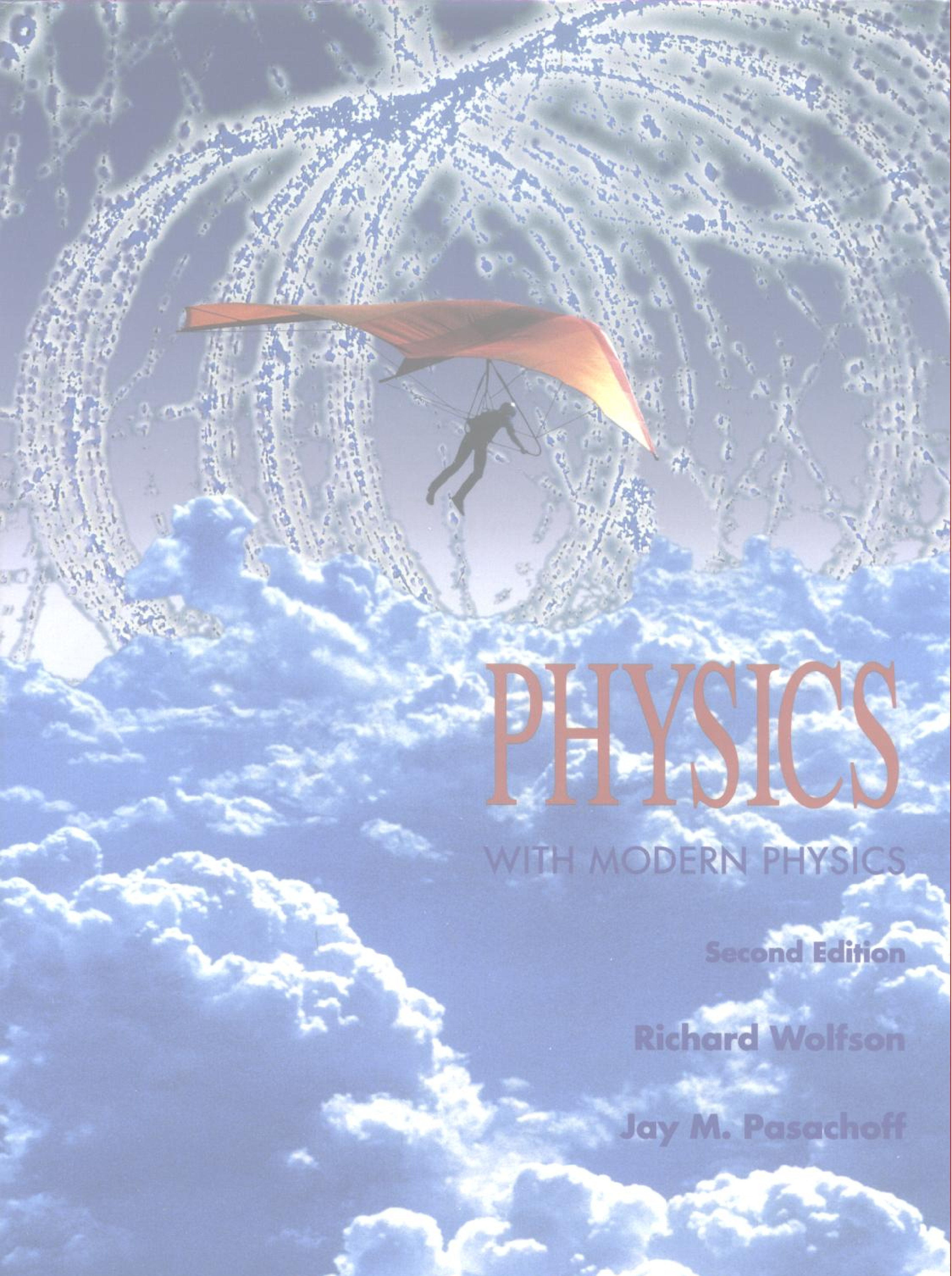

PHYSICS

WITH MODERN PHYSICS

Second Edition

Richard Wolfson

Jay M. Pasachoff

PHYSICS

WITH MODERN PHYSICS FOR SCIENTISTS AND ENGINEERS

Second Edition

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PREFACE

PHYSICS: CHALLENGE AND SIMPLICITY

Physics is fundamental. To understand physics is to understand how the world works, both at the everyday level and on scales of time and space so small and so large they defy intuition.

