4 Problem 32.

Figure 1.5 Problem 59.

Figure 1.6 Problem 60. (*a*) Noctilucent clouds. (*b*) Sunlight reaching the observer and the c...

CHAPTER 2

Figure 2.1.1 Position is determined on an axis that is marked in units of length (here meters...

Figure 2.1.2 The graph of $x(t)$ for an armadillo that is stationary at $x = -2$ m. The value of ...

Figure 2.1.3 The graph of $x(t)$ for a moving armadillo. The path associated with the graph is ...

Figure 2.1.4 Calculation of the average velocity between $t = 1$ s and $t = 4$ s as the slope of ...

Figure 2.1.5 The lines marked “Riding” and “Jogging” are the position–time plots for the ridi...

Figure 2.2.1 (*a*) The $x(t)$ curve for an elevator cab that moves upward along an x axis. (*b*) Th...

Figure 2.3.1 Colonel J. P. Stapp in a rocket sled as it is brought up to high speed (accelera...

Figure 2.3.2 Four stages of the particle’s motion.

Figure 2.4.1 (*a*) The position $x(t)$ of a particle moving with constant acceleration. (*b*) Its v...

Figure 2.4.2 (*a*) Trailing car’s radar system detects distance and speed of lead car. (*b*) Init...

Figure 2.5.1 A feather and an apple free fall in vacuum at the same magnitude of acceleration...

Figure 2.5.2 A pitcher tosses a baseball straight up into the air. The equations of free fall...

Figure 2.6.1 The area between a plotted curve and the horizontal time axis, from time t_0 to t...

Figure 2.6.2 (*a*) The $a(t)$ curve of the torso and head of a volunteer in a simulation of a rea...

Figure 2.1 Question 1.

Figure 2.2 Question 2.

Figure 2.3 Question 3.

Figure 2.4 Question 4.

Figure 2.5 Question 5.

Figure 2.6 Question 7.

Figure 2.7 Question 9.

Figure 2.8 Question 11.

Figure 2.9 Problem 8.

Figure 2.10 Problem 12.

Figure 2.11 Problem 23.

Figure 2.12 Problems 34 and 35.

Figure 2.13 Problem 35.

Figure 2.14 Problem 37.

Figure 2.15 Problem 39.

Figure 2.16 Problem 41.

Figure 2.17 Problem 43.

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Figure 2.18 Problem 50.

Figure 2.19 Problem 51.

Figure 2.20 Problem 56.

Figure 2.21 Problem 64.

Figure 2.22 Problem 66.

Figure 2.23 Problem 67.

Figure 2.24 Problem 68.

Figure 2.25 Problem 69.

Figure 2.26 Problem 74.

Figure 2.27 Problem 76.

Figure 2.28 Problem 79.

Figure 2.29 Problem 82.

Figure 2.30 Problem 83.

Figure 2.31 Problem 86.

Figure 2.32 Problem 87.

Figure 2.33 Problem 88.

Figure 2.34 Problem 89.

Figure 2.35 Problem 92.

Figure 2.36 Problem 96.

Figure 2.37 Problem 98.

Figure 2.38 Problem 103.

Figure 2.39 Problem 108.

Figure 2.40 Problem 109.

CHAPTER 3

Figure 3.1.1 (*a*) All three arrows have the same magnitude and direction and thus represent th...

Figure 3.1.2 (*a*) *AC* is the vector sum of the vectors *AB* and *BC*. (*b*) The same vectors relabele...

Figure 3.1.3 The two vectors and can be added in either order; see Eq. 3.1.2.

Figure 3.1.4 The three vectors , , and can be grouped in any way as they are added; se...

Figure 3.1.5 The vectors and have the same magnitude and opposite directions.

Figure 3.1.6 (*a*) Vectors , , and . (*b*) To subtract vector from vector , add vecto...

Figure 3.1.7 (*a*) The components a_x and a_y of vector . (*b*) The components are unchanged if t...

Figure 3.1.8 The component of on the *x* axis is positive, and that on the *y* axis is negativ...

Figure 3.1.9 (*a*) Part of the Mammoth–Flint cave system, with the spelunking team's route from...

Figure 3.1.10 A triangle used to define the trigonometric functions. See also Appendix E.

Figure 3.1.11 Three useful curves to remember. A calculator's range of operation for taking *in*...

Figure 3.2.1 Unit vectors , , and define the directions of a right-handed coordinate s...

Figure 3.2.2 (*a*) The vector components of vector . (*b*) The vector components of vector .

Figure 3.2.3 (*a*) The vector and its components. (*b*) The same vector, with the axes of the ...

Figure 3.2.4 Vector is the vector sum of the other three vectors.

Figure 3.3.1 (a) Two vectors and , with an angle *ϕ* between them. (*b*) Each vector has a c...

Figure 3.3.2 Illustration of the right-hand rule for vector products. (*a*) Sweep vector int...

Figure 3.3.3 Vector (in the *xy* plane) is the vector (or cross) product of vectors and .

Figure 3.1 Question 2.

Figure 3.2 Question 3.

Figure 3.3 Question 5.

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Figure 3.4 Question 9.
Figure 3.5 Question 10.
Figure 3.6 Problem 2.
Figure 3.7 Problem 6.
Figure 3.8 Problem 15.
Figure 3.9 Problem 29.
Figure 3.10 Problem 31.
Figure 3.11 Problem 32.
Figure 3.12 Problems 33 and 54.
Figure 3.13 Problem 43.
Figure 3.14 Problem 45.
Figure 3.15 Problem 51.
Figure 3.16 Problem 68.
Figure 3.17 Problem 69.
Figure 3.18 Problem 79.
Figure 3.19 Problem 82.
Figure 3.20 Problems 83–86.
Figure 3.21 Problem 87.
Figure 3.22 Problem 88.

CHAPTER 4

Figure 4.1.1 The position vector for a particle is the vector sum of its vector components...
Figure 4.1.2 (*a*) A rabbit’s position vector at time t = 15 s. The scalar components of ...
Figure 4.2.1 The displacement of a particle during a time interval Δt, from position 1 wi...
Figure 4.2.2 The velocity of a particle, along with the scalar components of .
Figure 4.2.3 The rabbit’s velocity at t = 15 s.
Figure 4.3.1 The acceleration of a particle and the scalar components of .
Figure 4.3.2 The acceleration of the rabbit at t = 15 s. The rabbit happens to have this s...
Figure 4.4.1 A stroboscopic photograph of a yellow tennis ball bouncing off a hard surface. B...
Figure 4.4.2 The *projectile motion* of an object launched into the air at the origin of a coor...
Figure 4.4.3 One ball is released from rest at the same instant that another ball is shot hor...
Figure 4.4.4 The projectile ball always hits the falling can. Each falls a distance h from wh...
Figure 4.4.5 The vertical component of this skateboarder’s velocity is changing but not the h...
Figure 4.4.6 (I) The path of a fly ball calculated by taking air resistance into account. (II...
Figure 4.4.7 (*a*) Handspring throw-in in football (soccer). (*b*) Flight of the ball. (*c*) Compon...
Figure 4.4.8 A plane drops a rescue capsule while moving at constant velocity in level flight...
Figure 4.5.1 Velocity and acceleration vectors for uniform circular motion.
Figure 4.5.2 Particle p moves in counterclockwise uniform circular motion. (*a*) Its position a...
Figure 4.6.1 Alex (frame A) and Barbara (frame B) watch car P, as both B and P move at differ...
Figure 4.7.1 Frame B has the constant two-dimensional velocity relative to frame A. The po...
Figure 4.7.2 A plane flying in a wind.
Figure 4.1 Question 1.
Figure 4.2 Question 2.
Figure 4.3 Question 5.
Figure 4.4 Question 6.
Figure 4.5 Question 8.
Figure 4.6 Question 9.
Figure 4.7 Question 10.

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Figure 4.8 Question 11.
Figure 4.9 Question 12.
Figure 4.10 Problem 9.
Figure 4.11 Problem 10.
Figure 4.12 Problem 20.
Figure 4.13 Problem 27.
Figure 4.14 Problem 28.
Figure 4.15 Problem 32.
Figure 4.16 Problem 38.
Figure 4.17 Problem 39.
Figure 4.18 Problem 41.
Figure 4.19 Problem 42.
Figure 4.20 Problem 45.
Figure 4.21 Problem 48.
Figure 4.22 Problem 51.
Figure 4.23 Problem 52.
Figure 4.24 Problem 53.
Figure 4.25 Problem 54.
Figure 4.26 Problem 73.
Figure 4.27 Problem 78.
Figure 4.28 Problem 84.
Figure 4.29 Problem 86.
Figure 4.30 Problem 90.
Figure 4.31 Problem 91.
Figure 4.32 Problem 94.
Figure 4.33 Problem 95.
Figure 4.34 Problem 99.
Figure 4.35 Problem 101.
Figure 4.36 Problem 107.
Figure 4.37 Problem 113.
Figure 4.38 Problem 116.
Figure 4.39 Problem 122.
Figure 4.40 Problem 124.
Figure 4.41 Problem 125.
Figure 4.42 Problem 128.

CHAPTER 5

Figure 5.1.1 A force on the standard kilogram gives that body an acceleration .
Figure 5.1.2 (*a*) The path of a puck sliding from the north pole as seen from a stationary poi...
Figure 5.1.3 In three situations, forces act on a puck that moves along an *x* axis. Free-body ...
Figure 5.1.4 (*a*) An overhead view of two of three horizontal forces that act on a cookie tin,...
Figure 5.2.1 An equal-arm balance. When the device is in balance, the gravitational force ...
Figure 5.2.2 A spring scale. The reading is proportional to the *weight* of the object on the p...
Figure 5.2.3 (*a*) A block resting on a table experiences a normal force perpendicular to t...
Figure 5.2.4 A frictional force opposes the attempted slide of a body over a surface.
Figure 5.2.5 (*a*) The cord, pulled taut, is under tension. If its mass is negligible, the cord...
Figure 5.3.1 (*a*) Book *B* leans against crate *C*. (*b*) Forces (the force on the book from th...
Figure 5.3.2 (*a*) A cantaloupe lies on a table that stands on Earth. (*b*) The forces *on the can*...

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 5.3.3 A block *S* of mass *M* is connected to a block *H* of mass *m* by a cord that wraps ove...

Figure 5.3.4 The forces acting on the two blocks of Fig. 5.3.3.

Figure 5.3.5 (*a*) A free-body diagram for block *S* of Fig. 5.3.3. (*b*) A free-body diagram for b...

Figure 5.3.6 (*a*) A box is pulled up a plane by a cord. (*b*) The three forces acting on the box...

Figure 5.3.7 A roller coaster with (*a*) the first car on a slope and (*b*) all but the last car ...

Figure 5.3.8 (*a*) A passenger stands on a platform scale that indicates either his weight or h...

Figure 5.3.9 (*a*) A constant horizontal force is applied to block *A*, which pushes agains...

Figure 5.1 Question 1.

Figure 5.2 Question 2.

Figure 5.3 Question 3.

Figure 5.4 Question 5.

Figure 5.5 Question 6.

Figure 5.6 Question 7.

Figure 5.7 Question 8.

Figure 5.8 Question 9.

Figure 5.9 Question 10.

Figure 5.10 Question 12.

Figure 5.11 Problem 5.

Figure 5.12 Problem 6.

Figure 5.13 Problem 7.

Figure 5.14 Problem 12.

Figure 5.15 Problem 13.

Figure 5.16 Problem 15.

Figure 5.17 Problem 16.

Figure 5.18 Problem 17.

Figure 5.19 Problem 18.

Figure 5.20 Problem 21.

Figure 5.21 Problem 24.

Figure 5.22 Problem 32.

Figure 5.23 Problem 34.

Figure 5.24 Problem 40.

Figure 5.25 Problem 42.

Figure 5.26 Problem 43.

Figure 5.27 Problem 48.

Figure 5.28 Problems 49 and 60.

Figure 5.29 Problem 50.

Figure 5.30 Problems 51 and 65.

Figure 5.31 Problem 53.

Figure 5.32 Problem 54.

Figure 5.33 Problem 55.

Figure 5.34 Problem 56.

Figure 5.35 Problem 57.

Figure 5.36 Problem 58.

Figure 5.37 Problem 59.

Figure 5.38 Problem 63.

Figure 5.39 Problem 64.

Figure 5.40 Problem 66.

Figure 5.41 Problem 67.

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Figure 5.42 Problem 69.
Figure 5.43 Problem 72.
Figure 5.44 Problem 73.
Figure 5.45 Problem 74.
Figure 5.46 Problem 76.
Figure 5.47 Problem 80
Figure 5.48 Problem 82.
Figure 5.49 Problem 83.

CHAPTER 6

Figure 6.1.1 (*a*) The forces on a stationary block. (*b*–*d*) An external force , applied to the...
Figure 6.1.2 The mechanism of sliding friction. (*a*) The upper surface is sliding to the right...
Figure 6.1.3 (*a*) A force is applied to an initially stationary block. (*b*) The components of t...
Figure 6.1.4 (*a*) Snowboarding. (*b*) A free-body diagram for the snowboarder.
Figure 6.2.1 This skier crouches in an "egg position" so as to minimize her effective cross-s...
Figure 6.2.2 The forces that act on a body falling through air: (*a*) the body when it has just...
Figure 6.2.3 Sky divers in a horizontal "spread eagle" maximize air drag.
Figure 6.3.1 An overhead view of a hockey puck moving with constant speed *v* in a circular pat...
Figure 6.3.2 (*a*) Contemporary advertisement for Diavolo and (*b*) free-body diagram for the per...
Figure 6.3.3 (*a*) A race car moves around a flat curved track at constant speed *v*. The frictio...
Figure 6.1 Question 1.
Figure 6.2 Question 3.
Figure 6.3 Question 6.
Figure 6.4 Question 8.
Figure 6.5 Question 9.
Figure 6.6 Problem 5.
Figure 6.7 Problem 8. What moved the stone?
Figure 6.8 Problems 9 and 32.
Figure 6.9 Problem 10.
Figure 6.10 Problem 12.
Figure 6.11 Problem 14.
Figure 6.12 Problems 16 and 22.
Figure 6.13 Problem 17.
Figure 6.14 Problem 18.
Figure 6.15 Problem 19.
Figure 6.16 Problem 20.
Figure 6.17 Problem 22.
Figure 6.18 Problem 23.
Figure 6.19 Problem 24.
Figure 6.20 Problem 25.
Figure 6.21 Problem 26.
Figure 6.22 Problems 27 and 28.
Figure 6.23 Problem 29.
Figure 6.24 Problem 30.
Figure 6.25 Problem 32.
Figure 6.26 Problem 34.
Figure 6.27 Problem 35.
Figure 6.28 Problem 49.
Figure 6.29 Problem 50.

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Figure 6.30 Problem 51.
Figure 6.31 Problem 55.
Figure 6.32 Problem 57.
Figure 6.33 Problem 58.
Figure 6.34 Problem 59.
Figure 6.35 Problem 60.
Figure 6.36 Problem 61.
Figure 6.37 Problem 62.
Figure 6.38 Problem 63.
Figure 6.39 Problem 66.
Figure 6.40 Problem 67.
Figure 6.41 Problem 69.
Figure 6.42 Problem 70.
Figure 6.43 Problem 73.
Figure 6.44 Problem 76.
Figure 6.45 Problem 79.
Figure 6.46 Problem 82.
Figure 6.47 Problem 84.
Figure 6.48 Problem 88.
Figure 6.49 Problem 90.
Figure 6.50 Problem 96.
Figure 6.51 Problem 98. (*a*) Chalk used in rock climbing. (*b*) Hang bar arrangement.

CHAPTER 7

Figure 7.1.1 The aftermath of an 1896 crash of two locomotives.
Figure 7.2.1 A constant force directed at angle ϕ to the displacement of a bead on a wi...
Figure 7.2.2 A contestant in a bed race. We can approximate the bed and its occupant as being...
Figure 7.2.3 (*a*) Two spies move a floor safe through a displacement . (*b*) A free-body diagr...
Figure 7.2.4 Force slows a crate during displacement .
Figure 7.3.1 Because the gravitational force acts on it, a particle-like tomato of mass *m*...
Figure 7.3.2 (*a*) An applied force lifts an object. The object’s displacement makes an a...
Figure 7.3.3 (*a*) A sleigh is pulled up a snowy slope. (*b*) The free-body diagram for the sleig...
Figure 7.3.4 An elevator cab, descending with speed v_i, suddenly begins to accelerate downwar...
Figure 7.4.1 (*a*) A spring in its relaxed state. The origin of an *x* axis has been placed at th...
Figure 7.4.2 A canister moves toward a spring.
Figure 7.5.1 (*a*) A one-dimensional force plotted against the displacement *x* of a partic...
Figure 7.5.2 (*a*) Epidural injection. (*b*) The force magnitude *F* versus displacement *x* of the n...
Figure 7.6.1 The power due to the truck’s applied force on the trailing load is the rate at w...
Figure 7.6.2 Two forces and act on a box that slides rightward across a frictionless ...
Figure 7.1 Question 2.
Figure 7.2 Question 4.
Figure 7.3 Question 5.
Figure 7.4 Question 6.
Figure 7.5 Question 7.
Figure 7.6 Question 8.
Figure 7.7 Question 10.
Figure 7.8 Question 12.

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Figure 7.9 Problem 6.
Figure 7.10 Problem 7.
Figure 7.11 Problem 12.
Figure 7.12 Problem 14.
Figure 7.13 Problem 15.
Figure 7.14 Problem 16.
Figure 7.15 Problem 19.
Figure 7.16 Problem 20.
Figure 7.17 Problem 23.
Figure 7.18 Problem 24.
Figure 7.19 Problem 25.
Figure 7.20 Problem 29.
Figure 7.21 Problem 30.
Figure 7.22 Problem 32.
Figure 7.23 Problem 34.
Figure 7.24 Problem 36.
Figure 7.25 Problem 37.
Figure 7.26 Problem 42.
Figure 7.27 Problem 53.
Figure 7.28 Problem 54.
Figure 7.29 Problem 57.
Figure 7.30 Problem 59.
Figure 7.31 Problem 62.
Figure 7.32 Problem 65.
Figure 7.33 Problem 67.
Figure 7.34 Problem 72.
Figure 7.35 Problem 74.
Figure 7.36 Problem 78.

CHAPTER 8

Figure 8.1.1 The kinetic energy of a bungee-cord jumper increases during the free fall, and t...
Figure 8.1.2 A tomato is thrown upward. As it rises, the gravitational force does negative wo...
Figure 8.1.3 A block, attached to a spring and initially at rest at is set in motion tow...
Figure 8.1.4 (*a*) As a conservative force acts on it, a particle can move from point *a* to poin...
Figure 8.1.5 (*a*) A block of cheese slides along a frictionless track from point *a* to point *b*....
Figure 8.1.6 Four choices of reference point . Each y axis is marked in units of meters. T...
Figure 8.2.1 A pendulum, with its mass concentrated in a bob at the lower end, swings back an...
Figure 8.2.2 A child slides down a water slide as she descends a height *h*.
Figure 8.3.1 (*a*) A plot of *U*(*x*), the potential energy function of a system containing a parti...
Figure 8.3.2 (*a*) A plot of potential energy *U* versus position *x*. (*b*) A section of the plot us...
Figure 8.4.1 (*a*) Positive work *W* done on an arbitrary system means a transfer of energy to th...
Figure 8.4.2 Positive work *W* is done on a system of a bowling ball and Earth, causing a chang...
Figure 8.4.3 (*a*) A block is pulled across a floor by force while a kinetic frictional forc...
Figure 8.4.4 Easter Island stone statues.
Figure 8.5.1 To descend, the rock climber must transfer energy from the gravitational potenti...
Figure 8.5.2 (*a*) As a skater pushes herself away from a railing, the force on her from the ra...
Figure 8.5.3 A vehicle accelerates to the right using four-wheel drive. The road exerts four ...
Figure 8.5.4 A spring-loaded amusement park water slide.
Figure 8.1 Question 1.

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Figure 8.2 Question 2.
Figure 8.3 Question 3.
Figure 8.4 Question 4.
Figure 8.5 Question 5.
Figure 8.6 Question 6.
Figure 8.7 Question 7.
Figure 8.8 Question 8.
Figure 8.9 Question 9.
Figure 8.10 Question 10.
Figure 8.11 Question 11.
Figure 8.12 Problems 2 and 9.
Figure 8.13 Problems 3 and 10.
Figure 8.14 Problems 4 and 14.
Figure 8.15 Problems 5 and 11.
Figure 8.16 Problems 6 and 17.
Figure 8.17 Problems 7, 18, and 21.
Figure 8.18 Problem 15.
Figure 8.19 Problem 19.
Figure 8.20 Problem 22.
Figure 8.21 Problems 23 and 70.
Figure 8.22 Problem 24.
Figure 8.23 Problem 27.
Figure 8.24 Problem 28.
Figure 8.25 Problems 29 and 35.
Figure 8.26 Problem 30.
Figure 8.27 Problem 31.
Figure 8.28 Problem 32.
Figure 8.29 Problem 33.
Figure 8.30 Problem 34.
Figure 8.31 Problem 36.
Figure 8.32 Problem 38.
Figure 8.33 Problem 39.
Figure 8.34 Problems 48 and 71.
Figure 8.35 Problem 53.
Figure 8.36 Problem 55.
Figure 8.37 Problem 57.
Figure 8.38 Problem 62.
Figure 8.39 Problem 63.
Figure 8.40 Problem 64.
Figure 8.41 Problem 65.
Figure 8.42 Problem 67.
Figure 8.43 Problem 69.
Figure 8.44 Problem 72.
Figure 8.45 Problem 74.
Figure 8.46 Problem 77.
Figure 8.47 Problem 78.
Figure 8.48 Problem 80.
Figure 8.49 Problems 81 and 82.

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Figure 8.50 Problem 86.

Figure 8.51 Problem 87.

Figure 8.52 Problem 91.

Figure 8.53 Problem 93.

Figure 8.54 Problem 129.

Figure 8.55 Problem 132.

Figure 8.56 Problem 133.

Figure 8.57 Problem 134.

Figure 8.58 Problem 136.

CHAPTER 9

Figure 9.1.1 (*a*) A ball tossed into the air follows a parabolic path. (*b*) The center of mass ...

Figure 9.1.2 (*a*) Two particles of masses m_1 and m_2 are separated by distance *d*. The dot label...

Figure 9.1.3 Three particles form an equilateral triangle of edge length *a*. The center of mas...

Figure 9.2.1 A fireworks rocket explodes in flight. In the absence of air drag, the center of...

Figure 9.2.2 A grand jeté. (Based on *The Physics of Dance*, by Kenneth Laws, Schirmer Books, 1...

Figure 9.2.3 (*a*) Three particles, initially at rest in the positions shown, are acted on by t...

Figure 9.4.1 The collision of a ball with a bat collapses part of the ball.

Figure 9.4.2 Force acts on a ball as the ball and a bat collide.

Figure 9.4.3 *(a)* The curve shows the magnitude of the time-varying force *F(t)* that acts on th...

Figure 9.4.4 A steady stream of projectiles, with identical linear momenta, collides with a t...

Figure 9.4.5 Heading a ball.

Figure 9.5.1 (*a*) A space hauler, with a cargo module, moving at initial velocity . (*b*) The...

Figure 9.5.2 Three pieces of an exploded coconut move off in three directions along a frictio...

Figure 9.6.1 Bodies 1 and 2 move along an *x* axis, before and after they have an inelastic col...

Figure 9.6.2 A completely inelastic collision between two bodies. Before the collision, the b...

Figure 9.6.3 Some freeze-frames of the two-body system in Fig. 9.6.2, which undergoes a compl...

Figure 9.6.4 (*a*) A head-on crash. (*b*) Two cars about to collide head-on.

Figure 9.7.1 Body 1 moves along an *x* axis before having an elastic collision with body 2, whi...

Figure 9.7.2 Two bodies headed for a one-dimensional elastic collision.

Figure 9.7.3 Block 1 collides with stationary block 2, which then collides with stationary bl...

Figure 9.8.1 An elastic collision between two bodies in which the collision is not head-on. T...

Figure 9.9.1 (*a*) An accelerating rocket of mass *M* at time *t*, as seen from an inertial referen...

Figure 9.1 Question 1.

Figure 9.2 Question 2.

Figure 9.3 Question 3.

Figure 9.4 Question 4.

Figure 9.5 Question 5.

Figure 9.6 Question 6.

Figure 9.7 Question 7.

Figure 9.8 Question 8.

Figure 9.9 Question 9.

Figure 10 Question 10.

Figure 11 Question 11.

Figure 9.12 Question 12.

Figure 9.13 Problem 2.

Figure 9.14 Problem 3.

Figure 9.15 Problem 4.

Figure 9.16 Problem 5.

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Figure 9.17 Problem 6.
Figure 9.18 Problem 7.
Figure 9.19 Problem 8.
Figure 9.20 Problem 13.
Figure 9.21 Problem 14.
Figure 9.22 Problem 15.
Figure 9.23 Problem 17.
Figure 9.24 Problem 20.
Figure 9.25 Problem 22.
Figure 9.26 Problem 23. Belly-flopping into 30 cm of water.
Figure 9.27 Problem 30.
Figure 9.28 Problem 32.
Figure 9.29 Problem 33.
Figure 9.30 Problem 34. Lizard running across water.
Figure 9.31 Problem 35.
Figure 9.32 Problem 38.
Figure 9.33 Problem 41.
Figure 9.34 Problem 43.
Figure 9.35 Problem 44.
Figure 9.36 Problem 51.
Figure 9.37 Problem 52.
Figure 9.38 Problem 56.
Figure 9.39 Problem 57.
Figure 9.40 Problem 58.
Figure 9.41 Problem 59.
Figure 9.42 Problem 60.
Figure 9.43 Problem 64.
Figure 9.44 Problem 67.
Figure 9.45 Problem 68.
Figure 9.46 Problem 69.
Figure 9.47 Problem 70.
Figure 9.48 Problem 77.
Figure 9.49 Problem 82.
Figure 9.50 Problem 83.
Figure 9.51 Problem 84.
Figure 9.52 Problem 85.
Figure 9.53 Problem 86.
Figure 9.54 Problem 97.
Figure 9.55 Problem 100.
Figure 9.56 Problem 104.
Figure 9.57 Problem 105.
Figure 9.58 Problem 106.
Figure 9.59 Problem 108.
Figure 9.60 Problem 110.
Figure 9.61 Problem 111.
Figure 9.62 Problem 112.
Figure 9.63 Problem 114.
Figure 9.64 Problem 115.

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Figure 9.65 Problem 116.
Figure 9.66 Problem 117.

