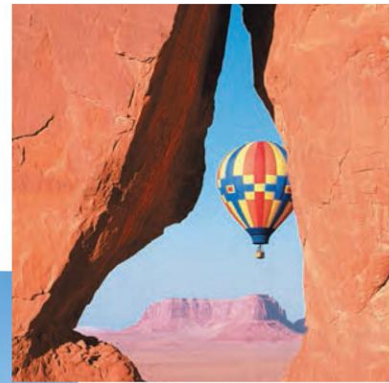


5th EDITION

PHYSICS

for SCIENTISTS and ENGINEERS



DOUGLAS
GIANCOLI

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DOUGLAS GIANCOLI

Pearson

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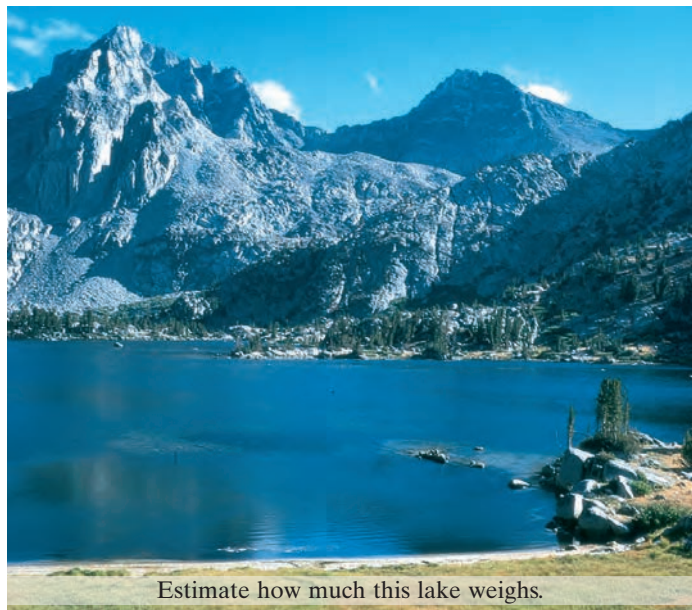
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Contents

Applications List	xii
Preface	xvi
To Students	xx
Use of Color	xxi



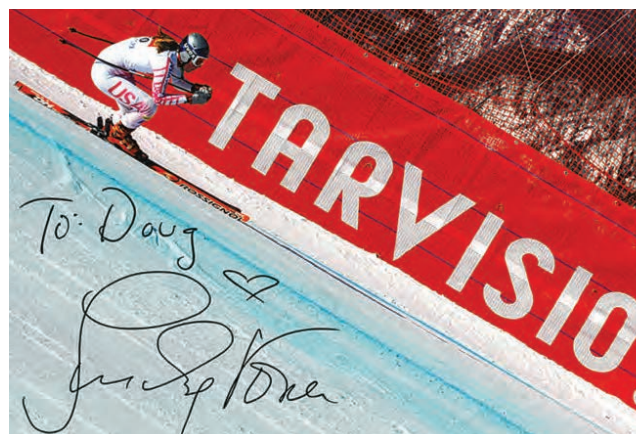
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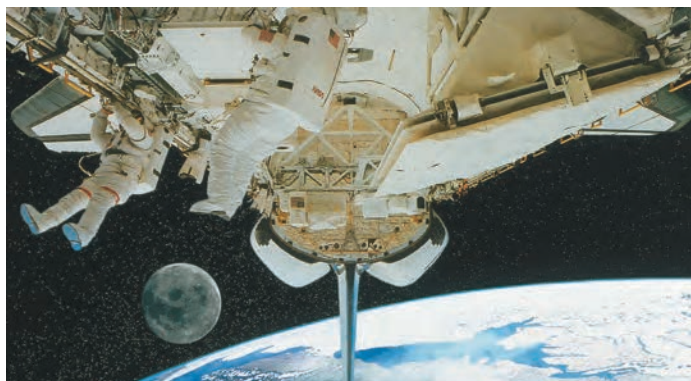
1	INTRODUCTION, MEASUREMENT, ESTIMATING	1
1-1	How Science Works	2
1-2	Models, Theories, and Laws	3
1-3	Measurement and Uncertainty; Significant Figures	3
1-4	Units, Standards, and the SI System	6
1-5	Converting Units	9
1-6	Order of Magnitude: Rapid Estimating	11
*1-7	Dimensions and Dimensional Analysis	14
	Questions, MisConceptions, Problems	15-19
2	DESCRIBING MOTION: KINEMATICS IN ONE DIMENSION	20
2-1	Reference Frames and Displacement	21
2-2	Average Velocity	22
2-3	Instantaneous Velocity	24
2-4	Acceleration	27
2-5	Motion at Constant Acceleration	30
2-6	Solving Problems	33
2-7	Freely Falling Objects	37
*2-8	Variable Acceleration; Integral Calculus	43
	Questions, MisConceptions, Problems	45-53

3	KINEMATICS IN TWO OR THREE DIMENSIONS; VECTORS	54
3-1	Vectors and Scalars	55
3-2	Addition of Vectors—Graphical Methods	55
3-3	Subtraction of Vectors, and Multiplication of a Vector by a Scalar	57
3-4	Adding Vectors by Components	58
3-5	Unit Vectors	62
3-6	Vector Kinematics	62
3-7	Projectile Motion	65
3-8	Solving Problems Involving Projectile Motion	67
3-9	Relative Velocity	73
	Questions, MisConceptions, Problems	76-84

4	DYNAMICS: NEWTON'S LAWS OF MOTION	85
4-1	Force	86
4-2	Newton's First Law of Motion	86
4-3	Mass	88
4-4	Newton's Second Law of Motion	88
4-5	Newton's Third Law of Motion	91
4-6	Weight—the Force of Gravity; and the Normal Force	94
4-7	Solving Problems with Newton's Laws: Free-Body Diagrams	97
4-8	Problem Solving—A General Approach	104
	Questions, MisConceptions, Problems	105-115

5	USING NEWTON'S LAWS: FRICTION, CIRCULAR MOTION, DRAG FORCES	116
5-1	Using Newton's Laws with Friction	117
5-2	Uniform Circular Motion—Kinematics	123
5-3	Dynamics of Uniform Circular Motion	126
5-4	Highway Curves: Banked and Unbanked	130
5-5	Nonuniform Circular Motion	133
*5-6	Velocity-Dependent Forces: Drag and Terminal Velocity	134
	Questions, MisConceptions, Problems	136-144





6 GRAVITATION AND NEWTON'S SYNTHESIS 145

6-1	Newton's Law of Universal Gravitation	146
6-2	Vector Form of Newton's Law of Universal Gravitation	149
6-3	Gravity Near the Earth's Surface	149
6-4	Satellites and "Weightlessness"	152
6-5	Planets, Kepler's Laws, and Newton's Synthesis	155
6-6	Moon Rises an Hour Later Each Day	161
6-7	Types of Forces in Nature	161
*6-8	Gravitational Field	162
*6-9	Principle of Equivalence; Curvature of Space; Black Holes	163
	Questions, MisConceptions, Problems	165-171

7 WORK AND ENERGY 172

7-1	Work Done by a Constant Force	173
7-2	Scalar Product of Two Vectors	176
7-3	Work Done by a Varying Force	177
7-4	Kinetic Energy and the Work-Energy Principle	181
	Questions, MisConceptions, Problems	186-193

8 CONSERVATION OF ENERGY 194

8-1	Conservative and Nonconservative Forces	195
8-2	Potential Energy	197
8-3	Mechanical Energy and Its Conservation	200
8-4	Problem Solving Using Conservation of Mechanical Energy	201
8-5	The Law of Conservation of Energy	207
8-6	Energy Conservation with Dissipative Forces: Solving Problems	208
8-7	Gravitational Potential Energy and Escape Velocity	210
8-8	Power	213
8-9	Potential Energy Diagrams; Stable and Unstable Equilibrium	215
*8-10	Gravitational Assist (Slingshot)	216
	Questions, MisConceptions, Problems	218-226

9 LINEAR MOMENTUM 227

9-1	Momentum and Its Relation to Force	228
9-2	Conservation of Momentum	230
9-3	Collisions and Impulse	234
9-4	Conservation of Energy and Momentum in Collisions	235
9-5	Elastic Collisions in One Dimension	236
9-6	Inelastic Collisions	239
9-7	Collisions in 2 or 3 Dimensions	241
9-8	Center of Mass (CM)	244
9-9	Center of Mass and Translational Motion	248
*9-10	Systems of Variable Mass; Rocket Propulsion	251
	Questions, MisConceptions, Problems	254-263

10 ROTATIONAL MOTION 264

10-1	Angular Quantities	265
10-2	Vector Nature of Angular Quantities	270
10-3	Constant Angular Acceleration	270
10-4	Torque	271
10-5	Rotational Dynamics; Torque and Rotational Inertia	274
10-6	Solving Problems in Rotational Dynamics	276
10-7	Determining Moments of Inertia	279
10-8	Rotational Kinetic Energy	281
10-9	Rotation plus Translational Motion; Rolling	283
*10-10	Why Does a Rolling Sphere Slow Down?	289
	Questions, MisConceptions, Problems	291-301

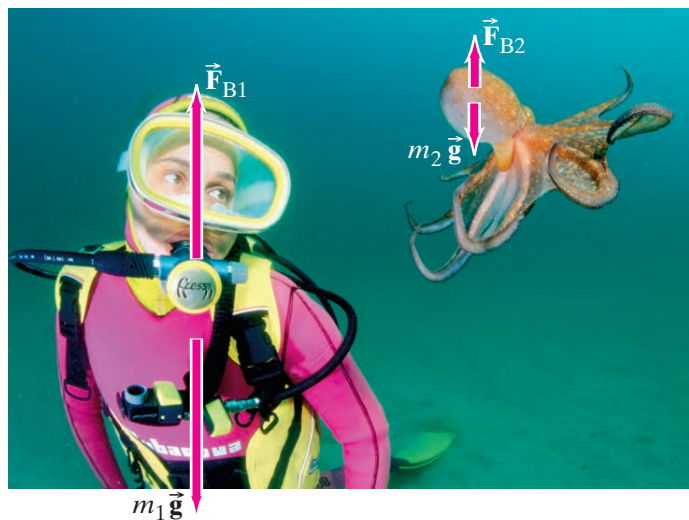
11 ANGULAR MOMENTUM; GENERAL ROTATION 302