To the student, physics can be at once fascinating, challenging, subtle, and yet simple. Physics fascinates with its applications throughout science and engineering and in its revelation of unexpected phenomena like superconductivity, black holes, and chaos. It challenges with its need for precise thinking and skillful application of mathematics. It can be subtle in its interpretation, especially in describing phenomena at odds with everyday intuition. Most importantly, physics is simple. Its few fundamental laws are stated in the simplest of terms, yet they encompass a universe of natural phenomena and technological devices. Students who recognize the simplicity of physics develop confidence that stems from understanding the physical universe at a fundamental level.

This text is for science and engineering students. The standard version covers a full sequence of calculus-based university physics, and the extended version adds seven chapters on modern physics. The extended version is also available as a two-volume set.

Coverage The book is organized into six parts. Part 1 (Chapters 2 through 14) covers the basics of mechanics. Part 2 (Chapters 15 through 18) studies motion in terms of oscillations, waves, and fluids. Part 3 (Chapters 19 through 22) is on thermodynamics. Part 4 (Chapters 23 through 34) deals with electricity and magnetism. Part 5 (Chapters 35 through 37) treats optics. Part 6 (Chapters 38 and 39) briefly introduces modern physics. Each part ends with Cumulative Problems that help students synthesize concepts from several chapters. Part 6 of the extended version (Chapters 38 through 45) begins with relativity and continues with quantum mechanics and its applications to atoms, molecules, and the solid state; nuclear physics and its applications; and particle physics and cosmology.

DISTINGUISHING FEATURES OF THE TEXT

In the second edition, like the first, we emphasize careful and thorough explanations. We have pared down wordiness without sacrificing clarity of explanation. And we've added many new features to help you learn.

Contents This revision includes many substantial changes and improvements, most of which were suggested by instructors who used the text or reviewed the manuscript. Here are the most important changes that were implemented in this edition:

- We added a separate chapter (Chapter 3) on vectors.
- We reorganized Chapter 9 on gravitation so that it is more focused than in the first edition.
- We added a second chapter on wave motion (Chapter 17) that includes extensive new material on sound.
- We reorganized the material on electricity and magnetism (Part 4) for a shorter, clearer presentation.
- The optics chapters in Part 5 are completely rewritten, and we added a chapter to this edition for more thorough coverage.

- Relativity (Chapter 38) is now treated after optics, for an introduction to modern physics at the end of the text.
- The number of problems in the second edition is double that of the previous edition.
- A complete package of supplements is offered for this edition.

Applications We include a rich array of practical applications—from the workings of the compact disc through skyscraper engineering, biomedical technology, antilock brakes, space exploration, global warming, microelectronics, lasers, and much more. We chose to integrate many shorter applications into the text, where they are more likely to be read, rather than presenting a few applications as guest essays. An index of examples and applications appears at the beginning of the text. High-quality color photographs and figures enhance the applications.

Questions These follow the chapter synopsis and can be used for class discussion or to get students thinking about concepts in the chapter before they start on the problem sets.

Problems Science and engineering students learn physics best by working physics problems. The second edition contains nearly *3,000* end-of-chapter problems—double the number from the first edition. Problems range from simple confidence builders, to more complex and realistic problems involving the application of multiple concepts, to difficult **Supplemental Problems** that will challenge the best students. A section of **Paired Problems** for each chapter lets students practice problem-solving techniques on a pair of problems whose solutions involve closely related physical concepts or mathematical approaches. **Cumulative Problems** at the end of each part of the text integrate the material from several chapters.

In-Text Exercises Reinforce the Examples Worked examples in the text are generally followed by an exercise to reinforce concepts or processes. A **Similar Problems** line after each exercise points out problems at the end of the chapter that relate to the in-text exercises.

Tip Boxes Tip boxes point out useful problem-solving techniques and warn against common pitfalls. Frequent text references to specific problems link text and problems in the common purpose of enhancing the student's understanding of physics.

Pedagogical Use of Color The book's design enhances its readability; from the carefully planned use of color in figures and to highlight important equations and definitions to the selection of photographs, design is an essential pedagogical feature. Physical elements are coded in color to make them more apparent. A list of the elements and the colors used for them follow this preface.