CHAPTER 10

Figure 10.1.1 Figure skater Sasha Cohen in motion of (*a*) pure translation in a fixed direction...
Figure 10.1.2 A rigid body of arbitrary shape in pure rotation about the *z* axis of a coordinat...
Figure 10.1.3 The rotating rigid body of Fig 10.1.2 in cross section, viewed from above. The p...
Figure 10.1.4 The reference line of the rigid body of Figs. 10.1.2 and 10.1.3 is at angular po...
Figure 10.1.5 (*a*) A rotating disk. (*b*) A plot of the disk's angular position $\theta(t)$. Five sketch...
Figure 10.1.6 (*a*) A record rotating about a vertical axis that coincides with the axis of the ...
Figure 10.1.7 (*a*) From its initial position, at the top, the book is given two successive 90°...
Figure 10.2.1 A grindstone. At $t = 0$ the reference line (which we imagine to be marked on the ...
Figure 10.3.1 The rotating rigid body of Fig. 10.1.2, shown in cross section viewed from above...
Figure 10.3.2 (*a*) Overhead view of a passenger ready to ride The Giant Ring. (*b*) The radial an...
Figure 10.4.1 A long rod is much easier to rotate about (*a*) its central (longitudinal) axis th...
Figure 10.5.1 A rigid body in cross section, with its center of mass at *O*. The parallel-axis t...
Figure 10.5.2 A rigid body consisting of two particles of mass *m* joined by a rod of negligible...
Figure 10.5.3 A uniform rod of length *L* and mass *M*. An element of mass *dm* and length *dx* is rep...
Figure 10.5.4 Some of the destruction caused by the explosion of a rapidly rotating steel disk.
Figure 10.6.1 (*a*) A force acts on a rigid body, with a rotation axis perpendicular to the p...
Figure 10.7.1 A simple rigid body, free to rotate about an axis through *O*, consists of a parti...
Figure 10.7.2 Sample Problem 10.7.1 (*a*) Moderate high heels. (*b*) Forces on forefoot and heel. ...
Figure 10.7.3 A judo hip throw (*a*) correctly executed and (*b*) incorrectly executed.
Figure 10.1 Question 1.
Figure 10.2 Question 2.
Figure 10.3 Question 4.
Figure 10.4 Question 5.
Figure 10.5 Question 6.
Figure 10.6 Questions 7 and 8.
Figure 10.7 Question 9.
Figure 10.8 Question 10.
Figure 10.9 Question 11.
Figure 10.10 Question 12.
Figure 10.11 Problem 7.
Figure 10.12 Problem 28.
Figure 10.13 Problem 29.
Figure 10.14 Problem 34.
Figure 10.15 Problem 36.
Figure 10.16 Problems 38 and 62.
Figure 10.17 Problem 40.
Figure 10.18 Problem 41.
Figure 10.19 Problems 43.
Figure 10.20 Problem 45.
Figure 10.21 Problem 46.
Figure 10.22 Problems 51 and 83.
Figure 10.23 Problem 52.
Figure 10.24 Problem 53.
Figure 10.25 Problem 54.
Figure 10.26 Problem 55.

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Figure 10.27 Problem 56.

Figure 10.28 Problem 66.

Figure 10.29 Problem 67.

Figure 10.30 Problem 69.

Figure 10.31 Problem 71.

Figure 10.32 Problem 74.

Figure 10.33 Problem 78.

Figure 10.34 Problem 81.

Figure 10.35 Problem 84.

Figure 10.36 Problem 86.

Figure 10.37 Problem 89.

Figure 10.38 Problem 90.

Figure 10.39 Problem 92.

Figure 10.40 Problem 94.

Figure 10.41 Problem 96.

CHAPTER 11

Figure 11.1.1 The Onewheel.

Figure 11.1.2 A time-exposure photograph of a rolling disk. Small lights have been attached to...

Figure 11.1.3 The center of mass *O* of a rolling wheel moves a distance *s* at velocity ...

Figure 11.1.4 Rolling motion of a wheel as a combination of purely rotational motion and purel...

Figure 11.1.5 A photograph of a rolling bicycle wheel. The spokes near the wheel's top are mor...

Figure 11.1.6 Rolling can be viewed as pure rotation, with angular speed *ω*, about an axis that...

Figure 11.2.1 A wheel rolls horizontally without sliding while accelerating with linear accele...

Figure 11.2.2 A round uniform body of radius *R* rolls down a ramp. The forces that act on it ar...

Figure 11.3.1 (*a*) A yo-yo, shown in cross section. The string, of assumed negligible thickness...

Figure 11.4.1 Defining torque. (*a*) A force , lying in an *xy* plane, acts on a particle at poi...

Figure 11.4.2 (*a*) A particle at point *A* is acted on by three forces, each parallel to a coordi...

Figure 11.5.1 Defining angular momentum. A particle passing through point *A* has linear momentu...

Figure 11.5.2 Two particles pass near point *O*.

Figure 11.6.1 (*a*) A particle moving in a straight line, shown at time *t* = 0. (*b*) The position ...

Figure 11.7.1 (*a*) A rigid body rotates about a *z* axis with angular speed *ω*. A mass element of...

Figure 11.7.2 The original Ferris wheel, built in 1893 near the University of Chicago, towered...

Figure 11.8.1 (*a*) The student has a relatively large rotational inertia about the rotation axi...

Figure 11.8.2 The diver's angular momentum is constant throughout the dive, being represent...

Figure 11.8.3 Windmill motion of the arms during a long jump helps maintain body orientation f...

Figure 11.8.4 (*a*) Initial phase of a tour jeté: large rotational inertia and small angular spe...

Figure 11.8.5 (*a*) A student holds a bicycle wheel rotating around a vertical axis. (*b*) The stu...

Figure 11.8.6 A cockroach rides at radius *r* on a disk rotating like a merry-go-round.

Figure 11.9.1 (*a*) A nonspinning gyroscope falls by rotating in an *xz* plane because of torque ...

Figure 11.1 Question 1.

Figure 11.2 Question 2.

Figure 11.3 Question 3.

Figure 11.4 Question 5.

Figure 11.5 Question 8.

Figure 11.6 Question 9.

Figure 11.7 Question 10.

Figure 11.8 Problem 6.

Figure 11.9 Problem 7.

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Figure 11.10 Problem 8.

Figure 11.11 Problem 9.

Figure 11.12 Problem 11.

Figure 11.13 Problem 12.

Figure 11.14 Problem 13.

Figure 11.15 Problem 14.

Figure 11.16 Problem 15.

Figure 11.17 Problem 16.

Figure 11.18 Problem 26.

Figure 11.19 Problem 29.

Figure 11.20 Problem 31.

Figure 11.21 Problem 36.

Figure 11.22 Problem 37.

Figure 11.23 Problem 41.

Figure 11.24 Problem 42.

Figure 11.25 Problem 43.

Figure 11.26 Problem 47.

Figure 11.27 Problem 48.

Figure 11.28 Problem 53.

Figure 11.29 Problem 54.

Figure 11.30 Problem 59.

Figure 11.31 Problem 60.

Figure 11.32 Problem 61.

Figure 11.33 Problem 62.

Figure 11.34 Problem 63.

Figure 11.35 Problem 65.

Figure 11.36 Problem 66.

Figure 11.37 Problem 66.

Figure 11.38 Problem 71.

Figure 11.39 Problems 80 and 82.

Figure 11.40 Problem 83.

CHAPTER 12

Figure 12.1.1 A balancing rock. Although its perch seems precarious, the rock is in static equ...

Figure 12.1.2 (*a*) A domino balanced on one edge, with its center of mass vertically above that...

Figure 12.1.3 A construction worker balanced on a steel beam is in static equilibrium but is m...

Figure 12.1.4 (*a*) An element of mass m_i in an extended body. The gravitational force on t..

Figure 12.2.1 (*a*) A beam of mass *m* supports a block of mass *M*. (*b*) A free-body diagram, showin...

Figure 12.2.2 (*a*) A heavy safe is hung from a boom consisting of a horizontal steel cable and ...

Figure 12.2.3 (*a*) A firefighter climbs halfway up a ladder that is leaning against a frictionl...

Figure 12.2.4 The forces on a climber resting in a rock chimney. The push of the climber on th...

Figure 12.3.1 The table is an indeterminate structure. The four forces on the table legs diffe...

Figure 12.3.2 The atoms of a metallic solid are distributed on a repetitive three-dimensional ...

Figure 12.3.3 (*a*) A cylinder subject to *tensile stress* stretches by an amount ΔL. (*b*) A cylind...

Figure 12.3.4 A test specimen used to determine a stress–strain curve such as that of Fig. 12....

Figure 12.3.5 A stress–strain curve for a steel test specimen such as that of Fig. 12.3.4. Th...

Figure 12.3.6 A strain gage of overall dimensions 9.8 mm by 4.6 mm. The gage is fastened with ...

Figure 12.1 Question 1.

Figure 12.2 Question 2.

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Figure 12.3 Question 3.
Figure 12.4 Question 5.
Figure 12.5 Question 6.
Figure 12.6 Question 7.
Figure 12.7 Question 8.
Figure 12.8 Question 9.
Figure 12.9 Question 10.
Figure 12.10 Question 12.
Figure 12.11 Problem 1.
Figure 12.12 Problem 3.
Figure 12.13 Problem 8.
Figure 12.14 Problem 10.
Figure 12.15 Problem 11.
Figure 12.16 Problem 12.
Figure 12.17 Problem 13.
Figure 12.18 Problem 14.
Figure 12.19 Problem 15.
Figure 12.20 Problem 17.
Figure 12.21 Problem 18.
Figure 12.22 Problem 19.
Figure 12.23 Problem 20.
Figure 12.24 Problem 21.
Figure 12.25 Problem 22.
Figure 12.26 Problem 23.
Figure 12.27 Problem 24.
Figure 12.28 Problem 25.
Figure 12.29 Problem 26.
Figure 12.30 Problem 27.
Figure 12.31 Problems 28 and 34.
Figure 12.32 Problem 30.
Figure 12.33 Problem 31.
Figure 12.34 Problem 32.
Figure 12.35 Problem 33.
Figure 12.36 Problem 36.
Figure 12.37 Problem 37.
Figure 12.38 Problem 38.
Figure 12.39 Problem 39.
Figure 12.40 Problem 40.
Figure 12.41 Problem 44.
Figure 12.42 Problem 45.
Figure 12.43 Problem 46.
Figure 12.44 Problem 47.
Figure 12.45 Problem 48.
Figure 12.46 Problem 49.
Figure 12.47 Problem 50.
Figure 12.48 Problem 51.
Figure 12.49 Problem 53.
Figure 12.50 Problem 55.

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Figure 12.51 Problem 56.
Figure 12.52 Problem 57.
Figure 12.53 Problem 58.
Figure 12.54 Problem 59.
Figure 12.55 Problem 60.
Figure 12.56 Problem 61.
Figure 12.57 Problem 63.
Figure 12.58 Problem 64.
Figure 12.59 Problem 65.
Figure 12.60 Problem 66.
Figure 12.61 Problem 68.
Figure 12.62 Problem 69.
Figure 12.63 Problem 72.
Figure 12.64 Problem 73.
Figure 12.65 Problem 75.
Figure 12.66 Problem 77.
Figure 12.67 Problem 78.
Figure 12.68 Problem 80.
Figure 12.69 Problem 82.
Figure 12.70 Problem 83.
Figure 12.71 Problem 84.
Figure 12.72 Problem 85.

CHAPTER 13

Figure 13.1.1 The Andromeda Galaxy. Located 2.3×10^6 light-years from us, and faintly visible...
Figure 13.1.2 (*a*) The gravitational force on particle 1 due to particle 2 is an attractive ...
Figure 13.1.3 The apple pulls up on Earth just as hard as Earth pulls down on the apple.
Figure 13.2.1 (*a*) An arrangement of three particles. The force on particle 1 due to (*b*) partic...
Figure 13.3.1 The density of Earth as a function of distance from the center. The limits of th...
Figure 13.3.2 (*a*) A crate sitting on a scale at Earth's equator, as seen by an observer positi...
Figure 13.4.1 A capsule of mass m falls from rest through a tunnel that connects Earth's south...
Figure 13.5.1 A system consisting of three particles. The gravitational potential energy *of th...*
Figure 13.5.2 A baseball is shot directly away from Earth, through point P at radial distance ...
Figure 13.5.3 Near Earth, a baseball is moved from point A to point G along a path consisting...
Figure 13.6.1 The path seen from Earth for the planet Mars as it moved against a background o...
Figure 13.6.2 A planet of mass m moving in an elliptical orbit around the Sun. The Sun, of mas...
Figure 13.6.3 (*a*) In time Δt, the line r connecting the planet to the Sun moves through an ang...
Figure 13.6.4 A planet of mass m moving around the Sun in a circular orbit of radius r.
Figure 13.6.5 The orbit of star S2 about Sagittarius A* (Sgr A*). The elliptical orbit appears...
Figure 13.7.1 Four orbits with different eccentricities e about an object of mass M. All four ...
Figure 13.7.2 The variation of kinetic energy K, potential energy U, and total energy E with r...
Figure 13.7.3 At point P a thruster is fired, changing a ship's orbit from circular to ellipti...
Figure 13.8.1 (*a*) A physicist in a box resting on Earth sees a cantaloupe falling with acceler...
Figure 13.8.2 (*a*) Two objects moving along lines of longitude toward the south pole converge b...
Figure 13.8.3 (*a*) Light from a distant quasar follows curved paths around a galaxy or a large ...
Figure 13.8.4 The first image of a black hole shows the supermassive black hole in the galaxy ...
Figure 13.1 Question 1.
Figure 13.2 Question 2.
Figure 13.3 Question 3.

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Figure 13.4 Question 4.
Figure 13.5 Question 5.
Figure 13.6 Question 6.
Figure 13.7 Question 8.
Figure 13.8 Question 9.
Figure 13.9 Question 10.
Figure 13.10 Question 11.
Figure 13.11 Question 12.
Figure 13.12 Problem 6.
Figure 13.13 Problem 7.
Figure 13.14 Problem 8.
Figure 13.15 Problem 10.
Figure 13.16 Problem 11.
Figure 13.17 Problem 12.
Figure 13.18 Problem 13.
Figure 13.19 Problem 14.
Figure 13.20 Problem 16.
Figure 13.21 Problem 24.
Figure 13.22 Problem 27.
Figure 13.23 Problems 29 and 34.
Figure 13.24 Problem 35.
Figure 13.25 Problem 37.
Figure 13.26 Problem 42.
Figure 13.27 Problem 54.
Figure 13.28 Problem 56. A tiny moon (at right) orbits asteroid 243 Ida.
Figure 13.29 Problem 58.
Figure 13.30 Problem 60.
Figure 13.31 Problem 68.
Figure 13.32 Problem 71.
Figure 13.33 Problem 73.
Figure 13.34 Problem 79.
Figure 13.35 Problem 94.

CHAPTER 14

Figure 14.1.1 (*a*) A fluid-filled vessel containing a small pressure sensor, shown in (*b*). The ...
Figure 14.2.1 (*a*) A tank of water in which a sample of water is contained in an imaginary cyli...
Figure 14.2.2 The pressure *p* increases with depth *h* below the liquid surface according to Eq. ...
Figure 14.2.3 The oil in the left arm stands higher than the water.
Figure 14.3.1 (*a*) A mercury barometer. (*b*) Another mercury barometer. The distance *h* is the sa...
Figure 14.3.2 An open-tube manometer, connected to measure the gauge pressure of the gas in th...
Figure 14.4.1 Lead shot (small balls of lead) loaded onto the piston create a pressure p_{ext} at...
Figure 14.4.2 A hydraulic arrangement that can be used to magnify a force . The work done i...
Figure 14.5.1 A thin-walled plastic sack of water is in static equilibrium in the pool. The gr...
Figure 14.5.2 (*a*) The water surrounding the hole in the water produces a net upward buoyant fo...
Figure 14.5.3 (*a*) Surfer. (*b*) Free-body diagram showing the forces on the surfer–surfboard sys...
Figure 14.5.4 Block of height *H* floats in a fluid, to a depth of *h*.
Figure 14.6.1 At a certain point, the rising flow of smoke and heated gas changes from steady ...
Figure 14.6.2 The steady flow of a fluid around a cylinder, as revealed by a dye tracer that w...
Figure 14.6.3 A fluid element traces out a streamline as it moves. The velocity vector of the ...

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Figure 14.6.4 Fluid flows from left to right at a steady rate through a tube segment of length...
Figure 14.6.5 Fluid flows at a constant speed *v* through a tube. (*a*) At time *t*, fluid element *e*...
Figure 14.6.6 A tube of flow is defined by the streamlines that form the boundary of the tube....
Figure 14.6.7 As water falls from a tap, its speed increases. Because the volume flow rate mus...
Figure 14.7.1 Fluid flows at a steady rate through a length *L* of a tube, from the input end at...
Figure 14.1 Question 2.
Figure 14.2 Question 4.
Figure 14.3 Question 5.
Figure 14.4 Question 6.
Figure 14.5 Question 7.
Figure 14.6 Question 8.
Figure 14.7 Question 9.
Figure 14.8 Question 10.
Figure 14.9 Problem 7.
Figure 14.10 Problem 10.
Figure 14.11 Problem 16.
Figure 14.12 Problem 18.
Figure 14.13 Problem 20.
Figure 14.14 Problem 23.
Figure 14.15 Problem 24.
Figure 14.16 Problem 28.
Figure 14.17 Problem 28.
Figure 14.18 Problem 32.
Figure 14.19 Problem 36.
Figure 14.20 Problem 38.
Figure 14.21 Problem 40.
Figure 14.22 Problem 43.
Figure 14.23 Problem 47.
Figure 14.24 Problem 48.
Figure 14.25 Problem 49.
Figure 14.26 Problem 50.
Figure 14.27 Problem 58.
Figure 14.28 Problems 62 and 63.
Figure 14.29 Problem 64.
Figure 14.30 Problems 65 and 66.
Figure 14.31 Problem 67.
Figure 14.32 Problem 68.
Figure 14.33 Problem 70.
Figure 14.34 Problem 71.
Figure 14.35 Problem 72.
Figure 14.36 Problem 80.
Figure 14.37 Problem 83.
Figure 14.38 Problem 86.
Figure 14.39 Problem 89.
Figure 14.40 Problem 89.
Figure 14.41 Problem 90.

CHAPTER 15

Figure 15.1.1 A particle repeatedly oscillates left and right along an *x* axis, between extreme...

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Figure 15.1.2 (*a*) A sequence of “freeze-frames” (taken at equal time intervals) showing the po...

Figure 15.1.3 A handy guide to the quantities in Eq. 15.1.3 for simple harmonic motion.

Figure 15.1.4 Values of ϕ corresponding to the position of the particle at time $t = 0$.

Figure 15.1.5 In all three cases, the blue curve is obtained from Eq. 15.1.3 with $\phi = 0$. (*a*) T...

Figure 15.1.6 (*a*) The displacement $x(t)$ of a particle oscillating in SHM with phase angle ϕ eq...

Figure 15.1.7 A linear simple harmonic oscillator. The surface is frictionless. Like the parti...

Figure 15.1.8 The dive by the penguin from the board causes the board and spring to oscillate.

Figure 15.2.1 (*a*) Potential energy $U(t)$, kinetic energy $K(t)$, and mechanical energy E as funct...

Figure 15.3.1 A torsion pendulum is an angular version of a linear simple harmonic oscillator....

Figure 15.3.2 Two torsion pendulums, consisting of (*a*) a wire and a rod and (*b*) the same wire ...

Figure 15.4.1 (*a*) A simple pendulum. (*b*) The forces acting on the bob are the gravitational fo...

Figure 15.4.2 A physical pendulum. The restoring torque is $hF_g \sin\theta$. When $\theta = 0$, center of ma...

Figure 15.4.3 (*a*) A meter stick suspended from one end as a physical pendulum. (*b*) A simple pe...

Figure 15.4.4 The angle between Jupiter and its moon Callisto as seen from Earth. Galileo’s 16...

Figure 15.4.5 (*a*) A reference particle P' moving with uniform circular motion in a reference c...

Figure 15.5.1 An idealized damped simple harmonic oscillator. A vane immersed in a liquid exer...

Figure 15.5.2 The displacement function $x(t)$ for the damped oscillator of Fig. 15.5.1. The amp...

Figure 15.6.1 The displacement amplitude x_m of a forced oscillator varies as the angular frequ...

Figure 15.6.2 In 1985, buildings of intermediate height collapsed in Mexico City as a result o...

Figure 15.1 Questions 1 and 2.

Figure 15.2 Question 3.

Figure 15.3 Question 5.

Figure 15.4 Question 6.

Figure 15.5 Question 7.

Figure 15.6 Question 8.

Figure 15.7 Question 9.

Figure 15.8 Question 10.

Figure 15.9 Question 11.

Figure 15.10 Question 12.

Figure 15.11 Problem 8.

Figure 15.12 Problems 11 and 21.

Figure 15.13 Problem 12.

Figure 15.14 Problem 20.

Figure 15.15 Problem 22.

Figure 15.16 Problem 24.

Figure 15.17 Problem 25.

Figure 15.18 Problem 26.

Figure 15.19 Problem 28.

Figure 15.20 Problem 32.

Figure 15.21 Problem 33.

Figure 15.22 Problem 34.

Figure 15.23 Problem 41.

Figure 15.24 Problem 44.

Figure 15.25 Problem 47.

Figure 15.26 Problem 48.

Figure 15.27 Problem 51.

Figure 15.28 Problem 52.

Figure 15.29 Problem 53.

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Figure 15.30 Problem 54.
Figure 15.31 Problem 56.
Figure 15.32 Problem 67.
Figure 15.33 Problem 70.
Figure 15.34 Problems 77 and 78.
Figure 15.35 Problem 79.
Figure 15.36 Problem 81.
Figure 15.37 Problem 92.
Figure 15.38 Problem 94.
Figure 15.39 Problem 97.
Figure 15.40 Problem 100.
Figure 15.41 Problem 105.
Figure 15.42 Problem 106.
Figure 15.43 Problem 108.
Figure 15.44 Problem 109.
Figure 15.45 Problem 110.
Figure 15.46 Problem 111.

CHAPTER 16

Figure 16.1.1 (*a*) A single pulse is sent along a stretched string. A typical string element (m...
Figure 16.1.2 A sound wave is set up in an air-filled pipe by moving a piston back and forth. ...
Figure 16.1.3 The names of the quantities in Eq. 16.1.2, for a transverse sinusoidal wave.
Figure 16.1.4 Five “snapshots” of a string wave traveling in the positive direction of an *x*...
Figure 16.1.5 A graph of the displacement of the string element at *x* = 0 as a function of time...
Figure 16.1.6 A sinusoidal traveling wave at *t* = 0 with a phase constant *ϕ* of (*a*)...
Figure 16.1.7 Two snapshots of the wave of Fig. 16.1.4, at time *t* = 0 and then at time *t* =...
Figure 16.1.8 (*a*) A snapshot of the displacement *y* versus position *x* along a string,...
Figure 16.2.1 A symmetrical pulse, viewed from a reference frame in which the pulse is station...
Figure 16.3.1 A snapshot of a traveling wave on a string at time *t* = 0. String element *a* is...
Figure 16.4.1 (*a*) A string element as a sinusoidal transverse wave travels on a stretched stri...
Figure 16.5.1 A series of snapshots that shows two pulses traveling in opposite directions alo...
Figure 16.5.2 The resultant wave of Eq. 16.5.6, due to the interference of two sinusoidal tran...
Figure 16.5.3 Two identical sinusoidal waves, y_1(*x*, *t*) and y_2...
Figure 16.6.1 (*a*)–(*d*) A phasor of magnitude y_{m1} rotating about...
Figure 16.6.2 (*a*) Two phasors of magnitudes y_{m1} and y_{m2}...
Figure 16.7.1 (*a*) Five snapshots of a wave traveling to the left, at the times *t* indicated...
Figure 16.7.2 The resultant wave of Eq. 16.7.3 is a standing wave and is due to the interferen...
Figure 16.7.3 (*a*) A pulse incident from the right is reflected at the left end of the string, ...
Figure 16.7.4 Stroboscopic photographs reveal (imperfect) standing wave patterns on a string b...
Figure 16.7.5 A string, stretched between two clamps, is made to oscillate in standing wave pa...
Figure 16.7.6 One of many possible standing wave patterns for a kettledrum head, made visible ...
Figure 16.7.7 Standing wave produced by an oscillating electric shaver.
Figure 16.1 Question 2.
Figure 16.2 Question 3.
Figure 16.3 Question 4.
Figure 16.4 Question 9.
Figure 16.5 Question 11.
Figure 16.6 Problem 2.
Figure 16.7 Problem 4.

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Figure 16.8 Problem 6.
Figure 16.9 Problem 8.
Figure 16.10 Problem 9.
Figure 16.11 Problem 11.
Figure 16.12 Problem 23.
Figure 16.13 Problem 24.
Figure 16.14 Problem 27.
Figure 16.15 Problem 33.
Figure 16.16 Problem 49.
Figure 16.17 Problem 50.
Figure 16.18 Problem 54.
Figure 16.19 Problems 58 and 60.
Figure 16.20 Problem 59.
Figure 16.21 Problem 66.
Figure 16.22 Problem 68.
Figure 16.23 Problem 70.
Figure 16.24 Problem 72.
Figure 16.25 Problem 88.
Figure 16.26 Problem 90.
Figure 16.27 Problem 95.

