

1 Measurement	728
2 Motion Along a Straight Line	728
3 Vectors	729
4 Motion in Two and Three Dimensions	729
5 Force and Motion—I	729
6 Force and Motion—II	729
7 Kinetic Energy and Work	729
8 Potential Energy and Conservation of Energy	729
9 Center of Mass and Linear Momentum	729
10 Rotation	729
11 Rolling, Torque, and Angular Momentum	729
12 Equilibrium and Elasticity	729
13 Gravitation	729
14 Fluids	729
15 Oscillations	729
16 Waves—I	729
17 Waves—II	729
18 Temperature, Heat, and the First Law of Thermodynamics	729
19 The Kinetic Theory of Gases	729
20 Entropy and the Second Law of Thermodynamics	729
REVIEW & SUMMARY	729
ANSWERS	729
APPENDICES	729
INDEX	729

1 Measurement	803
2 Motion Along a Straight Line	803
3 Vectors	803
4 Motion in Two and Three Dimensions	803
5 Force and Motion—I	803
6 Force and Motion—II	803
7 Kinetic Energy and Work	803
8 Potential Energy and Conservation of Energy	803
9 Center of Mass and Linear Momentum	803
10 Rotation	803
11 Rolling, Torque, and Angular Momentum	803
12 Equilibrium and Elasticity	803
13 Gravitation	803
14 Fluids	803
15 Oscillations	803
16 Waves—I	803
17 Waves—II	803
18 Temperature, Heat, and the First Law of Thermodynamics	803
19 The Kinetic Theory of Gases	803
20 Entropy and the Second Law of Thermodynamics	803
REVIEW & SUMMARY	803
ANSWERS	803
APPENDICES	803
INDEX	803

