

Contents

Preface vii

Note to the student xi

1 Units and Dimensions 1

How can such a simple observation be used to measure Earth?

1-1 Introduction 2

1-2 Measuring Things 2

1-3 The International System of Units 2

1-4 Standards of SI Quantities 3

1-5 Applications of Dimensional Analysis 8

Reasoning Type Questions 12

Multiple Choice Questions 13

Problems 16

Additional Problems 17

Answers 17

2 Vectors and Elementary Calculus 19

How does the ant know the way home with no guiding clues on the desert plain?

2-1 Introduction 20

2-2 Vector and Scalar Quantities 20

2-3 Vector Addition 21

2-4 Components of Vectors 22

2-5 Unit Vectors 25

2-6 Application of Unit Vector Form 26

2-7 Vectors and the Laws of Physics 30

2-8 Vector Multiplication 31

2-9 Calculus 33

2-10 Integral Calculus 37

Multiple Choice Questions 40

Questions 46

Problems 46

Additional Problems 48

Answers 48

3 Straight Line Motion 51

Why can a woodpecker survive the severe impacts with a tree limb?

3-1 Introduction 52

3-2 Motion 52

3-3 Position and Displacement 52

3-4 Average Velocity and Average Speed 53

3-5 Instantaneous Velocity and Speed 55

3-6 Acceleration 57

3-7 Constant Acceleration: A Special Case 59

3-8 Another Look at Constant Acceleration 62

3-9 Free-Fall Acceleration 62

3-10 Graphical Integration in Motion Analysis 65

Reasoning Type Questions 66

Multiple Choice Questions 67

Questions 77

Problems 78

Additional Problems 81

Answers 83

4 Two- and Three-Dimensional Motion 87

What clue is hidden in the ball's motion?

4-1 Introduction 88

4-2 Position and Displacement 88

4-3 Average Velocity and Instantaneous Velocity 90

4-4 Average Acceleration and Instantaneous Acceleration 92

4-5 Projectile Motion 94

4-6 Projectile Motion Analyzed 95

4-7 Projection on Inclined Plane 102

4-8 Relative Motion 104

4-9 Net Motion 110

4-10 Constraint Motion 113

Reasoning Type Questions 116

Multiple Choice Questions 116

Questions 120

Problems 121

Additional Problems 123

Answers 125

5 Newton's Laws of Motion 127

What is the subtle fear factor in riding the last car in a roller coaster?

5-1 Introduction 128

5-2 Newtonian Mechanics 128

5-3 Newton's First Law 128

5-4 Force 129

5-5 Mass 130

5-6	Newton's Second Law	131
5-7	Newton's Third Law	133
5-8	Some Particular Forces	134
5-9	Applying Newton's Laws	143
5-10	Motion in Accelerated Frames: Fictitious Force	157
	Reasoning Type Questions	158
	Multiple Choice Questions	158
	Questions	161
	Problems	163
	Additional Problems	166
	Answers	168

6 Friction 171

How did the ancient people move the blocks up and into position?

6-1	Introduction	172
6-2	Properties of Friction	173
6-3	Static Friction	174
6-4	Kinetic Friction	177
6-5	Some More Applications	178
	Reasoning Type Questions	183
	Multiple Choice Questions	183
	Questions	185
	Problems	186
	Additional Problems	187
	Answers	190

7 Circular Motion 193

How did he manage to accomplish this act without breaking his neck?

7-1	Introduction	194
7-2	Angular Variables	194
7-3	Relation Between Angular Velocity and Linear Velocity	196
7-4	Particle in Uniform Circular Motion	197
7-5	Particle in Nonuniform Circular Motion	200
7-6	Dynamics of Circular Motion	203
7-7	Dynamics of Nonuniform Circular Motion	210
7-8	Centrifugal Force	211
	Reasoning Type Questions	212
	Multiple Choice Questions	212
	Questions	216
	Problems	216
	Additional Problems	221
	Answers	222

8 Work, Power, and Energy 225

Why can large avalanches have such long runouts?

8-1	Introduction	226
8-2	Kinetic Energy	226
8-3	Work	227
8-4	Calculation of Work for Uniform Force	228
8-5	Work Done by a Spring Force	236
8-6	Calculation of Work for Nonuniform Force	239
8-7	Validity of Work–Kinetic Energy Theorem in Inertial Reference Frames	242
8-8	Work–Kinetic Energy Theorem for a System (Collection of Particles)	243
8-9	Potential Energy	244
8-10	Work and Potential Energy	244
8-11	Path Independence of Conservative Forces	245
8-12	Determining Potential Energy Values	247
8-13	Work–Mechanical Energy Theorem	250
8-14	Conservation of Mechanical Energy	250
8-15	Work Done on a System by an External Force	254
8-16	Conservation of Energy	257
8-17	Relation Between Conservative Force and Potential Energy	263
8-18	Vertical Circular Motion	266
	Reasoning Type Questions	269
	Multiple Choice Questions	269
	Questions	276
	Problems	279
	Additional Problems	284
	Answers	289

9 Center of Mass 293

How can the head-banging sheep withstand such violent clashes?