Chapter Synopses Chapter summaries emphasize key concepts and remind students of new terms and mathematical symbols. Even in a field as fundamental as physics, many theories and their equations have limited applicability, and each chapter concludes with a reminder of limitations students should keep in mind.

Appendices and Endpapers The book's appendices and endpapers contain a mathematical review and a wealth of up-to-date physical data, conversion factors, and information on measurement systems.

PHYSICS AND MATHEMATICS

For many students, the university physics course is their first contact with practical applications of calculus. We recognize that our readers bring a range of mathematical abilities, from those taking their first calculus course concurrently with physics to those fluent in both differential and integral calculus. The former will find tip boxes and figures to build understanding of and confidence in their new mathematical skills; the latter will find a selection of challenging calculus-based problems.

For all students, we refuse to let mathematical derivations dangle. We ask frequently after the derivation of an equation or an example solution: "Does this result make sense?" We show that it does by examining easily understood special cases, thus building both physical intuition and confidence in the application of mathematics. We explore the meaning of equations verbally and through figures, ensuring that concepts are clear as students begin to use the material qualitatively.

THE SUPPLEMENT PACKAGE TO ACCOMPANY THIS TEXT

Professors and students alike often find it useful to have supplements designed to complement their text. For the second edition, we provide a new expanded package.

For the Instructor

The *Solution Manual*, prepared by Edward S. Ginsberg, University of Massachusetts-Boston, includes worked solutions to all problems in the text.

TestMaster software, available in IBM and Macintosh formats, enables instructors to select problems for any chapter, scramble them as desired, or create problems. A print version of the Test Generator is also available.

Overhead transparencies are available to instructors who adopt the text. This set of 150 color acetates of figures from the text will be useful in classroom discussions.

For the Student

The *Student Study Guide*, by Jeffrey J. Braun, University of Evansville, briefly summarizes the text discussion and important equations in each chapter. It also gives some common pitfalls for students to avoid and includes plenty of practice problems (with solutions). To order, use ISBN 0-673-52369-1.

The *Student Solution Manual*, by Edward S. Ginsberg, University of Massachusetts-Boston, includes complete, worked-out solutions to some of the odd-numbered problems in the text. To order, use ISBN 0-06-501873-7.

PhysiCad Explorer, by Tara C. Woods, consists of approximately 200 examples from the text that have been adapted for use with Mathcad® for Windows software (version 4.0 or higher). The student can call up representative examples from the text and substitute new variables to see how the results differ. Mathcad® will perform all the calculations, generating numerical solutions and graphics where appropriate. Besides offering additional problem-solving drills, *PhysiCad Explorer* gives the student hands-on practice using one of the most powerful numerical tools available, Mathcad®. *PhysiCad Explorer* is self-contained and includes the Mathcad Reader, so students need not own the full Mathcad® software package.

A Calculus Laboratory Workshop with Applications to Physics, by Joan R. Hundhausen and F. Richard Yeatts, both from the Colorado School of Mines, contains 30 self-contained projects that can be used to strengthen the calculus skills of introductory physics students. To order, use ISBN 0-06-501719-6.

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It is frustrating for students and professors to find numerical errors in a textbook, especially in answers to problems. We have gone to considerable lengths to make this book as free from error as possible, and we credit the people who helped achieve this goal. Edward Ginsberg, University of Massachusetts-Boston, meticulously checked all numerical results in examples, exercises, and end-of-chapter problems. Alan Goldman of Iowa State University, Sven Rudin of Ohio State University, Kent Scheller of the University of Evansville, and Thomas Suleski of the Georgia Institute of Technology rechecked these numerical results. Claire D. Dewberry, Florida Community College at Jacksonville, checked the art proofs and made numerous suggestions. Naomi Pasachoff provided expert proofreading.

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We invite suggestions from readers—students, professors, and others—for improvements to our text. We promise a speedy reply to each correspondent and an effort to incorporate appropriate suggestions in subsequent printings. Please write us at our respective institutions or contact us by electronic mail.

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52. A drinking straw 20 cm long and 3.0 mm in diameter stands vertically in a cup of juice 8.0 cm in diameter. A section of straw 6.5 cm long extends above the juice. A child sucks on the straw, and the level of juice in the glass begins dropping at 0.20 cm/s. (a) By how much does the pressure in the child's mouth differ from atmospheric pressure? (b) What is the greatest height from which the child could drink, assuming this same mouth pressure?