CHAPTER 17

Figure 17.1.1 A loggerhead turtle is being checked with ultrasound (which has a frequency abov...
Figure 17.1.2 A sound wave travels from a point source *S* through a three-dimensional medium. T...
Figure 17.1.3 A compression pulse is sent from right to left down a long air-filled tube. The ...
Figure 17.2.1 (*a*) A sound wave, traveling through a long air-filled tube with speed *v*, consist...
Figure 17.2.2 (*a*) The displacement function and (*b*) the pressure-variation function of a...
Figure 17.2.3 (*a*) A plot of the displacement function (Eq. 17.2.1) for $t = 0$. (*b*)...
Figure 17.3.1 (*a*) Two point sources S_1 and S_2 emit spherical...
Figure 17.3.2 (*a*) Two point sources S_1 and S_2, separated by...
Figure 17.4.1 A point source *S* emits sound waves uniformly in all directions. The waves pass t...
Figure 17.4.2 Led Zeppelin
Figure 17.5.1 The air column within a didgeridoo (“a pipe”) oscillates when the instrument is...
Figure 17.5.2 (*a*) The simplest standing wave pattern of displacement for (longitudinal) sound ...
Figure 17.5.3 Standing wave patterns for string waves superimposed on pipes to represent stand...
Figure 17.5.4 The saxophone and violin families, showing the relations between instrument leng...
Figure 17.5.5 The wave forms produced by (*a*) a flute and (*b*) an oboe when played at the same...
Figure 17.5.6 Harmonic frequencies of four pipes.
Figure 17.6.1 (*a*, *b*) The pressure variations Δp of two sound waves as they would...
Figure 17.7.1 A stationary source of sound *S* emits spherical wavefronts, shown one wavelength ...
Figure 17.7.2 The wavefronts of Fig. 17.7.1, assumed planar, (*a*) reach and (*b*) pass a stationa...
Figure 17.7.3 Wavefronts traveling to the right (*a*) reach and (*b*) pass detector *D*, which...
Figure 17.7.4 A detector *D* is stationary, and a source *S* is moving toward it at speed v_S....
Figure 17.8.1 (*a*) A source of sound *S* moves at speed v_S equal to ...
Figure 17.8.2 Shock waves produced by the wings of a Navy FA 18 jet. The shock waves are visib...
Figure 17.1 Question 2.
Figure 17.2 Question 3.
Figure 17.3 Question 5.
Figure 17.4 Question 7.

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 17.5 Question 8.
Figure 17.6 Question 10.
Figure 17.7 Problem 10.
Figure 17.8 Problem 14.
Figure 17.9 Problem 15.
Figure 17.10 Problem 18.
Figure 17.11 Problem 19.
Figure 17.12 Problem 20.
Figure 17.13 Problem 21.
Figure 17.14 Problem 22.
Figure 17.15 Problem 23.
Figure 17.16 Problem 34.
Figure 17.17 Problem 43.
Figure 17.18 Problem 59.
Figure 17.19 Problem 62.
Figure 17.20 Problem 73.
Figure 17.21 Problem 77.
Figure 17.22 Problem 79.
Figure 17.23 Problem 83.
Figure 17.24 Problem 93.
Figure 17.25 Problem 94.
Figure 17.26 Problem 102.
Figure 17.27 Problem 103.
Figure 17.28 Problem 104.
Figure 17.29 Problem 107.
Figure 17.30 Problem 108.
Figure 17.31 Problem 109.

CHAPTER 18

Figure 18.1.1 Some temperatures on the Kelvin scale. Temperature $T = 0$ corresponds to $10^{-\infty}$...
Figure 18.1.2 A thermoscope. The numbers increase when the device is heated and decrease when ...
Figure 18.1.3 (*a*) Body *T* (a thermoscope) and body *A* are in thermal equilibrium. (Body...
Figure 18.1.4 A triple-point cell, in which solid ice, liquid water, and water vapor coexist i...
Figure 18.1.5 A constant-volume gas thermometer, its bulb immersed in a liquid whose temperatu...
Figure 18.1.6 Temperatures measured by a constant-volume gas thermometer, with its bulb immers...
Figure 18.2.1 The Kelvin, Celsius, and Fahrenheit temperature scales compared.
Figure 18.2.2 An unknown temperature scale compared with the Fahrenheit temperature scale.
Figure 18.3.1 When a Concorde flew faster than the speed of sound, thermal expansion due to th...
Figure 18.3.2 (*a*) A bimetal strip, consisting of a strip of brass and a strip of steel welded ...
Figure 18.3.3 The same steel ruler at two different temperatures. When it expands, the scale, ...
Figure 18.3.4 Apollo 15.
Figure 18.4.1 If the temperature of a system exceeds that of its environment as in (*a*), heat *Q*...
Figure 18.5.1 A gas is confined to a cylinder with a movable piston. Heat *Q* can be added to or...
Figure 18.5.2 (*a*) The shaded area represents the work *W* done by a system as it goes from an...
Figure 18.5.3 An adiabatic expansion can be carried out by slowly removing lead shot from the ...
Figure 18.5.4 The initial stage of a free-expansion process. After the stopcock is opened, the...
Figure 18.5.5 Water boiling at constant pressure. Energy is transferred from the thermal reser...
Figure 18.6.1 Thermal conduction. Energy is transferred as heat from a reservoir at temperatur...
Figure 18.6.2 Heat is transferred at a steady rate through a composite slab made up of two dif...

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 18.6.3 A false-color thermogram reveals the rate at which energy is radiated by a cat. ...

Figure 18.6.4 A rattlesnake’s face has thermal radiation detectors, allowing the snake to stri...

Figure 18.6.5 Steady-state heat transfer through a wall.

Figure 18.1 Question 2.

Figure 18.2 Questions 4 and 5.

Figure 18.3 Question 6.

Figure 18.4 Questions 7 and 8.

Figure 18.5 Question 9.

Figure 18.6 Question 11.

Figure 18.7 Problem 3.

Figure 18.8 Problem 20.

Figure 18.9 Problem 21.

Figure 18.10 Problem 30.

Figure 18.11 Problem 34.

Figure 18.12 Problem 38.

Figure 18.13 Problem 42.

Figure 18.14 Problem 43.

Figure 18.15 Problem 44.

Figure 18.16 Problem 45.

Figure 18.17 Problem 47.

Figure 18.18 Problem 48.

Figure 18.19 Problem 49.

Figure 18.20 Problem 50.

Figure 18.21 Problem 56.

Figure 18.22 Problem 59.

Figure 18.23 Problem 60.

Figure 18.24 Problem 61.

Figure 18.25 Problem 62.

Figure 18.26 Problem 63.

Figure 18.27 Problem 64.

Figure 18.28 Problem 69.

Figure 18.29 Problem 71.

Figure 18.30 Problem 74.

Figure 18.31 Problem 75.

Figure 18.32 Problem 78.

Figure 18.33 Problem 80.

Figure 18.34 Problem 81.

Figure 18.35 Problem 95.

Figure 18.36 Problem 96.

Figure 18.37 Problem 98.

Figure 18.38 Problem 101.

Figure 18.39 Problem 104.

Figure 18.40 Problem 108.

CHAPTER 19

Figure 19.2.1 (*a*) Before and (*b*) after images of a large steel tank crushed by atmospheric pre...

Figure 19.2.2 Three isotherms on a *p*-*V* diagram. The path shown along the middle isotherm repre...

Figure 19.2.3 The shaded area represents the work done by 1 mol of oxygen in expanding from V_i...

Figure 19.3.1 A cubical box of edge length *L*, containing *n* moles of an ideal gas. A molecule o...

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 19.5.1 A molecule traveling through a gas, colliding with other gas molecules in its pa...
Figure 19.5.2 (*a*) A collision occurs when the centers of two molecules come within a distance ...
Figure 19.5.3 In time Δt the moving molecule effectively sweeps out a cylinder of length v...
Figure 19.6.1 (*a*) The Maxwell speed distribution for oxygen molecules at $T = 300$ K. The three...
Figure 19.7.1 (*a*) The temperature of an ideal gas is raised from T to $T + \Delta T$ in a...
Figure 19.7.2 Three paths representing three different processes that take an ideal gas from a...
Figure 19.7.3 (*a*) The temperature of an ideal gas is raised from T to $T + \Delta T$ in a...
Figure 19.7.4 The relative values of Q for a monatomic gas (left side) and a diatomic gas unde...
Figure 19.8.1 Models of molecules as used in kinetic theory: (*a*) helium, a typical monatomic m...
Figure 19.8.2 C_V/R versus temperature for (diatomic) hydrogen gas. Because rotational...
Figure 19.9.1 (*a*) The volume of an ideal gas is increased by removing mass from the piston. Th...
Figure 19.9.2 A *p-V* diagram representing four special processes for an ideal monatomic gas.
Figure 19.1 Question 2.
Figure 19.2 Questions 4, 6, and 8.
Figure 19.3 Question 5.
Figure 19.4 Problem 13.
Figure 19.5 Problem 15.
Figure 19.6 Problem 17.
Figure 19.7 Problem 37.
Figure 19.8 Problem 38.
Figure 19.9 Problem 44.
Figure 19.10 Problem 59.
Figure 19.11 Problem 63.
Figure 19.12 Problem 77.
Figure 19.13 Problem 88.

CHAPTER 20

Figure 20.1.1 The free expansion of an ideal gas. (*a*) The gas is confined to the left half of ...
Figure 20.1.2 A *p-V* diagram showing the initial state *i* and the final state *f* of the free expa...
Figure 20.1.3 The isothermal expansion of an ideal gas, done in a reversible way. The gas has ...
Figure 20.1.4 A *p-V* diagram for the reversible isothermal expansion of Fig. 20.1.3. The interm...
Figure 20.1.5 (*a*) In the initial state, two copper blocks *L* and *R*, identical except for their ...
Figure 20.1.6 The blocks of Fig. 20.1.5 can proceed from their initial state to their final st...
Figure 20.1.7 A section of a rubber band (*a*) unstretched and (*b*) stretched, and a polymer with...
Figure 20.2.1 The elements of a Carnot engine. The two black arrowheads on the central loop su...
Figure 20.2.2 A pressure–volume plot of the cycle followed by the working substance of the Car...
Figure 20.2.3 The Carnot cycle of Fig. 20.2.2 plotted on a temperature–entropy diagram. During...
Figure 20.2.4 The elements of a perfect engine—that is, one that converts heat Q_H from a high-...
Figure 20.2.5 The North Anna nuclear power plant near Charlottesville, Virginia, which generat...
Figure 20.2.6 A *p-V* plot for the working substance of an ideal Stirling engine, with the worki...
Figure 20.3.1 The elements of a Carnot refrigerator. The two black arrowheads on the central l...
Figure 20.3.2 The elements of a perfect refrigerator—that is, one that transfers energy from a...
Figure 20.3.3 (*a*) Engine *X* drives a Carnot refrigerator. (*b*) If, as claimed, engine *X* is more ...
Figure 20.4.1 An insulated box contains six gas molecules. Each molecule has the same probabil...
Figure 20.4.2 For a *large* number of molecules in a box, a plot of the number of microstates th...
Figure 20.1 Question 1.
Figure 20.2 Question 4.
Figure 20.3 Question 5.
Figure 20.4 Problem 10.

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Figure 20.5 Problem 12.
Figure 20.6 Problem 14.
Figure 20.7 Problem 17.
Figure 20.8 Problem 18.
Figure 20.9 Problem 29.
Figure 20.10 Problem 32.
Figure 20.11 Problem 33.
Figure 20.12 Problem 33.
Figure 20.13 Problem 35.
Figure 20.14 Problem 43.
Figure 20.15 Problem 56.
Figure 20.16 Problem 61.
Figure 20.17 Problem 62.

CHAPTER 21

Figure 21.1.1 (*a*) The two glass rods were each rubbed with a silk cloth and one was suspended ...
Figure 21.1.2 (*a*) Two charged rods of the same sign repel each other. (*b*) Two charged rods of ...
Figure 21.1.3 A neutral copper rod is electrically isolated from its surroundings by being sus...
Figure 21.1.4 Two pieces of a wintergreen candy as they fall away from each other. Electrons j...
Figure 21.1.5 Two charged particles repel each other if they have the same sign of charge, eit...
Figure 21.1.6 The electrostatic force on particle 1 can be described in terms of a unit vector...
Figure 21.1.7 (*a*) Two charged particles of charges q_1 and q_2 are fixed in place on an *x* axis....
Figure 21.1.8 (*a*) Two particles of charges q_1 and q_2 are fixed in place on an *x* axis, with sep...
Figure 21.1.9 Two small conducting spheres *A* and *B*. (*a*) To start, sphere *A* is charged positive...
Figure 21.3.1 A photograph of trails of bubbles left in a bubble chamber by an electron and a ...
Figure 21.3.2 (*a*) Patient in a PET scan apparatus. (*b*) Annihilation of a positron and electron...
Figure 21.1 Question 1.
Figure 21.2 Question 2.
Figure 21.3 Question 3.
Figure 21.4 Question 4.
Figure 21.5 Question 5.
Figure 21.6 Question 7.
Figure 21.7 Question 8.
Figure 21.8 Question 9.
Figure 21.9 Question 10.
Figure 21.10 Question 11.
Figure 21.11 Question 12.
Figure 21.12 Problem 2.
Figure 21.13 Problems 7 and 40.
Figure 21.14 Problem 8.
Figure 21.15 Problems 10 and 11.
Figure 21.16 Problems 13, 19, 30, and 58.
Figure 21.17 Problem 16.
Figure 21.18 Problem 17.
Figure 21.19 Problem 18.
Figure 21.20 Problem 20.
Figure 21.21 Problem 22.
Figure 21.22 Problem 23.
Figure 21.23 Problem 29.

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Figure 21.24 Problem 32.
Figure 21.25 Problem 34.
Figure 21.26 Problem 35.
Figure 21.27 Problem 38.
Figure 21.28 Problem 39.
Figure 21.29 Problems 42 and 43.
Figure 21.30 Problem 46.
Figure 21.31 Problem 48.
Figure 21.32 Problem 50.
Figure 21.33 Problem 60.
Figure 21.34 Problem 62.
Figure 21.35 Problem 68.
Figure 21.36 Problem 72.

CHAPTER 22

Figure 22.1.1 How does charged particle 2 push on charged particle 1 when they have no contact...
Figure 22.1.2 (*a*) A positive test charge q_0 placed at point *P* near a charged object. An electr...
Figure 22.1.3 (*a*) The electrostatic force acting on a positive test charge near a sphere of ...
Figure 22.1.4 (*a*) The force on a positive test charge near a very large, nonconducting sheet w...
Figure 22.1.5 Field lines for two particles with equal positive charge. Doesn't the pattern it...
Figure 22.2.1 The electric field vectors at various points around a positive point charge.
Figure 22.2.2 (*a*) Three particles with charges q_1, q_2, and $q_3$are at the same distance *d* from t...
Figure 22.3.1 The pattern of electric field lines around an electric dipole, with an electric ...
Figure 22.3.2 (*a*) An electric dipole. The electric field vectors and at point *P* on...
Figure 22.3.3 (*a*) Photograph of a sprite. (*b*) Lightning in which a large amount of negative ch...
Figure 22.4.1 A ring of uniform positive charge. A differential element of charge occupies a l...
Figure 22.4.2 The electric fields set up at *P* by a charge element and its symmetric partner (o...
Figure 22.4.3 Available in *WileyPLUS* as an animation with voiceover. (*a*) A plastic rod of char...
Figure 22.4.4 (*a*) Point *P* is on an extension of the line of charge. (*b*) *P* is on a line of sym...
Figure 22.5.1 A disk of radius *R* and uniform positive charge. The ring shown has radius *r* and ...
Figure 22.6.1 The Millikan oil-drop apparatus for measuring the elementary charge *e*. When a ch...
Figure 22.6.2 Ink-jet printer. Drops shot from generator *G* receive a charge in charging unit *C*....
Figure 22.6.3 The metal wires are so charged that the electric fields they produce in the surr...
Figure 22.6.4 An ink drop of mass *m* and charge magnitude *Q* is deflected in the electric field ...
Figure 22.7.1 A molecule of H^{2}O, showing the three nuclei (represented by dots) and the region...
Figure 22.7.2 (*a*) An electric dipole in a uniform external electric field ...
Figure 22.7.3 A group of three water molecules. A torque due to an oscillating electric field ...
Figure 22.1 Question 1.
Figure 22.2 Question 2.
Figure 22.3 Question 3.
Figure 22.4 Question 4.
Figure 22.5 Question 5.
Figure 22.6 Question 6.
Figure 22.7 Question 9.
Figure 22.8 Question 10.
Figure 22.9 Question 11.
Figure 22.10 Question 12.
Figure 22.11 Question 13.

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Figure 22.12 Question 14.
Figure 22.13 Problem 2.
Figure 22.14 Problem 7.
Figure 22.15 Problem 8.
Figure 22.16 Problem 9.
Figure 22.17 Problem 10.
Figure 22.18 Problem 12.
Figure 22.19 Problem 13.
Figure 22.20 Problem 14.
Figure 22.21 Problem 15.
Figure 22.22 Problem 16.
Figure 22.23 Problem 17.
Figure 22.24 Problem 19.
Figure 22.25 Problem 21.
Figure 22.26 Problem 23.
Figure 22.27 Problem 24.
Figure 22.28 Problem 25.
Figure 22.29 Problem 26.
Figure 22.30 Problem 27.
Figure 22.31 Problem 29.
Figure 22.32 Problem 30.
Figure 22.33 Problem 31.
Figure 22.34 Problem 32.
Figure 22.35 Problem 33.
Figure 22.36 Problem 37.
Figure 22.37 Problem 38.
Figure 22.38 Problem 48.
Figure 22.39 Problem 53.
Figure 22.40 Problem 54.
Figure 22.41 Problem 58.
Figure 22.42 Problem 60.
Figure 22.43 Problem 65.
Figure 22.44 Problem 68.
Figure 22.45 Problem 75.
Figure 22.46 Problem 76.
Figure 22.47 Problem 81.
Figure 22.48 Problem 82.
Figure 22.49 Problem 84.

CHAPTER 23

Figure 23.1.1 Electric field vectors and field lines pierce an imaginary, spherical Gaussian s...
Figure 23.1.2 Now the enclosed particle has charge +2*Q*.
Figure 23.1.3 Can you tell what the enclosed charge is now?
Figure 23.1.4 (*a*) An electric field vector pierces a small square patch on a flat surface. (*b*)...
Figure 23.1.5 A Gaussian surface of arbitrary shape immersed in an electric field. The surface...
Figure 23.1.6 A cylindrical Gaussian surface, closed by end caps, is immersed in a uniform ele...
Figure 23.1.7 (*a*) A Gaussian cube with one edge on the *x* axis lies within a nonuniform electri...
Figure 23.2.1 Two charges, equal in magnitude but opposite in sign, and the field lines that r...
Figure 23.2.2 A spherical Gaussian surface centered on a particle with charge *q*.

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 23.2.3 (*a*) A charged plastic spherical shell encloses a charged particle. (*b*) To find t...

Figure 23.3.1 (*a*) A lump of copper with a charge *q* hangs from an insulating thread. A Gaussian...

Figure 23.3.2 (*a*) Perspective view and (*b*) side view of a tiny portion of a large, isolated co...

Figure 23.3.3 (*a*) A negatively charged particle is located within a spherical metal shell that...

Figure 23.4.1 A Gaussian surface in the form of a closed cylinder surrounds a section of a ver...

Figure 23.4.2 Lightning strikes tree. Because the tree was wet, most of the charge traveled th...

Figure 23.5.1 (*a*) Perspective view and (*b*) side view of a portion of a very large, thin plasti...

Figure 23.5.2 (*a*) A thin, very large conducting plate with excess positive charge. (*b*) An iden...

Figure 23.5.3 (*a*) Two large, parallel sheets, uniformly charged on one side. (*b*) The individua...

Figure 23.6.1 A thin, uniformly charged, spherical shell with total charge *q*, in cross section...

Figure 23.6.2 The dots represent a spherically symmetric distribution of charge of radius *R*, w...

Figure 23.1 Question 2.

Figure 23.2 Question 3.

Figure 23.3 Question 4.

Figure 23.4 Question 5.

Figure 23.5 Question 7.

Figure 23.6 Question 8.

Figure 23.7 Question 11.

Figure 23.8 Question 12.

Figure 23.9 Problem 1.

Figure 23.10 Problems 3, 6, and 9.

Figure 23.11 Problem 4.

Figure 23.12 Problem 5.

Figure 23.13 Problem 10.

Figure 23.14 Problem 11.

Figure 23.15 Problem 12.

Figure 23.16 Problem 14.

Figure 23.17 Problem 16.

Figure 23.18 Problem 20.

Figure 23.19 Problem 24.

Figure 23.20 Problem 26.

Figure 23.21 Problem 29.

Figure 23.22 Problem 30.

Figure 23.23 Problem 33.

Figure 23.24 Problem 34.

Figure 23.25 Problem 35.

Figure 23.26 Problem 36.

Figure 23.27 Problem 38.

Figure 23.28 Problem 39.

Figure 23.29 Problem 40.

Figure 23.30 Problem 43.

Figure 23.31 Problem 44.

Figure 23.32 Problem 48.

Figure 23.33 Problem 49.

Figure 23.34 Problem 50.

Figure 23.35 Problem 51.

Figure 23.36 Problem 52.

Figure 23.37 Problem 54.

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 23.38 Problem 69.
Figure 23.39 Problem 73.
Figure 23.40 Problem 75.

CHAPTER 24

Figure 24.1.1 Particle 1 is located at point *P* in the electric field of particle 2.
Figure 24.1.2 (*a*) A test charge has been brought in from infinity to point *P* in the electric f...
Figure 24.1.3 (*a*) A positive muon begins a trip to Earth's surface from the upper atmosphere a...
Figure 24.2.1 Portions of four equipotential surfaces at electric potentials V_1 = 100 V, V_2 = ...
Figure 24.2.2 Electric field lines (purple) and cross sections of equipotential surfaces (gold...
Figure 24.2.3 A test charge q_0 moves from point *i* to point *f* along the path shown in a nonunif...
Figure 24.2.4 We move between points *i* and *f*, between adjacent equipotential lines in a unifor...
Figure 24.2.5 (*a*) A test charge q_0 moves in a straight line from point *i* to point *f*, along the...
Figure 24.3.1 The particle with positive charge *q* produces an electric field and an electri...
Figure 24.3.2 A computer-generated plot of the electric potential *V*(*r*) due to a positively cha...
Figure 24.3.3 (*a*) Four charged particles. (*b*) The closed curve is a (roughly drawn) cross sect...
Figure 24.3.4 (*a*) Twelve electrons uniformly spaced around a circle. (*b*) The electrons nonunif...
Figure 24.4.1 (*a*) Point *P* is a distance *r* from the midpoint *O* of a dipole. The line *OP* makes a...
Figure 24.4.2 (*a*) An atom, showing the positively charged nucleus (green) and the negatively c...
Figure 24.5.1 (*a*) A thin, uniformly charged rod produces an electric potential *V* at point *P*. (...
Figure 24.5.2 A plastic disk of radius *R*, charged on its top surface to a uniform surface char...
Figure 24.6.1 A test charge q_0 moves a distance from one equipotential surface to another....
Figure 24.7.1 Two charges held a fixed distance *r* apart.
Figure 24.7.2 Three charges are fixed at the vertices of an equilateral triangle. What is the ...
Figure 24.7.3 An alpha particle, traveling head-on toward the center of a gold nucleus, comes ...
Figure 24.8.1 (*a*) A plot of *V*(*r*) both inside and outside a charged spherical shell of radius 1...
Figure 24.8.2 A large spark jumps to a car's body and then exits by moving across the insulati...
Figure 24.8.3 The static wicks continuously discharge to the air to avoid the airplane becomin...
Figure 24.8.4 An uncharged conductor is suspended in an external electric field. The free elec...
Figure 24.1 Question 1.
Figure 24.2 Question 2.
Figure 24.3 Questions 3 and 9.
Figure 24.4 Question 4.
Figure 24.5 Question 5.
Figure 24.6 Question 6.
Figure 24.7 Questions 7 and 8.
Figure 24.8 Question 10.
Figure 24.9 Question 11.
Figure 24.10 Question 12.
Figure 24.11 Problem 6.
Figure 24.12 Problem 8.
Figure 24.13 Problem 14.
Figure 24.14 Problem 16.
Figure 24.15 Problem 17.
Figure 24.16 Problem 18.
Figure 24.17 Problems 19and 20.
Figure 24.18 Problem 22.
Figure 24.19 Problem 23.

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Figure 24.20 Problem 24.
Figure 24.21 Problem 25.
Figure 24.22 Problem 26.
Figure 24.23 Problem 27.
Figure 24.24 Problems 28, 33, 38, and 40.
Figure 24.25 Problem 29.
Figure 24.26 Problem 30.
Figure 24.27 Problem 31.
Figure 24.28 Problem 39.
Figure 24.29 Problem 43.
Figure 24.30 Problem 44.
Figure 24.31 Problem 50.
Figure 24.32 Problem 51.
Figure 24.33 Problem 52.
Figure 24.34 Problem 54.
Figure 24.35 Problem 56.
Figure 24.36 Problem 58.
Figure 24.37 Problem 59.
Figure 24.38 Problem 60.
Figure 24.39 Problem 74.
Figure 24.40 Problem 78.
Figure 24.41 Problem 80.
Figure 24.42 Problem 81.
Figure 24.43 Problem 83.
Figure 24.44 Problem 85.
Figure 24.45 Problem 86.
Figure 24.46 Problem 88.
Figure 24.47 Problem 92.
Figure 24.48 Problem 95.
Figure 24.48 Problem 98.

CHAPTER 25

Figure 25.1.1 An assortment of capacitors.
Figure 25.1.2 Two conductors, isolated electrically from each other and from their surrounding...
Figure 25.1.3 (*a*) A parallel-plate capacitor, made up of two plates of area *A* separated by a d...
Figure 25.1.4 (*a*) Battery B, switch S, and plates *h* and *l* of capacitor C, connected in a circu...
Figure 25.2.1 A charged parallel-plate capacitor. A Gaussian surface encloses the charge on th...
Figure 25.2.2 A cross section of a long cylindrical capacitor, showing a cylindrical Gaussian ...
Figure 25.2.3 (*a*) A battery and capacitor circuit. (*b*) The lower capacitor plate.
Figure 25.3.1 (*a*) Three capacitors connected in parallel to battery B. The battery maintains p...
Figure 25.3.2 (*a*) Three capacitors connected in series to battery B. The battery maintains pot...
Figure 25.3.3 (*a*)–(*d*) Three capacitors are reduced to one equivalent capacitor. (*e*)–(*i*) Workin...
Figure 25.3.4 A potential difference V_0 is applied to capacitor 1 and the charging battery is ...
Figure 25.4.1 The result of a grain explosion.
Figure 25.4.2 (*a*) A hyperbaric chamber. (*b*) A gurney and the chamber's metal framework form a ...
Figure 25.5.1 The simple electrostatic apparatus used by Faraday. An assembled apparatus (seco...
Figure 25.5.2 (*a*) If the potential difference between the plates of a capacitor is maintained,...
Figure 25.5.3 (*a*) Molecules with a permanent electric dipole moment, showing their random orie...
Figure 25.5.4 (*a*) A nonpolar dielectric slab. The circles represent the electrically neutral a...

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Figure 25.6.1 (*a*) A parallel-plate capacitor (*a*) without and (*b*) with a dielectric slab inserted...

Figure 25.6.2 A parallel-plate capacitor containing a dielectric slab that only partially fill...

Figure 25.1 Question 1.

Figure 25.2 Question 3.