11-1	Angular Momentum—Objects Rotating About a Fixed Axis	303
11-2	Vector Cross Product; Torque as a Vector	307
11-3	Angular Momentum of a Particle	309
11-4	Angular Momentum and Torque for a System of Particles; General Motion	310
11-5	Angular Momentum and Torque for a Rigid Object	312
11-6	Conservation of Angular Momentum	315
*11-7	The Spinning Top and Gyroscope	317
11-8	Rotating Frames of Reference; Inertial Forces	318
*11-9	The Coriolis Effect	319
	Questions, MisConceptions, Problems	322-330



12 STATIC EQUILIBRIUM; ELASTICITY AND FRACTURE 331

12-1	The Conditions for Equilibrium	332
12-2	Solving Statics Problems	334
*12-3	Applications to Muscles and Joints	339
12-4	Stability and Balance	341
12-5	Elasticity; Stress and Strain	342
12-6	Fracture	345
*12-7	Trusses and Bridges	347
*12-8	Arches and Domes	350
	Questions, MisConceptions, Problems	353–364



13 FLUIDS 365

13-1	Phases of Matter	366
13-2	Density and Specific Gravity	366
13-3	Pressure in Fluids	367
13-4	Atmospheric Pressure and Gauge Pressure	371
13-5	Pascal's Principle	371
13-6	Measurement of Pressure; Gauges and the Barometer	372
13-7	Buoyancy and Archimedes' Principle	374
13-8	Fluids in Motion; Flow Rate and the Equation of Continuity	378
13-9	Bernoulli's Equation	380
13-10	Applications of Bernoulli's Principle: Torricelli, Airplanes, Baseballs, Blood Flow	382
13-11	Viscosity	385
*13-12	Flow in Tubes: Poiseuille's Equation, Blood Flow	385
*13-13	Surface Tension and Capillarity	386
*13-14	Pumps, and the Heart	388
	Questions, MisConceptions, Problems	390–398

14 OSCILLATIONS 399

14-1	Oscillations of a Spring	400
14-2	Simple Harmonic Motion	402
14-3	Energy in the Simple Harmonic Oscillator	408
14-4	Simple Harmonic Motion Related to Uniform Circular Motion	410
14-5	The Simple Pendulum	411
*14-6	The Physical Pendulum and the Torsion Pendulum	412
14-7	Damped Harmonic Motion	414
14-8	Forced Oscillations; Resonance	417
	Questions, MisConceptions, Problems	420–427

15 WAVE MOTION 428

15-1	Characteristics of Wave Motion	429
15-2	Types of Waves: Transverse and Longitudinal	431
15-3	Energy Transported by Waves	435
15-4	Mathematical Representation of a Traveling Wave	437
*15-5	The Wave Equation	440
15-6	The Principle of Superposition	441
15-7	Reflection and Transmission	443
15-8	Interference	444
15-9	Standing Waves; Resonance	446
15-10	Refraction	449
15-11	Diffraction	450
	Questions, MisConceptions, Problems	452–459

16 SOUND 460

16-1	Characteristics of Sound	461
16-2	Mathematical Representation of Longitudinal Waves	462
16-3	Intensity of Sound: Decibels	464
16-4	Sources of Sound: Vibrating Strings and Air Columns	467
*16-5	Quality of Sound, and Noise; Superposition	472
16-6	Interference of Sound Waves; Beats	473
16-7	Doppler Effect	476
*16-8	Shock Waves and the Sonic Boom	480
*16-9	Applications: Sonar, Ultrasound, and Medical Imaging	481
	Questions, MisConceptions, Problems	484–491

17 TEMPERATURE, THERMAL EXPANSION, AND THE IDEAL GAS LAW 492

17-1	Atomic Theory of Matter	493
17-2	Temperature and Thermometers	495
17-3	Thermal Equilibrium and the Zeroth Law of Thermodynamics	497
17-4	Thermal Expansion	497
*17-5	Thermal Stresses	501
17-6	The Gas Laws and Absolute Temperature	502
17-7	The Ideal Gas Law	503
17-8	Problem Solving with the Ideal Gas Law	504
17-9	Ideal Gas Law in Terms of Molecules: Avogadro's Number	506
*17-10	Ideal Gas Temperature Scale — a Standard	507
	Questions, MisConceptions, Problems	509–515

18 KINETIC THEORY OF GASES 516

18-1	The Ideal Gas Law and the Molecular Interpretation of Temperature	516
18-2	Distribution of Molecular Speeds	520
18-3	Real Gases and Changes of Phase	522
18-4	Vapor Pressure and Humidity	524
18-5	Temperature Decrease of Boiling Water with Altitude	526
18-6	Van der Waals Equation of State	527
18-7	Mean Free Path	528
18-8	Diffusion	530
	Questions, MisConceptions, Problems	532–537

19 HEAT AND THE FIRST LAW OF THERMODYNAMICS 538

19-1	Heat as Energy Transfer	539
19-2	Internal Energy	540
19-3	Specific Heat	541
19-4	Calorimetry — Solving Problems	542
19-5	Latent Heat	545
19-6	The First Law of Thermodynamics	549
19-7	Thermodynamic Processes and the First Law	551
19-8	Molar Specific Heats for Gases, and the Equipartition of Energy	556
19-9	Adiabatic Expansion of a Gas	559
19-10	Heat Transfer: Conduction, Convection, Radiation	560
	Questions, MisConceptions, Problems	568–575



20 SECOND LAW OF THERMODYNAMICS 576

20-1	The Second Law of Thermodynamics — Introduction	577
20-2	Heat Engines	578
20-3	The Carnot Engine; Reversible and Irreversible Processes	580
20-4	Refrigerators, Air Conditioners, and Heat Pumps	584
20-5	Entropy	587
20-6	Entropy and the Second Law of Thermodynamics	590
20-7	Order to Disorder	593
20-8	Unavailability of Energy; Heat Death	594
20-9	Statistical Interpretation of Entropy and the Second Law	595
*20-10	Thermodynamic Temperature; Third Law of Thermodynamics	597
20-11	Thermal Pollution, Global Warming, and Energy Resources	598
	Questions, MisConceptions, Problems	601–608





21 ELECTRIC CHARGE AND ELECTRIC FIELD 609

21-1	Static Electricity; Electric Charge and Its Conservation	610
21-2	Electric Charge in the Atom	611
21-3	Insulators and Conductors	611
21-4	Induced Charge; the Electroscope	612
21-5	Coulomb's Law	613
21-6	The Electric Field	618
21-7	Electric Field Calculations for Continuous Charge Distributions	622
21-8	Field Lines	626
21-9	Electric Fields and Conductors	627
21-10	Motion of a Charged Particle in an Electric Field	628
21-11	Electric Dipoles	629
*21-12	Electric Forces in Molecular Biology: DNA Structure and Replication	631
	Questions, MisConceptions, Problems	634-642

22 GAUSS'S LAW 643

22-1	Electric Flux	644
22-2	Gauss's Law	645
22-3	Applications of Gauss's Law	647
*22-4	Experimental Basis of Gauss's and Coulomb's Laws	652
	Questions, MisConceptions, Problems	653-659

23 ELECTRIC POTENTIAL 660

23-1	Electric Potential Energy and Potential Difference	661
23-2	Relation between Electric Potential and Electric Field	664
23-3	Electric Potential Due to Point Charges	666
23-4	Potential Due to Any Charge Distribution	669
23-5	Equipotential Lines and Surfaces	670
23-6	Potential Due to Electric Dipole; Dipole Moment	671
23-7	\vec{E} Determined from V	672
23-8	Electrostatic Potential Energy; the Electron Volt	674
23-9	Digital; Binary Numbers; Signal Voltage	676
*23-10	TV and Computer Monitors	679
*23-11	Electrocardiogram (ECG or EKG)	682
	Questions, MisConceptions, Problems	684-691

24 CAPACITANCE, DIELECTRICS, ELECTRIC ENERGY STORAGE 692

24-1	Capacitors	692
24-2	Determination of Capacitance	694
24-3	Capacitors in Series and Parallel	698
24-4	Storage of Electric Energy	700
24-5	Dielectrics	703
*24-6	Molecular Description of Dielectrics	706
	Questions, MisConceptions, Problems	708-716

25 ELECTRIC CURRENT AND RESISTANCE 717

25-1	The Electric Battery	718
25-2	Electric Current	720
25-3	Ohm's Law: Resistance and Resistors	722
25-4	Resistivity	724
25-5	Electric Power	726
25-6	Power in Household Circuits	729
25-7	Alternating Current	730
25-8	Microscopic View of Electric Current	732
*25-9	Superconductivity	735
*25-10	Electrical Conduction in the Human Nervous System	736
	Questions, MisConceptions, Problems	739-746



26 DC CIRCUITS 747

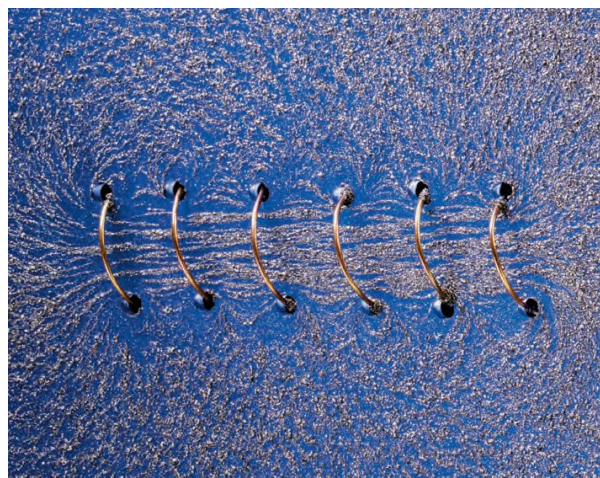
26-1	EMF and Terminal Voltage	748
26-2	Resistors in Series and in Parallel	749
26-3	Kirchhoff's Rules	754
26-4	EMFs in Series and in Parallel; Charging a Battery	757
26-5	RC Circuits—Resistor and Capacitor in Series	759
26-6	Electric Hazards and Safety	764
26-7	Ammeters and Voltmeters—Measurement Affects Quantity Measured	767
	Questions, MisConceptions, Problems	771-781

