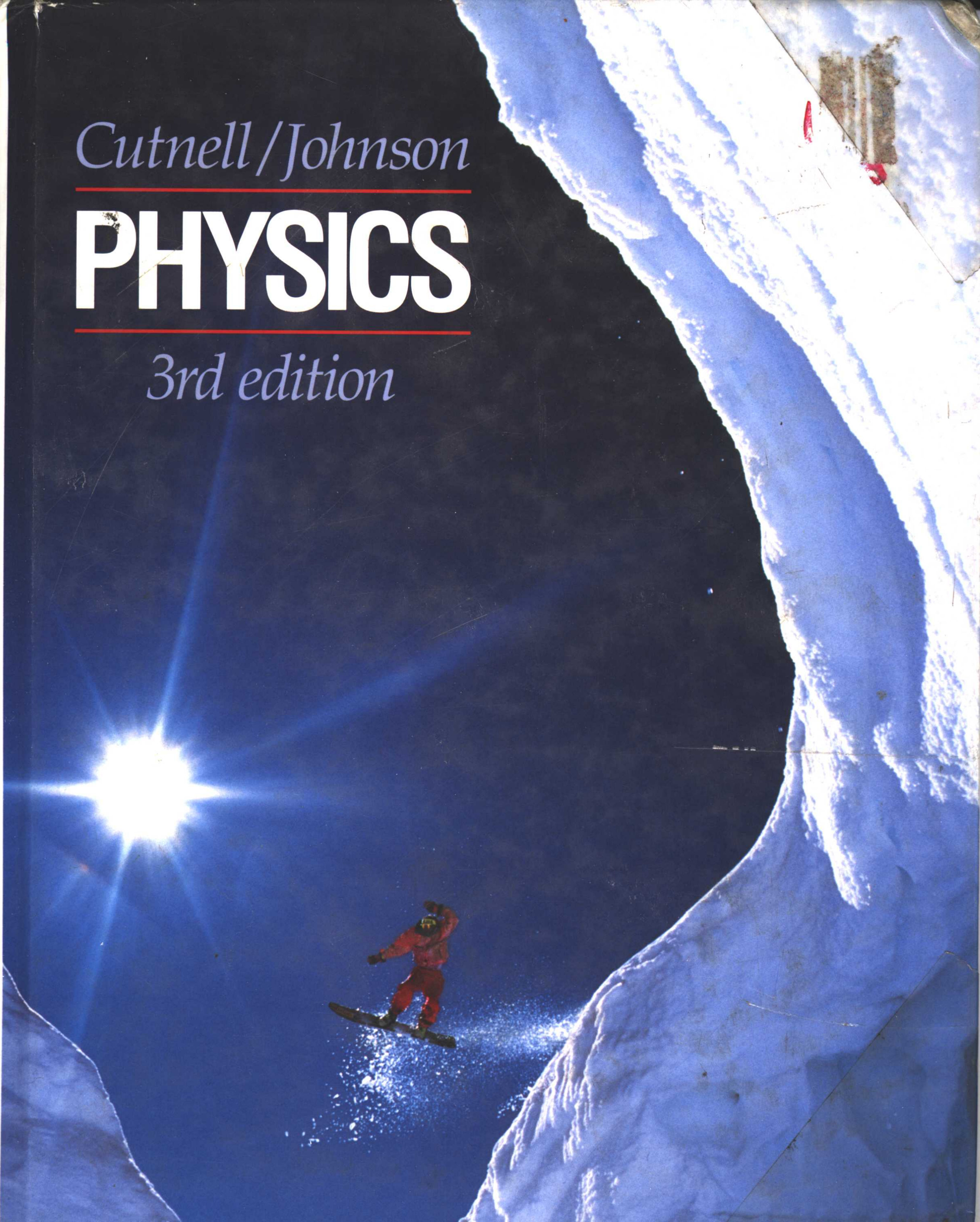
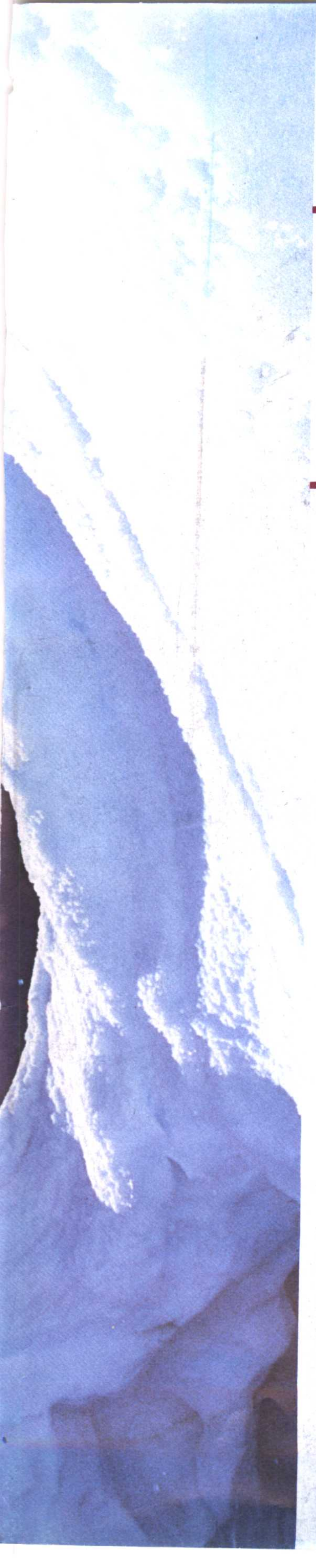
Cutnell / Johnson

PHYSICS

3rd edition





THIRD EDITION

PHYSICS

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PHYSICS

For my wife Joan Cutnell, whose patience, encouragement, and help have been beyond measure and generously given.

