

Discovering Design with Physics

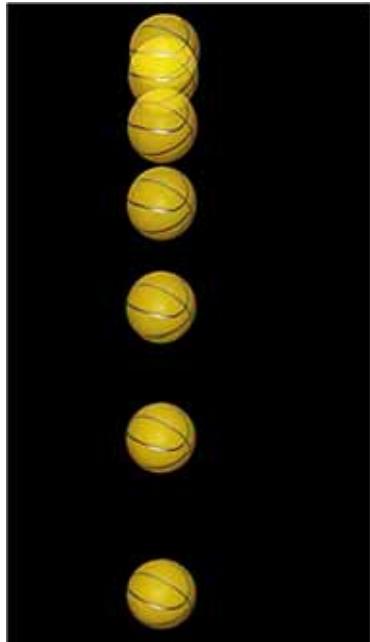
Table of Contents

| | |
|-------------------------------------|---|
| Chapter 1: Let's Move! | 1 |
|-------------------------------------|---|



| | |
|---|----|
| Introduction..... | 1 |
| Let's Make Sure You Are Ready..... | 1 |
| Sir Isaac Newton..... | 4 |
| Where Do We Start? | 5 |
| Speed and Velocity | 7 |
| Velocity is Relative | 9 |
| Experiment 1.1: Velocity is Relative | 10 |
| Relating Velocity and Displacement | 12 |
| Newton's First Law of Motion | 15 |
| Experiment 1.2: Newton's First Law | 16 |
| This Can Be a Bit Tricky! | 18 |
| Experiment 1.3: Motion in a Circle..... | 19 |
| Change Is a Part of Life..... | 21 |
| Experiment 1.4: Changing Velocity | 21 |
| A Picture Is Worth a Thousand Words | 23 |
| To Err Is Human | 25 |
| Sample Calculations for Experiment 1.4..... | 27 |
| Solutions to the "Comprehension Check" Questions..... | 28 |
| Review | 32 |

| | |
|--|----|
| Chapter 2: Force and Acceleration | 35 |
|--|----|



| | |
|--|----|
| Introduction..... | 35 |
| The Mathematical Definition of Acceleration..... | 35 |
| Experiment 2.1: Measuring Acceleration | 36 |
| More Graphs..... | 37 |
| Newton's Second Law..... | 40 |
| Experiment 2.2: Seeing Newton's Second Law in Action | 41 |
| Equations of Motion (Part 1) | 43 |
| Equations of Motion (Part 2) | 46 |
| Free Fall | 49 |
| Experiment 2.3: Measuring the Acceleration Due to Gravity..... | 50 |
| More Analysis of Free Fall | 51 |
| The Difference Between Mass and Weight..... | 54 |
| Sample Calculations for Experiment 2.1..... | 56 |
| Sample Calculations for Experiment 2.3..... | 57 |
| Solutions to the "Comprehension Check" Questions..... | 58 |
| Review | 63 |

| | |
|----------------------------------|-----------|
| Chapter 3: Friction | 65 |
|----------------------------------|-----------|



| | |
|---|----|
| Introduction..... | 65 |
| Newton's Third Law | 65 |
| Experiment 3.1: Newton's Third Law..... | 65 |
| Be Careful How You Apply Newton's Third Law | 67 |
| Newton's Third Law and the Normal Force..... | 68 |
| How Newton's Third Law Relates to Friction | 71 |
| Experiment 3.2: Friction and the Normal Force | 71 |
| Taking Friction into Account When Analyzing Situations | 74 |
| Revisiting Some Old Friends | 76 |
| I Sense Some Tension Here..... | 77 |
| Experiment 3.3: Tension and Its Limits..... | 77 |
| One More Thing About Tension | 79 |
| Air Resistance..... | 80 |
| Experiment 3.4: Some of the Factors that Affect Air Resistance..... | 81 |
| Solutions to the "Comprehension Check" Questions | 85 |
| Review | 89 |

| | |
|---|-----------|
| Chapter 4: Two-Dimensional Vectors | 91 |
|---|-----------|