27 MAGNETISM 782

27-1	Magnets and Magnetic Fields	782
27-2	Electric Currents Produce Magnetic Fields	785
27-3	Force on an Electric Current in a Magnetic Field; Definition of \vec{B}	786
27-4	Force on an Electric Charge Moving in a Magnetic Field	788
27-5	Torque on a Current Loop; Magnetic Dipole Moment	793
27-6	Applications: Motors, Loudspeakers, Galvanometers	795
27-7	Discovery and Properties of the Electron	797
27-8	The Hall Effect	799
27-9	Mass Spectrometer	800
	Questions, MisConceptions, Problems	802–810

28 SOURCES OF MAGNETIC FIELD 811

28-1	Magnetic Field Due to a Straight Wire	812
28-2	Force between Two Parallel Wires	813
28-3	Definitions of the Ampere and the Coulomb	814
28-4	Ampère's Law	815
28-5	Magnetic Field of a Solenoid and a Toroid	819
28-6	Biot-Savart Law	821
28-7	Magnetic Field Due to a Single Moving Charge	824
28-8	Magnetic Materials—Ferromagnetism	824
28-9	Electromagnets and Solenoids—Applications	826
28-10	Magnetic Fields in Magnetic Materials; Hysteresis	827
*28-11	Paramagnetism and Diamagnetism	828
	Questions, MisConceptions, Problems	830–837



29 ELECTROMAGNETIC INDUCTION AND FARADAY'S LAW 838

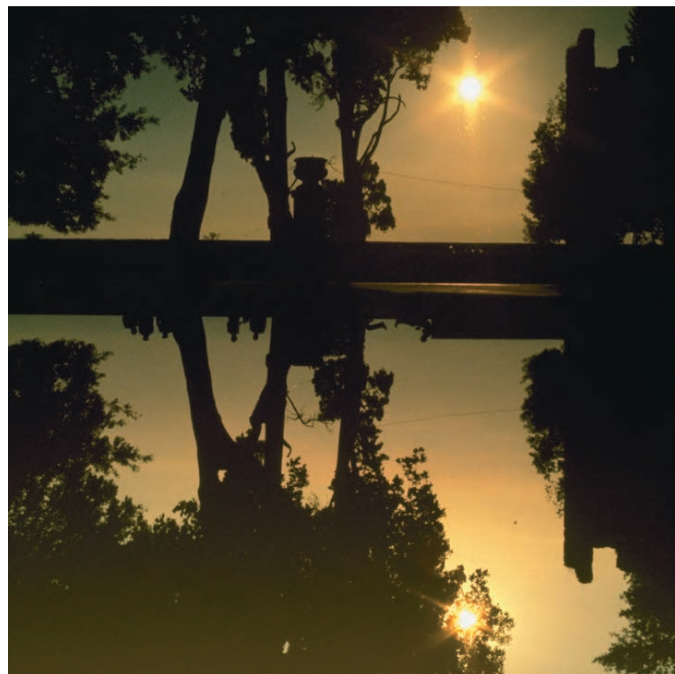
29-1	Induced EMF	839
29-2	Faraday's Law of Induction; Lenz's Law	840
29-3	EMF Induced in a Moving Conductor	845
29-4	Electric Generators	846
29-5	Back EMF and Counter Torque; Eddy Currents	848
29-6	Transformers and Transmission of Power	851
29-7	A Changing Magnetic Flux Produces an Electric Field	854
*29-8	Information Storage: Magnetic and Semiconductor	856
*29-9	Applications of Induction: Microphone, Seismograph, GFCI	858
	Questions, MisConceptions, Problems	860–868

30 INDUCTANCE, ELECTROMAGNETIC OSCILLATIONS, AND AC CIRCUITS 869

30-1	Mutual Inductance	870
30-2	Self-Inductance; Inductors	872
30-3	Energy Stored in a Magnetic Field	874
30-4	LR Circuits	875
30-5	LC Circuits and Electromagnetic Oscillations	877
30-6	LC Oscillations with Resistance (LRC Circuit)	880
30-7	AC Circuits and Reactance	881
30-8	LRC Series AC Circuit; Phasor Diagrams	885
30-9	Resonance in AC Circuits	887
30-10	Impedance Matching	888
*30-11	Three-Phase AC	889
	Questions, MisConceptions, Problems	890–897

31 MAXWELL'S EQUATIONS AND ELECTROMAGNETIC WAVES 898

31-1	Changing Electric Fields Produce Magnetic Fields; Displacement Current	899
31-2	Gauss's Law for Magnetism	902
31-3	Maxwell's Equations	903
31-4	Production of Electromagnetic Waves	903
31-5	Electromagnetic Waves, and Their Speed, Derived from Maxwell's Equations	905
31-6	Light as an Electromagnetic Wave and the Electromagnetic Spectrum	909
31-7	Measuring the Speed of Light	912
31-8	Energy in EM Waves; the Poynting Vector	913
31-9	Radiation Pressure	915
31-10	Radio and Television; Wireless Communication	917
	Questions, MisConceptions, Problems	921–925



32 LIGHT: REFLECTION AND REFRACTION 926

32-1	The Ray Model of Light	927
32-2	Reflection; Image Formation by a Plane Mirror	927
32-3	Formation of Images by Spherical Mirrors	931
32-4	Seeing Yourself in a Magnifying Mirror (Concave)	936
32-5	Convex (Rearview) Mirrors	938
32-6	Index of Refraction	939
32-7	Refraction: Snell's Law	939
32-8	The Visible Spectrum and Dispersion	941
32-9	Total Internal Reflection; Fiber Optics	943
*32-10	Refraction at a Spherical Surface	946
	Questions, MisConceptions, Problems	949-957

33 LENSES AND OPTICAL INSTRUMENTS 958

33-1	Thin Lenses; Ray Tracing and Focal Length	959
33-2	The Thin Lens Equation	962
33-3	Combinations of Lenses	966
33-4	Lensmaker's Equation	968
33-5	Cameras: Film and Digital	970
33-6	The Human Eye; Corrective Lenses	975
33-7	Magnifying Glass	979
33-8	Telescopes	980
33-9	Compound Microscope	983
33-10	Aberrations of Lenses and Mirrors	984
	Questions, MisConceptions, Problems	986-994

THE WAVE NATURE OF LIGHT: 34 INTERFERENCE AND POLARIZATION 995

34-1	Waves vs. Particles; Huygens' Principle and Diffraction	996
34-2	Huygens' Principle and the Law of Refraction; Mirages	997
34-3	Interference-Young's Double-Slit Experiment	998
*34-4	Intensity in the Double-Slit Interference Pattern	1002
34-5	Interference in Thin Films	1004
34-6	Michelson Interferometer	1010
34-7	Polarization	1010
*34-8	Liquid Crystal Displays (LCD)	1014
*34-9	Scattering of Light by the Atmosphere	1015
34-10	Brightness: Lumens and Luminous Intensity	1016
*34-11	Efficiency of Lightbulbs	1016
	Questions, MisConceptions, Problems	1018-1024

35 DIFFRACTION 1025

35-1	Diffraction by a Single Slit or Disk	1026
*35-2	Intensity in Single-Slit Diffraction Pattern	1028
*35-3	Diffraction in the Double-Slit Experiment	1031
35-4	Interference vs. Diffraction	1033
35-5	Limits of Resolution; Circular Apertures	1033
35-6	Resolution of Telescopes and Microscopes; the λ Limit	1035
35-7	Resolution of the Human Eye and Useful Magnification	1037
35-8	Diffraction Grating	1037
35-9	The Spectrometer and Spectroscopy	1040
*35-10	Peak Widths and Resolving Power for a Diffraction Grating	1041
35-11	X-Rays and X-Ray Diffraction	1043
*35-12	X-Ray Imaging and Computed Tomography (CT Scan)	1045
*35-13	Specialty Microscopes and Contrast	1048
	Questions, MisConceptions, Problems	1049-1054



36 THE SPECIAL THEORY OF RELATIVITY 1055

36-1	Galilean–Newtonian Relativity	1056
36-2	The Michelson–Morley Experiment	1058
36-3	Postulates of the Special Theory of Relativity	1061
36-4	Simultaneity	1062
36-5	Time Dilation and the Twin Paradox	1064
36-6	Length Contraction	1070
36-7	Four-Dimensional Space–Time	1072
36-8	Galilean and Lorentz Transformations	1072
36-9	Relativistic Momentum	1077
36-10	The Ultimate Speed	1079
36-11	$E = mc^2$; Mass and Energy	1080
36-12	Doppler Shift for Light	1085
36-13	The Impact of Special Relativity	1086
	Questions, MisConceptions, Problems	1088–1094

37 EARLY QUANTUM THEORY AND MODELS OF THE ATOM 1095

37-1	Blackbody Radiation; Planck’s Quantum Hypothesis	1096
37-2	Photon Theory of Light and the Photoelectric Effect	1098
37-3	Energy, Mass, and Momentum of a Photon	1101
37-4	Compton Effect	1102
37-5	Photon Interactions; Pair Production	1104
37-6	Wave–Particle Duality; the Principle of Complementarity	1105
37-7	Wave Nature of Matter	1106
37-8	Electron Microscopes	1108
37-9	Early Models of the Atom	1110
37-10	Atomic Spectra: Key to the Structure of the Atom	1111
37-11	The Bohr Model	1113
37-12	de Broglie’s Hypothesis Applied to Atoms	1120
	Questions, MisConceptions, Problems	1121–1127