For my wife Anne Johnson and children, Lauri, Rick, and Rob, who have given their unqualified love, understanding, and support during this special venture.

PREFACE

NEW TO THIS EDITION

This text is designed for a one-year course in college physics that uses algebra and trigonometry. In producing this new edition, we have been encouraged by considerable positive feedback from the many users of the second edition. Students and teachers alike have expressed their appreciation for a text that facilitates the learning and teaching process. As a result of this feedback, we have now included a number of changes that we believe markedly improve the text. The list below summarizes the major additions to the third edition:

★ **Conceptual Examples** These examples are worked out in a rigorous, but qualitative fashion that uses little or no mathematics. They have been added so that students will have explicit models to help them learn how to apply physics principles in a conceptual context and to use their conceptual understanding as a guide when solving problems. Related homework material has been provided that can be used as a quantitative follow-through for the qualitative analysis given in the Conceptual Examples.

★ **Reasoning Strategies** These strategies are summaries of the logic used in solving well-defined classes of problems.

★ **New Topics** The following new topics have been added: Work Done by a Variable Force, Gauss' Law, Ampere's Law, Holography, and Medical Imaging Techniques (CAT, MRI, PET).

★ **Homework Material** The number of problems and questions at the end of each chapter has been increased by 22%, including material explicitly referenced to the Conceptual Examples worked out within the chapters.

★ **Applications** A number of new real-world applications of physics principles have been added, such as A Dye-sublimation Color Printer, A Head-up Display for Automobiles, An Induction Stove, and Modern Archery and Bow Stabilizers.

★ **Answers to Qualitative Questions** Answers to all of the qualitative questions at the ends of the chapters are now available to teachers.

★ **Essays** Six new essays have been included that discuss mysteries that the application of physics principles has helped to solve.

In producing this new edition, we were guided by three goals. These goals, and the features associated with them, are outlined below. The new features are identified with a star (★).

GOALS AND FEATURES OF THE THIRD EDITION

GOAL 1: To help students develop conceptual understanding of physical principles, the ability to reason, and problem-solving skills. The features of the text that work toward this goal are:

★ **1. Conceptual Examples.** Many students tend to focus largely on finding the right equation to solve a problem. They do not see that equations are consequences of *concepts,* concepts that express physical ideas. We believe that good problem-solving techniques start with a foundation of conceptual understanding. Therefore, we have added to the text 108 examples (an average of about 3–4 per chapter) that are entirely conceptual in nature. These examples are worked out in a rigorous, but qualitative fashion, with no (or very few) equations. The emphasis is on how to apply a physics principle (as distinct from an equation that expresses the principle in mathematical terms) to arrive at a qualitative solution to a problem. The intent is to provide students with explicit models of how to "think through" a problem before attempting to solve it numerically.

The Conceptual Examples deal with a wide range of topics (see list on pages xxxii-xxxiv). We have addressed a large number of issues that confuse students, such as the difference between *mass and weight* (Conceptual Example 7 in Chapter 4). Some Conceptual Examples illustrate the use of symmetry, as in determining the net electric field due to a collection of point charges (Conceptual Example 12 in Chapter 18). Others deal with the use of limiting cases to gain insight into a problem, as in the behavior of ac circuits when the frequency is very large or very small. (Conceptual Example 4 in Chapter 23). Still others focus on real-world situations that have a surprisingly direct relationship to a physics principle, as in the mechanical equilibrium of an object (Conceptual Example 8 in Chapter 9). We have also included the use of classical physics concepts in modern physics contexts, as in the use of a solar sail to propel an interstellar spaceship (Conceptual Example 3 in Chapter 29).

Wherever possible, we have structured the Conceptual Examples so that they lead naturally to certain homework questions and problems. Thus, there are cross references between the Conceptual Examples and related homework material. These cross references encourage students to review the Conceptual Examples as background for the identified problems, and they emphasize the important role that conceptual understanding plays in problem solving.

2. Reasoning—The Cornerstone of Problem Solving. Careful reasoning is the cornerstone of problem solving, and we believe that students benefit from seeing the reasoning stated explicitly. Therefore, the format in which examples are worked out in the text includes an explicit reasoning step. In this step, we explain what motivates our procedure for solving the problem before any numerical solution is carried out. Teachers have applauded this feature of the second edition, and it has been strengthened considerably in the third edition. We have carefully reexamined the reasoning steps in each of the text's 308 calculational examples, to ensure that the main ideas guiding the subsequent numerical solution stand out clearly. The 108 new Conceptual Examples and their associated homework material also strengthen our focus on the importance of careful reasoning in problem solving.

★ **3. Reasoning Strategies.** A number of the examples in the text deal with well-defined strategies for solving certain types of problems. In such cases, we have now included summaries of the steps involved. These summaries, which are titled REASONING STRATEGIES, encourage and facilitate frequent review.

4. Examples Worked Out with Great Care. We believe that it is essential to provide students with good models for their own work in conceptualizing physics and solving problems. Therefore, the third edition includes 416 worked out examples, which is 35% more than in the second edition. Of the total, 108 deal entirely with conceptual issues, involve little mathematics, and are worked out in a two-part format: (i) Problem statement and (ii) Reasoning. The remaining 308 focus on illustrative calculations, and for them a three-part format is used: (i) Problem statement, (ii) Reasoning, and (iii) Solution. The explicit reasoning step emphasizes that careful thinking should precede any numerical calculations.