Figure 25.3 Question 4.

Figure 25.4 Question 7.

Figure 25.5 Question 8.

Figure 25.6 Question 10.

Figure 25.7 Problem 1.

Figure 25.8 Problem 2.

Figure 25.9 Problem 7.

Figure 25.10 Problem 9.

Figure 25.11 Problems 10 and 34.

Figure 25.12 Problems 11, 17, and 38.

Figure 25.13 Problem 14.

Figure 25.14 Problem 15.

Figure 25.15 Problem 16.

Figure 25.16 Problem 18.

Figure 25.17 Problem 19.

Figure 25.18 Problem 20.

Figure 25.19 Problem 21.

Figure 25.20 Problem 22.

Figure 25.21 Problem 23.

Figure 25.22 Problem 24.

Figure 25.23 Problem 25.

Figure 25.24 Problem 26.

Figure 25.25 Problem 27.

Figure 25.26 Problem 28.

Figure 25.27 Problem 36.

Figure 25.28 Problem 39.

Figure 25.29 Problem 46.

Figure 25.30 Problem 48.

Figure 25.31 Problem 49.

Figure 25.32 Problem 50.

Figure 25.33 Problem 56.

Figure 25.34 Problem 57.

Figure 25.35 Problem 58.

Figure 25.36 Problem 59.

Figure 25.37 Problem 61.

Figure 25.38 Problem 68.

Figure 25.39 Problem 69.

Figure 25.40 Problem 70.

Figure 25.41 Problem 71.

CHAPTER 26

Figure 26.1.1 (*a*) A loop of copper in electrostatic equilibrium. The entire loop is at a singl...

Figure 26.1.2 The current *i* through the conductor has the same value at planes *aa*′, *bb*′, and *c*...

Figure 26.1.3 The relation $i_0 = i_1 + i_2$ is true at junction *a* no matter what the orientation i...

Figure 26.2.1 Streamlines representing current density in the flow of charge through a constri...

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Figure 26.2.2 Positive charge carriers drift at speed v_d in the direction of the applied elect...
Figure 26.2.3 (*a*) Cross section of a wire of radius *R*. If the current density is uniform, the ...
Figure 26.3.1 An assortment of resistors. The circular bands are color-coding marks that ident...
Figure 26.3.2 Two ways of applying a potential difference to a conducting rod. The gray connec...
Figure 26.3.3 A potential difference *V* is applied between the ends of a wire of length *L* and c...
Figure 26.3.4 The resistivity of copper as a function of temperature. The dot on the curve mar...
Figure 26.3.5 (*a*) Current from a lightning strike spreads hemispherically through the ground a...
Figure 26.4.1 (*a*) A potential difference *V* is applied to the terminals of a device, establishi...
Figure 26.4.2 The gray lines show an electron moving from *A* to *B*, making six collisions en rou...
Figure 26.5.1 A battery B sets up a current *i* in a circuit containing an unspecified conductin...
Figure 26.5.2 The resistance of mercury drops to zero at a temperature of about 4 K.

CHAPTER 27

Figure 27.1.1 A simple electric circuit, in which a device of emf $\mathscr{E}$ does work on the charge ca...
Figure 27.1.2 (*a*) In the circuit, $\mathscr{E}_B > \mathscr{E}_A$; so battery B determines the direction of the curren...
Figure 27.1.3 A single-loop circuit in which a resistance *R* is connected across an ideal batte...
Figure 27.1.4 (*a*) A single-loop circuit containing a real battery having internal resistance *r*...
Figure 27.1.5 (*a*) Three resistors are connected in series between points *a* and *b*. (*b*) An equiv...
Figure 27.1.6 Points *a* and *b*, which are at the terminals of a real battery, differ in potentia...
Figure 27.1.7 (*a*) Point *a* is directly connected to ground. (*b*) Point *b* is directly connected t...
Figure 27.1.8 (*a*) A single-loop circuit containing two real batteries and a resistor. The batt...
Figure 27.2.1 A multiloop circuit consisting of three branches: left-hand branch *bad*, right-ha...
Figure 27.2.2 (*a*) Three resistors connected in parallel across points *a* and *b*. (*b*) An equivale...
Figure 27.2.3 (*a*) A circuit with an ideal battery. (*b*) Label the currents. (*c*) Replacing the p...
Figure 27.2.4 (*a*) A model of the electric circuit of an eel in water. Along each of 140 rows e...
Figure 27.2.5 A multiloop circuit with three ideal batteries and five resistances.
Figure 27.3.1 A single-loop circuit, showing how to connect an ammeter (A) and a voltmeter (V)...
Figure 27.4.1 When switch S is closed on *a*, the capacitor is *charged* through the resistor. Whe...
Figure 27.4.2 (*a*) A plot of Eq. 27.4.4, which shows the buildup of charge on the capacitor of ...
Figure 27.4.3 (*a*) A charged car and the pavement acts like a capacitor that can discharge thro...
Figure 27.1 Questions 1 and 2.
Figure 27.2 Question 4.
Figure 27.3 Question 5.
Figure 27.4 Question 6.
Figure 27.5 Question 10.
Figure 27.6 Question 12.
Figure 27.7 Question 13.
Figure 27.8 Problem 1.
Figure 27.9 Problem 2.
Figure 27.10 Problem 4.
Figure 27.11 Problem 10.
Figure 27.12 Problem 11.
Figure 27.13 Problem 12.
Figure 27.14 Problem 13.
Figure 27.15 Problem 14.
Figure 27.16 Problem 17.
Figure 27.17 Problem 22.
Figure 27.18 Problem 23.
Figure 27.19 Problem 24.

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Figure 27.20 Problem 26.

Figure 27.21 Problem 27.

Figure 27.22 Problem 28.

Figure 27.23 Problem 29.

Figure 27.24 Problems 30, 41, and 88.

Figure 27.25 Problem 31.

Figure 27.26 Problem 32.

Figure 27.27 Problem 33.

Figure 27.28 Problem 34.

Figure 27.29 Problem 35.

Figure 27.30 Problem 36.

Figure 27.31 Problem 37.

Figure 27.32 Problem 38.

Figure 27.33 Problems 39 and 40.

Figure 27.34 Problem 40.

Figure 27.35 Problem 42.

Figure 27.36 Problems 44 and 48.

Figure 27.37 Problem 45.

Figure 27.38 Problem 46.

Figure 27.39 Problem 49.

Figure 27.40 Problem 50.

Figure 27.41 Problem 51.

Figure 27.42 Problem 52.

Figure 27.43 Problem 54.

Figure 27.44 Problem 55.

Figure 27.45 Problem 56.

Figure 27.46 Problems 57 and 96.

Figure 27.47 Problem 62.

Figure 27.48 Problem 63.

Figure 27.49 Problem 65.

Figure 27.50 Problem 66.

Figure 27.51 Problem 70.

Figure 27.52 Problem 71.

Figure 27.53 Problem 72.

Figure 27.54 Problem 74.

Figure 27.55 Problem 75. Wrist strap to discharge static electric charge.

Figure 27.56 Problem 76.

Figure 27.57 Problem 80.

Figure 27.58 Problem 84.

Figure 27.59 Problem 87.

Figure 27.60 Problem 89.

Figure 27.61 Problem 91.

Figure 27.62 Problem 92.

Figure 27.63 Problem 94.

Figure 27.64 Problem 97.

Figure 27.65 Problem 98.

Figure 27.66 Problem 100. (*a*) An eel leaping up to a volunteer’s arm in an experiment. (*b*) Ci...

Figure 27.67 Problem 101. A grounding cable runs from truck into post and then down into the...

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Email: ebookyab.ir@gmail.com, Phone:+989359542944 (Telegram, WhatsApp, Eitaa)

Figure 28.1.1 Using an electromagnet to collect and transport scrap metal at a steel mill.
Figure 28.1.2 (*a*)–(*c*) The right-hand rule (in which is swept into through the smaller an...
Figure 28.1.3 The tracks of two electrons (e$^-$) and a positron (e$^+$) in a bubble chamber that is...
Figure 28.1.4 (*a*) The magnetic field lines for a bar magnet. (*b*) A “cow magnet”—a bar magnet t...
Figure 28.1.5 (*a*) A horseshoe magnet and (*b*) a C-shaped magnet. (Only some of the external fie...
Figure 28.1.6 An overhead view of a proton moving from south to north with velocity in a ch...
Figure 28.2.1 A modern version of J. J. Thomson’s apparatus for measuring the ratio of mass to...
Figure 28.3.1 A strip of copper carrying a current *i* is immersed in a magnetic field . (*a*) T...
Figure 28.3.2 The essential features of the silent drive for ships and submarines.
Figure 28.3.3 The *Yamato-1* was a full-scale ship driven by the magnetohydrodynamic effect.
Figure 28.3.4 (*a*) A solid metal cube moves at constant velocity through a uniform magnetic fie...
Figure 28.4.1 Electrons circulating in a chamber containing gas at low pressure (their path is...
Figure 28.4.2 (*a*) A charged particle moves in a uniform magnetic field , the particle’s velo...
Figure 28.4.3 An aurora is a curtain of light that is produced by extraterrestrial electrons.
Figure 28.4.4 The *auroral oval* surrounding Earth’s geomagnetic north pole (which is currently ...
Figure 28.4.5 A positive ion is accelerated from its source *S* by a potential difference *V*, ent...
Figure 28.5.1 The elements of a cyclotron, showing the particle source *S* and the dees. A unifo...
Figure 28.5.2 Because it is invisible, a beam of neutrons from the portal at the right is alig...
Figure 28.6.1 A flexible wire passes between the pole faces of a magnet (only the farther pole...
Figure 28.6.2 A close-up view of a section of the wire of Fig. 28.6.1*b*. The current direction ...
Figure 28.6.3 A wire carrying current *i* makes an angle ϕ with magnetic field . The wire has ...
Figure 28.6.4 A wire (shown in cross section) carrying current out of the page.
Figure 28.7.1 The elements of an electric motor. A rectangular loop of wire, carrying a curren...
Figure 28.7.2 A rectangular loop, of length *a* and width *b* and carrying a current *i*, is located...
Figure 28.8.1 The orientations of highest and lowest energy of a magnetic dipole (here a coil ...
Figure 28.8.2 A side view of a circular coil carrying a current and oriented so that its magne...
Figure 28.1 Question 1.
Figure 28.2 Question 2.
Figure 28.3 Question 3.
Figure 28.4 Question 4.
Figure 28.5 Question 6.
Figure 28.6 Question 7.
Figure 28.7 Question 8.
Figure 28.8 Question 10.
Figure 28.9 Question 11.
Figure 28.10 Question 12.
Figure 28.11 Problem 9.
Figure 28.12 Problem 12.
Figure 28.13 Problem 14.
Figure 28.14 Problems 15 and 16.
Figure 28.15 Problem 18.
Figure 28.16 Problem 19.
Figure 28.17 Problem 20.
Figure 28.18 Problem 26.
Figure 28.19 Problem 30.
Figure 28.20 Problem 41.

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Figure 28.21 Problem 42.
Figure 28.22 Problem 44.
Figure 28.23 Problem 46.
Figure 28.24 Problem 49.
Figure 28.25 Problem 51.
Figure 28.26 Problem 52.
Figure 28.27 Problem 55.
Figure 28.28 Problem 60.
Figure 28.29 Problem 61.
Figure 28.30 Problem 62.
Figure 28.31 Problem 64.
Figure 28.32 Problem 72.
Figure 28.33 Problem 76.
Figure 28.34 Problem 77.
Figure 28.35 Problem 87.

CHAPTER 29

Figure 29.1.1 A current-length element produces a differential magnetic field at poi...
Figure 29.1.2 The magnetic field lines produced by a current in a long straight wire form conc...
Figure 29.1.3 Iron filings that have been sprinkled onto cardboard collect in concentric circl...
Figure 29.1.4 The magnetic field vector is perpendicular to the radial line extending from ...
Figure 29.1.5 A right-hand rule gives the direction of the magnetic field due to a current in ...
Figure 29.1.6 Calculating the magnetic field produced by a current *i* in a long straight wire. ...
Figure 29.1.7 (*a*) A wire in the shape of a circular arc with center *C* carries current *i*. (*b*) F...
Figure 29.1.8 MEG apparatus.
Figure 29.1.9 A pulse along a fissure wall on the brain surface produces a magnetic field at p...
Figure 29.1.10 (*a*) Two wires carry currents i_1 and i_2 in opposite directions (out of and into t...
Figure 29.2.1 Two parallel wires carrying currents in the same direction attract each other. ...
Figure 29.2.2 (*a*) A rail gun, as a current *i* is set up in it. The current rapidly causes the c...
Figure 29.3.1 Ampere's law applied to an arbitrary Amperian loop that encircles two long strai...
Figure 29.3.2 A right-hand rule for Ampere's law, to determine the signs for currents encircle...
Figure 29.3.3 Using Ampere's law to find the magnetic field that a current *i* produces outside ...
Figure 29.3.4 Using Ampere's law to find the magnetic field that a current *i* produces inside a...
Figure 29.3.5 (*a*)–(*b*) To find the magnetic field at a point within this conducting cylinder, w...
Figure 29.4.1 A solenoid carrying current *i*.
Figure 29.4.2 A vertical cross section through the central axis of a “stretched-out” solenoid....
Figure 29.4.3 Magnetic field lines for a real solenoid of finite length. The field is strong a...
Figure 29.4.4 Application of Ampere's law to a section of a long ideal solenoid carrying a cur...
Figure 29.4.5 (*a*) A toroid carrying a current *i*. (*b*) A horizontal cross section of the toroid....
Figure 29.5.1 A current loop produces a magnetic field like that of a bar magnet and thus has ...
Figure 29.5.2 Cross section through a current loop of radius *R*. The plane of the loop is perpe...
Figure 29.1 Question 1.
Figure 29.2 Question 2.
Figure 29.3 Question 3.
Figure 29.4 Question 4.
Figure 29.5 Question 5.
Figure 29.6 Question 6.
Figure 29.7 Question 7.
Figure 29.8 Question 8.

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Figure 29.9 Question 9.
Figure 29.10 Question 10.
Figure 29.11 Question 11.
Figure 29.12 Problem 2.
Figure 29.13 Problem 4.
Figure 29.14 Problem 5.
Figure 29.15 Problem 6.
Figure 29.16 Problem 7.
Figure 29.17 Problem 8.
Figure 29.18 Problem 10.
Figure 29.19 Problem 11.
Figure 29.20 Problem 12.
Figure 29.21 Problems 13 and 17.
Figure 29.22 Problem 15.
Figure 29.23 Problem 16.
Figure 29.24 Problem 18.
Figure 29.25 Problem 20.
Figure 29.26 Problem 21.
Figure 29.27 Problem 22.
Figure 29.28 Problem 23.
Figure 29.29 Problem 24.
Figure 29.30 Problem 25.
Figure 29.31 Problem 26.
Figure 29.32 Problem 27.
Figure 29.33 Problem 28.
Figure 29.34 Problems 29, 37 and 40.
Figure 29.35 Problem 30.
Figure 29.36 Problem 31.
Figure 29.37 Problem 32.
Figure 29.38 Problem 33.
Figure 29.39 Problem 34.
Figure 29.40 Problem 35.
Figure 29.41 Problems 36 and 39.
Figure 29.42 Problem 38.
Figure 29.43 Problem 41.
Figure 29.44 Problem 43.
Figure 29.45 Problem 44.
Figure 29.46 Problem 45.
Figure 29.47 Problem 46.
Figure 29.48 Problem 48.
Figure 29.49 Problems 56 and 87.
Figure 29.50 Problem 58.
Figure 29.51 Problem 60.
Figure 29.52 Problem 62.
Figure 29.53 Problem 63.
Figure 29.54 Problem 64.
Figure 29.55 Problem 69.
Figure 29.56 Problem 70.

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Figure 29.57 Problem 73.
Figure 29.58 Problem 75.
Figure 29.59 Problem 76.
Figure 29.60 Problem 77.
Figure 29.61 Problems 81 and 85.
Figure 29.62 Problem 82.
Figure 29.63 Problem 83.
Figure 29.64 Problem 86.
Figure 29.65 Problem 88.

CHAPTER 30

Figure 30.1.1 An ammeter registers a current in the wire loop when the magnet is moving with r...
Figure 30.1.2 An ammeter registers a current in the left-hand wire loop just as switch S is cl...
Figure 30.1.3 A coil C is located inside a solenoid S, which carries current *i*.
Figure 30.1.4 Lenz's law at work. As the magnet is moved toward the loop, a current is induced...
Figure 30.1.5 The direction of the current *i* induced in a loop is such that the current's magn...
Figure 30.1.6 A Fender® Stratocaster® guitar.
Figure 30.1.7 A side view of an electric guitar pickup. When the metal string (which acts like...
Figure 30.1.8 A battery is connected to a conducting loop that includes a half-circle of radiu...
Figure 30.1.9 A closed conducting loop, of width *W* and height *H*, lies in a nonuniform, varying...
Figure 30.2.1 You pull a closed conducting loop out of a magnetic field at constant velocity ...
Figure 30.2.2 A circuit diagram for the loop of Fig. 30.2.1 while the loop is moving.
Figure 30.2.3 A patient about to enter an MRI apparatus.
Figure 30.2.4 A probe attached to a finger of a patient undergoing an MRI scan, in which a ver...
Figure 30.2.5 (*a*) As you pull a solid conducting plate out of a magnetic field, *eddy currents* ...
Figure 30.2.6 Molten metal pouring from a tilted induction furnace.
Figure 30.2.7 Basic design of an induction furnace.
Figure 30.3.1 (*a*) If the magnetic field increases at a steady rate, a constant induced current...
Figure 30.3.2 A plot of the induced electric field $E(r)$.
Figure 30.5.1 If the current in a coil is changed by varying the contact position on a variabl...
Figure 30.5.2 (*a*) The current *i* is increasing, and the self-induced emf $\mathcal{E}_L$ appears along the c...
Figure 30.6.1 An *RL* circuit. When switch S is closed on *a*, the current rises and approaches a ...
Figure 30.6.2 The circuit of Fig. 30.6.1 with the switch closed on *a*. We apply the loop rule f...
Figure 30.6.3 The variation with time of (*a*) V_R, the potential difference across the resistor ...
Figure 30.6.4 (*a*) A multiloop *RL* circuit with an open switch. (*b*) The equivalent circuit just ...
Figure 30.9.1 Mutual induction. (*a*) The magnetic field produced by current i_1 in coil 1 ex...
Figure 30.1 Question 1.
Figure 30.2 Question 2.
Figure 30.3 Question 3.
Figure 30.4 Question 4.
Figure 30.5 Question 5.
Figure 30.6 Question 6.
Figure 30.7 Question 7.
Figure 30.8 Question 8.
Figure 30.9 Question 9.
Figure 30.10 Question 10.
Figure 30.11 Question 11.
Figure 30.12 Question 12.
Figure 30.13 Problem 1.

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Figure 30.14 Problem 3.

Figure 30.15 Problem 4.

Figure 30.16 Problem 5.

Figure 30.17 Problem 6.

Figure 30.18 Problem 7.

Figure 30.19 Problem 10.

Figure 30.20 Problem 11.

Figure 30.21 Problem 12.

Figure 30.22 Problem 14.

Figure 30.23 Problem 15.

Figure 30.24 Problem 16.

Figure 30.25 Problem 18.

Figure 30.26 Problem 21.

Figure 30.27 Problem 23.

Figure 30.28 Problem 24.

Figure 30.29 Problem 26.

Figure 30.30 Problem 27.

Figure 30.31 Problem 28.

Figure 30.32 Problems 29 and 35.

Figure 30.33 Problem 30.

Figure 30.34 Problem 33.

Figure 30.35 Problem 34.

Figure 30.36 Problem 36.

Figure 30.37 Problem 38.

Figure 30.38 Problem 42.

Figure 30.39 Problem 45.

Figure 30.40 Problem 46.

Figure 30.41 Problem 49.

Figure 30.42 Problem 54.

Figure 30.43 Problem 56,80, and 83.

Figure 30.44 Problems 56.

Figure 30.45 Problem 57.

Figure 30.46 Problem 59.

Figure 30.47 Problem 70.

Figure 30.48 Problem 75.

Figure 30.49 Problem 76.

Figure 30.50 Problem 77.

Figure 30.51 Problem 79.

Figure 30.52 Problem 81.

Figure 30.53 Problem 84.

Figure 30.54 Problem 85.

Figure 30.55 Problem 86.

Figure 30.56 Problem 91.

Figure 30.57 Problem 93.

Figure 30.58 Problem 95.

Figure 30.59 Problem 96.

Figure 30.60 Problem 98.

CHAPTER 31

Figure 31.1.1 Eight stages in a single cycle of oscillation of a resistanceless *LC* circuit. Th

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Figure 31.1.1 Eight stages in a single cycle of oscillation in a resistanceless *LC* circuit. In...
Figure 31.1.2 (*a*) The potential difference across the capacitor in the circuit of Fig. 31.1.1 ...
Figure 31.1.3 An oscilloscope trace showing how the oscillations in an *RLC* circuit actually di...
Figure 31.1.4 The stored magnetic energy and electrical energy in the circuit of Fig. 31.1.1 a...
Figure 31.2.1 A series *RLC* circuit. As the charge contained in the circuit oscillates back and...
Figure 31.3.1 The basic mechanism of an alternating-current generator is a conducting loop rot...
Figure 31.3.2 A single-loop circuit containing a resistor, a capacitor, and an inductor. A gen...
Figure 31.3.3 A resistor is connected across an alternating-current generator.
Figure 31.3.4 (*a*) The current i_R and the potential difference v_R across the resistor are plott...
Figure 31.3.5 A capacitor is connected across an alternating-current generator.
Figure 31.3.6 (*a*) The current in the capacitor leads the voltage by 90° (= $\pi/2$ rad). (*b*) A pha...
Figure 31.3.7 An inductor is connected across an alternating-current generator.
Figure 31.3.8 (*a*) The current in the inductor lags the voltage by 90° (= $\pi/2$ rad). (*b*) A phaso...
Figure 31.4.1 (*a*) A phasor representing the alternating current in the driven *RLC* circuit of F...
Figure 31.4.2 Phasor diagrams and graphs of the alternating emf $\mathcal{E}$ and current i for the driven...
Figure 31.4.3 *Resonance curves* for the driven *RLC* circuit of Fig. 31.3.2 with $L = 100\ \mu$H, C = ...
Figure 31.4.4 Memory devices to help sort out the series *RLC* resonance curve.
Figure 31.5.1 (*a*) A plot of sin θ versus θ. The average value over one cycle is zero. (*b*) A pl...
Figure 31.6.1 An ideal transformer (two coils wound on an iron core) in a basic transformer ci...
Figure 31.6.2 A solar flare erupts from the surface of the Sun.
Figure 31.6.3 An electrojet (current) in the ionosphere produces a magnetic field B_x through a...
Figure 31.1 Question 1.
Figure 31.2 Question 2.
Figure 31.3 Question 5.
Figure 31.4 Question 7.
Figure 31.5 Question 9.
Figure 31.6 Question 10.
Figure 31.7 Questions 11 and 12.
Figure 31.8 Question 13.
Figure 31.9 Problem 8.
Figure 31.10 Problem 17.
Figure 31.11 Problem 36.
Figure 31.12 Problem 38.
Figure 31.13 Problem 42.
Figure 31.14 Problem 48.
Figure 31.15 Problem 49.
Figure 31.16 Problem 56.
Figure 31.17 Problems 58 and 66.
Figure 31.18 Problem 61.
Figure 31.19 Problem 64.
Figure 31.20 Problem 77.
Figure 31.21 Problem 87.
Figure 31.22 Problem 92.
Figure 31.23 Problem 93.

CHAPTER 32

Figure 32.1.1 Some of the inks used for tattoos contain magnetic particles.
Figure 32.1.2 A bar magnet is a magnetic dipole. The iron filings suggest the magnetic field l...
Figure 32.1.3 If you break a magnet, each fragment becomes a separate magnet, with its own nor...

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Figure 32.1.4 The field lines for the magnetic field of a short bar magnet. The red curves ...
Figure 32.2.1 (*a*) A circular parallel-plate capacitor, shown in side view, is being charged by...
Figure 32.2.2 A uniform magnetic field in a circular region. The field, directed into the p...
Figure 32.3.1 (*a*) Before and (*d*) after the plates are charged, there is no magnetic field. (*b*)...
Figure 32.4.1 Earth's magnetic field represented as a dipole field. The dipole axis *MM* makes a...
Figure 32.4.2 A magnetic profile of the seafloor on either side of the Mid-Atlantic Ridge. The...
Figure 32.5.1 The spin , spin magnetic dipole moment , and magnetic dipole field of an...
Figure 32.5.2 An electron moving at constant speed *v* in a circular path of radius *r* that enclo...
Figure 32.5.3 (*a*) A loop model for an electron orbiting in an atom while in a nonuniform magne...
Figure 32.6.1 An overhead view of a frog that is being levitated in a magnetic field produced ...
Figure 32.7.1 A *magnetization curve* for potassium chromium sulfate, a paramagnetic salt. The r...
Figure 32.8.1 A Rowland ring. A primary coil P has a core made of the ferromagnetic material t...
Figure 32.8.2 A magnetization curve for a ferromagnetic core material in the Rowland ring of F...
Figure 32.8.3 A photograph of domain patterns within a single crystal of nickel; white lines r...
Figure 32.8.4 The red pigments in the murals in the Vatican have been used to determine the di...
Figure 32.8.5 Overhead view of a cross section of a thin layer of paint lifted from a mural wi...
Figure 32.8.6 A magnetization curve (*ab*) for a ferromagnetic specimen and an associated hyster...
Figure 32.1 Question 1.
Figure 32.2 Question 2.
Figure 32.3 Question 3.
Figure 32.4 Question 4.
Figure 32.5 Question 7.
Figure 32.6 Questions 8, 9, and 10.
Figure 32.7 Question 11.
Figure 32.8 Question 12.
Figure 32.9 Problem 2.
Figure 32.10 Problem 4.
Figure 32.11 Problem 6.
Figure 32.12 Problems 7 to 10 and 19 to 22.
Figure 32.13 Problem 18.
Figure 32.14 Problem 23.
Figure 32.15 Problem 24.
Figure 32.16 Problem 27.
Figure 32.17 Problem 28.
Figure 32.18 Problem 29.
Figure 32.19 Problem 32.
Figure 32.20 Problem 37.
Figure 32.21 Problem 44.
Figure 32.22 Problem 60.
Figure 32.23 Problem 66.
Figure 32.24 Problem 67.
Figure 32.25 Problem 69.
Figure 32.26 Problem 70.
Figure 32.27 Problem 73.
Figure 32.28 Problem 74.