Paired Problems

(Both problems in a pair involve the same principles and techniques. If you can get the first problem, you should be able to solve the second one.)

53. A steel drum has volume 0.23 m^3 and mass 16 kg. Will it float in water when filled with (a) water or (b) gasoline (density 860 kg/m^3)? Neglect the thickness of the steel.
54. A 260-g circular pan 20 cm in diameter has straight sides 6.0 cm high and is made from metal of negligible thickness. To what maximum depth can the pan be filled with water and still float on water?
55. A spherical rubber balloon with mass 0.85 g and diameter 30 cm is filled with helium (density 0.18 kg/m^3). How many 1.0-g paper clips can you hang from the balloon before it loses its buoyancy?
56. A string of negligible diameter has mass per unit length 1.4 g/m. You tie a 3-m-long piece of the string to a spherical helium balloon 23 cm in diameter and find that the balloon floats with 1.8 m of string off the floor. Find the combined mass of the balloon and helium.
57. Water at a pressure of 230 kPa is flowing at 1.5 m/s through a pipe, when it encounters an obstruction where the pressure drops by 5%. What fraction of the pipe's area is obstructed?
58. A venturi flowmeter in an oil pipeline has a radius half that of the pipe. The flow speed in the unconstricted flow is 1.9 m/s. If the pressure difference between the unconstricted flow and the venturi is 16 kPa, what is the density of the oil?
59. Find an expression for the volume flow rate from the siphon shown in Fig. 18-51, assuming the siphon area A is much less than the tank area.
60. (a) Find the initial siphon flow speed in Fig. 18-51 if the tank is sealed, with its top at only one-fourth of atmospheric pressure. Answer in terms of atmospheric pressure P_a, liquid density ρ, height h, and g. (b) What is the maximum distance between the bend at the top of the siphon and the liquid level in the tank for which the siphon will work under these conditions, assuming the liquid is water? (Give a numerical value here.)

Supplementary Problems

61. A 1.0-m-diameter tank is filled with water to a depth of 2.0 m and is open to the atmosphere at the top. The water

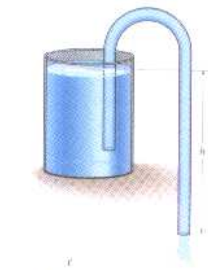
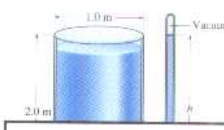


FIGURE 18-51 Problems 59, 60.

drains th ough a 1.0-cm-diameter pipe at the bottom; that pipe then joins a 1.5-cm-diameter pipe open to the atmosphere, as shown in Fig. 18-52. Find (a) the flow speed in the narrow section and (b) the water height in the *sealed* vertical tube shown.



62. Ho dia coe sun
63. Fig use the ang gau equ giv enc flov nor

Paired Problems let students practice problem-solving techniques on a pair of problems whose solutions involve closely related physical concepts or mathematical approaches.

PART 2 CUMULATIVE PROBLEMS

1. A cylindrical log of total mass M and uniform diameter d has an uneven mass distribution that causes it to float in a vertical position, as shown in Figure 1. (a) Find an expression for the length ℓ of the submerged portion of the log when it is floating in equilibrium, in terms of M, d, and the water density ρ. (b) If the log is displaced vertically from its equilibrium position and released, it will undergo simple harmonic motion. Find an expression for the period of this motion, neglecting viscosity and other frictional effects.

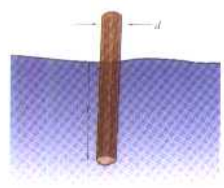


FIGURE 1 Cumulative Problem 1.

2. A cable of total mass m and length ℓ hangs vertically, with a mass M attached to its bottom end, as shown in Fig 2. The mass is given a sudden sideways blow that starts a low-amplitude pulse propagating up the cable. Show that the time it takes the pulse to reach the top of the cable is

$$t = 2\left(\sqrt{\frac{(m+M)\ell}{mg}} - \sqrt{\frac{M\ell}{mg}}\right).$$

FIGURE 2 Cumulative Problem 2.