5. Problem Solving Insights. To reinforce the problem-solving techniques illustrated in the worked-out examples, we have included short statements in the margins, identified by the label PROBLEM SOLVING INSIGHT. For instance, this PROBLEM SOLVING INSIGHT occurs in Chapter 4: "Applications of Newton's second law always involve the net force, which is the vector sum of all the forces that act on an object." The reinforcement provided by these Insights will supplement what teachers stress in class.

6. Free-Body Diagrams. Teachers are familiar with the importance of free-body diagrams. We use free-body diagrams throughout this text, not just in the early chapters where Newton's second law is introduced. For instance, in Chapter 11, when the relation between pressure and depth in a fluid is developed, a free-body diagram clarifies the discussion considerably. Free-body diagrams are also used in worked-out examples, as in Example 6 in Chapter 18 when we calculate the electrostatic forces that electric charges exert on each other.

7. Solved Problems. Another way in which we hope to build problem-solving skills is with a feature called SOLVED PROBLEMS. These innovative illustrative calculations are included at the end of many chapters, between the chapter summary and the homework material. They differ from the numbered examples that occur within the chapter exposition in three ways. (i) They deal with concepts that are more challenging than those treated in the numbered examples. (ii) At the end of each one, there is a summary of the important points that have been illustrated. (iii) The Solved Problems are intended for use in conjunction with homework assignments. Therefore, each one includes a reference list that identifies three to five homework problems dealing with the same general concepts as the Solved Problem. These associated problems have a higher level of difficulty and are not simple repetitions with only the data changed. Each includes a phrase such as "See Solved Problem 2 for a related problem." Thus, teachers can focus on the concepts in the solved problems by assigning the associated homework problems.

★ **8. Homework Problems and Questions.** The third edition contains 2966 problems and questions for assignment as homework. This represents an increase of 22% relative to the second edition. Of the total, 585 are in the form of qualitative questions. In providing so many problems and questions, we have used a wide variety of real-world situations with realistic data. A broad spectrum of situations is important, because it encourages students to focus on understanding the basic concepts. A limited variety of problem situations, in contrast, encourages students to hunt for that elusive "right equation." Solutions to all problems and questions are available for teachers.

Building problem-solving skills involves the use of homework problems that progress from relatively easy, to moderate, to challenging levels of difficulty. In this spirit, we have ranked the homework problems according to difficulty. The most difficult are marked with a double asterisk (**), while those of intermediate difficulty are marked with a single asterisk (*). The easiest are unmarked. Some of the problems are organized by section, whereas others are grouped without reference to any particular section under the heading ADDITIONAL PROBLEMS. In adding new problems and changing second edition problems, we have kept in mind the need to maintain a smooth transition, or ramping, in difficulty level from the easiest to the most difficult problems. Therefore, the transition from one difficulty level to the next is not a quantum transition, but a graded one. In our own teaching we often assign problems near the end of each difficulty level, so as to provide a challenge to students.

GOAL II: To help students see that physics is a wonderfully integrated body of knowledge. In support of this goal, the book includes the following key features:

1. Integration of Concepts. When learning something new, it can be difficult to grasp the overall picture while absorbing many new ideas. In physics, the overall picture is one, in which a surprisingly small number of fundamental ideas are unified into a coherent view of the physical world. To help convey the unity of physics, we have included at the end of most chapters a section entitled INTEGRATION OF CONCEPTS. These sections explore the common ground between fundamental ideas in the current chapter with those that have come before. The intent is to help students see that physics is an integrated body of knowledge.

2. Reviews of Previous Material. Since reviewing is an essential step in the learning process, a summary is provided at the end of each chapter. These summaries are condensed but thorough expositions of the chapter material, including equations.

Reviewing is not something to be done only once, after a chapter is read. Reviewing should be an ongoing process. We have tried to encourage reviewing in the worked-out examples in the text and in the homework questions and problems. In these places, we have taken special care to include situations that combine current chapter material with previous chapter material. Thus, students see that material studied early in the course is connected to material studied later.

★ **3. Essays.** There are two kinds of essays in the third edition; both are contributed by Professor Neil Comins. The INTERSECTION ESSAYS give a flavor of how physics is used in other disciplines, such as law enforcement, geology, music, environmental science, space science, and medicine. The MYSTERY ESSAYS are new to the third edition. They discuss mysteries that physics has helped to solve, such as the extinction of the dinosaurs, the behavior of geysers, how sharks locate their prey, sunken treasure, the lost city of Ubar, and counterfeit art. Like the INTERSECTION ESSAYS, the MYSTERY ESSAYS show that physics principles have uses that extend far beyond the boundaries of physics laboratories.

GOAL III: To show students that physics principles come into play over and over again in their lives. In working toward this goal, we have incorporated the following features:

★ **1. The Physics of . . .** The second edition contained a great number of applications of physics principles. These applications reflect our commitment to showing students just how prevalent physics is in their lives. In the third edition, we have updated the applications and have added about twenty new ones that students will find especially interesting, including modern archery and bow stabilizers, dye-sublimation color printers, and head-up displays for automobiles.

The devices and techniques discussed in the applications have been chosen from a wide variety of areas and include medicine, automobile features, transportation, home entertainment, athletics, household applications, information processing, detection devices, camera technology, satellite technology, and many more. To highlight the discussions of how physics principles are applied, each application is identified in the margin with the label THE PHYSICS OF. . . . A list of the applications can be found on pages xxxv–xxxvii, and it includes many that are not found in other texts.