CHAPTER 33

Figure 33.1.1 The electromagnetic spectrum.

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Figure 33.1.2 The relative sensitivity of the average human eye to electromagnetic waves at di...
Figure 33.1.3 An arrangement for generating a traveling electromagnetic wave in the shortwave ...
Figure 33.1.4 (*a*)–(*h*) The variation in the electric field and the magnetic field at the ...
Figure 33.1.5 (*a*) An electromagnetic wave represented with a ray and two wavefronts; the wavef...
Figure 33.1.6 As the electromagnetic wave travels rightward past point *P* in Fig. 33.1.5*b*, the ...
Figure 33.1.7 The sinusoidal variation of the electric field through this rectangle, located (...
Figure 33.2.1 A point source *S* emits electromagnetic waves uniformly in all directions. The sp...
Figure 33.4.1 (*a*) The plane of oscillation of a polarized electromagnetic wave. (*b*) To represe...
Figure 33.4.2 (*a*) Unpolarized light consists of waves with randomly directed electric fields. ...
Figure 33.4.3 Unpolarized light becomes polarized when it is sent through a polarizing sheet. ...
Figure 33.4.4 Polarized light approaching a polarizing sheet. The electric field of the lig...
Figure 33.4.5 The light transmitted by polarizing sheet P_1 is vertically polarized, as represe...
Figure 33.4.6 (*a*) Overlapping polarizing sheets transmit light fairly well when their polarizi...
Figure 33.4.7 (*a*) Initially unpolarized light of intensity I_0 is sent into a system of three p...
Figure 33.5.1 (*a*) A photograph showing an incident beam of light reflected and refracted by a ...
Figure 33.5.2 Refraction of light traveling from a medium with an index of refraction n_1 into ...
Figure 33.5.3 The index of refraction as a function of wavelength for fused quartz. The graph ...
Figure 33.5.4 Chromatic dispersion of white light. The blue component is bent more than the re...
Figure 33.5.5 (*a*) A triangular prism separating white light into its component colors. (*b*) Chr...
Figure 33.5.6 (*a*) The separation of colors when sunlight refracts into and out of falling rain...
Figure 33.5.7 (*a*) Light reflects and refracts at point *A* on the interface between materials 1 ...
Figure 33.6.1 (*a*) Total internal reflection of light from a point source *S* in glass occurs for...
Figure 33.6.2 An endoscope used to inspect an artery.
Figure 33.6.3 The da Vinci surgical instrument from Intuitive Surgical Inc. for a single-port ...
Figure 33.6.4 Light entering the top of a brilliant-cut diamond. Can the light leak from the b...
Figure 33.7.1 A ray of unpolarized light in air is incident on a glass surface at the Brewster...
Figure 33.1 Question 2.
Figure 33.2 Question 3.
Figure 33.3 Question 4.
Figure 33.4 Question 6.
Figure 33.5 Question 7.
Figure 33.6 Question 8.
Figure 33.7 Question 9.
Figure 33.8 Question 10.
Figure 33.9 Question 11.
Figure 33.10 Question 12.
Figure 33.11 Problem 16. Radio telescope at Arecibo.
Figure 33.12 Problem 18.
Figure 33.13 Problem 26.
Figure 33.14 Problem 31.
Figure 33.15 Problems 32 and 33.
Figure 33.16 Problems 34, 35, and 42.
Figure 33.17 Problems 38, 40, and 44.
Figure 33.18 Problem 38.
Figure 33.19 Problem 40.
Figure 33.21 Problem 45.
Figure 33.22 Problem 46.

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Figure 33.23 Problem 48.
Figure 33.24 Problem 49.
Figure 33.25 Problem 50.
Figure 33.26 Problem 51.
Figure 33.27 Problem 52.
Figure 33.28 Problems 53 and 64.
Figure 33.29 Problem 54.
Figure 33.30 Problem 55.
Figure 33.31 Problem 56.
Figure 33.32 Problem 59.
Figure 33.33 Problem 60.
Figure 33.34 Problem 61.
Figure 33.35 Problem 63.
Figure 33.36 Problem 65.
Figure 33.37 Problem 66.
Figure 33.38 Problem 67.
Figure 33.39 Problem 70.
Figure 33.40 Problem 75.
Figure 33.41 Problem 76.
Figure 33.42 Problem 77.
Figure 33.43 Problem 78.
Figure 33.44 Problem 79.
Figure 33.45 Problem 82.
Figure 33.46 Problem 90.
Figure 33.47 Problem 91.
Figure 33.48 Problem 94.
Figure 33.49 Problem 95.

CHAPTER 34

Figure 34.1.1 (*a*) A ray from a low section of the sky refracts through air that is heated by a...
Figure 34.1.2 A point source of light *O*, called the *object*, is a perpendicular distance *p* in f...
Figure 34.1.3 Two rays Fig 34.1.2. Ray *Oa* makes an arbitary angles θ with the normal to the mi...
Figure 34.1.4 A “pencil” of rays from *O* enters the eye after reflection at the mirror. Only a ...
Figure 34.1.5 An extended object *O* and its virtual image *I* in a plane mirror.
Figure 34.1.6 A maze of mirrors.
Figure 34.1.7 (*a*) Overhead view of a mirror maze. A ray from mirror *B* reaches you at *O* by refl...
Figure 34.2.1 (*a*) An object *O* forms a virtual image *I* in a plane mirror. (*b*) If the mirror is ...
Figure 34.2.2 A *crossover mirror* allows a truck or bus driver to see a pedestrian in the blind...
Figure 34.2.3 (*a*) In a concave mirror, incident parallel light rays are brought to a real focu...
Figure 34.2.3 (*a*) An object *O* inside the focal point of a concave mirror, and its virtual imag...
Figure 34.2.5 (*a,b*) Four rays that may be drawn to find the image formed by a concave mirror. ...
Figure 34.2.6 Blinding light reflections from the Walkie Talkie building in London.
Figure 34.2.7 Air-puff tonometer being used to measure interocular pressure in testing for gla...
Figure 34.2.8 (*a*) The reflections of light back to the light meter in the tonometer are spread...
Figure 34.3.1 Six possible ways in which an image can be formed by refraction through a spheri...
Figure 34.3.2 The fish that can see both above and below water.
Figure 34.3.3 A cross section of the eye that can see both above and below water.
Figure 34.4.1 (*a*) Rays initially parallel to the central axis of a converging lens are made to...
Figure 34.4.2 (*a*) A real, inverted image *I* is formed by a converging lens when the object *O* is...

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Figure 34.4.3 Three special rays allow us to locate an image formed by a thin lens whether the...
Figure 34.4.4 Several sketches (not to scale) of a two-lens system in which an object sits to ...
Figure 34.4.5 (*a*) Seed O_1 is distance p_1 from a two-lens system with lens separation *L*. We use...
Figure 34.5.1 (*a*) An object *O* of height *h* placed at the near point of a human eye occupies ang...
Figure 34.5.2 A thin-lens representation of a compound microscope (not to scale). The objectiv...
Figure 34.5.3 (*a*) A thin-lens representation of a refracting telescope. From rays that are app...
Figure 34.5.4 Headgear for optical imaging of the brain.
Figure 34.6.1 A concave spherical mirror forms a real point image *I* by reflecting light rays f...
Figure 34.6.2 A real point image *I* of a point object *O* is formed by refraction at a spherical ...
Figure 34.6.3 (*a*) Two rays from point object O' form a real image I'' after refracting through ...
Figure 34.1 Question 1.
Figure 34.2 Questions 2 and 10.
Figure 34.3 Question 3.
Figure 34.4 Questions 6 and 8.
Figure 34.5 Question 7.
Figure 34.6 Question 9.
Figure 34.7 Question 11.
Figure 34.8 Problem 3.
Figure 34.9 Problem 4.
Figure 1.1.1 Problem 5.
Figure 34.11 Problem 6.
Figure 34.12 Problem 8.
Figure 34.13 Problem 30.
Figure 34.14 Problem 39.
Figure 34.15 Problem 40.
Figure 34.16 Problem 42.
Figure 34.17 Problem 44.
Figure 34.18 Problem 46.
Figure 34.19 Problem 48.
Figure 34.20 Problem 68.
Figure 34.12 Problem 80 through 87.
Figure 34.22 Problem 90.
Figure 34.23 Problem 91.
Figure 34.24 Problem 94.
Figure 34.25 Problem 95 through 100.
Figure 34.26 Problem 102.
Figure 34.27 Problem 105.
Figure 34.28 Problem 106.
Figure 34.29 Problem 108.
Figure 34.30 Problem 109.
Figure 34.31 Problem 110.
Figure 34.32 Problem 111.
Figure 34.33 Problem 112.

CHAPTER 35

Figure 35.1.1 The blue of the top surface of a *Morpho* butterfly wing is due to optical interfe...
Figure 35.1.2 The propagation of a plane wave in vacuum, as portrayed by Huygens' principle.
Figure 35.1.3 The refraction of a plane wave at an air–glass interface, as portrayed by Huygen...
Figure 35.1.4 Two light rays travel through two media having different indexes of refraction.

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Figure 35.1.5 A primary rainbow and the faint supernumeraries below it are due to optical inte...
Figure 35.2.1 Waves produced by an oscillating paddle at the left flare out through an opening...
Figure 35.2.2 Diffraction represented schematically. For a given wavelength λ, the diffraction...
Figure 35.2.3 In Young's interference experiment, incident monochromatic light is diffracted b...
Figure 35.2.4 A photograph of the interference pattern produced by the arrangement shown in Fi...
Figure 35.2.5 (*a*) Waves from slits S_1 and S_2 (which extend into and out of the page) combine a...
Figure 35.3.1 A plot of Eq. 35.3.3, showing the intensity of a double-slit interference patter...
Figure 35.3.2 (*a*) Phasors representing, at time t, the electric field components given by Eqs....
Figure 35.3.3 Three phasors, representing waves with equal amplitudes E_0 and with phase consta...
Figure 35.4.1 Light waves, represented with ray i, are incident on a thin film of thickness L ...
Figure 35.4.2 Phase changes when a pulse is reflected at the interface between two stretched s...
Figure 35.4.3 Reflections from a thin film in air.
Figure 35.4.4 The reflection of light from a soapy water film spanning a vertical loop. The to...
Figure 35.4.5 Reflecting structure extending up from a *Morpho* butterfly wing. Reflections from...
Figure 35.4.6 Color-shifting ink is used for the number at the lower right.
Figure 35.4.7 (*a*) Color-shifting ink on a paper currency consists of multilayered thin-film fl...
Figure 35.4.8 Unwanted reflections from glass can be suppressed (at a chosen wavelength) by co...
Figure 35.4.9 (*a*) Red light is incident on a thin, air-filled wedge in the side of a transpare...
Figure 35.5.1 Michelson's interferometer, showing the path of light originating at point P of ...
Figure 35.5.2 The squeezing and stretching of space due to a gravitational wave.
Figure 35.5.3 The LIGO facility at Livingston, Louisiana. One arm extends leftward in the phot...
Figure 35.1 Question 3.
Figure 35.2 Question 4.
Figure 35.3 Question 6.
Figure 35.4 Question 7.
Figure 35.5 Question 8.
Figure 35.6 Question 10.
Figure 35.7 Question 11.
Figure 35.8 Question 12.
Figure 35.9 Question 13.
Figure 35.10 Problems 1 and 2.
Figure 35.11 Problem 4.
Figure 35.12 Problem 8.
Figure 35.13 Problem 10.
Figure 35.14 Problems 12 and 98.
Figure 35.15 Problem 13.
Figure 35.16 Problems 17 and 22.
Figure 35.17 Problem 23.
Figure 35.18 Problem 24.
Figure 35.19 Problems 25, 28, and 102.
Figure 35.20 Problem 28.
Figure 35.21 Problems 41 through 52.
Figure 35.22 Problems 57 through 68.
Figure 35.23 Problem 69.
Figure 35.24 Problems 70–74.
Figure 35.25 Problems 75–77.
Figure 35.26 Problem 78.
Figure 35.27 Problem 81.

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Figure 35.28 Problem 83.
Figure 35.29 Problem 84.
Figure 35.30 Problems 86 and 87.
Figure 35.31 Problem 87.
Figure 35.32 Problem 89.
Figure 35.33 Problem 90.
Figure 35.34 Problem 91.
Figure 35.35 Problem 92.
Figure 35.36 Problem 94.
Figure 35.37 Problem 99.
Figure 35.38 Problem 101.

CHAPTER 36

Figure 36.1.1 This diffraction pattern appeared on a viewing screen when light that had passed...
Figure 36.1.2 The diffraction pattern produced by a razor blade in monochromatic light. Note t...
Figure 36.1.3 A photograph of the diffraction pattern of a disk. Note the concentric diffracti...
Figure 36.1.4 Waves from the top points of two zones of width $a/2$ undergo fully destructive in...
Figure 36.1.5 For $D \gg a$, we can approximate rays r_1 and r_2 as being parallel, at angle θ to th...
Figure 36.1.6 (*a*) Waves from the top points of four zones of width $a/4$ undergo fully destructi...
Figure 36.2.1 Phasor diagrams for $N = 18$ phasors, corresponding to the division of a single sl...
Figure 36.2.2 The relative intensity in single-slit diffraction for three values of the ratio ...
Figure 36.2.3 A construction used to calculate the intensity in single-slit diffraction. The s...
Figure 36.3.1 The diffraction pattern of a circular aperture. Note the central maximum and the...
Figure 36.3.2 At the top, the images of two point sources formed by a converging lens. At the ...
Figure 36.3.3 The pointillistic painting *The Seine at Herblay* by Maximilien Luce consists of t...
Figure 36.3.4 (*a*) Representation of some dots on a pointillistic painting, showing an average ...
Figure 36.3.5 Light from two distant point objects P_1 and P_2 passes through a converging lens ...
Figure 36.4.1 (*a*) The intensity plot to be expected in a double-slit interference experiment w...
Figure 36.4.2 (*a*) Interference fringes for an actual double-slit system; compare with Fig. 36....
Figure 36.4.3 One side of the intensity plot for a two-slit interference experiment. The inset...
Figure 36.5.1 An idealized diffraction grating, consisting of only five rulings, that produces...
Figure 36.5.2 (*a*) The intensity plot produced by a diffraction grating with a great many rulin...
Figure 36.5.3 The rays from the rulings in a diffraction grating to a distant point *P* are appr...
Figure 36.5.4 The half-width $\Delta\theta_{hw}$ of the central line is measured from the center of that line...
Figure 36.5.5 The top and bottom rulings of a diffraction grating of *N* rulings are separated b...
Figure 36.5.6 A simple type of grating spectroscope used to analyze the wavelengths of light e...
Figure 36.5.7 The zeroth, first, second, and fourth orders of the visible emission lines from ...
Figure 36.5.8 The visible emission lines of cadmium, as seen through a grating spectroscope.
Figure 36.5.9 A card with OVG.
Figure 36.5.10 (*a*) Gratings at point *a* on the surface of an OVG device send light to a viewer a...
Figure 36.6.1 The intensity patterns for light of two wavelengths sent through the gratings of...
Figure 36.7.1 X rays are generated when electrons leaving heated filament *F* are accelerated th...
Figure 36.7.2 (*a*) The cubic structure of NaCl, showing the sodium and chlorine ions and a unit...
Figure 36.7.3 A family of planes through the structure of Fig. 36.7.2*a*, and a way to relate th...
Figure 36.1 Question 3.
Figure 36.2 Question 4.
Figure 36.3 Question 5.
Figure 36.4 Questions 9 and 10.
Figure 36.5 Question 11.

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Figure 36.6 Question 12.
Figure 36.7 Problem 8.
Figure 36.8 Problem 10.
Figure 36.9 Problem 12.
Figure 36.10 Problem 16.
Figure 36.11 Problem 22. The Great Wall of China.
Figure 36.12 Problem 28. Tiger beetles are colored by pointillistic mixtures of thin-film int...
Figure 36.13 Problem 30.
Figure 36.14 Problem 34. The corona around the Moon is a composite of the diffraction pattern...
Figure 36.15 Problem 39.
Figure 36.16 Problem 40.
Figure 36.17 Problem 67.
Figure 36.18 Problem 70.
Figure 36.19 Problems 71 and 72.
Figure 36.20 Problem 81.
Figure 36.21 Problem 98.

CHAPTER 37

Figure 37.1.1 Einstein posing for a photograph as fame began to accumulate.
Figure 37.1.2 The dots show measured values of the kinetic energy of an electron plotted again...
Figure 37.1.3 One section of a three-dimensional array of clocks and measuring rods by which a...
Figure 37.1.4 The spaceships of Sally and Sam and the occurrences of events from Sam's view. S...
Figure 37.1.5 (*a*) Sally, on the train, measures the time interval Δt_0 between events 1 and 2 u...
Figure 37.1.6 A plot of the Lorentz factor γ as a function of the speed parameter β (= v/c).
Figure 37.2.1 If you want to measure the front-to-back length of a penguin while it is moving,...
Figure 37.2.2 (*a*)–(*b*) Event 1 occurs when point *B* passes Sally (at point *A*) and event 2 occurs...
Figure 37.3.1 Two inertial reference frames: frame S' has velocity relative t...
Figure 37.3.2 planet and its moon in reference frame S' move rightward with speed v relative t...
Figure 37.4.1 Reference frame S' moves with velocity relative to frame *S*.A particle has vel...
Figure 37.5.1 A light source *S* travels with velocity past a detector at *D*. The special theo...
Figure 37.6.1 The relativistic (Eq. 37.6.13) and classical (Eq. 37.6.12) equations for the kin...
Figure 37.6.2 A useful memory diagram for the relativistic relations among the total energy *E*,...
Figure 37.1 Questions 1 and 3.
Figure 37.2 Question 2 and Problem 68.
Figure 37.3 Question 4.
Figure 37.4 Question 5.
Figure 37.5 Question 7.
Figure 37.6 Question 9.
Figure 37.7 Question 11.
Figure 37.8 Problem 6.
Figure 37.9 Problem 14.
Figure 37.10 Problem 20.
Figure 37.11 Problems 21, 22, 60, and 61.
Figure 37.12 Problem 20.
Figure 37.13 Problem 38.
Figure 37.14 Problem 62.
Figure 37.15 Problem 63.
Figure 37.16 Problem 64.
Figure 37.17 Problems 65, 66 and 67.

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Figure 37.18 Problem 69.
Figure 37.19 Problem 84.
Figure 37.20 Problem 85.
Figure 37.21 Problem 89.
Figure 37.22 Problem 91.
Figure 37.23 Problem 94.

CHAPTER 38

Figure 38.2.1 An apparatus used to study the photoelectric effect. The incident light shines o...
Figure 38.2.2 The stopping potential V_{stop} as a function of the frequency *f* of the incident li...
Figure 38.3.1 Compton's apparatus. A beam of x rays of wavelength λ = 71.1 pm is directed onto...
Figure 38.3.2 Compton's results for four values of the scattering angle φ. Note that the Compt...
Figure 38.3.3 (*a*) An x ray approaches a stationary electron. The x ray can (*b*) bypass the elec...
Figure 38.3.4 Light is directed onto screen *B*, which contains two parallel slits. Light emergi...
Figure 38.3.5 The light from a single photon emission in source S travels over two widely sepa...
Figure 38.4.1 The solid curve shows the experimental spectral radiancy for a cavity at 2000 K....
Figure 38.5.1 Photographs showing the buildup of an interference pattern by a beam of electron...
Figure 38.5.2 (*a*) An experimental arrangement used to demonstrate, by diffraction techniques, ...
Figure 38.5.3 Photographs showing the buildup of an interference pattern by a beam of electron...
Figure 38.5.4 A few of the many paths that connect two particle detection points *I* and *F*. Only...
Figure 38.6.1 A plot of the probability density $|\psi|^2$ for a particle moving in the positive x d...
Figure 38.8.1 The elements of a tube in which an electron (the dot) approaches a region with a...
Figure 38.8.2 An energy diagram containing two plots for the situation of Fig. 38.8.1: (1) The...
Figure 38.9.1 The elements of a narrow tube in which an electron (the dot) approaches a negati...
Figure 38.9.2 An energy diagram containing two plots for the situation of Fig. 38.9.1: (1) The...
Figure 38.9.3 A plot of the probability density $|\psi|^2$ of the electron matter wave for the situa...
Figure 38.9.4 The essence of a scanning tunneling microscope (STM). Three quartz rods are used...
Figure 38.1 Question 4.
Figure 38.2 Question 6.
Figure 38.3 Question 8.
Figure 38.4 Question 10.
Figure 38.5 Question 10.
Figure 38.6 Question 16.
Figure 38.7 Problem 14.

CHAPTER 39

Figure 39.1.1 The elements of an idealized "trap" designed to confine an electron to the centr...
Figure 39.1.2 The electric potential energy $U(x)$ of an electron confined to the central cylind...
Figure 39.1.3 Several of the allowed energies for an electron confined to the infinite well of...
Figure 39.1.4 (*a*) Excitation of a trapped electron from the energy level of its ground state t...
Figure 39.1.5 De-excitation from the second excited state to the ground state either directly ...
Figure 39.2.1 The probability density for four states of an electron trapped in a one-d...
Figure 39.3.1 A *finite* potential energy well. The depth of the well is U_0 and its width is *L*. ...
Figure 39.3.2 The first three probability densities for an electron confined to a finit...
Figure 39.3.3 The energy-level diagram corresponding to the probability densities of Fig. 39.3...
Figure 39.4.1 Two samples of powdered cadmium selenide, a semiconductor, differing only in the...
Figure 39.4.2 A quantum dot, or "artificial atom." (*a*) A central semiconducting layer forms a ...
Figure 39.4.3 A quantum corral during four stages of construction. Note the appearance of ripp...
Figure 39.4.4 >A rectangular corral—a two-dimensional version of the infinite potential well o...
Figure 39.4.5 A rectangular box—a three-dimensional version of the infinite potential well of ...

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Figure 39.4.6 Energy-level diagram for an electron trapped in a square corral.
Figure 39.5.1 (*a*) Circular orbit of an electron in the Bohr model of the hydrogen atom. (*b*) Th...
Figure 39.5.2 The potential energy *U* of a hydrogen atom as a function of the separation *r* bet...
Figure 39.5.3 (*a*) An energy-level diagram for the hydrogen atom. Some of the transitions for (...
Figure 39.5.4 A plot of the radial probability density *P*(*r*) for the ground state of the hydrog...
Figure 39.5.5 A “dot plot” showing the volume probability density $\psi^2(r)$—not the *radial* probabi...
Figure 39.5.6 A dot plot showing the volume probability density $\psi^2(r)$ for the hydrogen atom in...
Figure 39.5.7 The relationship between the coordinates *x*, *y*, and *z* of the rectangular coordina...
Figure 39.5.8 Dot plots of the volume probability density $\psi^2(r, \theta)$ for the hydrogen atom in st...
Figure 39.5.9 A dot plot of the radial probability density *P*(*r*) for the hydrogen atom in a qua...
Figure 39.1 Question 4.
Figure 39.2 Question 14.
Figure 39.3 Problem 8.
Figure 39.4 Problem 19.
Figure 39.5 Problem 20.
Figure 39.6 Problem 24.
Figure 39.7 Problem 25.
Figure 39.8 Problem 65.

CHAPTER 40

Figure 40.1.1 The blue dot is a photograph of the light emitted from a single barium ion held ...
Figure 40.1.2 A plot of the ionization energies of the elements as a function of atomic number...
Figure 40.1.3 A classical model showing a particle of mass *m* and charge−*e* moving with speed *v* ...
Figure 40.1.4 The Einstein–de Haas experimental setup. (*a*) Initially, the magnetic field in th...
Figure 40.1.5 The allowed values of L_z for an electron in a quantum state with $\ell = 2$. For ever...
Figure 40.1.6 The allowed values of S_z and μ_z for an electron.
Figure 40.1.7 A classical model showing the total angular momentum vector and the effective...
Figure 40.2.1 Apparatus used by Stern and Gerlach.
Figure 40.2.2 Results of a modern repetition of the Stern–Gerlach experiment. With the electro...
Figure 40.3.1 The *z* component of for a proton in the (*a*) lower-energy (spin-up) and (*b*) hig...
Figure 40.3.2 A nuclear magnetic resonance spectrum for ethanol, CH_3CH_2OH. The spectral lines ...
Figure 40.4.1 (*a*) Energy-level diagram for one electron in a square corral. (Energy *E* is in mu...
Figure 40.6.1 The distribution by wavelength of the x rays produced when 35 keV electrons stri...
Figure 40.6.2 An electron of kinetic energy K_0 passing near an atom in the target may generate...
Figure 40.6.3 A simplified energy-level diagram for a molybdenum atom, showing the transitions...
Figure 40.6.4 A Moseley plot of the K_α line of the characteristic x-ray spectra of 21 elements...
Figure 40.7.1 A patient’s head is scanned and mapped by (red) laser light in preparation for b...
Figure 40.7.2 The interaction of radiation and matter in the processes of (*a*) absorption, (*b*) ...
Figure 40.7.3 (*a*) The equilibrium distribution of atoms between the ground state E_0 and excite...
Figure 40.7.4 The elements of a helium-neon gas laser. An applied potential V_{dc} sends electron...
Figure 40.7.5 Five essential energy levels for helium and neon atoms in a helium–neon gas laser. Lase...
Figure 40.1 Question 8.
Figure 40.2 Problem 22.
Figure 40.3 Problem 59.
Figure 40.4 Problem 63.
Figure 40.5 Problem 64.
Figure 40.6 Problem 65.
Figure 40.7 Problem 66.