3. Let P_0 and ρ_0 be the atmospheric pressure and density at Earth's surface. Assume that the ratio P/ρ is the same throughout the atmosphere (this implies that the temperature is uniform). Show that the pressure a vertical height z above the surface is given by $P(z) = P_0 e^{-\rho_0 g z/P_0}$, for z much less than Earth's radius (this amounts to neglecting Earth's curvature, and thus taking g to be constant).
4. A piece of rope of length ℓ and mass m has its two ends spliced together to form a continuous loop. The loop is set spinning at so high a rate that it forms a circle with essentially uniform tension. It is then placed in contact with the ground, where it rolls, without slipping, like a rigid hoop. The loop is rolling on level ground when it rolls over a stick that produces a small distortion (see Fig. 3). As a result, two pulses, initially coinciding, propagate along the loop in opposite directions. (a) Where will they again coincide? (b) Through what angle will the loop have rotated while the pulses are separated?

FIGURE 3 Cumulative Problem 4.

5. A U-shaped tube containing liquid is mounted on a table that tilts back and forth through a slight angle, as shown in Fig. 4. The diameter of the tube is much less than either the height of its arms or their separation. When the table is rocked very slowly or very rapidly, nothing particularly dramatic happens. But when the rocking takes place at a few times per second, the liquid level in the tube oscillates violently, with maximum amplitude at a rocking frequency of 1.7 Hz. Explain what is going on, and find the total length of the liquid including both vertical and horizontal portions.

FIGURE 4 Cumulative Problem 5.

Supplementary Problems will challenge the best students, and **Cumulative Problems** at the end of each part integrate material from several chapters.

13. Can there be a true "line drive" in baseball? What is required for the ball to travel in a nearly straight, horizontal trajectory?
14. What is the vertical component of a projectile's velocity at the peak of its trajectory?
15. In terms of its initial velocity, what is the horizontal component of a projectile's velocity at the peak of its trajectory?
16. Is there any point on a projectile's trajectory where the velocity and acceleration are perpendicular?
17. How is the up-and-down motion of an object thrown straight up consistent with our conclusion that projectiles follow parabolic trajectories?
18. Projectiles launched at 30° and 60° have the same range. Does this mean they stay in the air the same amount of time?
19. Medieval invaders are attacking a walled village on a flat-topped hill, as shown in Fig 4-22. Is the horizontal range of the rocks they're catapulting given by Equation 4-10? Explain.
20. Earth's curvature renders Equation 4-10 inexact for projectiles with very long ranges. Do you expect the actual range of such a projectile to be longer or shorter than Equation 4-10 would imply? Explain.
21. A 45° launch angle maximizes the horizontal range of a projectile. Is this still true for the situation shown in Fig. 4-22?
22. A friend who's not taking physics insists that you can't be accelerating when you drive around a curve since the speedometer reading remains steady. Refute this argument.
23. You're driving around a curve. Is there any way of stepping on the gas or brake such that your tangential acceleration cancels your radial acceleration, giving a net acceleration of zero? How or why not?
24. An object starts from rest, accelerating with constant tangential acceleration on a circular path. Which is greater when it starts, its tangential or its radial acceleration? Which is greater after a long time? Explain.
25. An object moves outward along the spiral path shown in Fig. 4-23. Must its speed increase, decrease, or remain the same if the magnitude of its radial acceleration is to remain constant?

FIGURE 4-22 Questions 19, 21.

FIGURE 4-23 Question 25.

Nearly 3000 new, interesting, and diverse problems will help your students understand concepts and develop problem-solving skills.

PROBLEMS

Section 4-1 Velocity and Acceleration

1. A skater is gliding along the ice at 2.8 m/s, when she undergoes an acceleration of magnitude 1.1 m/s² for 2.0 s. At the end of that time she is moving at 5.0 m/s. What must be the angle between the acceleration vector and the initial velocity vector?
2. In the preceding problem, what would have been the magnitude of the skater's final velocity if the acceleration had been perpendicular to her initial velocity?
3. An object is moving in the x direction at 1.3 m/s when it is subjected to an acceleration given by $\mathbf{a} = 0.52\,\hat{\mathbf{j}}$ m/s². What is its velocity vector after 4.4 s of acceleration?
4. An airliner is flying at a velocity of $260\hat{\mathbf{i}}$ m/s, when a wind gust gives it an acceleration of $0.38\hat{\mathbf{i}} + 0.72\hat{\mathbf{j}}$ m/s² for a period of 24 s. (a) What is its velocity at the end of that time? (b) By what angle has it been deflected from its original course?