2. **Physics and Human Physiology.** We have also included discussions and examples that focus on human physiology. Among these are muscle forces, blood pressure, blood flow, breathing, the detection of sound by the ear, the refraction of light by the eye, and the physiological effects of radioactivity. Such topics have been selected because of the straightforward connection they have to physics principles.

3. **Worked-out Examples and Homework Material.** The emphasis on physics in daily life is carried over into the worked-out examples. For instance, Example 5 in Chapter 14 shows how to determine how long a SCUBA diver can stay under water, and Example 12 in Chapter 22 illustrates how to calculate the voltage produced by a bicycle generator. In a similar way, illustrations of everyday physics pervade the homework questions and problems.

Additional Features of the Third Edition

We have paid special attention to a number of additional features of the text. We feel that these features are important, because they have such an impact on the ease with which the book can be used.

1. **Full-Color Reproduction.** The third edition uses full color reproduction for virtually all figures and photographs, allowing a more realistic portrayal of physical situations. In addition, we have used color in a consistent way to denote vector concepts:

- displacement
- velocity or
- acceleration
- force
- electric and magnetic fields

Such consistency provides an added clarity that facilitates the learning process.

2. **Important Basic Concepts.** One of the tasks that face students as they study physics is to distinguish between important basic concepts and other related, but less fundamental ideas. To identify important basic concepts, we have enclosed them within a box headed by a colored band. Since applying these concepts entails using correct units, the appropriate SI units have also been included within the box. The boxes are used sparingly so that they can serve effectively as a guide to the truly basic concepts.

3. **Presentation of Equations.** We have presented equations in a style that provides maximum clarity and encourages correct usage. First, we have anticipated the common mistakes that students make. Consequently, the book is liberally sprinkled with explanations and cautionary notes to clarify difficult concepts and the conditions under which the concepts can be applied. For reinforcement, these conditions are included on the right-hand side of numbered equations as, for example, in Equation 8.9 ($v_T = r\omega$). This equation relates the angular speed ω to the tangential speed v_T and can be applied only if angles are measured in radians, not in degrees. Second, many equations, such as Equation 14.7, have a label on the left side that helps to identify the situation for which the equation is applicable. Lastly, we have written some equations, such as Equation 6.7a, with bracketed labels that explain the meaning of each term in the equation.

★ 4. **New Topics and Organization.** A number of new topics have been added to the third edition. Because of its relevance to real-world situations, a discussion of the work done by a variable force has been included. For teachers who wish to cover more advanced material in electricity and magnetism, sections on Gauss' law and Ampere's law have been provided. In view of their importance in medicine, discussions of CAT scanning, MRI, and PET scanning have been added. And finally, because of its close association with lasers, a section on holography has been included.

Material that is a likely candidate for omission is typically located in a subsection at the end of a main section or in a separate section near the end of a chapter. Sections marked with an asterisk can be omitted with little impact on the overall development of the material.

We have tried to produce an error-free book, but no doubt some errors still remain, all of which are solely our responsibility. Please feel free to let us know of any errors that you find.

We hope that this text is useful to both students and teachers and look forward to hearing about your experiences with it. We also hope that our efforts will make your lives easier and your work more enjoyable.

Carbondale, Illinois
1994

John D. Cutnell
Kenneth W. Johnson

SUPPLEMENTS

An innovative package of supplements to accompany *Physics,* 3rd edition, is available to assist both the teacher and the student.

1. **Study Guide with Selected Solutions,** prepared by Mark Comella (of Duquesne University), John D. Cutnell, and Kenneth W. Johnson. The Guide encourages and motivates students with chapter objectives and outlines, explanations of commonly misunderstood topics, worked-out examples, solutions to selected textbook problems, and quizzes.

★ 2. **Solutions Manual,** for instructors only, prepared by Mark Comella, author of the **Study Guide,** and by John D. Cutnell and Kenneth W. Johnson. The manual contains detailed solutions to all homework problems in the text. Answers to all of the qualitative questions that are located at the end of each chapter in the text are also available to instructors.

3. **Solutions Disk,** a computer disk version of the **Solutions Manual,** for instructors only, available in Microsoft Word for Macintosh and Windows.

4. **Homework Disk,** for instructors only. Teachers of large classes often use a computer-graded, multiple-choice homework format and spend considerable time modifying textbook homework problems to suit their own needs. As part of our computerized **Test Bank,** David T. Marx of Southern Illinois University at Carbondale has converted nearly 1200 of the chapter-ending problems into a multiple-choice format, so teachers can generate their homework assignments in a convenient and effective way.

5. **Instructor's Resource Manual,** prepared by Robert Lee Kernall of Old Dominion University. The Manual contains teaching suggestions, lecture notes, demonstration suggestions, alternative syllabi for courses of different lengths and emphases, strategies for incorporating supplements and materials from other texts, as well as conversion notes allowing the instructor to use class notes from other texts.

6. **Test Bank,** prepared by David T. Marx of Southern Illinois University at Carbondale. This **Test Bank** contains more than 1750 short-answer questions and problems, which represents an increase of about 23% relative to that available with the second edition.

7. **Computerized Test Bank.** IBM and Macintosh versions of the entire **Test Bank** are available with full editing features to help you customize tests.

8. **Four-color, Overhead Transparencies.** More than 300 four-color illustrations from the text are provided in a form suitable for projection in the classroom.