21 Coulomb's Law 609**21-1 COULOMB'S LAW** 609

What Is Physics? 610

Electric Charge 610

Conductors and Insulators 612

Coulomb's Law 613

21-2 CHARGE IS QUANTIZED 619

Charge Is Quantized 619

21-3 CHARGE IS CONSERVED 621

Charge Is Conserved 621

REVIEW & SUMMARY 622 QUESTIONS 623 PROBLEMS 624

22 Electric Fields 630**22-1 THE ELECTRIC FIELD** 630

What Is Physics? 630

The Electric Field 631

Electric Field Lines 631

22-2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE 633

The Electric Field Due to a Point Charge 633

22-3 THE ELECTRIC FIELD DUE TO A DIPOLE 635

The Electric Field Due to an Electric Dipole 636

22-4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE 638

The Electric Field Due to Line of Charge 638

22-5 THE ELECTRIC FIELD DUE TO A CHARGED DISK 643

The Electric Field Due to a Charged Disk 643

22-6 A POINT CHARGE IN AN ELECTRIC FIELD 645

A Point Charge in an Electric Field 645

22-7 A DIPOLE IN AN ELECTRIC FIELD 647

A Dipole in an Electric Field 648

REVIEW & SUMMARY 650 QUESTIONS 651 PROBLEMS 652

23 Gauss' Law 659**23-1 ELECTRIC FLUX** 659

What Is Physics 659

Electric Flux 660

23-2 GAUSS' LAW 664

Gauss' Law 664

Gauss' Law and Coulomb's Law 666

23-3 A CHARGED ISOLATED CONDUCTOR 668

A Charged Isolated Conductor 668

23-4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY 671

Applying Gauss' Law: Cylindrical Symmetry 671

23-5 APPLYING GAUSS' LAW: PLANAR SYMMETRY 673

Applying Gauss' Law: Planar Symmetry 673

23-6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY 675

Applying Gauss' Law: Spherical Symmetry 675

REVIEW & SUMMARY 677 QUESTIONS 677 PROBLEMS 679

24 Electric Potential 685**24-1 ELECTRIC POTENTIAL** 685

What Is Physics? 685

Electric Potential and Electric Potential Energy 686

24-2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD 690

Equipotential Surfaces 690

Calculating the Potential from the Field 691

24-3 POTENTIAL DUE TO A CHARGED PARTICLE 694

Potential Due to a Charged Particle 694

Potential Due a Group of Charged Particles 695

24-4 POTENTIAL DUE TO AN ELECTRIC DIPOLE 697

Potential Due to an Electric Dipole 697

24-5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION 698

Potential Due to a Continuous Charge Distribution 698

24-6 CALCULATING THE FIELD FROM THE POTENTIAL 701

Calculating the Field from the Potential 701

24-7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES 703

Electric Potential Energy of a System of Charged Particles 703

24-8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR 706

Potential of Charged Isolated Conductor 706

REVIEW & SUMMARY 707 QUESTIONS 708 PROBLEMS 710

25 Capacitance 717**25-1 CAPACITANCE** 717

What Is Physics? 717

Capacitance 717

25-2 CALCULATING THE CAPACITANCE 719

Calculating the Capacitance 720

25-3 CAPACITORS IN PARALLEL AND IN SERIES 723

Capacitors in Parallel and in Series 724

25-4 ENERGY STORED IN AN ELECTRIC FIELD	728
Energy Stored in an Electric Field	728
25-5 CAPACITOR WITH A DIELECTRIC	731
Capacitor with a Dielectric	731
Dielectrics: An Atomic View	733
25-6 DIELECTRICS AND GAUSS' LAW	735
Dielectrics and Gauss' Law	735
REVIEW & SUMMARY	738
QUESTIONS	738
PROBLEMS	739
26 Current and Resistance	745
26-1 ELECTRIC CURRENT	745
What Is Physics?	745
Electric Current	746
26-2 CURRENT DENSITY	748
Current Density	749
26-3 RESISTANCE AND RESISTIVITY	752
Resistance and Resistivity	753
26-4 OHM'S LAW	756
Ohm's Law	756
A Microscopic View of Ohm's Law	758
26-5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS	760
Power in Electric Circuits	760
Semiconductors	762
Superconductors	763
REVIEW & SUMMARY	763
QUESTIONS	764
PROBLEMS	765
27 Circuits	771
27-1 SINGLE-LOOP CIRCUITS	771
What Is Physics?	772
"Pumping" Charges	772
Work, Energy, and Emf	773
Calculating the Current in a Single-Loop Circuit	774
Other Single-Loop Circuits	776
Potential Difference Between Two Points	777
27-2 MULTILoop CIRCUITS	781
Multiloop Circuits	781
27-3 THE AMMETER AND THE VOLTMETER	788
The Ammeter and the Voltmeter	788
27-4 RC CIRCUITS	788
RC Circuits	789
REVIEW & SUMMARY	793
QUESTIONS	793
PROBLEMS	795

28 Magnetic Fields	803
28-1 MAGNETIC FIELDS AND THE DEFINITION OF \vec{B}	803
What Is Physics?	803
What Produces a Magnetic Field?	804
The Definition of \vec{B}	804
28-2 CROSSED FIELDS: DISCOVERY OF THE ELECTRON	808
Crossed Fields: Discovery of the Electron	809
28-3 CROSSED FIELDS: THE HALL EFFECT	810
Crossed Fields: The Hall Effect	811
28-4 A CIRCULATING CHARGED PARTICLE	814
A Circulating Charged Particle	814
28-5 CYCLOTRONS AND SYNCHROTRONS	817
Cyclotrons and Synchrotrons	818
28-6 MAGNETIC FORCE ON A CURRENT-CARRYING WIRE	820
Magnetic Force on a Current-Carrying Wire	820
28-7 TORQUE ON A CURRENT LOOP	822
Torque on a Current Loop	822
28-8 THE MAGNETIC DIPOLE MOMENT	824
The Magnetic Dipole Moment	825
REVIEW & SUMMARY	827
QUESTIONS	827
PROBLEMS	829
29 Magnetic Fields Due to Currents	836
29-1 MAGNETIC FIELD DUE TO A CURRENT	836
What Is Physics?	836
Calculating the Magnetic Field Due to a Current	837
29-2 FORCE BETWEEN TWO PARALLEL CURRENTS	842
Force Between Two Parallel Currents	842
29-3 AMPERE'S LAW	844
Ampere's Law	844
29-4 SOLENOIDS AND TOROIDS	848
Solenoids and Toroids	848
29-5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE	851
A Current-Carrying Coil as a Magnetic Dipole	851
REVIEW & SUMMARY	854
QUESTIONS	855
PROBLEMS	856
30 Induction and Inductance	864
30-1 FARADAY'S LAW AND LENZ'S LAW	864
What Is Physics	864
Two Experiments	865
Faraday's Law of Induction	865
Lenz's Law	868