APPENDICES

A	Mathematical Formulas	A-1
B	Derivatives and Integrals	A-6
C	Numerical Integration	A-8
D	More on Dimensional Analysis	A-12
E	Gravitational Force Due to a Spherical Mass Distribution	A-13
F	Differential Form of Maxwell’s Equations	A-16
G	Selected Isotopes	A-18
	Answers to Odd-Numbered Problems	A-23
	Index	A-47
	Photo Credits	A-77

38 QUANTUM MECHANICS 1128

38-1	Quantum Mechanics—A New Theory	1129
38-2	The Wave Function and Its Interpretation; the Double-Slit Experiment	1129
38-3	The Heisenberg Uncertainty Principle	1131
38-4	Philosophic Implications; Probability Versus Determinism	1135
38-5	The Schrödinger Equation in One Dimension—Time-Independent Form	1136
*38-6	Time-Dependent Schrödinger Equation	1138
38-7	Free Particles; Plane Waves and Wave Packets	1140
38-8	Particle in an Infinitely Deep Square Well Potential (a Rigid Box)	1142
38-9	Finite Potential Well	1147
38-10	Tunneling through a Barrier	1149
	Questions, MisConceptions, Problems	1152–1157

39 QUANTUM MECHANICS OF ATOMS 1158

39-1	Quantum-Mechanical View of Atoms	1159
39-2	Hydrogen Atom: Schrödinger Equation and Quantum Numbers	1159
39-3	Hydrogen Atom Wave Functions	1163
39-4	Multielectron Atoms; the Exclusion Principle	1166
39-5	Periodic Table of Elements	1167
39-6	X-Ray Spectra and Atomic Number	1169
*39-7	Magnetic Dipole Moment; Total Angular Momentum	1171
39-8	Fluorescence and Phosphorescence	1174
39-9	Lasers	1175
*39-10	Holography	1178
	Questions, MisConceptions, Problems	1180–1185

40 MOLECULES AND SOLIDS 1186

40-1	Bonding in Molecules	1187
40-2	Potential-Energy Diagrams for Molecules	1189
40-3	Weak (van der Waals) Bonds	1192
40-4	Molecular Spectra	1196
40-5	Bonding in Solids	1202
40-6	Free-Electron Theory of Metals; Fermi Energy	1203
40-7	Band Theory of Solids	1208
40-8	Semiconductors and Doping	1210
40-9	Semiconductor Diodes, LEDs, OLEDs	1212
40-10	Transistors: Bipolar and MOSFETs	1218
40-11	Integrated Circuits, 10-nm Technology	1219
	Questions, MisConceptions, Problems	1220–1225

41 NUCLEAR PHYSICS AND RADIOACTIVITY 1226

41-1	Structure and Properties of the Nucleus	1227
41-2	Binding Energy and Nuclear Forces	1230
41-3	Radioactivity	1233
41-4	Alpha Decay	1234
41-5	Beta Decay	1237
41-6	Gamma Decay	1239
41-7	Conservation of Nucleon Number and Other Conservation Laws	1240
41-8	Half-Life and Rate of Decay	1240
41-9	Decay Series	1245
41-10	Radioactive Dating	1246
41-11	Detection of Particles	1248
	Questions, MisConceptions, Problems	1250–1255

42 NUCLEAR ENERGY; EFFECTS AND USES OF RADIATION 1256

42-1	Nuclear Reactions and the Transmutation of Elements	1257
42-2	Cross Section	1260
42-3	Nuclear Fission; Nuclear Reactors	1261
42-4	Nuclear Fusion	1266
42-5	Passage of Radiation Through Matter; Biological Damage	1271
42-6	Measurement of Radiation—Dosimetry	1272
*42-7	Radiation Therapy	1276
*42-8	Tracers in Research and Medicine	1277
*42-9	Emission Tomography: PET and SPECT	1278
*42-10	Nuclear Magnetic Resonance (NMR); Magnetic Resonance Imaging (MRI)	1279
	Questions, MisConceptions, Problems	1283–1288

43 ELEMENTARY PARTICLES 1289

43-1	High-Energy Particles and Accelerators	1290
43-2	Beginnings of Elementary Particle Physics—Particle Exchange	1296
43-3	Particles and Antiparticles	1299
43-4	Particle Interactions and Conservation Laws	1300
43-5	Neutrinos	1302
43-6	Particle Classification	1304
43-7	Particle Stability and Resonances	1306
43-8	Strangeness? Charm? Towards a New Model	1307
43-9	Quarks	1308
43-10	The Standard Model: QCD and Electroweak Theory	1311
43-11	Grand Unified Theories	1314
43-12	Strings and Supersymmetry	1317
	Questions, MisConceptions, Problems	1318–1231

44 ASTROPHYSICS AND COSMOLOGY 1322

44-1	Stars and Galaxies	1323
44-2	Stellar Evolution: Birth and Death of Stars, Nucleosynthesis	1326
44-3	Distance Measurements	1332
44-4	General Relativity: Gravity and the Curvature of Space	1334
44-5	The Expanding Universe: Redshift and Hubble's Law	1338
44-6	The Big Bang and the Cosmic Microwave Background	1342
44-7	The Standard Cosmological Model: Early History of the Universe	1345
44-8	Inflation: Explaining Flatness, Uniformity, and Structure	1348
44-9	Dark Matter and Dark Energy	1350
44-10	Large-Scale Structure of the Universe	1353
44-11	Gravitational Waves—LIGO	1354
44-12	Finally . . .	1354
	Questions, MisConceptions, Problems	1356–1360

APPENDICES

A	Mathematical Formulas	A-1
B	Derivatives and Integrals	A-6
C	Numerical Integration	A-8
D	More on Dimensional Analysis	A-12
E	Gravitational Force Due to a Spherical Mass Distribution	A-13
F	Differential Form of Maxwell's Equations	A-16
G	Selected Isotopes	A-18
	Answers to Odd-Numbered Problems	A-23
	Index	
	Photo Credits	

Applications (Selected) to **Medicine and Biology** and to **Engineering, Environment, Everyday Life, Etc.**

(Entries with a star * include material new to this edition)

Chapter 1			
Viruses attack cell	7	Supermarket ramp design	113
Heartbeats in a lifetime	12	Doomsday asteroid	114, 262
Number of nucleons in human body	17	*Car stuck in mud	115
Lung capacity	19	Chapter 5	
Building collapse	2, 332, 346–7	Centrifugation	126
The 8000-m peaks	9	Skiing	116, 121, 136
Making estimates: volume of a lake	11	Push or pull a sled?	120
Page thickness	12	Skier speed in air vs. on snow	121
Building height by triangulation	12	*Simulating gravity	126, 136, 141, 168, 171
Earth radius estimate	13, 18	*Uranium enrichment, reactor, bomb	126
Fermi estimates	13	Ferris wheel	129
Particulate pollution	18	Avoid skidding on a curve	130–2
Global positioning satellite	18	Banked highway curves	132
Computer chips	18	Cross-country skiing friction	136
Chapter 2		Rotating space station	136, 141, 168
Airport runway design	32	*Rotor ride	137, 143
*Car air bag inflation time	32, 254	Airplane bank/turn	137, 144
Car braking distance	35, 183	Roller coaster upside down	141
CD bit size, bit rate, playing time	48, 53	Car flying up off road	141
*Baseball	49, 82, 83, 84, 172	Rock climbing friction	143
Basketball	50, 83, 109	Chapter 6	
Golf putt, uphill or down	52	Weightlessness	154–5
Rapid transit system	53	*Astronauts in orbit	145, 155, 165
Chapter 3		Gravity on tall peaks	150
Helicopter supply drop	54, 72, 83	Oil and mineral exploration	150, 165, 167
*Sports	54, 65, 69, 71, 76, 77, 79, 80, 81, 82, 83, 84	Satellites, spacecraft	145, 152–5, 168, 169
Kicked football	69, 71	Geostationary satellites	153
Truck escape lane	79, 110	Free fall, for athletes	155
Golf on the Moon	82	Planets	155–8, 167
Extreme sports	83	Determining the Sun's mass	158
Chapter 4		Planets around other stars	158, 250, 262
How we can walk	92	*Ocean tides	159, 165, 170
Whiplash	106	Lagrange point	160
*Force heart exerts	107	*Moon's orbit, periods, phases, diagram	161, 169
Rocket	85, 92, 108, 233, 252, 395	*Eclipses	161
Skater pushoff	91	Curved space	163–4
What force accelerates a car	92	Black holes	164, 167
You weigh less in a falling elevator	96	White dwarfs	167
Hockey	98	Comets, asteroids, moons	168, 169, 171
Elevator, discomfort	101, 108	GPS	169
Mechanical advantage, pulley	102, 188	Milky Way Galaxy	171
Accelerometer	102	Chapter 7	
*Sports	106, 107, 108, 109, 110, 112	Baseball pitch	172
*Bear sling	106, 355	Car stopping distance $\propto v^2$	183
Tug of war	106, 255	Lever	187, 334
Car accident "g's"	107	*Pulley	188
Optical tweezers	108, 916, 923	Jet catapults	189
*Tightrope walker	109	Bicycle, sprockets (teeth)	192, 299
Basketball shot	109	Climbing rope stretch	193
Mountain climbers	110, 114, 115, 193, 370	Chapter 8	
City planning, cars on hill	112	Stair-climbing power	213
Bicycling	112, 114	*ATP	216
		Hike over logs	218
		Pole vault	194, 203–4, (189)
		Downhill ski runs	194
		Roller coaster	198, 202, 209
		Escape velocity from Earth or Moon	212
		Power needs of car	214
		Efficiency of engine	215
		*Gravitational assist	216–7, 224, 263
		High jump	220
		Bungee jump	221
		Lunar module landing	222
		Escape velocity from solar system	223
		Ski jump	225
		Long jump	225
		Chapter 9	
		Impulse in fall: break a leg?	257
		Billiard balls	227, 230, 237, 242
		Tennis serve	229, 234
		Rocket propulsion	233, 252, 395
		Rifle recoil	233
		Karate blow	235
		Nuclear reactors	238
		Nuclear collisions	238, 239, 241, 243
		Ballistic pendulum, speed measured	240
		Distant planet discovery	250, 262
		Conveyor belt	253
		Car crashworthiness	261
		Asteroid danger	262
		Force wind exerts	263
		Bowling	263
		Chapter 10	
		Acuity of bird's eye	266
		Centrifuge	271
		*Biceps, triceps, torque	273, 295, 339
		Situps	291
		Fast mammal	291
		Rotating carnival rides	264, 267, 268
		Tire iron extension	272
		Flywheel, energy	282, 301
		Yo-yo	287
		Braking forces on a car	288–9
		Bicycle odometer	291
		Tightrope walking	291
		*Total solar eclipse	293
		Wrench torque	294
		Hammer throw	296
		CD rotation frequency	298
		Bicycle gears	299
		Cue stick, ball roll	300
		*Bicycle turn angle	301
		Chapter 11	
		Rotating skaters/divers	302, 304, 330
		Neutron star collapse	305, 330
		Strange spinning bike wheel	307, 314