| | |
|--|-----|
| Introduction..... | 91 |
| Two-Dimensional Vectors | 91 |
| Two-Dimensional Vectors Can Be Added..... | 92 |
| Experiment 4.1: Adding Forces in Two Dimensions | 92 |
| Adding and Subtracting Two-Dimensional Vectors, the Easy Way | 94 |
| Mathematical Properties of Two-Dimensional Vectors | 96 |
| Adding Two-Dimensional Vectors, the Hard Way | 101 |
| One Very Obvious Application of Adding Vectors Analytically | 102 |
| Experiment 4.2: Adding Vectors Analytically | 102 |
| Other Applications of Adding Vectors Analytically | 105 |
| This Goes Beyond Adding Vectors | 110 |
| Sample Calculations for Experiment 4.2 | 111 |
| Solutions to the "Comprehension Check" Questions | 112 |
| Review | 117 |

Chapter 5: Two-Dimensional Motion..... 119



| | |
|--|-----|
| Introduction..... | 119 |
| Two-Dimensional Motion With Some Old Friends..... | 119 |
| Projectiles in Two Dimensions..... | 123 |
| Experiment 5.1: Gravity's Effect on Two-Dimensional Motion | 123 |
| The Range Equation..... | 128 |
| Experiment 5.2: The Range Equation..... | 130 |
| Thinking About the Dimensions Independently..... | 132 |
| When the Range Equation Doesn't Apply..... | 133 |
| Experiment 5.3: Measuring Velocity Without a Timer..... | 136 |
| What About Air Resistance?..... | 138 |
| Sample Calculations for Experiment 5.2..... | 139 |
| Sample Calculations for Experiment 5.3..... | 140 |
| Solutions to the “Comprehension Check” Questions | 141 |
| Review | 147 |

Chapter 6: Newton’s Second Law and Two-Dimensional Motion 149



| | |
|--|-----|
| Introduction..... | 149 |
| Translational Equilibrium..... | 149 |
| Experiment 6.1: An Accelerometer | 150 |
| Static Translational Equilibrium in Two Dimensions..... | 151 |
| Dynamic Translational Equilibrium..... | 155 |
| Experiment 6.2: Measuring the Coefficient of Static Friction | 157 |
| Non-Equilibrium Motion on an Incline..... | 159 |
| Analyzing the Translational Motion of Two Objects | 160 |
| Rotational Motion | 163 |
| Experiment 6.3: Making Your Own Mass Scale..... | 166 |
| Rotational Equilibrium..... | 168 |
| Sample Calculations for Experiment 6.2..... | 169 |
| Sample Calculations for Experiment 6.3..... | 170 |
| Solutions to the “Comprehension Check” Questions | 171 |
| Review | 175 |

Chapter 7: Uniform Circular Motion and Gravity..... 177

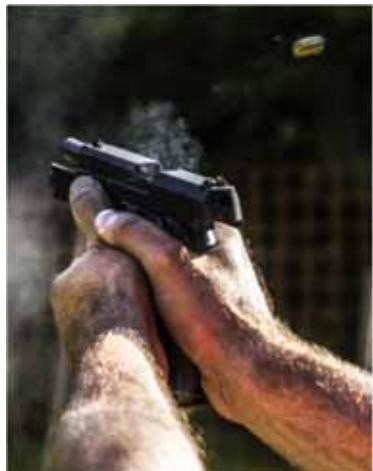


| | |
|---|-----|
| Introduction | 177 |
| Uniform Circular Motion | 177 |
| Experiment 7.1: Centripetal Force | 178 |
| Terms and Equations | 180 |
| Two Sources of Centripetal Force | 182 |
| Gravity: Another Source of Centripetal Force | 185 |
| But Isn't Gravity Constant Near the Surface of the Earth? | 188 |
| Gravity at Work in the Solar System..... | 189 |
| Kepler's Laws..... | 192 |
| One Consequence of Centripetal Force..... | 195 |
| Experiment 7.2: One Consequence of Centripetal Force for the Earth. 196 | |
| Centrifugal Force..... | 197 |
| Solutions to the "Comprehension Check" Questions | 198 |
| Review | 202 |