Section 4-2 Constant Acceleration

5. The position of an object as a function of time is given by $\mathbf{r} = (2.4t + 1.2t^2)\hat{\mathbf{i}} + (0.89t - 1.9t^2)\hat{\mathbf{j}}$ m, where t is the time in seconds. What are the magnitude and direction of the acceleration?
6. An airplane heads northeastward down a runway, accelerating from rest at the rate of 2.1 m/s². Express the plane's velocity and position at $t = 30$ s in unit vector notation, using a coordinate system with x axis eastward and y axis northward, and with origin at the start of the plane's takeoff roll.

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ng this time?
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inal direction of

l velocity $\mathbf{v}_0$ =
cceleration given
does the particle cross the y axis? (b) What is its y coordinate at the time? (c) How fast is it moving, and in what direction, at that time?

12. A particle starts from the origin with initial velocity $\mathbf{v}_0 = v_0\hat{\mathbf{i}}$ and constant acceleration $\mathbf{a} = a\hat{\mathbf{j}}$. Show that the particle's distance from the origin and its direction relative to the x axis are given by $d = t\sqrt{v_0^2 + \frac{1}{4}a^2t^2}$ and $\theta = \tan^{-1}(at/2v_0)$.
13. Figure 4-24 shows a cathode-ray tube, used to display electrical signals in oscilloscopes and other scientific instruments. Electrons are accelerated by the electron gun, then move down the center of the tube at 2.0×10^9 cm/s. In the 4.2-cm-long deflecting region they undergo an acceleration directed perpendicular to the long axis of the tube. The acceleration "steers" them to a particular spot on the screen, where they produce a visible glow. (a) What acceleration is needed to deflect the electrons through 15°, as shown in the figure? (b) What is the shape of an electron's path in the deflecting region?

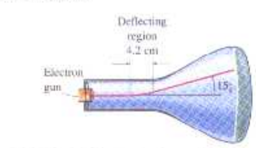


FIGURE 4-24 A cathode-ray tube (Problem 13).

Section 4-3 Projectile Motion

14. You toss an apple horizontally at 9.5 m/s from a height of 1.8 m. Simultaneously, you drop a peach from the same height. How long does each take to reach the ground?
15. A carpenter tosses a shingle off a 9.4-m-high roof, giving it an initially horizontal velocity of 7.2 m/s. (a) How long does it take to reach the ground? (b) How far does it move horizontally in this time?
16. An arrow fired horizontally at 41 m/s travels 23 m horizontally before it hits the ground. From what height was it fired?
17. A kid fires a blob of water horizontally from a squirt gun held 1.6 m above the ground. It hits another kid 2.1 m away square in the back, at a point 0.93 m above the ground (see Fig. 4-25). What was the initial speed of the blob?

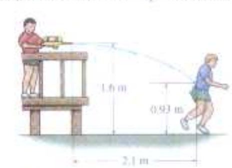


FIGURE 4-25 Problem 17.

18. You are trying to roll a ball off a 80.0-cm-high table to squash a bug on the floor 50.0 cm from the table's edge. How fast should you roll the ball?
19. Repeat the preceding problem, now with the bug moving away from the table at 30.0 mm/s and 50.0 cm from the table when the ball leaves the table edge.
20. Mike is standing outside the physics building, 5.0 m from the wall. Debbie, at a window 4.0 m above, tosses a physics book horizontally. What speed should she give it if it is to reach Mike?
21. Ink droplets in an ink-jet printer are ejected horizontally at 12 m/s, and travel a horizontal distance of 1.0 mm to the paper. How far do they fall in this interval?
22. Protons in a particle accelerator drop 1.2 μm over the 1.7-km length of the accelerator. What is their approximate average speed?
23. You're on the ground 3.0 m from the wall of a building, and want to throw a package from your 1.5-m shoulder level to someone in a second floor window 4.2 m above the ground. At what speed and angle should you throw it so it just barely reaches the window?
24. Derive a general formula for the horizontal distance covered by a projectile launched horizontally at speed v_0 from a height h.
25. A car moving at 40 km/h strikes a pedestrian a glancing blow, breaking both the car's front signal light lens and the pedestrian's hip. Pieces of the lens are found 4.0 m down the road from the center of a 1.2-m wide crosswalk, and a lawsuit hinges on whether or not the pedestrian was in the crosswalk at the time of the accident. Assuming that the lens

Section-referenced problems allow students to refer back to the corresponding section for help using a worked example.