30-2 INDUCTION AND ENERGY TRANSFERS	871
Induction and Energy Transfers	871
30-3 INDUCED ELECTRIC FIELDS	874
Induced Electric Fields	875
30-4 INDUCTORS AND INDUCTANCE	879
Inductors and Inductance	879
30-5 SELF-INDUCTION	881
Self-Induction	881
30-6 RL CIRCUITS	882
RL Circuits	883
30-7 ENERGY STORED IN A MAGNETIC FIELD	887
Energy Stored in a Magnetic Field	887
30-8 ENERGY DENSITY OF A MAGNETIC FIELD	889
Energy Density of a Magnetic Field	889
30-9 MUTUAL INDUCTION	890
Mutual Induction	890
REVIEW & SUMMARY	893
QUESTIONS	893
PROBLEMS	895

31 Electromagnetic Oscillations and Alternating Current	903
31-1 LC OSCILLATIONS	903
What Is Physics?	904
LC Oscillations, Qualitatively	904
The Electrical-Mechanical Analogy	906
LC Oscillations, Quantitatively	907
31-2 DAMPED OSCILLATIONS IN AN RLC CIRCUIT	910
Damped Oscillations in an RLC Circuit	911
31-3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS	912
Alternating Current	913
Forced Oscillations	914
Three Simple Circuits	914
31-4 THE SERIES RLC CIRCUIT	921
The Series RLC Circuit	921
31-5 POWER IN ALTERNATING-CURRENT CIRCUITS	927
Power in Alternating-Current Circuits	927
31-6 TRANSFORMERS	930
Transformers	930
REVIEW & SUMMARY	933
QUESTIONS	934
PROBLEMS	935

32 Maxwell's Equations; Magnetism of Matter	941
32-1 GAUSS' LAW FOR MAGNETIC FIELDS	941
What Is Physics?	941
Gauss' Law for Magnetic Fields	942

32-2 INDUCED MAGNETIC FIELDS	943
Induced Magnetic Fields	943
32-3 DISPLACEMENT CURRENT	946
Displacement Current	947
Maxwell's Equations	949
32-4 MAGNETS	950
Magnets	950
32-5 MAGNETISM AND ELECTRONS	952
Magnetism and Electrons	953
Magnetic Materials	956
32-6 DIAMAGNETISM	957
Diamagnetism	957
32-7 PARAMAGNETISM	959
Paramagnetism	959
32-8 FERROMAGNETISM	961
Ferromagnetism	961
REVIEW & SUMMARY	964
QUESTIONS	965
PROBLEMS	967

33 Electromagnetic Waves	972
33-1 ELECTROMAGNETIC WAVES	972
What Is Physics?	972
Maxwell's Rainbow	973
The Traveling Electromagnetic Wave, Qualitatively	974
The Traveling Electromagnetic Wave, Quantitatively	977
33-2 ENERGY TRANSPORT AND THE POYNTING VECTOR	980
Energy Transport and the Poynting Vector	981
33-3 RADIATION PRESSURE	983
Radiation Pressure	983
33-4 POLARIZATION	985
Polarization	985
33-5 REFLECTION AND REFRACTION	990
Reflection and Refraction	991
33-6 TOTAL INTERNAL REFLECTION	996
Total Internal Reflection	996
33-7 POLARIZATION BY REFLECTION	997
Polarization by Reflection	998
REVIEW & SUMMARY	999
QUESTIONS	1000
PROBLEMS	1001