9-1	Introduction	294
9-2	The Center of Mass	294
9-3	Newton's Second Law for a System of Particles	300
9-4	Linear Momentum	307
9-5	The Linear Momentum of a System of Particles	307
9-6	Impulse and Momentum	309
9-7	Conservation of Momentum	315
9-8	Collisions	321
9-9	Inelastic Collisions in One Dimension	324
9-10	Elastic Collisions in One Dimension	328
9-11	Collisions in Two Dimensions	331
9-12	C-Frame	333

9-13 Impulse Momentum Equation for Continuous Processes 336

9-14 Systems with Varying Mass: A Rocket 337

9-15 Some Extra Derivations 341

Reasoning Type Questions 343

Multiple Choice Questions 344

Linked Comprehension 352

Questions 354

Problems 356

Additional Problems 361

Answers 365

10 Rigid Body Dynamics-I 369

How can a shrimp claw generate such a powerful sound wave?

10-1 Introduction 370

10-2 Kinematics of Rigid Body 370

10-3 The Rotational Variables 371

10-4 Are Angular Quantities Vectors? 373

10-5 Rotation with Constant Angular Acceleration 374

10-6 Relating the Linear and Angular Variables 376

10-7 Kinetic Energy of Rotation 379

10-8 Calculating the Moment of Inertia 380

10-9 Torque 387

10-10 The Vector Product 388

10-11 Vector Product and Torque 390

10-12 The Center of Gravity 393

10-13 The Rigid Object Under a Net Torque 395

10-14 Work and Rotational Kinetic Energy 396

10-15 Angular Momentum 404

10-16 Newton's Second Law in Angular Form 405

10-17 The Angular Momentum of a System of Particles 407

10-18 The Angular Momentum of a Rigid Body Symmetrically Rotating About a Fixed Axis 408

10-19 Conservation of Angular Momentum 415

Reasoning Type Questions 426

Multiple Choice Questions 426

Questions 428

Problems 430

Additional Problems 437

Answers 440

11 Rigid Body Dynamics-II 443

So, what was the danger to the tower?

11-1 Introduction 444

11-2 Kinematics of Combined Rotation and Translation 444

11-3 Kinetic Energy of Combined Translation and Rotation 447

11-4 Forces of Rolling 448

11-5 Torque About Center of Mass 451

11-6 Angular Momentum of Rigid Body About a Point Lying Outside the Body 451

11-7 The Yo-Yo 452

11-8 Torque Revisited 452

11-9 Problem Solving in Rolling 453

11-10 Rigid Body in Equilibrium 459

11-11 The Requirements of Equilibrium 460

11-12 Some Examples of Static Equilibrium 462

11-13 Toppling 466

11-14 Instantaneous Center of Zero Velocity 468

Reasoning Type Questions 470

Multiple Choice Questions 471

Linked Comprehension 475

Questions 475

Problems 476

Additional Problems 477

Answers 481

12 Elasticity 483

How much impact can he withstand while landing?

12-1 Introduction 484

12-2 Stress and Strain 485

12-3 Elastic Potential Energy 489

12-4 Poisson's Ratio 490

12-5 Mechanical Properties of Materials 491

Multiple Choice Questions 492

Problems 493

Additional Problems 494

Answers 495

13 Newtonian Gravitation 497

What monster lies at our galaxy's center?

13-1 Introduction 498

13-2 Newton's Law of Gravitation 498

13-3 Gravitation and the Principle of Superposition 500

13-4 Gravitation Near Earth's Surface 502

13-5 Gravitation Inside Earth 504

13-6 Gravitational Potential Energy 505

13-7 Planets and Satellites: Kepler's Laws 509

13-8	Satellites: Orbits and Energy	512
13-9	Einstein and Gravitation	514
	Reasoning Type Questions	516
	Multiple Choice Questions	517
	Linked Comprehension	519
	Questions	521
	Problems	523
	Additional Problems	528
	Answers	531

14 Fluids 535

In short, how does a surfer surf?

14-1	Introduction	536
14-2	Density and Pressure	536
14-3	Fluids at Rest	538
14-4	Measuring Pressure	541
14-5	Pascal's Principle	542
14-6	Archimedes' Principle	543
14-7	Hydrostatic Force on a Curved Surface	550
14-8	Linear Accelerated Motion of a Fluid	551
14-9	Motion of a Fluid in Rotating vessel	553
14-10	Buoyant Force	554
14-11	Fluid Dynamics	556
14-12	Bernoulli's Equation	559
	Reasoning Type Questions	568
	Multiple Choice Questions	569
	Linked Comprehension	578
	Questions	578
	Problems	579
	Additional Problems	586
	Answers	588

15 Simple Harmonic Motion 593

How can the ball counter the building's sway?