Automobile wheel balancing	314–5	Rocket thrust	395	Chapter 17	
Precessing top	317–8	Reynolds number	395	Life under ice	500–1
Gyroscope	318	Barrel broken by thin liquid column	397	Molecules in one breath	507, 514
Hurricanes, cyclones, typhoons	321, 394	Chapter 14		Snorkels are short	515
*Anticyclonic weather	321	Spider web oscillations	405	*Hot air balloon	492, 515
Precession of the equinoxes	327	Human leg as pendulum	424	Expansion joints	495, 498, 501
SUV rollover	328	Shock absorbers	399, 415	Do holes expand?	499
Baseball bat sweet spot	330	Unwanted floor vibrations	406	Opening a tight lid	499
Chapter 12		Loudspeaker	406–7	Gas tank overflow	500
*Forces in muscles & joints	339, 358, (273)	*Pendulum clock	412, 421, 424	Highway buckling	501
*What can make an athlete	339	Geology	412, 415	Closed jars in fires	503
*Forces on the spine and back pain	340	Measure g with pendulum	412	Mass (weight) of air in a room	505
Human balance with loads	342	Earthquake dampers	415	Cold and hot tire pressure	506
*Bone fracture	346, 359, 364	Child on a swing, resonance	417–8	Thermostat	509
Buildings, statics	331–352	Resonance damage	418	Pyrex glass	509
Lever, mechanical advantage	334	Q-value	419, 425, 896	*Tape measure inaccuracy	510, 513
Balancing a seesaw	335	Bungee jumper	422	Scuba	512, 513, 514, 515
Cantilever	336	*Metronome	424	Potato chip bag puff up	513
Fracture	345–7	Natural stride	424		
Tragic collapse	346–7, (332)	Tall building sway	426	Chapter 18	
Trusses and bridges	347–9, 363	Chapter 15		KE of molecules in cells	519
Architecture: arches and domes	350–2	Echolocation by bats, dolphins, whales	434	Humidity, and comfort	525–6
*Forces in a dome	352	Water waves	428, 435	Chromatography	531
Chapter 13		Sound wave	431, 460 ff	Diffusion in living organisms	531–2, 536
Pressure in cells	371	Geology	435, 452, 457	Temperature effect on chemical reactions	521
Blood flow	380, 384, 386	Earthquake waves	435, 437, 450, 453	Evaporation cools	524, 548
Human circulatory system	380	Square wave	442	Humidity, weather	526
Blood loss to brain, TIA	384	*Cell phone signal	451	*Temperature decrease of boiling water with altitude	526–7
*Air flow in animal burrow	384	AM and FM radio wave bending	452	Pressure cooker	535
Heart disease, artery clogging	386	Fish and fisher: internal reflection	456		
Walking on water, insect	387	Seismic reflection: oil prospecting	457	Chapter 19	
Heart as a pump	388–9	Coffee spill	457	Working off Calories	540
*Blood pressure measurement	389	Tsunami	459	Measuring Calorie content	545, 570
Blood transfusion	395, 396	Chapter 16		Evaporation and body temperature	548–9, (524)
Water supply pressure	369	Wide range of human hearing	464	Body heat: convection by blood	563, 574
Atmospheric pressure decrease with elevation	370	Sensitivity of the ear	467, (466)	Body's radiative heat loss	564
Altitude where air pressure is half	370	Bats use Doppler	479	Room comfort: cool air, warm walls	565
Finger holds water in straw	371	Doppler blood-flow meter	479, 491	Medical thermography	567
Hydraulic lift	372	Ultrasound medical imaging	482–3	Avoid plants freezing	568
Hydraulic brakes	372	*Doppler ultrasound imaging	483	Eating snow makes you colder	571
Pressure gauges	372–3	Stringed instruments	460, 468–9	Heat conduction to skin, blood capillaries	573
Barometer	373	Wind instruments	460, 469–72	Leaf's energy absorption	575
Suction	374	Piano strings	460, 468, 469	Metabolizing fat	575
Hydrometer	377	Distance from lightning, seconds	461	Cold tile, warm rugs	561
Continental drift, plate tectonics	378	Autofocusing camera	462	Heat loss through windows	562
*Lake level change, rock thrown overboard	378, 390	Loudspeaker output	465	Thermal windows (two panes)	562
Helium balloon lift	378	Musical scale	468	How clothing insulates	562
Heating duct	380	Guitar, violin	468, 469, 484, 487	R-values of thermal insulation	562
Hot-water heating system flow	382	Organ pipes	471–2	Ocean currents and wind	563
Perfume atomizer	383	Tuning with beats	475–6	Convective home heating	563
Airplane wing lift	383	Doppler in weather forecasting	480	Dark vs. light clothing	564
Sailing upwind	383	*Radar speed gun	480	Radiation from the sun, seasons	566
Baseball curve	384	Galaxy redshift	480	Astronomy—size of a star	566
Why smoke goes up a chimney	384	Sonic boom; sound barrier	481, 489	Goose down loft	568
Soaps and detergents	387	Sonar: depth in sea, Earth “soundings”	481–2, 489	Thermos bottle	568
Pumps	388–9, (374)	Signal-to-noise ratio	486, 490, 679	Emergency blanket	568
Siphon	390	Quartz oscillator clock	487	Air parcels, weather, adiabatic lapse rate	573
Hydraulic press	393	Motion sensor	489		
		Audio gain	490		

Chapter 20			
Biological development, evolution	594		
*Trees offsetting CO ₂ buildup	608		
Steam engine	576, 578, 582, 606		
Internal combustion engines	578–80, 583–4		
Engine efficiency	582–3		
Refrigerators, air conditioners	584–6, 603		
Heat pump	586–7, 603		
*SEER rating	587		
Thermal pollution, climate	598–600		
*Carbon footprint	598		
Energy resources	599, 605–6		
Solar, thermal, wind energy	599, 605		
Diesel engine	607, (575)		
Stirling cycle	607		
Jet engine, Brayton cycle	607		
Dehumidifier	608, (537)		
Chapter 21			
Inside a cell: kinetic theory plus electrostatic force	631		
DNA structure, replication	631–3, 640		
Static electricity	609, 610, 635, 640		
Photocopiers and printers	619		
Electrical shielding, safety	628		
Chapter 23			
Electrocardiogram (ECG)	660, 682–3, 779		
Dipoles in molecular biology	672		
Heart beat, depolarization process	682–3		
Common voltages 10 ⁻⁴ V to 10 ⁸ V	663		
Breakdown voltage	666		
Lightning rods	666		
*Supply voltage, signal voltage	676		
*Digital, bits, bytes, binary numbers	676		
*Analog-to-digital converter (ADC)	676		
*Morse code	676		
*Bit-rate, TV transmission	676, 678–9, 682		
*Data compression, jpeg	677–8		
*Quantization error	677		
*Sampling rate, bit depth	677		
*Digital-to-analog converter (DAC)	677, 780		
*Bandwidth	678		
*Noise, bit flips	678–9		
*Digital error correction, parity bit	678		
*Bit error rate	679		
*Signal-to-noise ratio (S/N)	679		
*TV and computer monitors	679–82		
*Digital TV, pixels, subpixels	680		
*Flat screens, HD	680–1		
*Addressing pixels	680–1		
*Data stream	681		
*Active matrix, TFT, data lines	681–2		
*TV refresh rate	682		
Oscilloscope	682		
*ASCII code	688		
Photocell	689		
Chapter 24			
Capacitor shocks, burns	703		
Heart defibrillator	703, 712, 764		
Capacitor use as power backup, surge protector, memory	692, 695		
Condenser microphone	695		
Computer key	695		
Camera flash energy	701		
Electrostatic air cleaner	710		
Tiny distance measurement	710		
Coaxial cable	714, 818, 874, 911		
*Dynamic random access memory (DRAM)	716, 857		
Chapter 25			
Electrical conduction in human nervous system, neurons	736–8		
Action potential	737		
Battery construction, terminals	718–9		
*Electric cars	720, 744		
Battery connections	721, 724		
Loudspeaker wire thickness	725		
Heating element	726–8		
Resistance thermometer	726		
Lightning bolt	728, (690, 716)		
Household circuits, shorts	729–30		
Fuses, circuit breakers	729, 766		
Safety—wires getting hot	729, 764–6		
Extension cord danger	730		
Hair dryer	732		
Strain gauge	746		
Chapter 26			
*Blood sugar phone app	747		
Heart pacemaker	764		
Electricity dangers to humans	764–6		
Ventricular fibrillation	764		
Two-speed fan	752–3		
Car battery charging	757		
*Jump-starting a car, safely	758–9		
RC: sawtooth, flashers, wipers	763, 780		
Hazards, electric safety	764–6		
Proper grounding, plugs	765–6		
Leakage current	766		
Dangerous downed power line	766		
Ammeters, voltmeters, ohmmeters	767–9		
Meter connection, corrections	768–9, 781		
*Measurement affects quantity measured	769		
Voltage divider	774		
Solar panel	778		
Potentiometer and bridge circuits	778–9		
Car battery corrosion	780		
Digital-to-analog converter (DAC)	780, (677)		
Chapter 27			
Electromagnetic blood pump	802		
Blood flow rate, Hall effect	807		
Use of a compass	784		
Magnetic declination	784		
Maps and true north	784		
Aurora borealis	792		
Electric motors, DC and AC	795–6		
Loudspeakers and headsets	796		
Chapter 28			
Coaxial cable	818, 874, 911		
Solenoid switches: doorbell, car starter	826		
Magnetic circuit breakers	826		
Relay (magnetic)	830		
Chapter 29			
EM blood-flow measurement	845		
Induction stove	842		
Generators, power plants	846–7		
Alternators, in cars	848		
Motor overload	849		
Eddy-current damping	850, 861		
Airport metal detector	850		
Transformers, power transmission	851–3		
Cell phone charger	852		
Car ignition system	852		
*Wireless electric power transmission	854		
Inductive charger	854		
Magnetic information storage	856		
*Semiconductor memory	857–8		
*RAM, DRAM	857		
*Bit-line & word-line	857		
*Writing and reading memory	857		
*Volatile and non volatile memory	858		
*Flash memory, MOSFET, MRAM	858		
Microphone	858		
Card reader, magnetic strip	858		
Seismograph	859		
Ground fault circuit interrupter (GFCI)	859		
Shielded cable	861		
Recycling solid waste	861		
Chapter 30			
*Electric car inductive charging	869		
Surge protection	877		
Capacitors as filters	884, 896, 897		
Loudspeaker cross-over	884		
Impedance matching	888		
3-phase AC	889		
Q-value	896, (419, 425)		
Filter circuit	896		
Chapter 31			
Optical tweezers	916, 923		
*TV from the Moon	898, 920, 924		
Wireless devices, transmission	898, 917–20		
Antennas	911, 919		
Phone call time lag	912		
*Solar sail	916, 925		
Radio and TV	917–9		
AM and FM	918		
Cell phones, remotes, cable TV, satellite TV	920		
*GPS	924		
Solar power use	924		