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CHAPTER 41

Figure 41.1.1 (*a*) The unit cell for copper is a cube. There is one copper atom (darker) at eac...
Figure 41.1.2 (*a*) Two copper atoms separated by a large distance; their electron distributions...
Figure 41.1.3 The band–gap pattern of energy levels for an idealized crystalline solid. As the...
Figure 41.1.4 The band–gap pattern for an insulator; filled levels are shown in red and empty ...
Figure 41.1.5 The band–gap pattern for a metal. The highest filled level, called the Fermi lev...
Figure 41.1.6 The density of states $N(E)$—that is, the number of electron energy levels per uni...
Figure 41.1.7 The occupancy probability $P(E)$ is the probability that an energy level will be o...
Figure 41.1.8 (*a*) The density of occupied states $N_0(E)$ for copper at absolute zero. The area u...
Figure 41.2.1 (*a*) The band–gap pattern for a semiconductor. It resembles that of an insulator ...
Figure 41.2.2 (*a*) A flattened-out representation of the lattice structure of pure silicon. Eac...
Figure 41.2.3 (*a*) In a doped *n*-type semiconductor, the energy levels of donor electrons lie a ...
Figure 41.3.1 (*a*) A*p*-*n* junction. (*b*) Motions of the majority charge carriers across the juncti...
Figure 41.3.2 A current–voltage plot for a *p*-*n* junction, showing that the junction is highly c...
Figure 41.3.3 A *p*-*n* junction connected as a junction rectifier. The action of the circuit in (...
Figure 41.3.4 (*a*) The forward-bias connection of a *p*-*n* junction, showing the narrowed depletio...
Figure 41.3.5 A forward-biased *p*-*n* junction, showing electrons being injected into the *n*-type ...
Figure 41.3.6 Cross section of an LED (the device has rotational symmetry about the central ax...
Figure 41.3.7 A junction laser developed at the AT&T Bell Laboratories. The cube at the right ...
Figure 41.3.8 A circuit containing a generalized field-effect transistor through which electro...
Figure 41.3.9 A particular type of field-effect transistor known as a MOSFET. The magnitude of...
Figure 41.1 Question 4.
Figure 41.2 Problem 37.

CHAPTER 42

Figure 42.1.1 An arrangement (top view) used in Rutherford's laboratory in 1911–1913 to study ...
Figure 42.1.2 The dots are alpha-particle scattering data for a gold foil, obtained by Geiger ...
Figure 42.1.3 The angle through which an incident alpha particle is scattered depends on how c...
Figure 42.1.4 An alpha particle (*a*) approaches and (*b*) then enters a gold atom, headed toward ...
Figure 42.2.1
Figure 42.2.2
Figure 42.2.3
Figure 42.2.4
Figure 42.3.1 A semilogarithmic plot of the decay of a sample of ^{128}I, based on the data in th...
Figure 42.4.1 A potential energy function for the emission of an alpha particle by ^{238}U. The h...
Figure 42.5.1 The distribution of the kinetic energies of positrons emitted in the beta decay ...
Figure 42.5.2 A burst of neutrinos from the supernova SN 1987A, which occurred at (relative) t...
Figure 42.5.3 A portion of the valley of the nuclides, showing only the nuclides of low mass. ...
Figure 42.8.1 The formation modes and the decay modes of the compound nucleus ^{20}Ne.
Figure 42.8.2 A plot of the relative number of reaction events of the type described by Eq. 42...
Figure 42.1 Question 6.
Figure 42.2 Question 10.
Figure 42.3 Question 12.
Figure 42.4 Problem 44.
Figure 42.5 Problem 81.

CHAPTER 43

Figure 43.1.1 The distribution by mass number of the fragments that are found when many fissio...
Figure 43.1.2 The stages of a typical fission process, according to the collective model of Bo...
Figure 43.1.3 The potential energy at various stages in the fission process, as predicted from...

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Figure 43.1.1 This image has transfixed the world since World War II. When Robert Oppenheimer...

Figure 43.2.1 Neutron bookkeeping in a reactor. A generation of 1000 thermal neutrons interact...

Figure 43.2.2 A simplified layout of a nuclear power plant, based on a pressurized-water react...

Figure 43.2.3 The thermal power released by the radioactive wastes from one year's operation o...

Figure 43.3.1 A painting of the first nuclear reactor, assembled during World War II on a squa...

Figure 43.3.2 The distribution by mass number of the isotopes of neodymium as they occur in (*a*...

Figure 43.4.1 The curve marked $n(K)$ gives the number density per unit energy for protons at th...

Figure 43.5.1 The proton–proton mechanism that accounts for energy production in the Sun. In t...

Figure 43.5.2 (*a*) The star known as Sanduleak, as it appeared until 1987. (*b*) We then began to...

Figure 43.6.1 The small spheres on the quarter are deuterium–tritium fuel pellets, designed to...

Figure 43.1 Problem 15. A "button" of ^{235}U ready to be recast and machined for a warhead.

Figure 43.2 Problem 43.

CHAPTER 44

Figure 44.1.1 One of the detectors at the Large Hadron Collider at CERN, where the Standard Mo...

Figure 44.1.2 Three plots of the particle speed distribution in a vapor of rubidium-87 atoms. ...

Figure 44.1.3 (*a*) A bubble-chamber photograph of a series of events initiated by an antiproton...

Figure 44.2.1 (*a*) The eightfold way pattern for the eight spin- baryons listed in Table 44.2.2...

Figure 44.3.1 The violent head-on collision of two 30 GeV beams of gold atoms in the RHIC acce...

Figure 44.3.2 (*a*) The quark compositions of the eight spin-¯ baryons plotted in Fig. 44.2.1*a*....

Figure 44.4.1 The rotational speed of stars in a typical galaxy as a function of their distanc...

Figure 44.4.2 An illustration of the universe from the initial quantum fluctuations just after...

Figure 44.4.3 This color-coded image is effectively a photograph of the universe when it was o...

Figure 44.4.4 Light rays from two adjacent spots in our view of the cosmic background radiatio...

Figure 44.4.5 The distribution of energy (including mass) in the universe.

Figure 44.1 Question 3

Figure 44.2 Question 8

Figure 44.3 Problem 46.

Figure 44.4 Problem 48.

Figure 44.5 Problem 49.

Figure 44.6 Problem 51.

Figure 44.7 Problem 51.

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PREFACE

As requested by instructors, here is a new edition of the textbook originated by David Halliday and Robert Resnick in 1963 and that I used as a first-year student at MIT. (Gosh, time has flown by.) Constructing this new edition allowed me to discover many delightful new examples and revisit a few favorites from my earlier eight editions. Here below are some highlights of this 12th edition.

Entertainment Pictures/Zuma Press

Figure 10.39 What tension was required by the Achilles tendons in Michael Jackson in his gravity-defying 45º lean during his video *Smooth Criminals*?

Evgeniy Skripnichenko/123RF

Figure 10.7.2 What is the increase in the tension of the Achilles tendons when high heels are worn?

Sergii Gnatiuk/123 RF

Figure 9.65 Falling is a chronic and serious condition among skateboarders, in-line skaters, elderly people, people with seizures, and many others. Often, they fall onto one outstretched hand, fracturing the wrist. What fall height can result in such fracture?

Bloomberg/Getty Images

Figure 34.5.4 In functional near infrared spectroscopy (fNIRS), a person wears a close-fitting cap with LEDs emitting in the near infrared range. The light can penetrate into the outer layer of the brain and reveal when that portion is activated by a given activity, from playing baseball to flying an airplane.

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Fermilab/Science Source

Figure 28.5.2 Fast-neutron therapy is a promising weapon against salivary gland malignancies. But how can electrically neutral particles be accelerated to high speeds?

ZUMA Press Inc/Alamy Stock Photo

Figure 29.63 Parkinson's disease and other brain disorders have been treated with transcranial magnetic stimulation in which pulsed magnetic fields force neurons several centimeters deep to discharge.

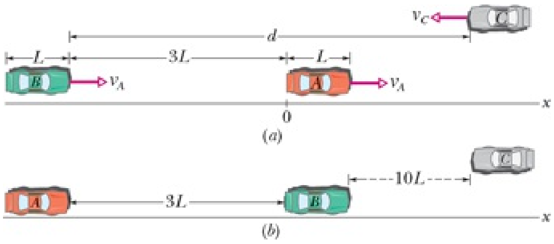


Figure 2.37 How should autonomous car *B* be programmed so that it can safely pass car *A* without being in danger from oncoming car *C*?

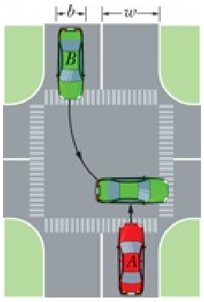
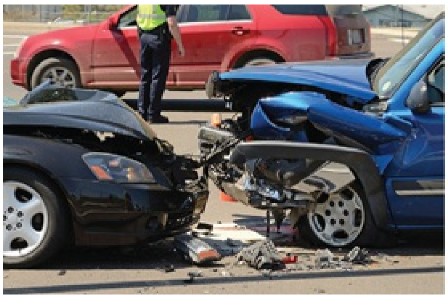


Figure 4.39 In a Pittsburgh left, a driver in the opposite lane anticipates the onset of the green light and rapidly pulls in front of your car during the red light. In a crash reconstruction, how soon before the green did the other driver start the turn?



Tracy Fox/123 RF

Figure 9.6.4 The most dangerous car crash is a head-on crash. In a head-on crash of cars of identical mass, by how much does the probability of a fatality of a driver decrease if the driver has a passenger in the car?

In addition, there are problems dealing with

- remote detection of the fall of an elderly person,
- the illusion of a rising fastball,
- hitting a fastball in spite of momentary vision loss,

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- ship squat in which a ship rides lower in the water in a channel,
- the common danger of a bicyclist disappearing from view at an intersection,
- measurement of thunderstorm potentials with muons,

and more.

WHAT'S IN THE BOOK

- Checkpoints, one for every module
- Sample problems
- Review and summary at the end of each chapter
- Nearly 300 new end-of-chapter problems

In constructing this new edition, I focused on several areas of research that intrigue me and wrote new text discussions and many new homework problems. Here are a few research areas:

We take a look at the first image of a black hole (for which I have waited my entire life), and then we examine gravitational waves (something I discussed with Rainer Weiss at MIT when I worked in his lab several years before he came up with the idea of using an interferometer as a wave detector).

I wrote a new sample problem and several homework problems on autonomous cars where a computer system must calculate safe driving procedures, such as passing a slow car with an oncoming car in the passing lane.

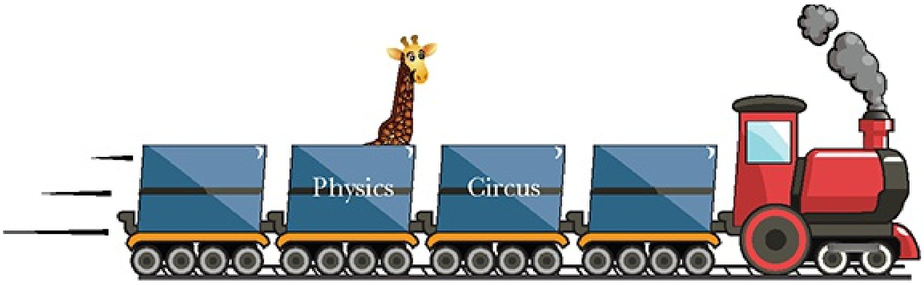
I explored cancer radiation therapy, including the use of Augur-Meitner electrons that were first understood by Lise Meitner.

I combed through many thousands of medical, engineering, and physics research articles to find clever ways of looking inside the human body without major invasive surgery. Some are listed in the index under "medical procedures and equipment." Here are three examples:

(1) Robotic surgery using single-port incisions and optical fibers now allows surgeons to access internal organs, with patient recovery times of only hours instead of days or weeks as with previous surgery techniques.

(2) Transcranial magnetic stimulation is being used to treat chronic depression, Parkinson's disease, and other brain malfunctions by applying pulsed magnetic fields from coils near the scalp to force neurons several centimeters deep to discharge.

(3) Magnetoencephalography (MEG) is being used to monitor a person's brain as the person performs a task such as reading. The task causes weak electrical pulses to be sent along conducting paths between brain cells, and each pulse produces a weak magnetic field that is detected by extremely sensitive SQUIDs.



THE *WILEYPLUS* ADVANTAGE

WileyPLUS is a research-based online environment for effective teaching and learning. The customization features, quality question banks, interactive eTextbook, and analytical tools allow you to quickly create a customized course that tracks student learning trends. Your students can stay engaged and on track with the use of intuitive tools like the syncing calendar and the student mobile app. Wiley is committed to providing accessible resources to instructors and students. As such, all Wiley educational products and services are born accessible, designed for users of all abilities.

Links Between Homework Problems and Learning Objectives

In *WileyPLUS*, every question and problem at the end of the chapter is linked to a learning objective, to answer the (usually unspoken) questions, "Why am I working this problem? What am I supposed to learn from it?" By being explicit about a problem's purpose, I believe that a student might better transfer the learning objective to other problems with a different wording but the same key idea. Such transference would help defeat the common trouble that a student learns to work a particular problem but cannot then apply its key idea to a problem in a different setting.

Animations of one of the key figures in each chapter.

Here in the book, those figures are flagged with the swirling icon. In the online chapter in *WileyPLUS*, a mouse click begins the animation. I have chosen the figures that are rich in information so that a student can see the physics in action and played out over a minute or two instead of just being flat on a printed page. Not only does this give life to the physics, but the animation can be repeated as many times as a student wants.

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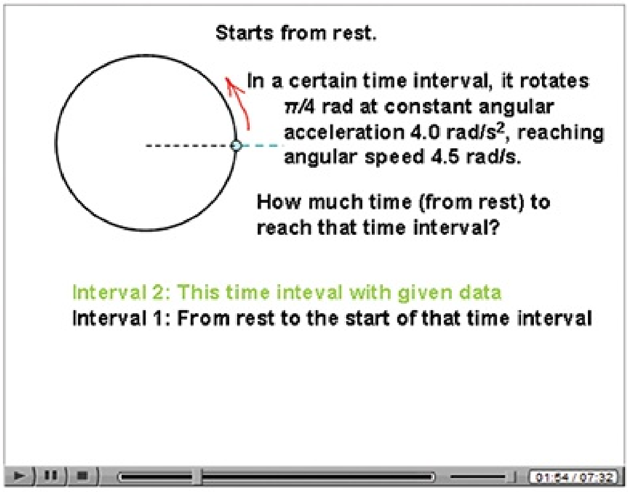
Video Illustrations

David Maiullo of Rutgers University has created video versions of approximately 30 of the photographs and figures from the chapters. Much of physics is the study of things that move, and video can often provide better representation than a static photo or figure.



Starts from rest.

In a certain time interval, it rotates $\pi/4$ rad at constant angular acceleration 4.0 rad/s^2, reaching angular speed 4.5 rad/s.

How much time (from rest) to reach that time interval?

Interval 2: This time inteval with given data

Interval 1: From rest to the start of that time interval

Videos

I have made well over 1500 instructional videos, with more coming. Students can watch me draw or type on the screen as they hear me talk about a solution, tutorial, sample problem, or review, very much as they would experience were they sitting next to me in my office while I worked out something on a notepad. An instructor's lectures and tutoring will always be the most valuable learning tools, but my videos are available 24 hours a day, 7 days a week, and can be repeated indefinitely.

- **Video tutorials on subjects in the chapters.** I chose the subjects that challenge the students the most, the ones that my students scratch their heads about.
- **Video reviews of high school math**, such as basic algebraic manipulations, trig functions, and simultaneous equations.
- **Video introductions to math**, such as vector multiplication, that will be new to the students.
- **Video presentations of sample problems.** My intent is to work out the physics, starting with the key ideas instead of just grabbing a formula. However, I also want to demonstrate how to read a sample problem, that is, how to read technical material to learn problem-solving procedures that can be transferred to other types of problems.
- **Video solutions to 20% of the end-of chapter problems.** The availability and timing of these solutions are controlled by the instructor. For example, they might be available after a homework deadline or a quiz. Each solution is not simply a plug-and-chug recipe. Rather I build a solution from the key ideas to the first step of reasoning and to a final solution. The student learns not just how to solve a particular problem but how to tackle any problem, even those that require *physics courage*.
- **Video examples of how to read data from graphs** (more than simply reading off a number with no comprehension of the physics).
- Many of the sample problems in the textbook are available online in both reading and video formats.

Problem-Solving Help

I have written a large number of resources for *WileyPLUS* designed to help build the students' problem-solving skills.

- **Hundreds of additional sample problems.** These are available as stand-alone resources but (at the discretion of the instructor) they are also linked out of the homework problems. So, if a homework problem deals with, say, forces on a block on a ramp, a link to a related sample problem is provided. However, the sample problem is not just a replica of the homework problem and thus does not provide a solution that can be merely duplicated without comprehension.
- **GO Tutorials** for 15% of the end-of-chapter homework problems. In multiple steps, I lead a student through a homework problem, starting with the key ideas and giving hints when wrong answers are submitted. However, I purposely leave the last step (for the final answer) to the students so that they are responsible at the end. Some online tutorial systems trap a student when wrong answers are given, which can generate a lot of frustration. My GO Tutorials are not traps, because at any step along the way, a student can return to the main problem.
- **Hints on every end-of-chapter homework problem** are available (at the discretion of the instructor). I wrote these as true hints about the main ideas and the general procedure for a solution, not as recipes that provide an answer without any comprehension.

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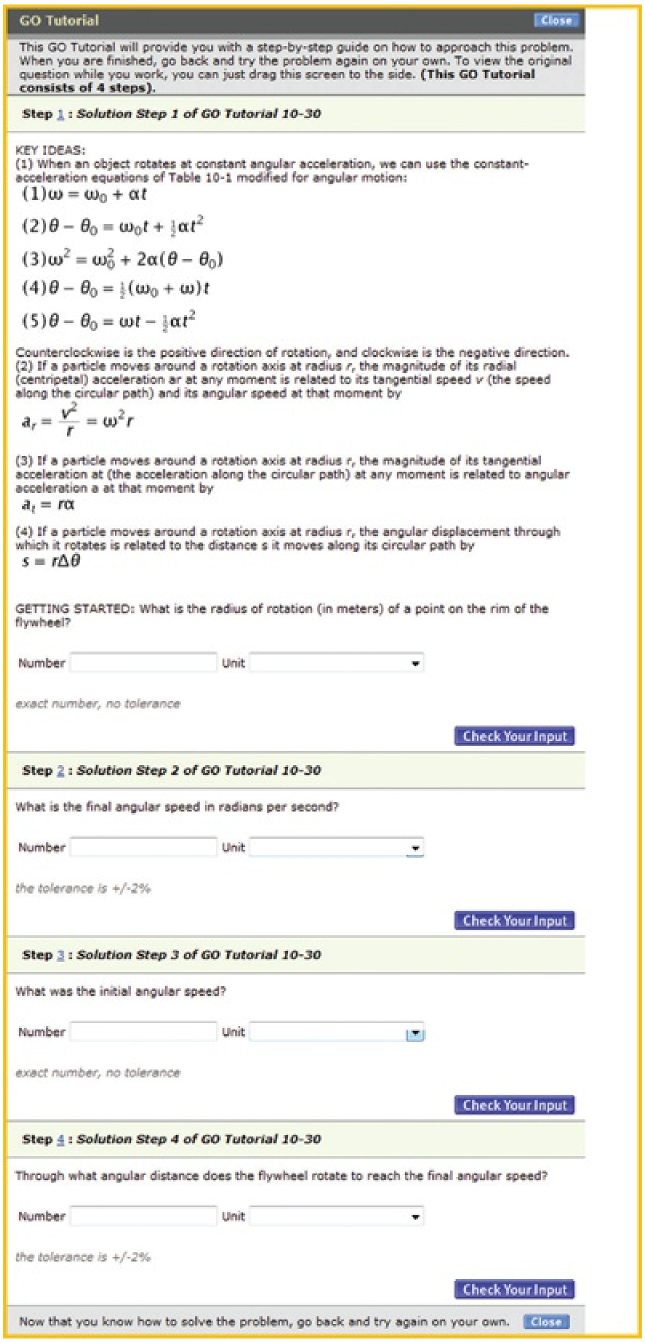
- **Pre-lecture videos.** At an instructor's discretion, a pre-lecture video is available for every module. Also, assignable questions are available to accompany these videos. The videos were produced by Melanie Good of the University of Pittsburgh.



This GO Tutorial will provide you with a step-by-step guide on how to approach this problem. When you are finished, go back and try the problem again on your own. To view the original question while you work, you can just drag this screen to the side. **(This GO Tutorial consists of 4 steps).**

Step 1 : *Solution Step 1 of GO Tutorial 10-30*

KEY IDEAS:
(1) When an object rotates at constant angular acceleration, we can use the constant-acceleration equations of Table 10-1 modified for angular motion:

(1) $\omega = \omega_0 + \alpha t$

(2) $\theta - \theta_0 = \omega_0 t + \frac{1}{2}\alpha t^2$

(3) $\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$

(4) $\theta - \theta_0 = \frac{1}{2}(\omega_0 + \omega)t$

(5) $\theta - \theta_0 = \omega t - \frac{1}{2}\alpha t^2$

Counterclockwise is the positive direction of rotation, and clockwise is the negative direction.
(2) If a particle moves around a rotation axis at radius r, the magnitude of its radial (centripetal) acceleration ar at any moment is related to its tangential speed v (the speed along the circular path) and its angular speed at that moment by

$$a_r = \frac{v^2}{r} = \omega^2 r$$

(3) If a particle moves around a rotation axis at radius r, the magnitude of its tangential acceleration at (the acceleration along the circular path) at any moment is related to angular acceleration a at that moment by

$$a_t = r\alpha$$

(4) If a particle moves around a rotation axis at radius r, the angular displacement through which it rotates is related to the distance s it moves along its circular path by

$$s = r\Delta\theta$$

GETTING STARTED: What is the radius of rotation (in meters) of a point on the rim of the flywheel?

Number ☐ Unit ☐

exact number, no tolerance

Step 2 : *Solution Step 2 of GO Tutorial 10-30*

What is the final angular speed in radians per second?

Number ☐ Unit ☐

the tolerance is +/-2%

Step 3 : *Solution Step 3 of GO Tutorial 10-30*

What was the initial angular speed?

Number ☐ Unit ☐

exact number, no tolerance

Step 4 : *Solution Step 4 of GO Tutorial 10-30*

Through what angular distance does the flywheel rotate to reach the final angular speed?

Number ☐ Unit ☐

the tolerance is +/-2%

Now that you know how to solve the problem, go back and try again on your own.

Evaluation Materials

- **Pre-lecture reading questions are available in *WileyPLUS* for each chapter section.** I wrote these so that they do not require analysis or any deep understanding; rather they simply test whether a student has read the section. When a student opens up a section, a randomly chosen reading question (from a bank of questions) appears at the end. The instructor can decide whether the question is part of the grading for that section or whether it is just for the benefit of the student.

- **Checkpoints are available within each chapter module.** I wrote these so that they require analysis and decisions about the physics in the section. Answers are provided in the back of the book.

- **All end-of-chapter homework problems** (and many more problems) are available in *WileyPLUS*. The instructor can construct a homework assignment and control how it is graded when the answers are submitted online. For example, the instructor controls the deadline for submission and how many attempts a student is allowed on an answer. The instructor also controls which, if any, learning aids are available with each homework problem. Such links can include hints, sample problems, in-chapter reading materials, video tutorials, video math reviews, and even video solutions (which can be made available to the students after, say, a homework deadline).

- **Symbolic notation problems** that require algebraic answers are available in every chapter.

- **All end-of-chapter homework questions** are available for assignment in *WileyPLUS*. These questions (in a multiple-choice format) are designed to evaluate the students' conceptual understanding.

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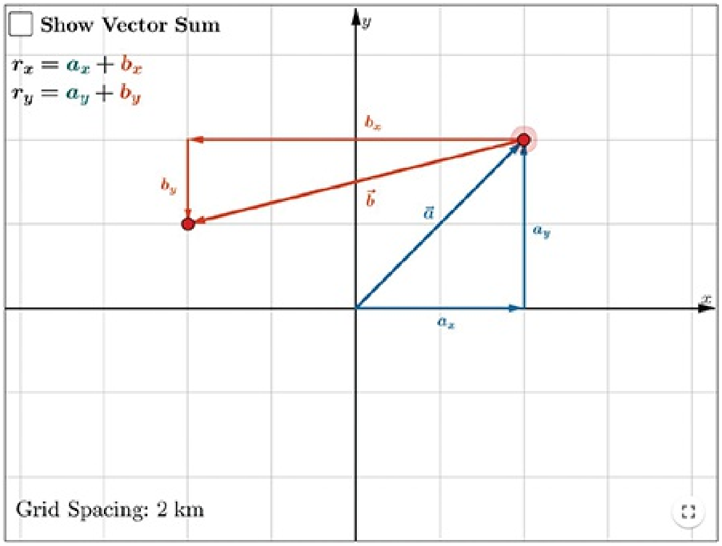
- **Interactive Exercises and Simulations**, by Brad Trees of Ohio Wesleyan University. How do we help students understand challenging concepts in physics? How do we motivate students to engage with core content in a meaningful way? The simulations are intended to address these key questions. Each module in the Etext is linked to one or more simulations that convey concepts visually. A simulation depicts a physical situation in which time dependent phenomena are animated and information is presented in multiple representations including a visual representation of the physical system as well as a plot of related variables. Often, adjustable parameters allow the user to change a property of the system and to see the effects of that change on the subsequent behavior. For visual learners, the simulations provide an opportunity to "see" the physics in action. Each simulation is also linked to a set of interactive exercises, which guide the student through a deeper interaction with the physics underlying the simulation. The exercises consist of a series of practice questions with feedback and detailed solutions. Instructors may choose to assign the exercises for practice, to recommend the exercises to students as additional practice, and to show individual simulations during class time to demonstrate a concept and to motivate class discussion.



Icons for Additional Help

When worked-out solutions are provided either in print or electronically for certain of the odd-numbered problems, the statements for those problems include an icon to alert both student and instructor. There are also icons indicating which problems have a GO Tutorial or a link to the *The Flying Circus of Physics*, which require calculus, and which involve a biomedical application. An icon guide is provided here and at the beginning of each set of problems.

GO Tutoring problem available (at instructor's discretion) in *WileyPLUS*

SSM Worked-out solution available in Student Solutions Manual

E Easy

M Medium

H Hard

FCP Additional information available in *The Flying Circus of Physics* and at flyingcircusofphysics.com

CALC Requires calculus

BIO Biomedical application

FUNDAMENTALS OF PHYSICS—FORMAT OPTIONS

Fundamentals of Physics was designed to optimize students' online learning experience. We highly recommend that students use the digital course within *WileyPLUS* as their primary course material. Here are students' purchase options:

- 12th Edition *WileyPLUS* course
- *Fundamentals of Physics* Looseleaf Print Companion bundled with *WileyPLUS*
- *Fundamentals of Physics* volume 1 bundled with *WileyPLUS*
- *Fundamentals of Physics* volume 2 bundled with *WileyPLUS*
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SUPPLEMENTARY MATERIALS AND ADDITIONAL RESOURCES

Supplements for the instructor can be obtained online through *WileyPLUS* or by contacting your Wiley representative. The following supplementary materials are available for this edition:

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Instructor's Solutions Manual

by Sen-Ben Liao, Lawrence Livermore National Laboratory. This manual provides worked-out solutions for all problems found at the end of each chapter. It is available in both MSWord and PDF.