9. **Interactive Conceptual Example Software.** Selected Conceptual Examples are provided in an interactive format, supported by simulation-driven animation that allows students to vary parameters and observe the corresponding effects. Students are guided through the solution of an end-of-chapter homework problem that is related to the Conceptual Example. The solution process is developed interactively, with appropriate feedback and access to error-specific help for the most common mistakes.

10. **CD-ROM Image Manager.** All text line drawings will be available in electronic form for a greater selection of text images to display for an enhanced classroom presentation.

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A book derives enormous benefits from having the insights of someone knowledgeable in marketing strategies, and we are fortunate in having one of the best, Catherine Faduska. She combined an outstanding knowledge of science textbooks with keen marketing savvy and gave us valuable input during all stages of preparation and production.

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USER'S GUIDE

The phrase "centripetal fo... by nature. The phrase merely labels the net force pointing ... center of the circular path, and this net force is the vector sum of all the force components that point along the radial direction.

In some cases it is easy to identify the source of the centripetal force, as in Conceptual Example 5.

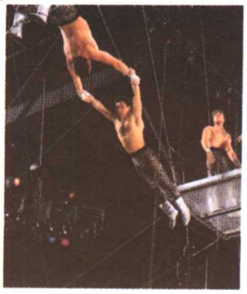


Figure 5.6 The man hanging upside down from the trapeze has a harder job holding his partner when the team is swinging back and forth than when they are stationary.

Conceptual Example 5 A Trapeze Act

In a circus, a man hangs upside down from a trapeze, legs bent over the bar and arms downward. He is holding his partner, who is hanging beneath him. Is it harder for the man to hold his partner while stationary or while swinging back and forth, as in Figure 5.6?

REASONING When the man and his partner are stationary, the man's arms must support his partner's weight. When the two are swinging, however, the man's arms must do an additional job. Then, the partner is moving on a circular arc and has a centripetal acceleration. The man's arms must exert an additional pull on the partner to produce this acceleration. Thus, the additional pull by the man's arms is the source of the centripetal force. Because of this additional pull, it is harder for the man to hold his partner while swinging back and forth than while stationary.

Related Homework Material: *Problem 46*

REAL-LIFE EXAMPLES

Many examples are taken from real-life situations. Such examples help to show students that physics principles come into play over and over again in their lives.

CONCEPTUAL EXAMPLES

These new examples are worked out in a rigorous, but qualitative fashion that uses little or no mathematics. They provide students with explicit models to help them learn how to apply physics principles in a conceptual context and to use their conceptual understanding as a guide when solving problems.

HOMEWORK MATERIAL RELATED TO CONCEPTUAL EXAMPLES

Related homework material is identified so that the qualitative analysis given in the Conceptual Examples can be used as the basis for a quantitative analysis of the same or a closely related situation.

The thi... as follows: "For every action ...

Figure 4.8 illustrates how the third law applies to an astronaut who is drifting just outside a spacecraft and who pushes on the spacecraft with a force **F**. According to the third law, the spacecraft pushes back on the astronaut with a force −**F** that is equal in magnitude, but opposite in direction. In Example 4, we examine the accelerations produced by each of these forces.

Figure 4.8 The astronaut pushes on the spacecraft with a force +**F**. According to Newton's third law, the spacecraft simultaneously pushes back on the astronaut with a force −**F**.

Example 4 The Effects of Action and Reaction

Suppose that the mass of the spacecraft in Figure 4.8 is $m_S = 11\,000$ kg and that the mass of the astronaut is $m_A = 92$ kg. In addition, assume that the astronaut exerts a force of **F** = +36 N on the spacecraft. Find the accelerations of the spacecraft and the astronaut.

REASONING According to Newton's third law, when the astronaut applies the force **F** = +36 N to the spacecraft, the spacecraft applies a reaction force −**F** = −36 N to the astronaut. As a result, the spacecraft and the astronaut accelerate in opposite directions. While the action and reaction forces have the same magnitude, they do not create accelerations of the same magnitude. The reason is that the spacecraft and the astronaut have different masses. According to Newton's second law, the astronaut, having a much smaller mass, will experience a much larger acceleration.

SOLUTION The acceleration of the spacecraft is

$$\mathbf{a}_S = \frac{\mathbf{F}}{m_S} = \frac{+36 \text{ N}}{11\,000 \text{ kg}} = \boxed{+0.0033 \text{ m/s}^2}$$

The acceleration of the astronaut is

$$\mathbf{a}_A = \frac{-\mathbf{F}}{m_A} = \frac{-36 \text{ N}}{92 \text{ kg}} = \boxed{-0.39 \text{ m/s}^2}$$

PROBLEM SOLVING INSIGHT

Even though the magnitudes of the action and reaction forces are always equal, these forces do not necessarily produce accelerations that have equal magnitudes, since each force acts on a different object that may have a different mass.

...actions occur all the time. Figure 4.9 illustrates the process ...shoe exerts a force on the ...

REASONING — THE CORNERSTONE OF PROBLEM SOLVING

The examples in the text have an explicit reasoning step that precedes the numerical solution. In this step, the pertinent physics principles and the reasons for choosing a particular method for solving a problem are discussed.

PROBLEM SOLVING INSIGHT

Brief comments in the margin reinforce important aspects of problem solving that might otherwise go unnoticed.

REASONING STRATEGIES

These strategies provide students with convenient summaries of the reasoning used in solving well-defined classes of problems.