Chapter 32			
Medical endoscope, bronchoscope, colonoscope	945		
How tall a mirror do you need	930		
Seeing yourself in a magnifying mirror (concave)	936–7		
Convex (rearview mirrors)	938		
Optical illusions	939, 998		
Apparent water depth	939–40, 941		
Rainbows	942, 957		
Colors underwater	943		
Diamonds sparkle	944		
Prism binoculars	944		
Fiber optic cables	945, 954, 956		
*High-frequency trading, interception	945		
Solar cooker	951		
Washing machine water level detector	956		
Road reflectors	957		
Chapter 33			
Human eye	975–8		
Fovea, denser in cones	976, 1037		
Near- and far-sighted	976–8		
Corrective lenses	976–7, 987		
Contact lenses	978		
Seeing underwater	978		
Light microscopes	983–4, 1048		
Where your eye can see a lens image	961		
Cameras, film and digital	970–5		
*CCD, CMOS sensors, potential well	970–1		
*Bayer pixels, Fovean	971		
Digital artifacts	971		
Camera adjustments, <i>f</i> -stop	971–3		
Depth of field	973		
*Resolution, compression, JPEG, raw	973–4		
Telephoto, wide angle	975		
Optical vs. digital zoom	975		
Magnifying glass	979–80		
Telescopes	980–2		
*Microscopes	983–4, 1048		
Lens aberrations	984–5		
Film projector	989		
Pinhole camera	990		
Chapter 34			
Soap bubbles, oil films, colors	995, 1004–8		
Highway mirages	998		
Lens coatings	1008–9		
Polarizing sunglasses	1012–13		
Liquid crystal displays, TV and computer screens	1014–5		
Sky color	1015–6		
*Lightbulb efficiency, LED	1016–7		
Stealth aircraft coating	1022		
CD bits, pits & lands	1024		
Chapter 35			
Resolution of eye	1035, 1037		
Useful magnification	1037		
Spectroscopy in biology	1041		
X-ray diffraction in biology	1044		
Medical imaging: X-rays, CT	1045–7		
*Interference microscope	1048		
*Phase-contrast microscope	1048		
Hubble space telescope	1034–5		
Telescope and microscope resolution	1035–7		
X-rays	1043–7		
Tomography	1045–7		
Chapter 36			
Space travel	1067–8		
Global position system (GPS)	1068–9		
Fantasy supertrain	1071		
Radar speed gun	1092		
Chapter 37			
Electron microscope image: blood vessel, clot, retina, viruses	1095, 1109, (7)		
Photosynthesis	1102		
Measuring bone density	1103		
Electron microscopes (EM), TEM, SEM	1109, 1151, (1095)		
Photocells	1098		
Photodiodes, soundtracks	1101		
Chapter 38			
Scanning tunneling electron microscope	1151		
Atomic force microscope	1151		
Chapter 39			
Fluorescence analysis	1174–5		
Medical uses of lasers, surgery	1178, 1183		
Neon lights	1158		
Fluorescent lightbulbs	1175		
Lasers	1175–9, 1216		
Bar code readers	1177		
DVD, CD, Blu-ray	1177–8		
Holography	1178–9		
Chapter 40			
Cell energy—ATP	1192		
Weak bonds, DNA	1192–4		
Protein synthesis	1194–6		
*Pulse oximeter	1216		
Computer processor chips	1186		
Transparent objects	1210		
Zener diode voltage regulator	1213–4, 1225		
Rectifiers	1214		
*Photovoltaic cells	1214–5		
*LED displays, bulbs	1215–6		
TV remote	1215, 1225		
*Solid-state lighting	1215–6		
* <i>pn</i> diode laser	1216		
*OLED, AMOLED displays	1216–7		
Amplifiers	1218		
*MOSFET switch	1218–9		
*Technology generation	1219		
Chapter 41			
Earliest life	1248		
Radiation film badges	1249, 1274		
Smoke detector	1237		
Radioactive activity and safety	1243–4		
Carbon-14 dating	1246–7		
Archeological & geological dating	1246–8		
Oldest Earth rocks	1248		
Geiger counter	1248		
Rubidium-strontium dating	1253		
Tritium dating	1254		
*Mass excess, mass defect	1254		
Chapter 42			
Biological radiation damage	1271–6		
Radiation dosimetry, RBE	1272–6		
Radon exposure	1274, 1276		
Natural radioactive background	1274		
Radiation exposure, film badge	1274		
Radiation sickness	1274		
Whole-body dose	1275		
Radiation therapy	1276–7		
Proton therapy	1277		
Radioactive tracers	1277–8		
Gamma camera	1278		
Medical imaging, PET, SPECT, MRI	1278–82		
*Brain PET scan using cell phone	1279		
Imaging resolutions compared	1282		
Radiation and thyroid	1286		
Nuclear reactors, power plants	1256, 1263–5, 1269–71		
Breeder reactors	1265		
Manhattan project	1266		
Nuclear fusion	1266–71		
Why stars shine	1267–9		
Thermonuclear devices	1269		
Fusion energy reactors	1269–71		
Chapter 43			
Linacs and tumor irradiation	1294		
Chapter 44			
Stars and galaxies	1323–32		
Black holes	1331, 1337–8		
Big Bang storyline	1345–8		

Preface

New Stuff!

1. **MisConceptual Questions**, 10 or 15 at the end of each chapter. The multiple-choice answers include common misconceptions as well as correct responses. Pedagogically, asking students to think, to consider the options, is more effective than just telling them what is valid and what is wrong. (These are in addition to the one at the start of each chapter).
2. **Digital** is all around us. Yet that word is not always used carefully. In this new edition we have 20 new pages describing the basics from the ground up. **Binary** numbers, *bits* and *bytes*, are introduced in Chapter 23 along with analog-to-digital conversion (ADC), and vice versa, including *digital audio* and how video screens work. Also information **compression**, *sampling rate*, *bit depth*, *pixel addressing*, *digital transmission* and, in later chapters, information **storage** (RAM, DRAM, flash), *digital cameras* and their *sensors* (CCD, CMOS).
3. **Gravitational Assist** (Slingshot) to accelerate spacecraft (Chapter 8).
4. **Magnetic field** of a **single moving charge**, rarely treated (and if it is, maybe not well), and it shows the need for relativity theory.
5. Seeing **yourself** in a **magnifying mirror** (concave), angular magnification and blurriness with a paradox. Also **convex** (rearview) **mirrors** (Chapter 32).
6. Pedagogical clarification on defining **potential energy**, and energy itself (Chapter 8), and on hundreds of other topics.
7. The **Moon** rises an hour later each day (Chapter 6), its *phases*, *periods*, and diagram.
8. Efficiency of **lightbulbs** (Chapter 34).
9. **Idealization** vs. reality emphasized—such as PV diagrams (Chapter 19) as an idealized approximation.
10. Many new Problems (~ 500) plus new Questions as well as the 500 or so MisConceptual Questions (point 1 above).
11. Many new worked-out Examples.
12. More **math** steps included in derivations and Examples.
13. **State** of a system and *state variables* clarified (Chapter 17).
14. Contemporary physics: Gravitational waves, LIGO and Virgo, Higgs, WIMPS, OLEDs and other semiconductor physics, nuclear fusion updates, neutrino-less double beta decay.
15. New SI units (Chapter 1, Chapter 21, Tables).
16. *Boiling* temperature of water vs. *elevation* (Chapter 18).
17. Modern physics in earlier classical Chapters (sometimes in Problems): Light-years, observable universe (Chapter 1); optical tweezers (Chapter 4); uranium enrichment (Chapter 5); black holes and curved space, white dwarfs (Chapter 6); crystal structure (Chapter 7); Yukawa potential, Lennard-Jones potential (Chapter 8); neutrons, nuclear reactors, moderator, nuclear collisions, radioactive decay, neutron star collapse (Chapter 9); galaxy redshift (Chapter 16); gas diffusion of uranium (Chapter 18); quarks (Chapter 21); liquid-drop model of nucleus, Geiger counter, Van de Graaff (Chapter 23); transistors (Chapters 23, 29); isotopes, cyclotron (Chapter 27); MOSFET (Chapter 29); semiconductor (camera sensor), photon (Chapter 33); line spectra, X-ray crystallography (Chapter 35).
18. Second law of thermodynamics and heat energy reorganized (Chapter 20).
19. **Symmetry** emphasized throughout.
20. *Uranium enrichment*, % needed in reactors, bombs (Chapters 5, 42).
21. Mass excess, mass defect (Chapter 41).
22. The *mole*, more careful definition (Chapter 17).
23. Liquid-gas ambiguity above critical temperature (Chapter 18).
24. Measurement affects quantity measured, new emphasis.