- **Instructor's Manual** This resource contains lecture notes outlining the most important topics of each chapter; demonstration experiments; laboratory and computer projects; film and video sources; answers to all questions, exercises, problems, and checkpoints; and a correlation guide to the questions, exercises, and problems in the previous edition. It also contains a complete list of all problems for which solutions are available to students.
- **Classroom Response Systems ("Clicker") Questions** by David Marx, Illinois State University. There are two sets of questions available: Reading Quiz questions and Interactive Lecture questions.The Reading Quiz questions are intended to be relatively straightforward for any student who reads the assigned material. The Interactive Lecture questions are intended for use in an interactive lecture setting.
- **Wiley Physics Simulations** by Andrew Duffy, Boston University and John Gastineau, Vernier Software. This is a collection of 50 interactive simulations (Java applets) that can be used for classroom demonstrations.
- **Wiley Physics Demonstrations** by David Maiullo, Rutgers University. This is a collection of digital videos of 80 standard physics demonstrations. They can be shown in class or accessed from *WileyPLUS*. There is an accompanying Instructor's Guide that includes "clicker" questions.
- **Test Bank** by Suzanne Willis, Northern Illinois University. The Test Bank includes nearly 3,000 multiple-choice questions. These items are also available in the Computerized Test Bank, which provides full editing features to help you customize tests (available in both IBM and Macintosh versions).
- **All text illustrations** suitable for both classroom projection and printing.
- **Lecture PowerPoint Slides** These PowerPoint slides serve as a helpful starter pack for instructors, outlining key concepts and incorporating figures and equations from the text.

STUDENT SUPPLEMENTS

Student Solutions Manual

(ISBN 9781119455127) by Sen-Ben Liao, Lawrence Livermore National Laboratory. This manual provides students with complete worked-out solutions to 15 percent of the problems found at the end of each chapter within the text. The Student Solutions Manual for the 12th edition is written using an innovative approach called TEAL, which stands for Think, Express, Analyze, and Learn. This learning strategy was originally developed at the Massachusetts Institute of Technology and has proven to be an effective learning tool for students. These problems with TEAL solutions are indicated with an SSM icon in the text.

Introductory Physics with Calculus as a Second Language

(ISBN 9780471739104) *Mastering Problem Solving* by Thomas Barrett of Ohio State University. This brief paperback teaches the student how to approach problems more efficiently and effectively. The student will learn how to recognize common patterns in physics problems, break problems down into manageable steps, and apply appropriate techniques. The book takes the student step by step through the solutions to numerous examples.

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Blaine Norum, *University of Virginia*

Michael O'Shea, *Kansas State University*

Don N. Page, *University of Alberta*

Patrick Papin, *San Diego State University*

Kiumars Parvin, *San Jose State University*

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CHAPTER 1

Measurement

1.1 MEASURING THINGS, INCLUDING LENGTHS

Learning Objectives

After reading this module, you should be able to …

1.1.1 Identify the base quantities in the SI system.

1.1.2 Name the most frequently used prefixes for SI units.

1.1.3 Change units (here for length, area, and volume) by using chain-link conversions.

1.1.4 Explain that the meter is defined in terms of the speed of light in a vacuum.

Key Ideas

- Physics is based on measurement of physical quantities. Certain physical quantities have been chosen as base quantities (such as length, time, and mass); each has been defined in terms of a standard and given a unit of measure (such as meter, second, and kilogram). Other physical quantities are defined in terms of the base quantities and their standards and units.
- The unit system emphasized in this book is the International System of Units (SI). The three physical quantities displayed in Table 1.1.1 are used in the early chapters. Standards, which must be both accessible and invariable, have been established for these base quantities by international agreement. These standards are used in all physical measurement, for both the base quantities and the quantities derived from them. Scientific notation and the prefixes of Table 1.1.2 are used to simplify measurement notation.
- Conversion of units may be performed by using chain-link conversions in which the original data are multiplied successively by conversion factors written as unity and the units are manipulated like algebraic quantities until only the desired units remain.
- The meter is defined as the distance traveled by light during a precisely specified time interval.

What Is Physics?

Science and engineering are based on measurements and comparisons. Thus, we need rules about how things are measured and compared, and we need experiments to establish the units for those measurements and comparisons. One purpose of physics (and engineering) is to design and conduct those experiments.

For example, physicists strive to develop clocks of extreme accuracy so that any time or time interval can be precisely determined and compared. You may wonder whether such accuracy is actually needed or worth the effort. Here is one example of the worth: Without clocks of extreme accuracy, the Global Positioning System (GPS) that is now vital to worldwide navigation would be useless.

Measuring Things

We discover physics by learning how to measure the quantities involved in physics. Among these quantities are length, time, mass, temperature, pressure, and electric current.

We measure each physical quantity in its own units, by comparison with a **standard**. The **unit** is a unique name we assign to measures of that quantity—for example, meter (m) for the quantity length. The standard corresponds to exactly 1.0 unit of the quantity. As you will see, the standard for length, which corresponds to exactly 1.0 m, is the distance traveled by light in a vacuum during a certain fraction of a second. We can define a unit and its standard in any way we care to. However, the important thing is to do so in such a way that scientists around the world will agree that our definitions are both sensible and practical.

Once we have set up a standard—say, for length—we must work out procedures by which any length whatever, be it the radius of a hydrogen atom, the wheelbase of a skateboard, or the distance to a star, can be expressed in terms of the standard. Rulers, which approximate our length standard, give us one such procedure for measuring length. However, many of our comparisons must be indirect. You cannot use a ruler, for example, to measure the radius of an atom or the distance to a star.

Base Quantities. There are so many physical quantities that it is a problem to organize them. Fortunately, they are not all independent; for example, speed is the ratio of a length to a time. Thus, what we do is pick out—by international agreement—a small number of physical quantities, such as length and time, and assign standards to them alone. We then define all other physical quantities in terms of these *base quantities* and their standards (called *base standards*). Speed, for example, is defined in terms of the base quantities length and time and their base standards.

Base standards must be both accessible and invariable. If we define the length standard as the distance between one’s nose and the index finger on an outstretched arm, we certainly have an accessible standard—but it will, of course, vary

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from person to person. The demand for precision in science and engineering pushes us to aim first for invariability. We then exert great effort to make duplicates of the base standards that are accessible to those who need them.

The International System of Units

In 1971, the 14th General Conference on Weights and Measures picked seven quantities as base quantities, thereby forming the basis of the International System of Units, abbreviated SI from its French name and popularly known as the *metric system*. Table 1.1.1 shows the units for the three base quantities—length, mass, and time—that we use in the early chapters of this book. These units were defined to be on a "human scale."

Table 1.1.1 Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

Many SI *derived units* are defined in terms of these base units. For example, the SI unit for power, called the **watt** (W), is defined in terms of the base units for mass, length, and time. Thus, as you will see in Chapter 7,

(1.1.1)

where the last collection of unit symbols is read as kilogram-meter squared per second cubed.

To express the very large and very small quantities we often run into in physics, we use *scientific notation*, which employs powers of 10. In this notation,

(1.1.2)

and

(1.1.3)

Scientific notation on computers sometimes takes on an even briefer look, as in 3.56 E9 and 4.92 E−7, where E stands for "exponent of ten." It is briefer still on some calculators, where E is replaced with an empty space.

As a further convenience when dealing with very large or very small measurements, we use the prefixes listed in Table 1.1.2. As you can see, each prefix represents a certain power of 10, to be used as a multiplication factor. Attaching a prefix to an SI unit has the effect of multiplying by the associated factor. Thus, we can express a particular electric power as

(1.1.4)

or a particular time interval as

(1.1.5)

Table 1.1.2 Prefixes for SI Units

Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y
10^{21}	zetta-	Z
10^{18}	exa-	E
10^{15}	peta-	P
10^{12}	tera-	T
10^{9}	**giga-**	**G**
10^{6}	**mega-**	**M**
10^{3}	**kilo-**	**k**

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Factor	Prefix[a]	Symbol
10^{2}	hecto-	h
10^{1}	deka-	da
10^{-1}	deci-	d
10^{-2}	**centi-**	**c**
10^{-3}	**milli-**	**m**
10^{-6}	**micro-**	***μ***
10^{-9}	**nano-**	**n**
10^{-12}	**pico-**	**p**
10^{-15}	femto-	f
10^{-18}	atto-	a
10^{-21}	zepto-	z
10^{-24}	yocto-	y

[a] The most frequently used prefixes are shown in bold type.

Some prefixes, as used in milliliter, centimeter, kilogram, and megabyte, are probably familiar to you.

Changing Units

We often need to change the units in which a physical quantity is expressed. We do so by a method called *chain-link conversion*. In this method, we multiply the original measurement by a **conversion factor** (a ratio of units that is equal to unity). For example, because 1 min and 60 s are identical time intervals, we have

Thus, the ratios (1 min)/(60 s) and (60 s)/(1 min) can be used as conversion factors. This is *not* the same as writing ; each *number* and its *unit* must be treated together.

Because multiplying any quantity by unity leaves the quantity unchanged, we can introduce conversion factors wherever we find them useful. In chain-link conversion, we use the factors to cancel unwanted units. For example, to convert 2 min to seconds, we have

(1.1.6)

If you introduce a conversion factor in such a way that unwanted units do *not* cancel, invert the factor and try again. In conversions, the units obey the same algebraic rules as variables and numbers.

Appendix D gives conversion factors between SI and other systems of units, including non-SI units still used in the United States. However, the conversion factors are written in the style of “1 min = 60 s” rather than as a ratio. So, you need to decide on the numerator and denominator in any needed ratio.

Length

In 1792, the newborn Republic of France established a new system of weights and measures. Its cornerstone was the meter, defined to be one ten-millionth of the distance from the north pole to the equator. Later, for practical reasons, this Earth standard was abandoned and the meter came to be defined as the distance between two fine lines engraved near the ends of a platinum–iridium bar, the **standard meter bar**, which was kept at the International Bureau of Weights and Measures near Paris. Accurate copies of the bar were sent to standardizing laboratories throughout the world. These **secondary standards** were used to produce other, still more accessible standards, so that ultimately every measuring device derived its authority from the standard meter bar through a complicated chain of comparisons.

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Eventually, a standard more precise than the distance between two fine scratches on a metal bar was required. In 1960, a new standard for the meter, based on the wavelength of light, was adopted. Specifically, the standard for the meter was redefined to be 1 650 763.73 wavelengths of a particular orange-red light emitted by atoms of krypton-86 (a particular isotope, or type, of krypton) in a gas discharge tube that can be set up anywhere in the world. This awkward number of wavelengths was chosen so that the new standard would be close to the old meter-bar standard.

By 1983, however, the demand for higher precision had reached such a point that even the krypton-86 standard could not meet it, and in that year a bold step was taken. The meter was redefined as the distance traveled by light in a specified time interval. In the words of the 17th General Conference on Weights and Measures:

> The meter is the length of the path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.

This time interval was chosen so that the speed of light *c* is exactly

Measurements of the speed of light had become extremely precise, so it made sense to adopt the speed of light as a defined quantity and to use it to redefine the meter.

Table 1.1.3 shows a wide range of lengths, from that of the universe (top line) to those of some very small objects.

Table 1.1.3 **Some Approximate Lengths**

Measurement	**Length in Meters**
Distance to the first galaxies formed	2×10^{26}
Distance to the Andromeda galaxy	2×10^{22}
Distance to the nearby star Proxima Centauri	4×10^{16}
Distance to Pluto	6×10^{12}
Radius of Earth	6×10^{6}
Height of Mt. Everest	9×10^{3}
Thickness of this page	1×10^{-4}
Length of a typical virus	1×10^{-8}
Radius of a hydrogen atom	5×10^{-11}
Radius of a proton	1×10^{-15}

Significant Figures and Decimal Places

Suppose that you work out a problem in which each value consists of two digits. Those digits are called **significant figures** and they set the number of digits that you can use in reporting your final answer. With data given in two significant figures, your final answer should have only two significant figures. However, depending on the mode setting of your calculator, many more digits might be displayed. Those extra digits are meaningless.

In this book, final results of calculations are often rounded to match the least number of significant figures in the given data. (However, sometimes an extra significant figure is kept.) When the leftmost of the digits to be discarded is 5 or more, the last remaining digit is rounded up; otherwise it is retained as is. For example, 11.3516 is rounded to three significant figures as 11.4 and 11.3279 is rounded to three significant figures as 11.3. (The answers to sample problems in this book are usually presented with the symbol = instead of ≈ even if rounding is involved.)

When a number such as 3.15 or 3.15×10^3 is provided in a problem, the number of significant figures is apparent, but how about the number 3000? Is it known to only one significant figure (3×10^3)? Or is it known to as many as four significant figures (3.000×10^3)? In this book, we assume that all the zeros in such given numbers as 3000 are significant, but you had better not make that assumption elsewhere.

Don't confuse *significant figures* with *decimal places*. Consider the lengths 35.6 mm, 3.56 m, and 0.00356 m. They all have three significant figures but they have one, two, and five decimal places, respectively.

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Sample Problem 1.1.1

Estimating order of magnitude, ball of string

The world's largest ball of string is about 2 m in radius. To the nearest order of magnitude, what is the total length *L* of the string in the ball?

KEY IDEA

We could, of course, take the ball apart and measure the total length *L*, but that would take great effort and make the ball's builder most unhappy. Instead, because we want only the nearest order of magnitude, we can estimate any quantities required in the calculation.

Calculations: Let us assume the ball is spherical with radius $R = 2$ m. The string in the ball is not closely packed (there are uncountable gaps between adjacent sections of string). To allow for these gaps, let us somewhat overestimate the cross-sectional area of the string by assuming the cross section is square, with an edge length $d =$ 4 mm. Then, with a cross-sectional area of d^2 and a length *L*, the string occupies a total volume of

This is approximately equal to the volume of the ball, given by – , which is about $4R^3$ because π is about 3. Thus, we have the following

(Answer)

(Note that you do not need a calculator for such a simplified calculation.) To the nearest order of magnitude, the ball contains about 1000 km of string!

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1.2 TIME

Learning Objectives

After reading this module, you should be able to ...

- **1.2.1** Change units for time by using chain-link conversions.
- **1.2.2** Use various measures of time, such as for motion or as determined on different clocks.

Key Idea

- The second is defined in terms of the oscillations of light emitted by an atomic (cesium-133) source. Accurate time signals are sent worldwide by radio signals keyed to atomic clocks in standardizing laboratories.

Time

Time has two aspects. For civil and some scientific purposes, we want to know the time of day so that we can order events in sequence. In much scientific work, we want to know how long an event lasts. Thus, any time standard must be able to answer two questions: "*When* did it happen?" and "What is its *duration*?" Table 1.2.1 shows some time intervals.

Table 1.2.1 Some Approximate Time Intervals

Measurement	**Time Interval in Seconds**	**Measurement**	**Time Interval in Seconds**
Lifetime of the proton (predicted)	3×10^{40}	Time between human heartbeats	8×10^{-1}
Age of the universe	5×10^{17}	Lifetime of the muon	2×10^{-6}
Age of the pyramid of Cheops	1×10^{11}	Shortest lab light pulse	1×10^{-16}
Human life expectancy	2×10^{9}	Lifetime of the most unstable particle	1×10^{-23}

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Measurement	Time Interval in Seconds	Measurement	Time Interval in Seconds
Length of a day	9×10^4	The Planck time[a]	1×10^{-43}

[a] This is the earliest time after the big bang at which the laws of physics as we know them can be applied.

Any phenomenon that repeats itself is a possible time standard. Earth's rotation, which determines the length of the day, has been used in this way for centuries; Fig. 1.2.1 shows one novel example of a watch based on that rotation. A quartz clock, in which a quartz ring is made to vibrate continuously, can be calibrated against Earth's rotation via astronomical observations and used to measure time intervals in the laboratory. However, the calibration cannot be carried out with the accuracy called for by modern scientific and engineering technology.

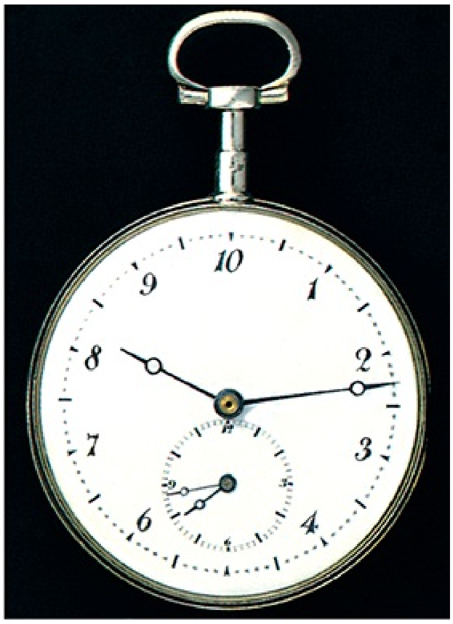
Steven Pitkin

Figure 1.2.1 When the metric system was proposed in 1792, the hour was redefined to provide a 10-hour day. The idea did not catch on. The maker of this 10-hour watch wisely provided a small dial that kept conventional 12-hour time. Do the two dials indicate the same time?

To meet the need for a better time standard, atomic clocks have been developed. An atomic clock at the National Institute of Standards and Technology (NIST) in Boulder, Colorado, is the standard for Coordinated Universal Time (UTC) in the United States. Its time signals are available by shortwave radio (stations WWV and WWVH) and by telephone (303-499-7111). Time signals (and related information) are also available from the United States Naval Observatory at website https://www.usno.navy.mil/USNO/time. (To set a clock extremely accurately at your particular location, you would have to account for the travel time required for these signals to reach you.)

Figure 1.2.2 shows variations in the length of one day on Earth over a 4-year period, as determined by comparison with a cesium (atomic) clock. Because the variation displayed by Fig. 1.2.2 is seasonal and repetitious, we suspect the rotating Earth when there is a difference between Earth and atom as timekeepers. The variation is due to tidal effects caused by the Moon and to large-scale winds.

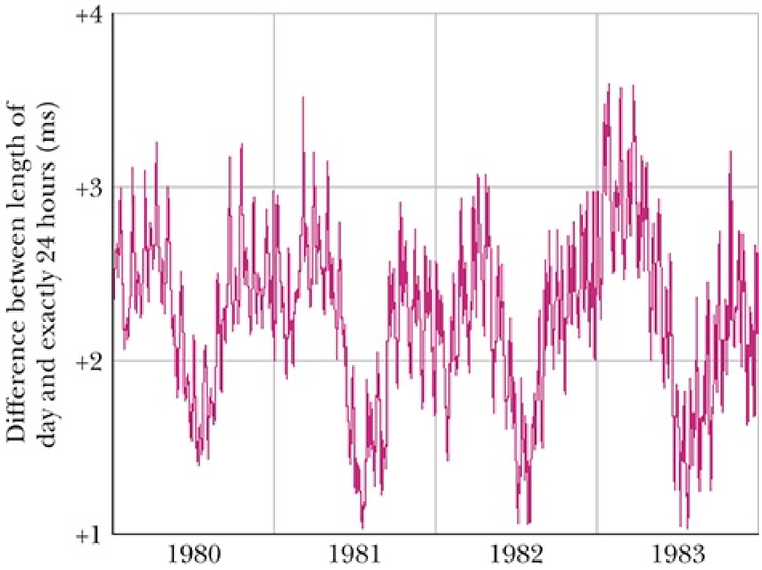

Figure 1.2.2 Variations in the length of the day over a 4-year period. Note that the entire vertical scale amounts to only 3 ms (= 0.003 s).

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The 13th General Conference on Weights and Measures in 1967 adopted a standard second based on the cesium clock:

> One second is the time taken by 9 192 631 770 oscillations of the light (of a specified wavelength) emitted by a cesium-133 atom.

Atomic clocks are so consistent that, in principle, two cesium clocks would have to run for 6000 years before their readings would differ by more than 1 s. Even such accuracy pales in comparison with that of clocks currently being developed; their precision may be 1 part in 10^{18}—that is, 1 s in 1×10^{18} s (which is about 3×10^{10} y).

1.3 MASS

Learning Objectives

After reading this module, you should be able to ...

- **1.3.1** Change units for mass by using chain-link conversions.
- **1.3.2** Relate density to mass and volume when the mass is uniformly distributed.

Key Ideas

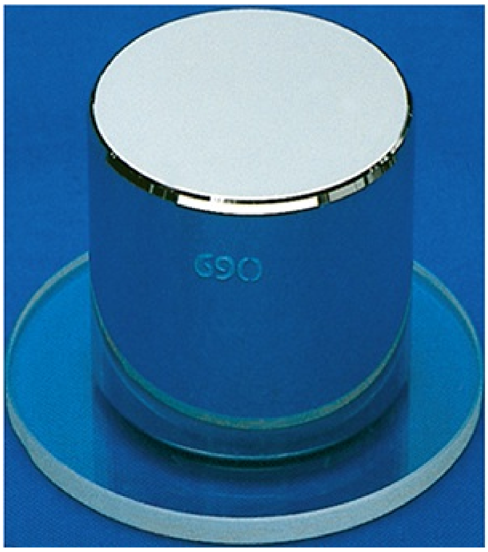
- The kilogram is defined in terms of a platinum–iridium standard mass kept near Paris. For measurements on an atomic scale, the atomic mass unit, defined in terms of the atom carbon-12, is usually used.
- The density ρ of a material is the mass per unit volume:

—

Mass

The Standard Kilogram

The SI standard of mass is a cylinder of platinum and iridium (Fig. 1.3.1) that is kept at the International Bureau of Weights and Measures near Paris and assigned, by international agreement, a mass of 1 kilogram. Accurate copies have been sent to standardizing laboratories in other countries, and the masses of other bodies can be determined by balancing them against a copy. Table 1.3.1 shows some masses expressed in kilograms, ranging over about 83 orders of magnitude.



Courtesy Bureau International des Poids et Mesures. Reproduced with permission of the BIPM.

Figure 1.3.1 The international 1 kg standard of mass, a platinum–iridium cylinder 3.9 cm in height and in diameter.

Table 1.3.1 Some Approximate Masses

Object	**Mass in Kilograms**
Known universe	1×10^{53}

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Object	Mass in Kilograms
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}

The U.S. copy of the standard kilogram is housed in a vault at NIST. It is removed, no more than once a year, for the purpose of checking duplicate copies that are used elsewhere. Since 1889, it has been taken to France twice for recomparison with the primary standard.

Kibble Balance

A far more accurate way of measuring mass is now being adopted. In a Kibble balance (named after its inventor Brian Kibble), a standard mass can be measured when the downward pull on it by gravity is balanced by an upward force from a magnetic field due to an electrical current. The precision of this technique comes from the fact that the electric and magnetic properties can be determined in terms of quantum mechanical quantities that have been precisely defined or measured. Once a standard mass is measured, it can be sent to other labs where the masses of other bodies can be determined from it.

A Second Mass Standard

The masses of atoms can be compared with one another more precisely than they can be compared with the standard kilogram. For this reason, we have a second mass standard. It is the carbon-12 atom, which, by international agreement, has been assigned a mass of 12 **atomic mass units** (u). The relation between the two units is

(1.3.1)

with an uncertainty of ±10 in the last two decimal places. Scientists can, with reasonable precision, experimentally determine the masses of other atoms relative to the mass of carbon-12. What we presently lack is a reliable means of extending that precision to more common units of mass, such as a kilogram.

Density

As we shall discuss further in Chapter 14, **density** ρ (lowercase Greek letter rho) is the mass per unit volume:

$$\frac{}{} \tag{1.3.2}$$

Densities are typically listed in kilograms per cubic meter or grams per cubic centimeter. The density of water (1.00 gram per cubic centimeter) is often used as a comparison. Fresh snow has about 10% of that density; platinum has a density that is about 21 times that of water.

Review & Summary

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Measurement in Physics Physics is based on measurement of physical quantities. Certain physical quantities have been chosen as **base quantities** (such as length, time, and mass); each has been defined in terms of a **standard** and given a **unit** of measure (such as meter, second, and kilogram). Other physical quantities are defined in terms of the base quantities and their standards and units.

SI Units The unit system emphasized in this book is the International System of Units (SI). The three physical quantities displayed in Table 1.1.1 are used in the early chapters. Standards, which must be both accessible and invariable, have been established for these base quantities by international agreement. These standards are used in all physical measurement, for both the base quantities and the quantities derived from them. Scientific notation and the prefixes of Table 1.1.2 are used to simplify measurement notation.

Changing Units Conversion of units may be performed by using *chain-link conversions* in which the original data are multiplied successively by conversion factors written as unity and the units are manipulated like algebraic quantities until only the desired units remain.

Length The meter is defined as the distance traveled by light during a precisely specified time interval.

Time The second is defined in terms of the oscillations of light emitted by an atomic (cesium-133) source. Accurate time signals are sent worldwide by radio signals keyed to atomic clocks in standardizing laboratories.

Mass The kilogram is defined in terms of a platinum–iridium standard mass kept near Paris. For measurements on an atomic scale, the atomic mass unit, defined in terms of the atom carbon-12, is usually used.

Density The density ρ of a material is the mass per unit volume:

$$\frac{}{} \qquad (1.3.2)$$

Problems

GO Tutoring problem available (at instructor's discretion) in *WileyPLUS*

SSM Worked-out solution available in Student Solutions Manual

E Easy

M Medium

H Hard

FCP Additional information available in *The Flying Circus of Physics* and at flyingcircusofphysics.com

CALC Requires calculus

BIO Biomedical application

Module 1.1 Measuring Things, Including Lengths

1 **E** **SSM** Earth is approximately a sphere of radius 6.37×10^6 m. What are (a) its circumference in kilometers, (b) its surface area in square kilometers, and (c) its volume in cubic kilometers?

2 **E** A *gry* is an old English measure for length, defined as 1/10 of a line, where *line* is another old English measure for length, defined as 1/12 inch. A common measure for length in the publishing business is a *point*, defined as 1/72 inch. What is an area of 0.50 gry^2 in points squared (points^2)?

3 **E** The micrometer (1 μm) is often called the *micron.* (a) How many microns make up 1.0 km? (b) What fraction of a centimeter equals 1.0 μm? (c) How many microns are in 1.0 yd?

4 **E** Spacing in this book was generally done in units of points and picas: 12 points = 1 pica, and 6 picas = 1 inch. If a figure was misplaced in the page proofs by 0.80 cm, what was the misplacement in (a) picas and (b) points?

5 **E** **SSM** Horses are to race over a certain English meadow for a distance of 4.0 furlongs. What is the race distance in (a) rods and (b) chains? (1 furlong = 201.168 m, 1 rod = 5.0292 m, and 1 chain = 20.117 m.)