Chapter 8: Energy 203



| | |
|---|-----|
| Introduction..... | 203 |
| The Modern Definition of Energy..... | 203 |
| Experiment 8.1: Work and Energy | 205 |
| Different Forms of Energy..... | 207 |
| The Interplay Between Kinetic and Potential Energy | 210 |
| Taking Friction Into Account..... | 213 |
| Experiment 8.2: The Work Done by Friction | 214 |
| What About That Equation We Have Been Using in Experiments? | 217 |
| Experiment 8.3: Rotational Energy..... | 217 |
| Energy and Power | 220 |
| Household Energy and Power..... | 223 |
| Solutions to the "Comprehension Check" Questions | 224 |
| Review | 228 |

Chapter 9: Momentum and Its Conservation..... 229

| | |
|--|-----|
| Introduction..... | 229 |
| Momentum | 229 |
| Impulse: The Change in Momentum | 230 |
| Experiment 9.1: Impulse and Time | 230 |
| The Conservation of Momentum..... | 234 |
| Experiment 9.2: The Conservation of Momentum | 234 |
| Using Momentum Conservation to Analyze Situations..... | 237 |
| Energy Conservation in Collisions..... | 240 |
| Angular Momentum | 245 |
| Experiment 9.3: Angular Momentum | 245 |
| Solutions to the “Comprehension Check” Questions | 250 |
| Review | 255 |

Chapter 10: Periodic Motion..... 257

| | |
|---|-----|
| Introduction..... | 257 |
| Hooke’s Law | 257 |
| Experiment 10.1: Hooke’s Law | 258 |
| Using Hooke’s Law | 261 |
| Periodic Motion in a Mass/Spring System..... | 262 |
| Experiment 10.2: The Properties of a Mass/Spring System | 265 |
| Terminology and the Use of Equation (10.5)..... | 266 |
| Energy in a Mass/Spring System | 269 |
| The Simple Pendulum | 272 |
| Experiment 10.3: Properties of a Simple Pendulum..... | 272 |
| But What About Friction? | 275 |
| Keeping Time | 276 |
| Sample Calculations for Experiment 10.1 | 277 |
| Sample Calculations for Experiment 10.2 | 277 |
| Solutions to the “Comprehension Check” Questions | 278 |
| Review | 281 |

Chapter 11: Sound and Light 283



| | |
|--|-----|
| Introduction..... | 283 |
| Two Kinds of Waves and an Equation That Goes Along with Them.... | 283 |
| Sound Waves..... | 286 |
| Experiment 11.1: Wavelength, Frequency, and Amplitude..... | 286 |
| The Speed of Sound | 289 |
| The Doppler Effect..... | 291 |
| How We Hear Sounds..... | 294 |
| Sound In Other Media | 295 |
| The Wave Nature of Light..... | 297 |
| A Few Details about Light..... | 300 |
| It's Actually a Bit More Complicated Than That!..... | 302 |
| Is Light a Particle or a Wave? | 304 |
| The Doppler Effect and Light | 305 |
| Solutions to the "Comprehension Check" Questions | 307 |
| Review | 310 |

Chapter 12: Optics 311



| | |
|--|-----|
| Introduction | 311 |
| The Law of Reflection..... | 311 |
| Experiment 12.1: The Law of Reflection | 312 |
| Reflection In Flat Mirrors..... | 313 |
| Curved Mirrors..... | 314 |
| More Ray Tracing with Concave Spherical Mirrors..... | 319 |
| Ray Tracing with Convex Spherical Mirrors | 322 |
| Experiment 12.2: Convex and Concave Mirrors | 325 |
| Refraction and Snell's Law | 327 |
| Refraction and Rainbows..... | 330 |
| Refraction and Converging Lenses | 331 |
| Refraction and Diverging Lenses..... | 334 |
| Our Eyes and Corrective Lenses | 336 |
| Solutions to the "Comprehension Check" Questions | 338 |
| Review | 346 |