25. New Applications:

- Ocean Tides (Chapter 6)
- Anticyclonic weather (Chapter 11)
- Jump starting a car safely (Chapter 26)
- Light bulb efficiency (Chapter 34)
- Specialty microscopes and contrast (Chapter 35)
- Forces on Muscles and Joints (Chapter 12)
- Doppler ultrasound imaging (Chapter 16)
- Lake level change when rock thrown from boat (Chapter 13)
- Skier speed on snow vs. flying through the air (Chapter 5)
- Inductive charging (Chapter 29)
- Human body internal heat transfer is convection (blood) (Chapter 19)
- Blood pressure measurement (Chapter 13)
- Sports (lots)
- Voltage divider (Chapter 26, Problems)
- Flat screen TV (Chapters 23, 34, 40)
- Carbon footprint and climate (Chapter 20)
- Electrocardiogram (Chapter 23)
- Wireless from the Moon unimaginable (Chapter 31)
- Why snorkels are short (Chapter 17 Problem)
- Electric cars (Chapter 25)
- Digital (Chapters 23, 29, 33, 40) includes (in addition to details in point 2 above) quantization error, digital error correction, noise, bit error rate, digital TV data stream, refresh rate, active matrix, thin film transistors, digital memory, bit-line, reading and writing of memory cells (MOSFET), floating gate, volatile and nonvolatile memory, Bayer, JPEG, ASCII code, and more.

Seeing the World through Eyes that Know Physics

I was motivated to write a textbook different from others which typically present physics as a sequence of facts, like a catalog. Instead of beginning formally and dogmatically, I aim to begin each topic with everyday observations and experiences the students can relate to: start with specifics, the real world, and then go to the great generalizations and the more formal aspects of the physics, showing why we believe what we believe. This approach reflects how science is actually practiced.

The aim is to give students a thorough understanding of the basic concepts of physics in all its aspects, from mechanics to modern physics. Also important is to show students how useful physics is in their own everyday lives and in their future professions by means of interesting applications to biology, medicine, engineering, architecture, and more.

Much effort has gone into approaches for the practical techniques of solving problems: worked-out Examples, Problem Solving sections, and Problem Solving Strategies.

Chapter 1 is *not* a throwaway. It is fundamental to physics to realize that every measurement has an *uncertainty*, and how significant figures are used. Being able to make rapid *estimates* is a powerful tool useful for every student, and used throughout the book starting in Chapter 1 (you can estimate the Earth's radius!).

Mathematics can be an obstacle to students. I have aimed at including all steps in a derivation. Important mathematical tools, such as addition of vectors and vector product, are incorporated in the text where first needed, so they come with a context rather than in a forbidding introductory Chapter. Appendices contain a basic math review, derivatives and integrals, plus some more advanced topics including numerical integration, gravitational field of spherical mass distribution, Maxwell's equations in differential form, and a Table of selected nuclear isotopes (carefully updated, as are the Periodic Table and the Fundamental Constants found inside the back and front covers).

Some instructors may find this book contains more material than can be covered in their courses. The text offers great flexibility. Sections marked with a star * may be considered optional. These contain slightly more advanced

Versions of this Book

Complete version: 44 Chapters including 9 Chapters of modern physics.

Classic version: 37 Chapters, 35 on classical physics, plus one each on relativity and quantum theory.

3 Volume version: Available separately or packaged together

Volume 1: Chapters 1–20 on mechanics, including fluids, oscillations, waves, plus heat and thermodynamics.

Volume 2: Chapters 21–35 on electricity and magnetism, plus light and optics.

Volume 3: Chapters 36–44 on modern physics: relativity, quantum theory, atomic physics, condensed matter, nuclear physics, elementary particles, cosmology and astrophysics.

physics material, or material not usually covered in typical courses, or interesting applications; they contain no material needed in later Chapters (except perhaps in later optional Sections). For a brief course, all optional material could be dropped as well as significant parts of Chapters 13, 16, 26, 30, and 35, and selected parts of Chapters 9, 12, 19, 20, 33. Topics not covered in class can be a valuable resource for outside study by students. Indeed, this text can serve as a useful reference for years because of its wide range of coverage.

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The final responsibility for all errors lies with me. I welcome comments, corrections, and suggestions as soon as possible to benefit students for the next reprint.

D.G.

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His mentors include Nobel winners Emilio Segrè, Barry Barish, and Donald Glaser.

He has taught a wide range of undergraduate courses, traditional as well as innovative ones, and works to improve his textbooks meticulously, seeking ways to provide a better understanding of physics for students.

Doug loves the outdoors, especially climbing peaks. He says climbing peaks is like learning physics: it takes effort and the rewards are great.



Students Advice

HOW TO STUDY
















1. Read the Chapter. Learn new vocabulary and notation. Respond to questions and exercises as they occur. Follow carefully the steps of worked-out Examples and derivations. Avoid time looking at a screen. Paper is better than pixels when it comes to learning and thinking.
2. Attend all class meetings. Listen. Take notes. Ask questions (everyone wants to, but maybe you will have the courage). You will get more out of class if you read the Chapter first.
3. Read the Chapter again, paying attention to details. Follow derivations and worked-out Examples. Absorb their logic. Answer Exercises and as many of the end-of-Chapter Questions as you can, and all MisConceptual Questions.
4. Solve at least 10 to 20 end-of-Chapter Problems, especially those assigned. In doing Problems you may find out what you learned and what you didn't. Discuss them with other students. Problem solving is one of the great learning tools. Don't just look for a formula—it might be the wrong one.

NOTES ON THE FORMAT AND PROBLEM SOLVING








1. Sections marked with a star (*) may be considered optional or advanced. They can be omitted without interrupting the main flow of topics. No later material depends on them except possibly later starred Sections. They may be fun to read, though.
2. The customary **conventions** are used: symbols for quantities (such as m for mass) are italicized, whereas units (such as m for meter) are not italicized. Symbols for vectors are shown in boldface with a small arrow above: \vec{F} .
3. Few equations are valid in all situations. Where practical, the **range of validity** of important equations are stated in square brackets next to the equation. The equations that represent the great laws of physics are displayed with a tan background, as are a few other indispensable equations.
4. At the end of each Chapter is a set of **Questions** you should try to answer. Attempt all the multiple-choice **MisConceptual Questions**, which are intended to get common misconceptions “out on the table” by including them as responses (temptations) along with correct answers. Most important are **Problems** which are ranked as Level I, II, or III, according to estimated difficulty. Level I Problems are easiest, Level II are standard Problems, and Level III are “challenge problems.” These ranked Problems are arranged by Section, but Problems for a given Section may depend on earlier material too. There follows a group of **General Problems**, not arranged by Section or ranked. Problems that relate to optional Sections are starred (*). Answers to odd-numbered Problems are given at the end of the book.
5. Being able to solve **Problems** is a crucial part of learning physics, and provides a powerful means for understanding the concepts and principles. This book contains many aids to problem solving: (a) worked-out **Examples**, including an Approach and a Solution, which should be studied as an integral part of the text; (b) some of the worked-out Examples are **Estimation Examples**, which show how rough or approximate results can be obtained even if the given data are sparse (see Section 1-6); (c) **Problem Solving Strategies** placed throughout the text to suggest a step-by-step approach to problem solving for a particular topic—but the basics remain the same; most of these “Strategies” are followed by an Example that is solved by explicitly following the suggested steps; (d) special problem-solving Sections; (e) “Problem Solving” marginal notes which refer to hints within the text for solving Problems; (f) **Exercises** within the text that you should work out immediately, and then check your response against the answer given at the bottom of the last page of that Chapter; (g) the Problems themselves at the end of each Chapter.
6. **Conceptual Examples** pose a question which hopefully starts you to think about a response. Give yourself a little time to come up with your own response before reading the Response given.
7. Math review, plus additional topics, are found in **Appendices**. **Useful data**, **conversion factors**, and math **formulas** are found inside the front and back covers.