34 Images	1010
34-1 IMAGES AND PLANE MIRRORS	1010
What Is Physics?	1010

Two Types of Image 1010	36-4 DIFFRACTION BY A DOUBLE SLIT 1094
Plane Mirrors 1012	Diffraction by a Double Slit 1095
34-2 SPHERICAL MIRRORS 1014	36-5 DIFFRACTION GRATINGS 1098
Spherical Mirrors 1015	Diffraction Gratings 1098
Images from Spherical Mirrors 1016	36-6 GRATINGS: DISPERSION AND RESOLVING POWER 1101
34-3 SPHERICAL REFRACTING SURFACES 1020	Gratings: Dispersion and Resolving Power 1101
Spherical Refracting Surfaces 1020	36-7 X-RAY DIFFRACTION 1104
34-4 THIN LENSES 1023	X-Ray Diffraction 1104
Thin Lenses 1023	REVIEW & SUMMARY 1107 QUESTIONS 1107 PROBLEMS 1108
34-5 OPTICAL INSTRUMENTS 1030	37 Relativity 1116
Optical Instruments 1030	37-1 SIMULTANEITY AND TIME DILATION 1116
34-6 THREE PROOFS 1033	What Is Physics? 1116
REVIEW & SUMMARY 1036 QUESTIONS 1037 PROBLEMS 1038	The Postulates 1117
35 Interference 1047	Measuring an Event 1118
35-1 LIGHT AS A WAVE 1047	The Relativity of Simultaneity 1120
What Is Physics? 1047	The Relativity of Time 1121
Light as a Wave 1048	37-2 THE RELATIVITY OF LENGTH 1125
35-2 YOUNG'S INTERFERENCE EXPERIMENT 1053	The Relativity of Length 1126
Diffraction 1053	37-3 THE LORENTZ TRANSFORMATION 1129
Young's Interference Experiment 1054	The Lorentz Transformation 1129
35-3 INTERFERENCE AND DOUBLE-SLIT INTENSITY 1059	Some Consequences of the Lorentz Equations 1131
Coherence 1059	37-4 THE RELATIVITY OF VELOCITIES 1133
Intensity in Double-Slit Interference 1060	The Relativity of Velocities 1133
35-4 INTERFERENCE FROM THIN FILMS 1063	37-5 DOPPLER EFFECT FOR LIGHT 1134
Interference from Thin Films 1064	Doppler Effect for Light 1135
35-5 MICHELSON'S INTERFEROMETER 1070	37-6 MOMENTUM AND ENERGY 1137
Michelson's Interferometer 1071	A New Look at Momentum 1138
REVIEW & SUMMARY 1072 QUESTIONS 1072 PROBLEMS 1074	A New Look at Energy 1138
36 Diffraction 1081	REVIEW & SUMMARY 1143 QUESTIONS 1144 PROBLEMS 1145
36-1 SINGLE-SLIT DIFFRACTION 1081	38 Photons and Matter Waves 1153
What Is Physics? 1081	38-1 THE PHOTON, THE QUANTUM OF LIGHT 1153
Diffraction and the Wave Theory of Light 1081	What Is Physics? 1153
Diffraction by a Single Slit: Locating the Minima 1083	The Photon, the Quantum of Light 1154
36-2 INTENSITY IN SINGLE-SLIT DIFFRACTION 1086	38-2 THE PHOTOELECTRIC EFFECT 1155
Intensity in Single-Slit Diffraction 1086	The Photoelectric Effect 1156
Intensity in Single-Slit Diffraction, Quantitatively 1088	38-3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE 1158
36-3 DIFFRACTION BY A CIRCULAR APERTURE 1090	Photons Have Momentum 1159
Diffraction by a Circular Aperture 1091	Light as a Probability Wave 1162