The reasoning strategy for analyzing the forces and torques acting on a rigid body in equilibrium is given below. The first four steps of the strategy are essentially the same as those outlined in Section 4.11, when only forces were being considered. Steps 5 and 6 have been added now to account for any torques that may be present. Example 3 illustrates how this reasoning strategy is applied to a diving board.

Reasoning Strategy Applying the Conditions of Equilibrium to a Rigid Body

1. Select the object to which the conditions for equilibrium are to be applied.
2. Draw a free-body diagram that shows all the external forces acting on the object, each force with its proper direction.
3. Choose a convenient set of x, y axes and resolve all forces into components that lie along these axes.
4. Apply the conditions that specify the balance of forces at equilibrium: $\Sigma F_x = 0$ and $\Sigma F_y = 0$.
5. Select a convenient axis of rotation. Identify the point where each force acts on the object, and calculate the torque produced by each force about the axis of rotation. Set the sum of the torques about this axis equal to zero: $\Sigma\tau = 0$.
6. Solve the equations in steps 4 and 5 for the desired unknown quantities.

DEFINITIONS AND LAWS

Key definitions and laws are highlighted by enclosing them in a "box." This helps students to identify important concepts quickly.

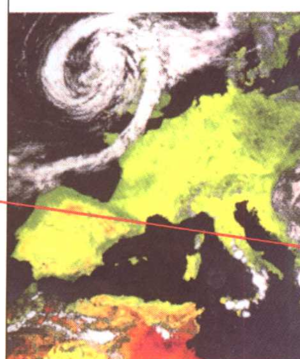
CAUTIONARY NOTES

Short notes are added to emphasize the condition under which a relation is valid. They help students to apply the relation correctly.

SI UNITS

The SI units of newly defined quantities are clearly identified. Units are an important part of any problem-solving strategy.

264 CHAPTER 9/ROTATIONAL DYNAMICS



In this satellite image, there is a severe storm over the British Isles. The swirling air mass has a large

is called the ***angular momentum*** L. The mathematical form of angular momentum is identical to that of linear momentum, with the mass m and the linear velocity v being replaced with their rotational counterparts, the moment of inertia I and the angular velocity ω.

Definition of Angular Momentum

The angular momentum L of a body rotating about a fixed axis is the product of the body's moment of inertia I and its angular velocity ω:

$$L = I\omega \tag{9.10}$$

Requirement: ω must be expressed in rad/s.

SI Unit of Angular Momentum: $kg \cdot m^2/s$

Linear momentum is an important concept in physics, because the total momentum P of a system is conserved when the net external force acting on the system is zero. Then, the final linear momentum P_f and the initial linear momentum P_0 of the system are the same: $P_f = P_0$. Similarly, when no net external torque acts on a system, the final and the initial angular momenta are the same: $L_f = L_0$. This is the ***principle of conservation of angular momentum***.

THE PHYSICS OF . . .

The physics of interesting applications is integrated into the text. These applications show the relevancy of physics to everyday life.

viewing port that looks down through a plastic rod, which ex... battery acid. Attached to the end of this rod is a "cage," containing a green ball. When the battery is charged, the density of the acid is large enough so that its buoyant force makes the ball rise to the top of the cage, to just beneath the plastic rod. The viewing port shows a green dot. As the battery discharges, the density of the acid decreases. Since the buoyant force is the weight of the acid displaced by the ball, the buoyant force also decreases. As a result, the ball sinks into one of the chambers oriented at an angle. With the ball no longer visible, the viewing port shows a dark or black dot, warning the owner that the battery charge is low.

Archimedes' principle has allowed us to determine how an object can float in a liquid. This principle also applies to gases, as the next example illustrates.

Figure 11.21 (*a*) A ship floating in the ocean. (*b*) This is the water that the ship displaces. (*c*) The ship floats here in a canal that has a cross section matching the shape in part *b*. Only a thin layer of water is needed to separate the hull of the ship from the canal walls.

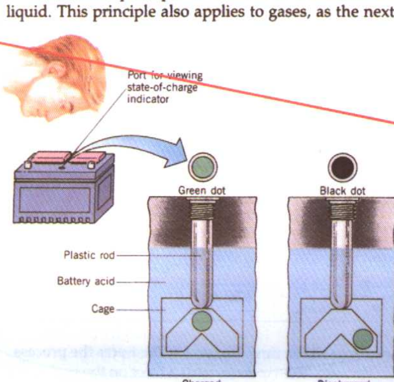


Figure 11.22 A state-of-charge indicator for a car battery.

THE PHYSICS OF . . .

a state-of-charge battery indicator.

INTEGRATION OF CONCEPTS

These sections explore the common ground between the fundamental ideas in the current chapter and ideas from earlier chapters. The emphasis is on the unity of physics as an integrated body of knowledge built on fundamental concepts.

INTEGRATION OF CONCEPTS

CONSERVATION OF LINEAR MOMENTUM AND CONSERVATION OF ENERGY

In physics, conservation principles are among the most important of all principles. They deal with quantities that remain unchanged throughout the motion of an object, the initial and final values of the quantity being the same. We have discussed two of these conservation principles so far. Here in Chapter 7, we have studied the principle of conservation of linear momentum, and in Chapter 6, we learned about the principle of conservation of energy. While these two principles focus on different aspects of motion, they deal with them in similar ways. In both principles, it is the *total quantity* (linear momentum or energy) that is conserved. When one part of the total increases, the other part decreases by the same amount, so that the sum of the two parts remains unchanged. Suppose, for example, that the total linear momentum of a system consists of two parts, each part belonging to one of the two objects that comprise the system. Momentum conservation dictates that when the momentum of one object increases, the

FREE-BODY DIAGRAMS

Free-body diagrams are used throughout the text. They are a valuable problem-solving aid when Newton's second law is being applied to equilibrium and nonequilibrium situations.