6 **E** You can easily convert common units and measures electronically, but you still should be able to use a conversion table, such as those in Appendix D. Table 1.1 is part of a conversion table for a system of volume measures once common in Spain; a volume of 1 fanega is equivalent to 55.501 dm^3 (cubic decimeters). To complete the table, what numbers (to three significant figures) should be entered in (a) the cahiz column, (b) the fanega column, (c) the cuartilla column, and (d) the almude column, starting with the top blank? Express 7.00 almudes in (e) medios, (f) cahizes, and (g) cubic centimeters (cm^3).

Table 1.1 Problem 6

	cahiz	fanega	cuartilla	almude	medio
1 cahiz =	1	12	48	144	288

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	cahiz	fanega	cuartilla	almude	medio
1 fanega =		1	4	12	24
1 cuartilla =			1	3	6
1 almude =				1	2
1 medio =					1

7 **M** Hydraulic engineers in the United States often use, as a unit of volume of water, the *acre-foot*, defined as the volume of water that will cover 1 acre of land to a depth of 1 ft. A severe thunderstorm dumped 2.0 in. of rain in 30 min on a town of area 26 km^2. What volume of water, in acre-feet, fell on the town?

8 **M** GO Harvard Bridge, which connects MIT with its fraternities across the Charles River, has a length of 364.4 Smoots plus one ear. The unit of one Smoot is based on the length of Oliver Reed Smoot, Jr., class of 1962, who was carried or dragged length by length across the bridge so that other pledge members of the Lambda Chi Alpha fraternity could mark off (with paint) 1-Smoot lengths along the bridge. The marks have been repainted biannually by fraternity pledges since the initial measurement, usually during times of traffic congestion so that the police cannot easily interfere. (Presumably, the police were originally upset because the Smoot is not an SI base unit, but these days they seem to have accepted the unit.) Figure 1.1 shows three parallel paths, measured in Smoots (S), Willies (W), and Zeldas (Z). What is the length of 50.0 Smoots in (a) Willies and (b) Zeldas?

Figure 1.1 **Problem 8**.

9 **M** Antarctica is roughly semicircular, with a radius of 2000 km (Fig. 1.2). The average thickness of its ice cover is 3000 m. How many cubic centimeters of ice does Antarctica contain? (Ignore the curvature of Earth.)

Figure 1.2 **Problem 9**.

Module 1.2 **Time**

10 **E** Until 1883, every city and town in the United States kept its own local time. Today, travelers reset their watches only when the time change equals 1.0 h. How far, on the average, must you travel in degrees of longitude between the time-zone boundaries at which your watch must be reset by 1.0 h? (*Hint:* Earth rotates 360° in about 24 h.)

11 **E** For about 10 years after the French Revolution, the French government attempted to base measures of time on multiples of ten: One week consisted of 10 days, one day consisted of 10 hours, one hour consisted of 100 minutes, and one minute consisted of 100 seconds. What are the ratios of (a) the French decimal week to the standard week and (b) the French decimal second to the standard second?

12 **E** The fastest growing plant on record is a *Hesperoyucca whipplei* that grew 3.7 m in 14 days. What was its growth rate in micrometers per second?

13 **E** GO Three digital clocks A, B, and C run at different rates and do not have simultaneous readings of zero. Figure 1.3 shows simultaneous readings on pairs of the clocks for four occasions. (At the earliest occasion, for example, B reads 25.0 s and C reads 92.0 s.) If two events are 600 s apart on clock A, how far apart are they on (a) clock B and (b) clock C? (c) When clock A reads 400 s, what does clock B read? (d) When clock C reads 15.0 s, what does clock B read? (Assume negative readings for prezero times.)

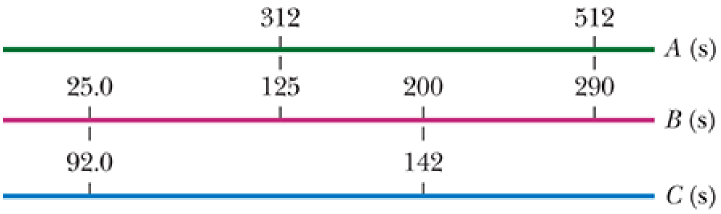

Figure 1.3 **Problem 13**.

14 **E** A lecture period (50 min) is close to 1 microcentury. (a) How long is a microcentury in minutes? (b) Using

find the percentage difference from the approximation.

15 E A fortnight is a charming English measure of time equal to 2.0 weeks (the word is a contraction of “fourteen nights”). That is a nice amount of time in pleasant company but perhaps a painful string of microseconds in unpleasant company. How many microseconds are in a fortnight?

16 E Time standards are now based on atomic clocks. A promising second standard is based on *pulsars*, which are rotating neutron stars (highly compact stars consisting only of neutrons). Some rotate at a rate that is highly stable, sending out a radio beacon that sweeps briefly across Earth once with each rotation, like a lighthouse beacon. Pulsar PSR 1937 + 21 is an example; it rotates once every 1.557 806 448 872 75 ± 3 ms, where the trailing ±3 indicates the uncertainty in the last decimal place (it does *not* mean ±3 ms). (a) How many rotations does PSR 1937 + 21 make in 7.00 days? (b) How much time does the pulsar take to rotate exactly one million times and (c) what is the associated uncertainty?

17 E SSM Five clocks are being tested in a laboratory. Exactly at noon, as determined by the WWV time signal, on successive days of a week the clocks read as in the following table. Rank the five clocks according to their relative value as good timekeepers, best to worst. Justify your choice.

Clock	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
A	12:36:40	12:36:56	12:37:12	12:37:27	12:37:44	12:37:59	12:38:14
B	11:59:59	12:00:02	11:59:57	12:00:07	12:00:02	11:59:56	12:00:03
C	15:50:45	15:51:43	15:52:41	15:53:39	15:54:37	15:55:35	15:56:33
D	12:03:59	12:02:52	12:01:45	12:00:38	11:59:31	11:58:24	11:57:17
E	12:03:59	12:02:49	12:01:54	12:01:52	12:01:32	12:01:22	12:01:12

18 M Because Earth’s rotation is gradually slowing, the length of each day increases: The day at the end of 1.0 century is 1.0 ms longer than the day at the start of the century. In 20 centuries, what is the total of the daily increases in time?

19 H Suppose that, while lying on a beach near the equator watching the Sun set over a calm ocean, you start a stopwatch just as the top of the Sun disappears. You then stand, elevating your eyes by a height H = 1.70 m, and stop the watch when the top of the Sun again disappears. If the elapsed time is t = 11.1 s, what is the radius r of Earth?

Module 1.3 Mass

20 E GO The record for the largest glass bottle was set in 1992 by a team in Millville, New Jersey—they blew a bottle with a volume of 193 U.S. fluid gallons. (a) How much short of 1.0 million cubic centimeters is that? (b) If the bottle were filled with water at the leisurely rate of 1.8 g/min, how long would the filling take? Water has a density of 1000 kg/m^3.

21 E Earth has a mass of 5.98 × 10^{24} kg. The average mass of the atoms that make up Earth is 40 u. How many atoms are there in Earth?

22 E Gold, which has a density of 19.32 g/cm^3, is the most ductile metal and can be pressed into a thin leaf or drawn out into a long fiber. (a) If a sample of gold, with a mass of 27.63 g, is pressed into a leaf of 1.000 μm thickness, what is the area of the leaf? (b) If, instead, the gold is drawn out into a cylindrical fiber of radius 2.500 μm, what is the length of the fiber?

23 E SSM (a) Assuming that water has a density of exactly 1 g/cm^3, find the mass of one cubic meter of water in kilograms. (b) Suppose that it takes 10.0 h to drain a container of 5700 m^3 of water. What is the “mass flow rate,” in kilograms per second, of water from the container?

24 M GO Grains of fine California beach sand are approximately spheres with an average radius of 50 μm and are made of silicon dioxide, which has a density of 2600 kg/m^3. What mass of sand grains would have a total surface area (the total area of all the individual spheres) equal to the surface area of a cube 1.00 m on an edge?

25 M FCP During heavy rain, a section of a mountainside measuring 2.5 km horizontally, 0.80 km up along the slope, and 2.0 m deep slips into a valley in a mud slide. Assume that the mud ends up uniformly distributed over a surface area of the valley measuring 0.40 km × 0.40 km and that mud has a density of 1900 kg/m^3. What is the mass of the mud sitting above a 4.0 m^2 area of the valley floor?

26 M One cubic centimeter of a typical cumulus cloud contains 50 to 500 water drops, which have a typical radius of 10 μm. For that range, give the lower value and the higher value, respectively, for the following. (a) How many cubic meters of water are in a cylindrical cumulus cloud of height 3.0 km and radius 1.0 km? (b) How many 1-liter pop bottles would that water fill? (c) Water has a density of 1000 kg/m^3. How much mass does the water in the cloud have?

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27 M Iron has a density of 7.87 g/cm^3, and the mass of an iron atom is 9.27×10^{-26} kg. If the atoms are spherical and tightly packed, (a) what is the volume of an iron atom and (b) what is the distance between the centers of adjacent atoms?

28 M A mole of atoms is 6.02×10^{23} atoms. To the nearest order of magnitude, how many moles of atoms are in a large domestic cat? The masses of a hydrogen atom, an oxygen atom, and a carbon atom are 1.0 u, 16 u, and 12 u, respectively. (*Hint:* Cats are sometimes known to kill a mole.)

29 M On a spending spree in Malaysia, you buy an ox with a weight of 28.9 piculs in the local unit of weights: 1 picul = 100 gins, 1 gin = 16 tahils, 1 tahil = 10 chees, and 1 chee = 10 hoons. The weight of 1 hoon corresponds to a mass of 0.3779 g. When you arrange to ship the ox home to your astonished family, how much mass in kilograms must you declare on the shipping manifest? (*Hint:* Set up multiple chain-link conversions.)

30 M CALC GO Water is poured into a container that has a small leak. The mass m of the water is given as a function of time t by $m = 5.00t^{0.8} - 3.00t + 20.00$, with $t \geq 0$, m in grams, and t in seconds. (a) At what time is the water mass greatest, and (b) what is that greatest mass? In kilograms per minute, what is the rate of mass change at (c) $t = 2.00$ s and (d) $t = 5.00$ s?

31 H CALC A vertical container with base area measuring 14.0 cm by 17.0 cm is being filled with identical pieces of candy, each with a volume of 50.0 mm^3 and a mass of 0.0200 g. Assume that the volume of the empty spaces between the candies is negligible. If the height of the candies in the container increases at the rate of 0.250 cm/s, at what rate (kilograms per minute) does the mass of the candies in the container increase?

Additional Problems

32 In the United States, a doll house has the scale of 1:12 of a real house (that is, each length of the doll house is — that of the real house) and a miniature house (a doll house to fit within a doll house) has the scale of 1:144 of a real house. Suppose a real house (Fig. 1.4) has a front length of 20 m, a depth of 12 m, a height of 6.0 m, and a standard sloped roof (vertical triangular faces on the ends) of height 3.0 m. In cubic meters, what are the volumes of the corresponding (a) doll house and (b) miniature house?

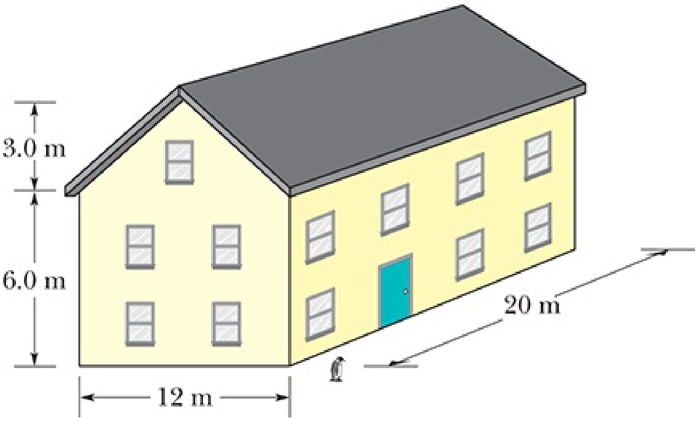

Figure 1.4 **Problem 32**.

33 SSM A ton is a measure of volume frequently used in shipping, but that use requires some care because there are at least three types of tons: A *displacement ton* is equal to 7 barrels bulk, a *freight ton* is equal to 8 barrels bulk, and a *register ton* is equal to 20 barrels bulk. A *barrel bulk* is another measure of volume: 1 barrel bulk = 0.1415 m^3. Suppose you spot a shipping order for “73 tons” of M&M candies, and you are certain that the client who sent the order intended “ton” to refer to volume (instead of weight or mass, as discussed in Chapter 5). If the client actually meant displacement tons, how many extra U.S. bushels of the candies will you erroneously ship if you interpret the order as (a) 73 freight tons and (b) 73 register tons? (1 m^3 = 28.378 U.S. bushels.)

34 Two types of *barrel* units were in use in the 1920s in the United States. The apple barrel had a legally set volume of 7056 cubic inches; the cranberry barrel, 5826 cubic inches. If a merchant sells 20 cranberry barrels of goods to a customer who thinks he is receiving apple barrels, what is the discrepancy in the shipment volume in liters?

35 An old English children’s rhyme states, “Little Miss Muffet sat on a tuffet, eating her curds and whey, when along came a spider who sat down beside her….” The spider sat down not because of the curds and whey but because Miss Muffet had a stash of 11 tuffets of dried flies. The volume measure of a tuffet is given by 1 tuffet = 2 pecks = 0.50 Imperial bushel, where 1 Imperial bushel = 36.3687 liters (L). What was Miss Muffet’s stash in (a) pecks, (b) Imperial bushels, and (c) liters?

36 Table 1.2 shows some old measures of liquid volume. To complete the table, what numbers (to three significant figures) should be entered in (a) the wey column, (b) the chaldron column, (c) the bag column, (d) the pottle column, and (e) the gill column, starting from the top down? (f) The volume of 1 bag is equal to 0.1091 m^3. If an old story has a witch cooking up some vile liquid in a cauldron of volume 1.5 chaldrons, what is the volume in cubic meters?

Table 1.2 **Problem 36**

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	wey	chaldron	bag	pottle	gill
1 wey =	1	10/9	40/3	640	120 240
1 chaldron =					
1 bag =					
1 pottle =					
1 gill =					

37 A typical sugar cube has an edge length of 1 cm. If you had a cubical box that contained a mole of sugar cubes, what would its edge length be? (One mole = 6.02×10^{23} units.)

38 An old manuscript reveals that a landowner in the time of King Arthur held 3.00 acres of plowed land plus a livestock area of 25.0 perches by 4.00 perches. What was the total area in (a) the old unit of roods and (b) the more modern unit of square meters? Here, 1 acre is an area of 40 perches by 4 perches, 1 rood is an area of 40 perches by 1 perch, and 1 perch is the length 16.5 ft.

39 SSM A tourist purchases a car in England and ships it home to the United States. The car sticker advertised that the car's fuel consumption was at the rate of 40 miles per gallon on the open road. The tourist does not realize that the U.K. gallon differs from the U.S. gallon:

For a trip of 750 miles (in the United States), how many gallons of fuel does (a) the mistaken tourist believe she needs and (b) the car actually require?

40 Using conversions and data in the chapter, determine the number of hydrogen atoms required to obtain 1.0 kg of hydrogen. A hydrogen atom has a mass of 1.0 u.

41 SSM A *cord* is a volume of cut wood equal to a stack 8 ft long, 4 ft wide, and 4 ft high. How many cords are in 1.0 m^3?

42 One molecule of water (H_2O) contains two atoms of hydrogen and one atom of oxygen. A hydrogen atom has a mass of 1.0 u and an atom of oxygen has a mass of 16 u, approximately. (a) What is the mass in kilograms of one molecule of water? (b) How many molecules of water are in the world's oceans, which have an estimated total mass of 1.4×10^{21} kg?

43 A person on a diet might lose 2.3 kg per week. Express the mass loss rate in milligrams per second, as if the dieter could sense the second-by-second loss.

44 What mass of water fell on the town in Problem 7? Water has a density of 1.0×10^3 kg/m^3.

45 (a) A unit of time sometimes used in microscopic physics is the *shake*. One shake equals 10^{-8} s. Are there more shakes in a second than there are seconds in a year? (b) Humans have existed for about 10^6 years, whereas the universe is about 10^{10} years old. If the age of the universe is defined as 1 "universe day," where a universe day consists of "universe seconds" as a normal day consists of normal seconds, how many universe seconds have humans existed?

46 A unit of area often used in measuring land areas is the *hectare*, defined as 10^4 m^2. An open-pit coal mine consumes 75 hectares of land, down to a depth of 26 m, each year. What volume of earth, in cubic kilometers, is removed in this time?

47 SSM An astronomical unit (AU) is the average distance between Earth and the Sun, approximately 1.50×10^8 km. The speed of light is about 3.0×10^8 m/s. Express the speed of light in astronomical units per minute.

48 The common Eastern mole, a mammal, typically has a mass of 75 g, which corresponds to about 7.5 moles of atoms. (A mole of atoms is 6.02×10^{23} atoms.) In atomic mass units (u), what is the average mass of the atoms in the common Eastern mole?

49 A traditional unit of length in Japan is the ken (1 ken = 1.97 m). What are the ratios of (a) square kens to square meters and (b) cubic kens to cubic meters? What is the volume of a cylindrical water tank of height 5.50 kens and radius 3.00 kens in (c) cubic kens and (d) cubic meters?

50 You receive orders to sail due east for 24.5 mi to put your salvage ship directly over a sunken pirate ship. However, when your divers probe the ocean floor at that location and find no evidence of a ship, you radio back to your source of information, only to discover that the sailing distance was supposed to be 24.5 *nautical miles*, not regular miles. Use the Length table in Appendix D to calculate how far horizontally you are from the pirate ship in kilometers.

51 *Density and liquefaction.* A heavy object can sink into the ground during an earthquake if the shaking causes the ground to undergo *liquefaction*, in which the soil grains experience little friction as they slide over one another. The ground is then effectively quicksand. The possibility of liquefaction in sandy ground can be predicted in terms of the *void*

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ratio e for a sample of the ground: $e = V_{\text{voids}}/V_{\text{grains}}$. Here, V_{grains} is the total volume of the sand grains in the sample and V_{voids} is the total volume between the grains (in the *voids*). If e exceeds a critical value of 0.80, liquefaction can occur during an earthquake. What is the corresponding sand density ρ_{sand}? Solid silicon dioxide (the primary component of sand) has a density of

52 *Billion and trillion.* Until 1974, the U.S. and the U.K. used the same names to mean different large numbers. Here are two examples: In American English a billion means a number with 9 zeros after the 1 and in British English it formerly meant a number with 12 zeros after the 1. In American English a trillion means a number with 12 zeros after the 1 and in British English it formerly meant a number with 18 zeros after the 1. In scientific notation with the prefixes in Table 1.1.2, what is 4.0 billion meters in (a) the American use and (b) the former British use? What is 5.0 trillion meters in (c) the American use and (d) the former British use?

53 *Townships.* In the United States, real estate can be measured in terms of *townships*: 1 township = 36 mi^2, 1 mi^2 = 640 acres, 1 acre = 4840 yd^2, 1 yd^2 = 9 ft^2. If you own 3.0 townships, how many square feet of real estate do you own?

54 *Measures of a man.* Leonardo da Vinci, renowned for his understanding of human anatomy, valued the measures of a man stated by Vitruvius Pollio, a Roman architect and engineer of the first century BC: four fingers make one palm, four palms make one foot, six palms make one cubit, and four cubits make a man's height. If we take a finger width to be 0.75 in., what then are (a) the length of a man's foot and (b) the height of a man, both in centimeters?

55 *Dog years.* Dog owners like to convert the age of a dog (dubbed *dog years*) to the usual meaning of years to account for the more rapid aging of dogs. One measure of the aging process in both dogs and humans is the rate at which the DNA changes in a process called methylation. Research on that process shows that after the first year, the equivalent age of a dog is given by

where ln is the natural logarithm. What then is the equivalent age of a dog on its 13th birthday?

56 *Galactic years.* The time the Solar System takes to circle around the center of the Milky Way galaxy, a galactic year, is about 230 My. In galactic years, how long ago did (a) the *Tyrannosaurus rex* dinosaurs live (67 My ago), (b) the first major ice age occur (2.2 Gy ago), and (c) Earth form (4.54 Gy ago)?

57 *Planck time.* The smallest time interval defined in physics is the Planck time , which is the time required for light to travel across a certain length in a vacuum. The universe began with the big bang 13.772 billion years ago. What is the number of Planck times since that beginning?

58 *20,000 Leagues Under the Sea.* In Jules Verne's classic science fiction story (published as a serial from 1869 to 1870), Captain Nemo travels in his underwater ship *Nautilus* through the seas of the world for a distance of 20,000 leagues, where a (metric) league is equal to 4.000 km. Assume Earth is spherical with a radius of 6378 km. How many times could Nemo have traveled around Earth?

59 *Sea mile.* A sea mile is a commonly used measure of distance in navigation but, unlike the *nautical mile*, it does not have a fixed value because it depends on the latitude at which it is measured. It is the distance measured along any given longitude that subtends 1 arc minute, as measured from Earth's center (Fig. 1.5). That distance depends on the radius r of Earth at that point, but because Earth is not a perfect sphere but is wider at the equator and has slightly flattened polar regions, the radius depends on the latitude. At the equator, the radius is 6378 km; at the pole it is 6356 km. What is the difference in a sea mile measured at the equator and at the pole?

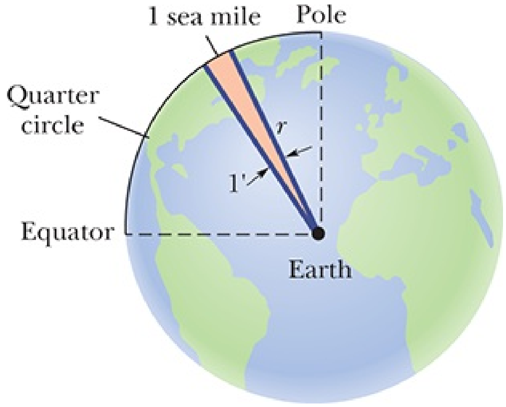

Figure 1.5 **Problem 59**.

60 *Noctilucent clouds*. Soon after the huge 1883 volcanic explosion of Krakatoa Island (near Java in the southeast Pacific), silvery, blue clouds began to appear nightly in the Northern Hemisphere early at night. The explosion was so violent that it hurled dust to the *mesosphere*, a cool portion of the atmosphere located well above the stratosphere. There water collected and froze on the dust to form the particles that made the first of these clouds. Termed *noctilucent clouds* ("night shining"), these clouds are now appearing frequently (Fig. 1.6*a*), signaling a major change in Earth's atmosphere, not because of volcanic explosions, but because of the increased production of methane by industries, rice paddies, landfills, and livestock flatulence.

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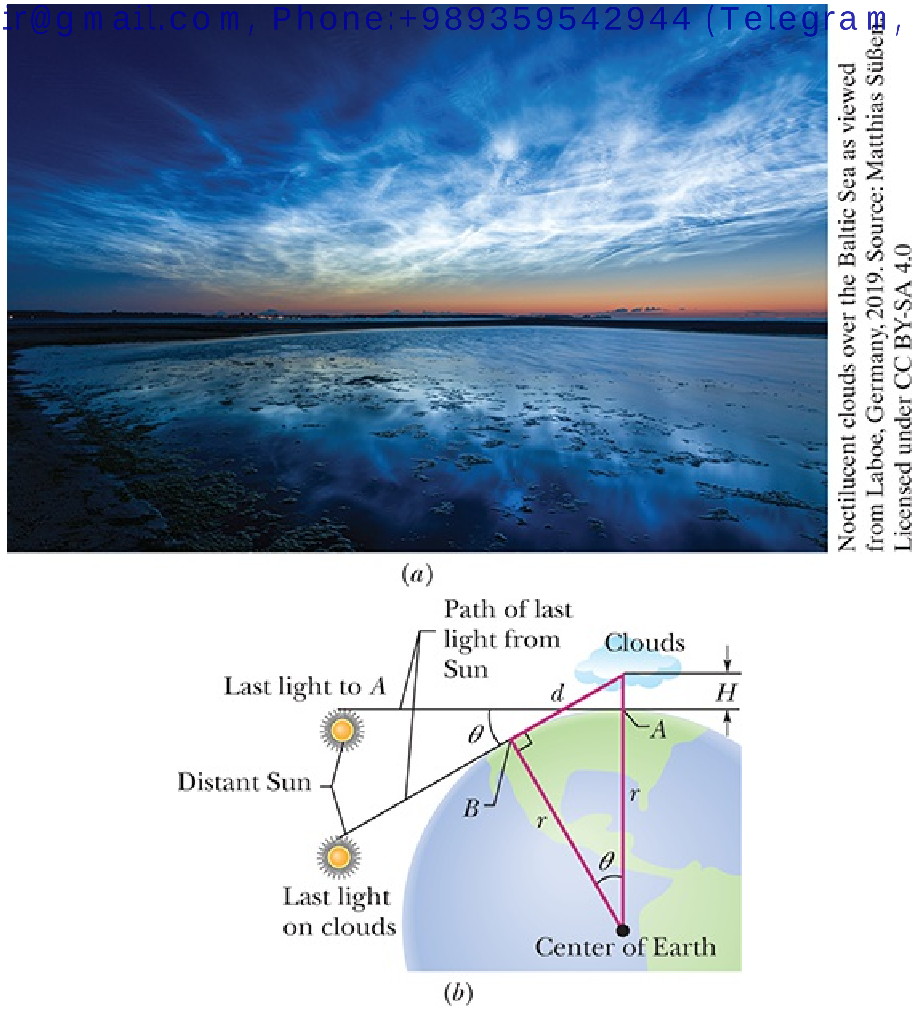

Noctilucent clouds over the Baltic Sea as viewed from Laboe, Germany, 2019. Source: Matthias Süßen. Licensed under CC BY-SA 4.0

Figure 1.6 Problem 60. (*a*) Noctilucent clouds. (*b*) Sunlight reaching the observer and the clouds.

The clouds are visible after sunset because they are in the upper portion of the atmosphere that is still illuminated by sunlight. Figure 1.6*b* shows the situation for an observer at point *A* who sees the clouds overhead 38 min after sunset. The two lines of light are tangent to Earth's surface at *A* and *B*, at radius *r* from Earth's center. Earth rotates through angle θ between the two lines of light. What is the height *H* of the clouds?

61 *Class time, the long of it.* For a common four-year undergraduate program, what are the total number of (a) hours and (b) seconds spent in class? Enter your answer in scientific notation.