Chapter 13: The Electrostatic Force 347

| | |
|---|-----|
| Introduction..... | 347 |
| Charging Objects..... | 347 |
| Experiment 13.1: Charging by Induction and Conduction..... | 348 |
| The Electrostatic Force | 352 |
| The Electrostatic Force as a Centripetal Force | 354 |
| The Electrostatic Force with Multiple Charges | 355 |
| The Electric Field..... | 358 |
| Conductors, Insulators, and the Reality of the Electric Field | 362 |
| Experiment 13.2: There is No Electric Field Inside a Conductor..... | 363 |
| The Strength of an Electric Field..... | 364 |
| A Few Words About Michael Faraday..... | 366 |
| Solutions to the “Comprehension Check” Questions | 367 |
| Review | 371 |

Chapter 14: Electricity Has Potential! 373

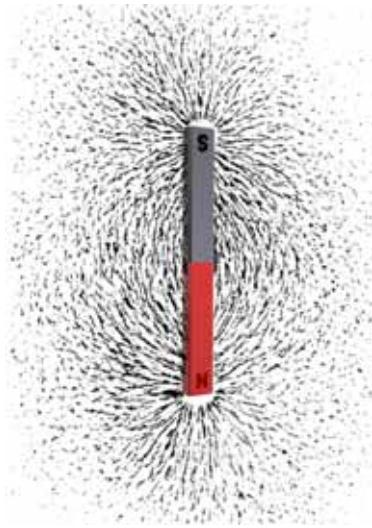
| | |
|---|-----|
| Introduction..... | 373 |
| The Electric Potential..... | 373 |
| Potential Difference | 375 |
| The Voltage Rating of a Battery | 378 |
| Experiment 14.1: The Major Difference Between 1.5-volt and 9-volt.... | 379 |
| Potential Difference Due to Multiple Charges..... | 381 |
| Storing Charges in a Leyden Jar..... | 383 |
| Experiment 14.2: A Leyden Jar..... | 384 |
| Storing Charges in a Capacitor | 386 |
| Putting Charges in a Parallel Plate Capacitor..... | 388 |
| Electric Circuits and Conventional Current | 391 |
| Solutions to the “Comprehension Check” Questions | 393 |
| Review | 396 |

| | |
|---|-----|
| Chapter 15: Electric Circuits..... | 397 |
|---|-----|



| | |
|--|-----|
| Introduction..... | 397 |
| Current Flow in a Circuit..... | 397 |
| Current and Ohm's Law..... | 399 |
| Experiment 15.1: Building Two Simple Circuits | 403 |
| Comparing Series and Parallel Circuits | 406 |
| More on Series and Parallel Circuits | 407 |
| This Can Get a Little Complicated | 410 |
| Fuses and Circuit Breakers | 412 |
| Capacitors and Multiple Batteries | 416 |
| André-Marie Ampère | 418 |
| Solutions to the "Comprehension Check" Questions | 419 |
| Review | 423 |

| | |
|-----------------------------------|-----|
| Chapter 16: Magnetism..... | 425 |
|-----------------------------------|-----|



| | |
|--|-----|
| Introduction..... | 425 |
| Magnets, Poles, and the Basic Law of Magnetism..... | 425 |
| Magnetic Fields and the Speed of Light..... | 426 |
| The Relationship Between Electricity and Magnetism | 429 |
| Experiment 16.1: Ørsted's Experiment | 429 |
| More on the Relationship Between Electricity and Magnetism | 432 |
| Experiment 16.2: A Variation of Ørsted's Experiment | 432 |
| Faraday's Law of Magnetic Induction..... | 435 |
| A Consequence of Faraday's Law of Magnetic Induction | 439 |
| Optional Experiment 16.3: One Magnetic Field Making Another..... | 439 |
| Some Final Thoughts | 441 |
| Solutions to the "Comprehension Check" Questions | 442 |
| Review | 443 |

| | |
|-------------------------|-----|
| Appendix A | 445 |
|-------------------------|-----|

| | |
|-------------------------|-----|
| Appendix B | 449 |
|-------------------------|-----|

| | |
|-------------------------|-----|
| Appendix C | 457 |
|-------------------------|-----|

| | |
|----------------------|-----|
| Glossary..... | 463 |
|----------------------|-----|

| | |
|---|-----|
| Photo and Illustration Credits | 469 |
|---|-----|

| | |
|--------------------|-----|
| Index | 471 |
|--------------------|-----|