15-1	Introduction	594
15-2	Simple Harmonic Motion	595
15-3	Force Law for Simple Harmonic Motion	599
15-4	Simple Harmonic Motion and Uniform Circular Motion	601
15-5	Energy in Simple Harmonic Motion	607
	Multiple Choice Questions	611
	Questions	612
	Problems	614
	Additional Problems	617
	Answers	620

16 Mechanical Waves 623

What causes such oscillations, which can be the nightmare of structural engineers?

16-1	Introduction	624
16-2	Propagation of Distance and Wave Equation	624
16-3	Wave Equation	626
16-4	Speed of Waves on String	630
16-5	General Differential Equation of Wave	634
16-6	Phasors	636
16-7	Superposition	637
16-8	Interference	639
16-9	Standing Waves	643
16-10	Generation of Standing Wave Due to Reflection of a Traveling Wave	645
16-11	Normal Modes of Vibrations	647
16-12	Energy and Power of a Wave	651
16-13	Propagation of Wave in Two Connected Strings	655
	Multiple Choice Questions	656
	Questions	659
	Problems	660
	Additional Problems	664
	Answers	667

17 Longitudinal Waves 669

What causes this musical echo, said to be a chirped echo?

17-1	Sound	670
17-2	The Speed of Sound	670
17-3	Traveling Sound Waves	673
17-4	Intensity and Characteristics	675
17-5	Three-Dimensional Propagation of Waves	679
17-6	Standing Waves	681
17-7	Interference	687
17-8	Beats	689
17-9	The Doppler Effect	691
17-10	Supersonic Speeds, Shock Waves	696
	Reasoning Type Questions	697
	Multiple Choice Questions	697
	Questions	699
	Problems	700
	Additional Problems	705
	Answers	708

18 Temperature and Thermal Expansion 711

Why did the length of aircraft increase?

- 18-1 Introduction 712
- 18-2 The Zeroth Law of Thermodynamics 712
- 18-3 Measuring Temperature 713
- 18-4 Thermal Expansion 714
- 18-5 Expansion of Solids 715
- 18-6 Expansion of Liquids 720
- Reasoning Type Questions 724
- Multiple Choice Questions 724
- Questions 729
- Problems 729
- Additional Problems 730
- Answers 731

19 Heat, Calorimetry, and Heat Transfer 733

How can the beetles detect a distant fire?

- 19-1 Temperature and Heat 734
- 19-2 Thermal Parameters 735
- 19-3 Absorption of Heat 736
- 19-4 Calorimetry 738
- 19-5 Conduction 739
- 19-6 Convection and Radiation 742
- 19-7 Approximate Surface Temperature of the Sun 747
- 19-8 Wien's Displacement Law 748
- 19-9 Newton's Law of Cooling 749
- 19-10 Cooling Curves 750
- Reasoning Type Questions 751
- Multiple Choice Questions 751
- Questions 758
- Problems 759
- Additional Problems 762
- Answers 766

20 The Kinetic Theory of Gases 769

What actually crushed the railroad tank car?

- 20-1 Introduction 770
- 20-2 Avogadro's Number 770
- 20-3 Ideal Gases 771
- 20-4 Pressure, Temperature, and RMS Speed 775
- 20-5 Translational Kinetic Energy 778
- 20-6 The Distribution of Molecular Speeds 778
- 20-7 The Equipartition of Energy and Degrees of Freedom 783

20-8 A Hint of Quantum Theory 785

- Reasoning Type Questions 786
- Multiple Choice Questions 786
- Questions 789
- Problems 789
- Additional Problems 791
- Answers 793

21 First Law of Thermodynamics 795

What causes the fog?

- 21-1 Work and Heat 796
- 21-2 The First Law of Thermodynamics 800
- 21-3 Some Applications of the First Law of Thermodynamics 801
- 21-4 The Adiabatic Expansion of an Ideal Gas 806
- 21-5 The Carnot Engine 808
- Reasoning Type Questions 817
- Multiple Choice Questions 817
- Questions 823
- Problems 824
- Additional Problems 826
- Answers 830

Appendices

- A The International System of Unit (SI) 833
- B Some Fundamental Constants of Physics 835
- C Some Astronomical Data 836
- D Conversion Factors 837
- E Mathematical Formulas 841
- F Properties of the Elements 844
- G Solved IIT-JEE Problems 847

Solved IIT-JEE Physics Paper 2012 867