04 CHAPTER 4/FORCES AND NEWTON'S LAWS OF MOTION

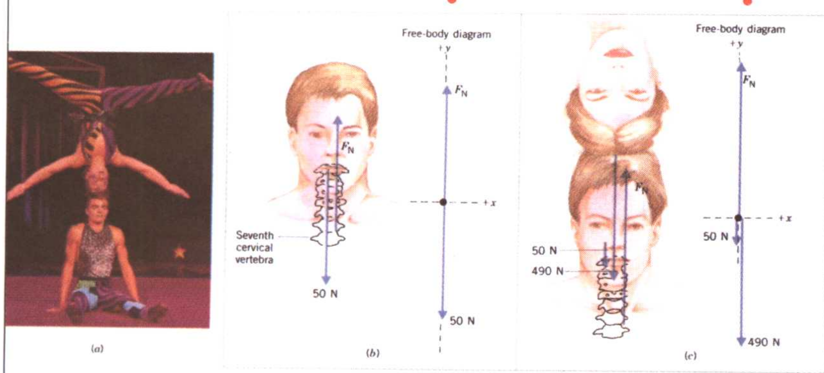


Figure 4.16 (*a*) A balancing act and free-body diagrams for the man's body above the shoulders (*b*) before the act and (*c*) during the act. For convenience, the scales used for the vectors in parts *b* and *c* are different.

...ily have the same magnitude as

PROBLEMS RANKED IN DIFFICULTY

Intermediate-level problems are marked with a single star (*), and advanced-level problems are indicated by a double star (**). Within each level, the problems are arranged to provide a smooth transition from the easier to the more difficult problems.

(coefficient of performance = 3.00) does when it freezes 1.50 kg of water at 20.0 °C into ice at 0.0 °C?

*72. Review Conceptual Example 10 before attempting this problem. A window air conditioner has a coefficient of performance of 2.0. This unit has been placed on the floor by the bed, in a futile attempt to cool the bedroom. During this attempt 7.6×10^4 J of heat is pulled in the front of the unit. The room is sealed and contains 3800 mol of air. Assuming that the molar specific heat of the air is $C_V = \frac{5}{2}R$, determine the rise in temperature caused by operating the air conditioner in this manner.

**73. A Carnot engine uses hot and cold reservoirs that have temperatures of 1684 and 842 K, respectively. The input heat for this engine is Q_H. The work delivered by the engine is used to operate a Carnot heat pump. The pump removes heat from the 842-K reservoir and puts it into a hot reservoir at a temperature T'. The amount of heat removed equals the amount Q_H. Find the unknown temperature T'.

Section 15.10 Entropy and the Second Law of Thermodynamics

74. Suppose the entropy of a system decreases by 25 J/K because of some process. (a) Based on the second law of thermodynamics, what can you conclude about the entropy change of the environment that surrounds this system? (b) Interpret your answer to part (a) in terms of order and disorder of the environment.

75. Four kilograms of carbon dioxide sublimes from solid "dry ice" to a gas at a pressure of 1.00 atm and a temperature of 194.7 K. The latent heat of sublimation is 5.77×10^5 J/kg. Find the change in entropy of the carbon dioxide.

so the total entropy...

(c) Assuming that the coldest reservoir at hand has a temperature of 273 K, determine the amount of energy that becomes unavailable for doing work because of the irreversible process.

*79. (a) Five kilograms of water at 80.0 °C is mixed in a perfect thermos with 2.00 kg of ice at 0.0 °C, and the mixture is allowed to reach equilibrium. Using the expression $\Delta S = mc \ln(T_f/T_i)$ [see problem 78] and the change in entropy for melting, find the change in entropy that occurs. (b) Should the entropy of the universe increase or decrease as a result of the mixing process? Give your reasoning and state whether your answer in part (a) is consistent with your answer here.

ADDITIONAL PROBLEMS

These problems are not keyed to a particular section, and they often combine concepts from different sections. This problem set challenges students to use the material from the entire chapter.

ADDITIONAL PROBLEMS

80. Two grams of helium (molecular mass = 4.0 u) expands isothermally at 350 K and does 1600 J of work. Assuming that helium is an ideal gas, determine the ratio of the final volume of the gas to the initial volume.

81. One-half mole of a monatomic ideal gas absorbs 1200 J of heat while performing 2500 J of work. By how much does the temperature of the gas change? Is the change an increase or a decrease?

82. An engine rejects three times more heat than it converts into work. What is the efficiency of the engine?

83. The internal energy of a system increases by 1350 J when the system absorbs 1150 J of heat at a constant pressure of 1.01×10^5 Pa. By how much does the volume of the system change? Does the volume increase or decrease?

84. The coefficient of performance of a refrigerator is 4.6. ... used in removing 4100 J of ...

PROBLEMS KEYED TO SECTIONS

Students can review the material in a particular section while they are solving these problems. Instructors can assign problems from different sections to ensure the desired coverage of the material in the chapter.

SUMMARY

A thorough, but concise, review of the ideas discussed is presented at the end of each chapter. Important concepts are highlighted in boldface type.

