530 SEM C.2

# CONTENTS


Preface to the Revised Edition vii
Preface to the First Edition ix

***ONE / MECHANICS***

**1. FUNDAMENTAL CONCEPTS**

1-1 Scope of physics 3
1-2 Relationship of physics to other sciences 4
1-3 Fundamental concepts of mechanics 5
1-4 Concept of length. Standard and Units 5
1-5 Concept of time. Standard and Units 8
1-6 Concept of mass. Standard and Units 9
1-7 Force 10
Questions 12
Problems 13

**2. FORCES AND EQUILIBRIUM**

2-1 Vectors and scalars 14
2-2 Addition of forces 14
2-3 Equilibrium under the action of three forces 18
2-4 Resolution of vectors 21
2-5 Moment of a force; Torque 23
2-6 Equilibrium of a rigid body 25
2-7 Center of gravity 28
2-8 Center of gravity and stability 30
2-9 Special method in statics 32
Questions 34
Problems 35

**3. MOTION OF A PARTICLE**

3-1 Motion is relative 38
3-2 Uniform motion in a straight line 38
3-3 Relative velocities 41
3-4 Instantaneous speed and velocity 43
3-5 Acceleration 46
3-6 Straight-line motion under constant acceleration 47

3-7 Equations of motion for constant acceleration 48
3-8 Freely falling bodies 52
3-9 Motion of a projectile 58
3-10 Range of a projectile 60
Questions 62
Problems 63

**4. FORCE AND MOTION**

4-1 Starting and stopping motion 65
4-2 Newton's laws of motion 66
4-3 Newton's first law 67
4-4 Newton's second law 69
4-5 Absolute systems of units 72
4-6 Gravitational systems of units 75
4-7 Weight and mass 79
4-8 Motion on a smooth inclined plane 80
4-9 Frictional forces 82
4-10 Coefficient of sliding friction 84
4-11 Motion on a rough inclined plane 87
4-12 Motion through the air 90
4-13 Pairs of forces. Newton's third law 92
4-14 Impulse and momentum 93
Questions 96
Problems 97

**5. PERIODIC MOTION**

5-1 Uniform circular motion 100
5-2 Centripetal and centrifugal forces 101
5-3 Banking of a curved road 103
5-4 Nature of centrifugal force 106
5-5 Motion in a vertical circle 107
5-6 Periodicity of uniform circular motion 110
5-7 Planetary motion 112
5-8 Newton's law of universal gravitation 114
5-9 The gravitational field 117
5-10 Simple harmonic motion 119
5-11 Acceleration in simple harmonic motion 121
5-12 Period of simple harmonic motion 122
5-13 Properties of simple harmonic motion 125
5-14 The simple pendulum 129
Questions 132
Problems 133

## 6. WORK AND ENERGY


| | | |
|---|---|---|
| 6-1 | Work done by forces | 136 |
| 6-2 | Units for expressing work | 137 |
| 6-3 | Notation in powers of ten | 138 |
| 6-4 | Work and energy | 139 |
| 6-5 | Potential energy of position | 139 |
| 6-6 | Kinetic energy | 141 |
| 6-7 | Power | 142 |
| 6-8 | Conservation and transformation of energy | 143 |
| 6-9 | Kinetic and potential energy transformations | 145 |
| 6-10 | The simple pendulum | 146 |
| 6-11 | Elastic vibrations | 147 |
| 6-12 | Determining work by graphical methods | 150 |
| 6-13 | Mechanical efficiency of simple machines | 151 |
| | Questions | 156 |
| | Problems | 156 |


## 7. FLUIDS AT REST


| | | |
|---|---|---|
| 7-1 | Three phases of matter | 160 |
| 7-2 | Density | 160 |
| 7-3 | Pressure | 162 |
| 7-4 | Pressure due to weight of a liquid | 162 |
| 7-5 | Pressure in a confined liquid | 167 |
| 7-6 | Balanced columns of liquid | 168 |
| 7-7 | Archimedes' principle | 169 |
| 7-8 | Stability of a ship | 170 |
| 7-9 | Specific gravity | 173 |
| 7-10 | Atmospheric pressure | 174 |
| 7-11 | Barometers | 175 |
| 7-12 | Variation of atmospheric pressure with altitude | 176 |
| 7-13 | Compressibility of gases: Boyle's law | 176 |
| 7-14 | Archimedes' principle applied to gases | 179 |
| 7-15 | Pressure gauges: Manometers | 179 |
| | Questions | 180 |
| | Problems | 181 |