USE OF COLOR







Vectors

A general vector	
resultant vector (sum) is slightly thicker	
components of any vector are dashed	
Displacement (\vec{D} , \vec{r})	
Velocity (\vec{v})	
Acceleration (\vec{a})	
Force (\vec{F})	
Force on second object	
or third object in same figure	
Momentum (\vec{p} or $m\vec{v}$)	
Angular momentum (\vec{L})	
Angular velocity ($\vec{\omega}$)	
Torque ($\vec{\tau}$)	
Electric field (\vec{E})	
Magnetic field (\vec{B})	





Electricity and magnetism

Electric field lines	
Equipotential lines	
Magnetic field lines	
Electric charge (+)	 or 
Electric charge (-)	 or 



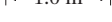

Electric circuit symbols

Wire, with switch S	
Resistor	
Capacitor	
Inductor	
Battery	
Ground	

Optics

Light rays	
Object	
Real image (dashed)	
Virtual image (dashed and paler)	

Other

Energy level (atom, etc.)	
Measurement lines	
Path of a moving object	
Direction of motion or current	

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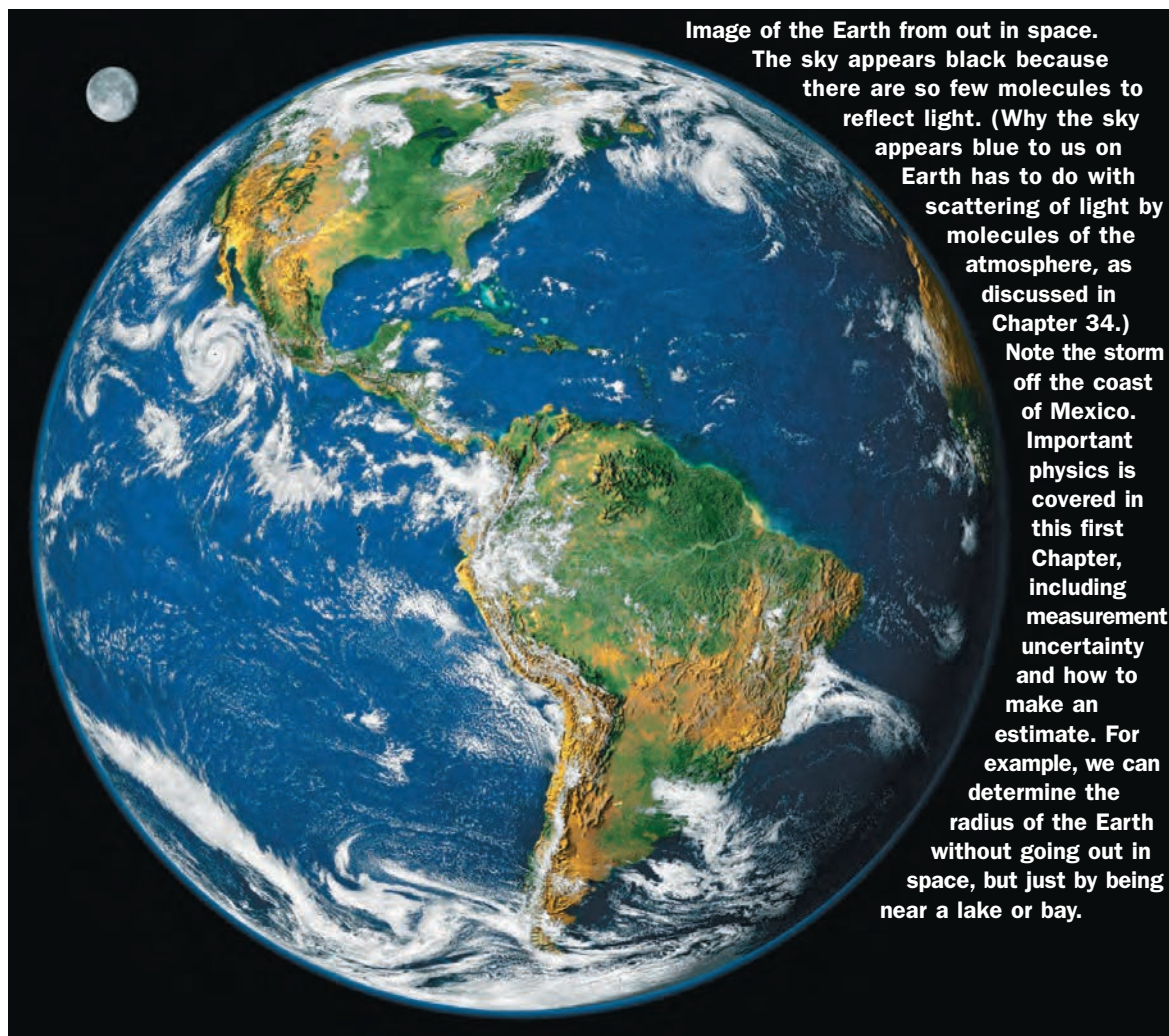


Image of the Earth from out in space. The sky appears black because there are so few molecules to reflect light. (Why the sky appears blue to us on Earth has to do with scattering of light by molecules of the atmosphere, as discussed in Chapter 34.) Note the storm off the coast of Mexico. Important physics is covered in this first Chapter, including measurement uncertainty and how to make an estimate. For example, we can determine the radius of the Earth without going out in space, but just by being near a lake or bay.

Introduction, Measurement, Estimating

CHAPTER 1

CHAPTER-OPENING QUESTIONS—Guess now!

1. How many cm^3 are in 1.0 m^3 ?
(a) 10. (b) 100. (c) 1000. (d) 10,000. (e) 100,000. (f) 1,000,000.
2. Suppose you wanted to actually measure the radius of the Earth, at least roughly, rather than taking other people's word for what it is. Which response below describes the best approach?
(a) Use an extremely long measuring tape.
(b) It is only possible by flying high enough to see the actual curvature of the Earth.
(c) Use a standard measuring tape, a stepladder, and a large smooth lake.
(d) Use a laser and a mirror on the Moon or on a satellite.
(e) Give up; it is impossible using ordinary means.

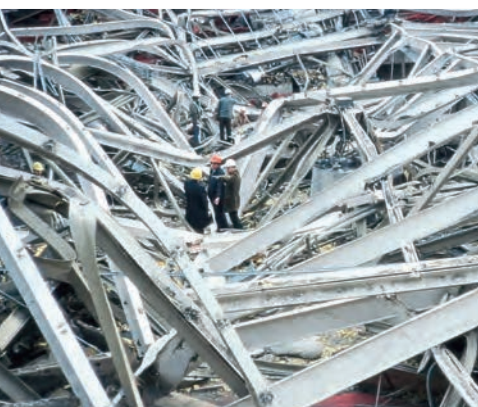
[We start each Chapter with a Question—sometimes two. Try to answer right away. Don't worry about getting the right answer now—the idea is to get your preconceived notions out on the table. If they are misconceptions, we expect them to be cleared up as you read the Chapter. You will get another chance at the Question later in the Chapter when the appropriate material has been covered. These Chapter-Opening Questions will also help you see the power and usefulness of physics.]

CONTENTS

- 1-1 How Science Works
- 1-2 Models, Theories, and Laws
- 1-3 Measurement and Uncertainty; Significant Figures
- 1-4 Units, Standards, and the SI System
- 1-5 Converting Units
- 1-6 Order of Magnitude: Rapid Estimating
- *1-7 Dimensions and Dimensional Analysis



(a)



(b)

FIGURE 1–1 (a) This bridge over the River Tiber in Rome was built 2000 years ago and still stands. (b) The Hartford Civic Center collapsed in 1978, just two years after it was built.



CAUTION

*Science is not static.
It changes and develops*

Physics is the most basic of the sciences. It deals with the behavior and structure of matter. The field of physics is usually divided into *classical physics* which includes motion, fluids, heat, sound, light, electricity and magnetism; and *modern physics* which includes the topics of relativity, atomic structure, condensed matter, nuclear physics, elementary particles, and cosmology and astrophysics. We will cover all these topics in this book, beginning with motion (or mechanics, as it is often called) and ending with the most recent results in our study of the cosmos.

An understanding of physics is wonderfully useful for anyone making a career in science or technology. Engineers, for example, must know how to calculate the forces within a structure to design it so that it remains standing (Fig. 1–1a). Indeed, in Chapter 12 we will see a worked-out Example of how a simple physics calculation—or even intuition based on understanding the physics of forces—would have saved hundreds of lives (Fig. 1–1b). We will see many examples in this book of how physics is useful in many fields, and in everyday life.

1–1 How Science Works

There is a real physical world out there. We could just walk through it, not thinking much about it. Or, we can instead examine it carefully. That is what scientists do. The aim of science is the search for order in our observations of the physical world so as to provide a deeper picture or description of this world around us. Sometimes we just want to understand how things work.

Some people seem to think that science is a mechanical process of collecting facts and devising theories. But it is not so simple. Science is a creative activity, and in many ways resembles other creative activities of the human mind.

One important aspect of science is **observation** of events (which great writers and artists also do), and includes the design and carrying out of experiments. But observation and experiment require imagination, because scientists can never include everything in a description of what they observe. In other words, scientists must make judgments about what is relevant in their observations and experiments.

Consider, for example, how two great minds, Aristotle (384–322 B.C.) and Galileo (1564–1642), interpreted motion along a horizontal surface. Aristotle noted that objects given an initial push along the ground (or on a level tabletop) always slow down and stop. Consequently, Aristotle argued, the natural state of an object is to be at rest. Galileo, in his reexamination of horizontal motion in the 1600s, had the idea that friction is a kind of force like a push or a pull; and he imagined that if friction could be eliminated, an object given an initial push along a horizontal surface would continue to move indefinitely without stopping. He concluded that for an object to be in motion was *just as natural* as for it to be at rest. By inventing a new approach, Galileo founded our modern view of motion (Chapters 2, 3, and 4), and he did so with a leap of the imagination. Galileo made this leap conceptually, without actually eliminating friction.

Observation, with careful experimentation and measurement, is one side of the scientific process. The other side is the invention or creation of **theories** to explain and order the observations. Theories are never derived directly from observations. Observations may help inspire a theory, and theories are accepted or rejected based on the results of observation and experiment.

Theories are inspirations that come from the minds of humans. For example, the idea that matter is made up of atoms (the atomic theory) was not arrived at by direct observation of atoms. Rather, the idea sprang from creative minds. The theory of relativity, the electromagnetic theory of light, and Newton’s law of universal gravitation were likewise the result of human imagination.

The great theories of science may be compared, as creative achievements, with great works of art or literature. But how does science differ from these other creative activities? One important difference is that science requires **testing** of its ideas or theories to see if their predictions are borne out by experiment.

But theories are not “proved” by testing. First of all, no measuring instrument is perfect, so exact confirmation is not possible. Furthermore, it is not possible to test a theory in every single possible circumstance. Hence a theory cannot be absolutely verified.