SUMMARY

Each element in the periodic table is assigned an **atomic mass.** One **atomic mass unit** (u) is exactly one-twelfth the mass of an atom of carbon-12. The **molecular mass** of a molecule is the sum of the atomic masses of its atoms. One **mole** of a substance contains **Avogadro's number** N_A of particles, where $N_A = 6.022 \times 10^{23}$ particles per mole. The mass in grams of one mole of a substance is equal to the atomic or molecular mass of its particles.

The **ideal gas law** relates the absolute pressure P, the volume V, the number of moles n, and the Kelvin temperature T of an ideal gas according to $PV = nRT$, where $R = 8.31$ J/(mol·K) is the universal gas constant. An alternative form of the ideal gas law is $PV = NkT$, where N is the number of particles and $k = R/N_A$ is Boltzmann's constant. A real gas behaves as an ideal gas when the density of the real gas is low enough that its particles do not interact, except via elastic collisions.

The distribution of particle speeds in an ideal gas at constant temperature is the **Maxwell speed distribution.** According to the **kinetic theory of gases,** an ideal gas consists of a large number of particles (atoms or molecules) that are in constant random motion. The particles are far apart compared to their dimensions, so they do not interact except when elastic collisions occur. The pressure on the walls of a container is produced by the impacts of the particles with the walls. According to the kinetic theory of gases, the Kelvin temperature T of an ideal gas is a measure of the average translational kinetic energy $\overline{KE}$ per particle through the relation $\overline{KE} = \frac{3}{2}kT$. The **internal energy** U of n moles of a monatomic ideal gas is $U = \frac{3}{2}nRT$.

Diffusion is the process whereby solute molecules move through a solvent from a region of higher concentration to a region of lower concentration. **Fick's law of diffusion** states that the mass m of solute that diffuses in a time t through a solvent contained in a channel of length L and cross-sectional area A is given by $m = (DA\,\Delta C t)/L$, where ΔC is the concentration difference between the ends of the channel and D is the diffusion constant

QUESTIONS

The set of questions at the end of each chapter provides an opportunity for students to develop qualitative reasoning skills.

QUESTIONS

1. (a) Which, if either, contains a greater number of molecules, a mole of hydrogen (H_2) or a mole of oxygen (O_2)? (b) Which one has more mass? Give reasons for your answers.

2. Suppose two different substances, A and B, have the same mass density ... Does 1 m³ of substance A have the same mass as 1 m³ of substance B? Justify each answer.

3. A tightly sealed house has a large ceiling fan that blows air out of the house and into the attic. This fan is turned on, and the owners forget to open any windows or doors. What happens to the air pressure in the house after the fan has been

PRESENTATION OF EQUATIONS

Equations often have bracketed labels that explain the physical meaning of each term within the equation.

TECHNIQUES FOR PROBLEM SOLVING

Good techniques make it easier for students to find errors in problem solving. First, the unknown variable in an equation is obtained algebraically in terms of the known variables. Then, numbers are substituted for the known variables.

Example 5 Assembling a Freight Train

A freight train is being assembled in a switching yard, and Figure 7.5 shows two boxcars in the process of being coupled together. Car 1 has a mass of $m_1 = 65 \times 10^3$ kg and moves at a velocity of $v_{01} = +0.80$ m/s. Car 2, with a mass of $m_2 = 92 \times 10^3$ kg and a velocity of $v_{02} = +1.2$ m/s, overtakes car 1 and couples to it. Neglecting friction, find the common velocity v_f of the two cars after they become coupled.

REASONING The two boxcars constitute the system. The sum of the external forces acting on the system is zero, because the weight of each car is balanced by a corresponding normal force, and friction is being neglected. Thus, the system is isolated, and the principle of conservation of linear momentum applies. The coupling forces that each car exerts on the other are internal forces and do not affect the applicability of this principle.

SOLUTION Momentum conservation indicates that

$$\underbrace{(m_1 + m_2)v_f}_{\text{Total momentum after collision}} = \underbrace{m_1 v_{01} + m_2 v_{02}}_{\text{Total momentum before collision}}$$

This equation can be solved for v_f, the common velocity of the two cars after the collision:

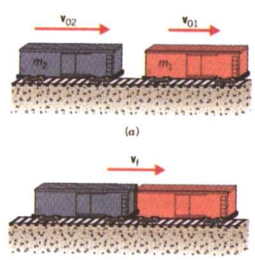
$$v_f = \frac{m_1 v_{01} + m_2 v_{02}}{m_1 + m_2}$$

$$= \frac{(65 \times 10^3\ \text{kg})(0.80\ \text{m/s}) + (92 \times 10^3\ \text{kg})(1.2\ \text{m/s})}{(65 \times 10^3\ \text{kg} + 92 \times 10^3\ \text{kg})}$$

$$= \boxed{+1.0\ \text{m/s}}$$

PROBLEM SOLVING INSIGHT

The conservation of linear momentum is applicable only when the net external force acting on the system is zero. Therefore, the first step in applying momentum conservation to problem solving is to be sure that the net external force is zero.



(a)

(b)

Figure 7.5 (a) One boxcar eventually catches up with the other and couples to it. (b) The coupled cars move together with a common velocity after the collision.

In the previous example it can be seen that the velocity of car 1 increases, while the velocity of car 2 decreases as a result of the collision. The acceleration and deceleration arise at the moment the cars become coupled, because the cars exert internal forces on each other. These forces are equal in magnitude and opposite in direction, in accord with Newton's third law. The powerful feature of the momentum conservation principle is that it allows us to determine the changes in velocity without knowing what the internal forces are. Example 6 further illustrates this feature.