## 8. FLUIDS IN MOTION


| | | |
|---|---|---|
| 8-1 | Steady flow of liquid | 184 |
| 8-2 | Kinetic energy of a liquid | 185 |
| 8-3 | Bernoulli's theorem | 187 |
| 8-4 | Lift of an airplane | 190 |
| 8-5 | Air speed; Pitot tube | 193 |

8-6 Pitching a curve ball 194
8-7 Fluid friction, Viscosity 194
8-8 The siphon 195
8-9 Liquid pumps 196
8-10 Vacuum pumps 199
8-11 The centrifuge 200
Questions 201
Problems 202

**9. PROPERTIES OF MATTER**

9-1 Internal forces 204
9-2 Elasticity 206
9-3 Tensile stress and strain 207
9-4 Compressive stress and strain 210
9-5 Volume change: Bulk modulus 212
9-6 Shearing stress and strain 216
9-7 Cohesion and adhesion 218
9-8 Surface tension 220
9-9 Capillarity 223
9-10 Pressure and curved surfaces 225
9-11 Phenomena associated with surface tension 228
Questions 228
Problems 229

**10. ROTATIONAL MOTION**

10-1 Motion of a rigid body 232
10-2 Motion about a fixed axis 233
10-3 Angular speed of a rigid body 234
10-4 Angular speed and linear speed 234
10-5 Kinetic energy of rotation 235
10-6 Vector representation of angular velocity 238
10-7 Angular acceleration 239
10-8 Angular acceleration and linear acceleration 240
10-9 Torque and angular acceleration 242
10-10 Work and rotational energy 245
10-11 Rolling motion 246
10-12 Angular momentum 250
10-13 The gyroscope 251
Questions 253
Problems 253

## TWO / HEAT

### 11. TEMPERATURE


| | | |
|---|---|---|
| 11-1 | Concept of temperature | 257 |
| 11-2 | Temperature scales | 258 |
| 11-3 | Thermometers | 259 |
| 11-4 | Thermal expansion of solids | 261 |
| 11-5 | Thermal expansion of liquids | 264 |
| 11-6 | Expansion of gases | 266 |
| 11-7 | Absolute scale of temperature | 268 |
| | Questions | 270 |
| | Problems | 271 |


### 12. HEAT AND WORK


| | | |
|---|---|---|
| 12-1 | Heat | 273 |
| 12-2 | Heat units | 273 |
| 12-3 | Heat capacity. Specific heat | 274 |
| 12-4 | Heat measurements | 275 |
| 12-5 | Work and heat | 276 |
| 12-6 | Internal energy | 278 |
| 12-7 | The first law of thermodynamics | 279 |
| 12-8 | Work done by a gas | 280 |
| 12-9 | Specific heats of a gas | 282 |
| 12-10 | Adiabatic processes | 285 |
| | Questions | 286 |
| | Problems | 286 |


### 13. KINETIC THEORY OF MATTER


| | | |
|---|---|---|
| 13-1 | General gas law | 288 |
| 13-2 | The universal gas constant $R$ | 290 |
| 13-3 | Kinetic theory of gases | 291 |
| 13-4 | Avogadro's hypothesis | 295 |
| 13-5 | Diffusion of gases | 296 |
| 13-6 | Dalton's law of partial pressures | 298 |
| 13-7 | Diffusion of liquids and solids | 300 |
| 13-8 | Osmosis | 300 |
| 13-9 | Brownian motion | 301 |
| | Questions | 304 |
| | Problems | 304 |


### 14. CHANGE OF PHASE


| | | |
|---|---|---|
| 14-1 | Phases of a substance | 306 |
| 14-2 | Vaporization. Vapor pressure | 306 |

14-3 Boiling 308
14-4 Heat of vaporization 310
14-5 The critical point 311
14-6 Evaporation 312
14-7 Diffusion pump 315
14-8 Melting. Fusion 315
14-9 Dependence of melting point on pressure 317
14-10 Supercooling of a liquid 318
14-11 Sublimation 318
14-12 Triple point 319
Questions 320
Problems 321