38-4 THE BIRTH OF QUANTUM PHYSICS	1164
The Birth of Quantum Physics	1165
38-5 ELECTRONS AND MATTER WAVES	1166
Electrons and Matter Waves	1167
38-6 SCHRÖDINGER'S EQUATION	1170
Schrödinger's Equation	1170
38-7 HEISENBERG'S UNCERTAINTY PRINCIPLE	1172
Heisenberg's Uncertainty Principle	1173
38-8 REFLECTION FROM A POTENTIAL STEP	1174
Reflection from a Potential Step	1174
38-9 TUNNELING THROUGH A POTENTIAL BARRIER	1176
Tunneling Through a Potential Barrier	1176
REVIEW & SUMMARY	1179
QUESTIONS	1180
PROBLEMS	1181
39 More About Matter Waves	1186
39-1 ENERGIES OF A TRAPPED ELECTRON	1186
What Is Physics?	1186
String Waves and Matter Waves	1187
Energies of a Trapped Electron	1187
39-2 WAVE FUNCTIONS OF A TRAPPED ELECTRON	1191
Wave Functions of a Trapped Electron	1192
39-3 AN ELECTRON IN A FINITE WELL	1195
An Electron in a Finite Well	1195
39-4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS	1197
More Electron Traps	1197
Two- and Three-Dimensional Electron Traps	1200
39-5 THE HYDROGEN ATOM	1201
The Hydrogen Atom Is an Electron Trap	1202
The Bohr Model of Hydrogen, a Lucky Break	1203
Schrödinger's Equation and the Hydrogen Atom	1205
REVIEW & SUMMARY	1213
QUESTIONS	1213
PROBLEMS	1214
40 All About Atoms	1219
40-1 PROPERTIES OF ATOMS	1219
What Is Physics?	1220
Some Properties of Atoms	1220
Angular Momentum, Magnetic Dipole Moments	1222
40-2 THE STERN-GERLACH EXPERIMENT	1226
The Stern-Gerlach Experiment	1226
40-3 MAGNETIC RESONANCE	1229
Magnetic Resonance	1229
40-4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP	1230
The Pauli Exclusion Principle	1230
Multiple Electrons in Rectangular Traps	1231
40-5 BUILDING THE PERIODIC TABLE	1234
Building the Periodic Table	1234
40-6 X RAYS AND THE ORDERING OF THE ELEMENTS	1236
X Rays and the Ordering of the Elements	1237
40-7 LASERS	1240
Lasers and Laser Light	1241
How Lasers Work	1242
REVIEW & SUMMARY	1245
QUESTIONS	1246
PROBLEMS	1247
41 Conduction of Electricity in Solids	1252
41-1 THE ELECTRICAL PROPERTIES OF METALS	1252
What Is Physics?	1252
The Electrical Properties of Solids	1253
Energy Levels in a Crystalline Solid	1254
Insulators	1254
Metals	1255
41-2 SEMICONDUCTORS AND DOPING	1261
Semiconductors	1262
Doped Semiconductors	1263
41-3 THE p-n JUNCTION AND THE TRANSISTOR	1265
The p-n Junction	1266
The Junction Rectifier	1267
The Light-Emitting Diode (LED)	1268
The Transistor	1270
REVIEW & SUMMARY	1271
QUESTIONS	1272
PROBLEMS	1272
42 Nuclear Physics	1276
42-1 DISCOVERING THE NUCLEUS	1276
What Is Physics?	1276
Discovering the Nucleus	1276
42-2 SOME NUCLEAR PROPERTIES	1279
Some Nuclear Properties	1280
42-3 RADIOACTIVE DECAY	1286
Radioactive Decay	1286
42-4 ALPHA DECAY	1289
Alpha Decay	1289
42-5 BETA DECAY	1292
Beta Decay	1292

42-6 RADIOACTIVE DATING 1295

Radioactive Dating 1295

42-7 MEASURING RADIATION DOSAGE 1296

Measuring Radiation Dosage 1296

42-8 NUCLEAR MODELS 1297

Nuclear Models 1297

REVIEW & SUMMARY 1300 QUESTIONS 1301 PROBLEMS 1302**43 Energy from the Nucleus 1309****43-1 NUCLEAR FISSION 1309**

What Is Physics? 1309

Nuclear Fission: The Basic Process 1310

A Model for Nuclear Fission 1312

43-2 THE NUCLEAR REACTOR 1316

The Nuclear Reactor 1316

43-3 A NATURAL NUCLEAR REACTOR 1320

A Natural Nuclear Reactor 1320

43-4 THERMONUCLEAR FUSION: THE BASIC PROCESS 1322

Thermonuclear Fusion: The Basic Process 1322

43-5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS 1324

Thermonuclear Fusion in the Sun and Other Stars 1324

43-6 CONTROLLED THERMONUCLEAR FUSION 1326

Controlled Thermonuclear Fusion 1326

REVIEW & SUMMARY 1329 QUESTIONS 1329 PROBLEMS 1330**44 Quarks, Leptons, and the Big Bang 1334****44-1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES 1334**

What Is Physics? 1334

Particles, Particles, Particles 1335

An Interlude 1339

44-2 LEPTONS, HADRONS, AND STRANGENESS 1343

The Leptons 1343

The Hadrons 1345

Still Another Conservation Law 1346

The Eightfold Way 1347

44-3 QUARKS AND MESSENGER PARTICLES 1349

The Quark Model 1349

Basic Forces and Messenger Particles 1352

44-4 COSMOLOGY 1355

A Pause for Reflection 1355

The Universe Is Expanding 1356

The Cosmic Background Radiation 1357

Dark Matter 1358

The Big Bang 1358

A Summing Up 1361

REVIEW & SUMMARY 1362 QUESTIONS 1362 PROBLEMS 1363**APPENDICES**

A The International System of Units (SI) A-1

B Some Fundamental Constants of Physics A-3

C Some Astronomical Data A-4

D Conversion Factors A-5

E Mathematical Formulas A-9

F Properties of The Elements A-12

G Periodic Table of The Elements A-15

ANSWERS

to Checkpoints and Odd-Numbered Questions and Problems AN-1

INDEX I-1