**15. TRANSFER OF HEAT**

15-1 Methods of transmitting heat 323
15-2 Conduction 323
15-3 Convection 326
15-4 Radiation 327
15-5 Heat and radiant energy 329
15-6 Heat insulation 330
Questions 331
Problems 331

**16. HEAT ENGINES**

16-1 Heat-engine cycles 333
16-2 The Carnot cycle 334
16-3 Absolute thermodynamic temperature scale 336
16-4 The gasoline engine 337
16-5 The Diesel engine 339
16-6 The second law of thermodynamics 340
16-7 The steam engine 341
16-8 The turbine 343
16-9 Jet engines 345
16-10 The rocket engine 347
16-11 The refrigerator 350
16-12 A heat pump 353
Questions 354
Problems 356

**17. APPLICATION TO METEOROLOGY**

17-1 Meteorology 357
17-2 Physical state of the atmosphere: Air masses and fronts 357

17-3 Humidity of the atmosphere 358
17-4 Dew-point temperature 361
17-5 Fog and cloud 362
17-6 Precipitation 363
17-7 Heating of the atmosphere 364
17-8 Structure of the atmosphere 365
Questions 367
Problems 367

## *THREE / WAVE MOTION AND SOUND*

### 18. WAVE MOTION

18-1 Vibrating bodies and wave motion 371
18-2 Production of longitudinal waves 372
18-3 Production of transverse waves 376
18-4 Huygens' principle 380
18-5 Reflection of a wave 380
18-6 Refraction of a wave 382
18-7 Diffraction of waves 385
18-8 Vibrations and stationary waves 387
18-9 Measurement of the speed of a wave 389
18-10 Sound ranging 391
Questions 392
Problems 392

### 19. VIBRATIONS AND SOUND

19-1 Sound 394
19-2 Frequency of a musical tone 394
19-3 Resonance 395
19-4 Beats 397
19-5 Doppler effect 398
19-6 Velocity of source greater than velocity of sound 402
19-7 Intensity and loudness 404
19-8 The ear 405
19-9 Quality of a musical sound 406
19-10 Vibrations of strings 407
19-11 Vibrating air columns 410
Questions 412
Problems 413

## FOUR / ELECTRICITY AND MAGNETISM

### 20. MAGNETISM


| | | |
|---|---|---|
| 20-1 | Natural and permanent magnets | 417 |
| 20-2 | Coulomb's law of force | 418 |
| 20-3 | Magnetizing by induction | 420 |
| 20-4 | Intensity of magnetic field | 421 |
| 20-5 | Mapping the magnetic field | 422 |
| 20-6 | Magnetic moment of a magnet | 427 |
| 20-7 | Measurement of magnetic field intensity | 429 |
| 20-8 | A theory of magnetism | 430 |
| 20-9 | Terrestrial magnetism | 431 |
| | Questions | 432 |
| | Problems | 433 |


### 21. ELECTROSTATICS


| | | |
|---|---|---|
| 21-1 | Introduction | 435 |
| 21-2 | Electrified or charged bodies | 435 |
| 21-3 | Coulomb's law of force between charges | 436 |
| 21-4 | Insulators and conductors | 438 |
| 21-5 | The electrical theory of matter | 439 |
| 21-6 | Charging by induction | 440 |
| 21-7 | The electroscope | 441 |
| 21-8 | The electrophorus | 442 |
| 21-9 | The electric field | 443 |
| 21-10 | Potential difference | 447 |
| 21-11 | Equipotential surfaces. Conductors | 449 |
| 21-12 | Equality of induced and inducing charges | 452 |
| 21-13 | Capacitors | 453 |
| 21-14 | Energy of a charged capacitor | 458 |
| 21-15 | Capacitors in parallel | 459 |
| 21-16 | Capacitances in series | 463 |
| | Questions | 465 |
| | Problems | 466 |


### 22. THE ELECTRIC CIRCUIT


| | | |
|---|---|---|
| 22-1 | Sources of electrical energy | 468 |
| 22-2 | Electric current | 469 |
| 22-3 | Electrical work | 470 |
| 22-4 | Heating effect of an electric current | 471 |

22-5 Specific resistance of a conducting substance 473
22-6 Temperature and resistance 475
22-7 Series and parallel connections 476
22-8 Resistance measurements: Wheatstone bridge 480
Questions 481
Problems 482

**23. ELECTROCHEMICAL EFFECTS**

23-1 Conductivity of liquids. Electrolytes 485
23-2 Electrolysis. Electroplating 486
23-3 Faraday's laws of electrolysis 488
23-4 The charge of an electron 490
23-5 Primary or voltaic cells 492
23-6 Secondary or storage cell 496
23-7 Combinations of cell. Batteries 498
23-8 Thermoelectric effect 499
23-9 The potentiometer 501
Questions 503
Problems 503

**24. ELECTROMAGNETIC EFFECTS**

24-1 Magnetic field around an electric current 505
24-2 Equivalence of a moving charge and a current 507
24-3 Electromagnetic unit of current 508
24-4 Systems of electrical units 512
24-5 Magnetic field intensity of a current in a long straight wire 514
24-6 Magnetic field intensity inside a solenoid 515
24-7 Force on a wire carrying current in a magnetic field 516
24-8 Galvanometer: Moving-coil type 519
24-9 Ammeters and voltmeters 523
24-10 A charge moving in a magnetic field 525
Questions 527
Problems 528

**25. ELECTROMAGNETIC INDUCTION**

25-1 Induced electromotive forces 530
25-2 Faraday's law of electromagnetic induction 531
25-3 Lenz's law for induced currents 534
25-4 Motion of a wire in a magnetic field 535
25-5 Electric dynamo or generator 537
25-6 Direct-current generator 541

25-7 Direct-current motor 544
25-8 Self-induced electromotive force 546
25-9 Measurement of magnetic fields 549
25-10 Magnetic field intensity and flux density 550
25-11 The permeability of iron 553
25-12 Hysteresis 555
25-13 Magnetic properties of matter 557
25-14 The induction coil 559
Questions 561
Problems 562

**26. ALTERNATING CURRENTS**

26-1 Measurement of alternating current 565
26-2 Instantaneous and effective values 565
26-3 Inductance in an A-C circuit 568
26-4 Vector diagram for an A-C circuit 569
26-5 Power in an A-C circuit 572
26-6 Capacitance in an A-C circuit 573
26-7 Capacitance, inductance, and resistance in series 576
26-8 Resonance in an A-C circuit 579
26-9 The transformer 580
Questions 584
Problems 584

**27. ELECTRICAL COMMUNICATION**

27-1 Modes of electrical communication 586
27-2 The electromagnetic telegraph 586
27-3 The telephone 588
27-4 Electrical oscillations and waves 590
27-5 Resonant frequency of a circuit 592
27-6 Thermionic emission 594
27-7 The rectifier tube 595
27-8 The triode 597
27-9 Modulated waves 600
27-10 Transmission of electromagnetic waves 602
27-11 The crystal detector 604
27-12 A simple receiver 606
Questions 608
Problems 609

## FIVE / LIGHT

### 28. PHOTOMETRY


| | | |
|---|---|---|
| 28-1 | The nature of light | 613 |
| 28-2 | Sources of light | 614 |
| 28-3 | Intensity of a source of light | 617 |
| 28-4 | Illuminance | 619 |
| 28-5 | Photometry | 621 |
| 28-6 | Photoelectric photometers | 623 |
| 28-7 | Speed of light | 624 |
| | Questions | 627 |
| | Problems | 627 |


### 29. REFLECTION AND REFRACTION


| | | |
|---|---|---|
| 29-1 | Passage of light through a medium | 629 |
| 29-2 | Laws of reflection | 630 |
| 29-3 | Rotating mirror | 631 |
| 29-4 | Images formed by a plane mirror | 632 |
| 29-5 | Refraction of light | 632 |
| 29-6 | Refraction and dispersion | 635 |
| 29-7 | Refraction effects | 637 |
| 29-8 | Critical angle. Total reflection | 639 |
| 29-9 | Totally reflecting prism | 640 |
| | Questions | 641 |
| | Problems | 641 |


### 30. LENSES AND MIRRORS


| | | |
|---|---|---|
| 30-1 | Lenses | 643 |
| 30-2 | Thin lenses | 644 |
| 30-3 | Image formation by converging lenses | 645 |
| 30-4 | The lens equation | 646 |
| 30-5 | Image formation by diverging lenses | 649 |
| 30-6 | Combinations of lenses | 650 |
| 30-7 | Spherical mirrors | 654 |
| 30-8 | Image formation by concave mirrors | 655 |
| 30-9 | The mirror equation | 656 |
| 30-10 | Image formation by convex mirrors | 660 |
| 30-11 | Spherical aberration of lenses and mirrors | 660 |
| 30-12 | Chromatic aberration of a lens | 662 |
| | Questions | 663 |
| | Problems | 663 |

## 31. OPTICAL INSTRUMENTS


| | | |
|---|---|---|
| 31-1 | The camera | 666 |
| 31-2 | Projection lantern | 667 |
| 31-3 | The eye | 668 |
| 31-4 | The magnifying glass | 672 |
| 31-5 | The astronomical telescope | 673 |
| 31-6 | The terrestrial telescope | 674 |
| 31-7 | The compound microscope | 677 |
| 31-8 | The prism spectroscope | 678 |
| 31-9 | Color sensitivity of the eye | 680 |
| | Questions | 681 |
| | Problems | 682 |


## 32. LIGHT AS A WAVE MOTION


| | | |
|---|---|---|
| 32-1 | Interference of light from two sources | 683 |
| 32-2 | Interference from thin films | 685 |
| 32-3 | Diffraction of light | 690 |
| 32-4 | The diffraction grating | 692 |
| 32-5 | The diffraction grating spectrometer | 694 |
| 32-6 | Polarization. Transverse waves | 697 |
| 32-7 | Polarization by reflection | 697 |
| 32-8 | Polarization by crystal absorption | 700 |
| 32-9 | Polarization by double refraction | 703 |
| | Questions | 704 |
| | Problems | 704 |


# SIX / ATOMIC PHYSICS

## 33. CHARGED PARTICLES


| | | |
|---|---|---|
| 33-1 | Elements and atoms | 709 |
| 33-2 | Electric discharge through gases | 711 |
| 33-3 | Ratio of charge to mass of an electron | 713 |
| 33-4 | Variation of mass with velocity | 715 |
| 33-5 | Positive ions. Mass spectrograph | 717 |
| 33-6 | Masses of isotopes and atomic structure | 721 |
| 33-7 | Mass and energy | 722 |
| | Questions | 723 |
| | Problems | 724 |

## 34. SPECTRA AND ATOMIC STRUCTURE


| | | |
|---|---|---|
| 34-1 | Types of optical spectra | 725 |
| 34-2 | The continuous spectrum | 726 |
| 34-3 | Spectrum of hydrogen | 728 |
| 34-4 | Bohr's theory of the hydrogen atom | 729 |
| 34-5 | Additional successes of the theory | 735 |
| 34-6 | The hydrogen energy-level diagram | 736 |
| 34-7 | The discovery of deuterium | 738 |
| 34-8 | Changes in our fundamental concepts | 739 |
| 34-9 | Discovery of X rays | 741 |
| 34-10 | Some properties of X rays | 745 |
| 34-11 | Diffraction and interference of X rays | 746 |
| 34-12 | X rays and crystal structure | 750 |
| 34-13 | X-ray spectra and atomic structure | 753 |
| 34-14 | Particles and waves | 759 |
| 34-15 | The electron microscope | 763 |
| | Questions | 764 |
| | Problems | 766 |


## 35. NUCLEAR PHYSICS


| | | |
|---|---|---|
| 35-1 | The discovery of radioactivity. Evidence from the nucleus | 768 |
| 35-2 | Properties and nature of the alpha rays | 770 |
| 35-3 | Nature of beta rays | 773 |
| 35-4 | Gamma rays | 773 |
| 35-5 | Radioactive transformations | 774 |
| 35-6 | Scattering of alpha particles by nuclei | 776 |
| 35-7 | Nuclear disintegration by alpha-particle bombardment | 779 |
| 35-8 | The neutron | 783 |
| 35-9 | The positron | 784 |
| 35-10 | Artificial or induced radioactivity | 786 |
| 35-11 | High-energy particles | 786 |
| 35-12 | Nuclear disintegrations by protons and deuterons | 789 |
| 35-13 | Nuclear processes | 791 |
| 35-14 | Nuclear fission | 793 |
| 35-15 | A nuclear chain reaction | 795 |
| | Questions | 798 |
| | Problems | 799 |


## APPENDICES


| | |
|---|---|
| Tables | 802 |
| Glossary | 817 |
| Answers to odd-numbered problems | 831 |
| Index | 837 |