446 CHAPTER 18 FLUID MOTION

CHAPTER SYNOPSIS

Chapter Synopses emphasize key concepts and remind students of new terms and mathematical symbols.

Summary

1. **Fluid** is matter that readily deforms and flows under the influence of forces. Fluids are characterized by **density,** or mass per unit volume, and **pressure,** or force per unit area. Liquids are nearly **incompressible,** meaning liquid density hardly changes. Gases are **compressible,** capable of large density changes, but such changes generally occur only when flow speeds approach or exceed the sound speed.
2. In **hydrostatic equilibrium** there is no net force on any element of a fluid. In the absence of external forces, hydrostatic equilibrium implies uniform pressure throughout the fluid. In the presence of gravity, fluid pressure increases with depth so pressure forces balance the gravitational force; in a liquid, that increase is described by

$$P = P_0 + \rho gh,$$

where P_0 is the surface pressure and h the depth.
3. In hydrostatic equilibrium, a pressure increase at any point is transmitted throughout the fluid, a fact known as **Pascal's law.**
4. **Buoyancy** is the upward pressure force on an object wholly or partly immersed in a fluid. The buoyancy force is equal to the weight of fluid displaced by the object– a fact known as **Archimedes's principle.** If an object is less dense than the fluid, the buoyancy force exceeds the gravitational force, and the object rises.
5. A moving fluid is characterized by its flow velocity at each point in space and time. In **steady flow** the velocity is always the same at a given point; such flow is represented by **streamlines** that mark the paths of the fluid elements. In **unsteady flow** the flow velocity varies with time as well as position.
6. The laws of conservation of mass and conservation of energy provide a simplified description of a fluid in steady flow. Both laws are applied to a narrow **flow tube**– a volume bounded by nearby streamlines. Conservation of mass results in the **continuity equation:**

$$\rho vA = \text{constant along a flow tube},$$

where A is the tube area and ρvA the **mass flow rate.** In a liquid, or a gas with flow speed well below the sound speed, the density ρ is constant and therefore the **volume flow rate** vA remains constant along a flow tube.

In steady, incompressible flow in the absence of viscosity or other forms of energy loss or addition, conservation of energy yields **Bernoulli's equation:**

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant along a flow tube}.$$

The continuity equation and Bernoulli's equation together help explain a great many fluid phenomena; other phenomena, like airplane flight, are more simply explained through the action-reaction forces of Newton's third law.
7. Fluid friction, or **viscosity,** is especially important near fluid boundaries, particularly in narrowly confined flows. Viscosity exerts a stabilizing influence on flows that would otherwise become **turbulent,** or chaotically unstable.

Terms You Should Understand

(Pairs are closely related terms whose distinction is important; number in parentheses is chapter section where term first appears.)

fluid (introduction)
density (18-1)
pressure (18-1)
pascal (18-1)
hydrostatic equilibrium (18-2)
barometer, manometer (18-2)
gauge pressure (18-2)
Pascal's law (18-2)
buoyancy force (18-3)
Archimedes's principle (18-3)
neutral buoyancy (18-3)
streamlines (18-4)
steady flow, unsteady Øow (18-4)
flow tube (18-4)
continuity equation (18-4)
mass flow rate, volume Øow rate (18-4)
Bernoulli's equation (18-4)
venturi (18-5
Bernoulli effe
lift (18-5)
viscosity (18-
turbulence (1

Symbols Yo

P (18-1)
ρ (18-1)
Pa (18-1)

Problems Y

calculating pr
calculating pr
analyzing sim
determining d
objects (18
determining fl
using the cont
(18-4)
using the cont
gether to s

447 QUESTIONS

Limitations to Keep in Mind

Treating matter as a continuous fluid is an approximation valid only when the spacing between molecules is much smaller than any length of interest– including the wavelength of any significant wave motion.

Bernoulli's equation applies only to incompressible flows– that is, to liquids or to gases moving at much less than the sound speed.

Even in a field as fundamental as physics, many theories and their equations have limited applicability. Each chapter concludes with a reminder of limitations that students should keep in mind.

QUESTIONS

1. Explain the difference between hydrostatic equilibrium, steady flow, and unsteady flow.
2. Why do your ears "pop" when you drive up a mountain?
3. The cabins of commercial jet aircraft are usually pressurized to the pressure of the atmosphere at about 2 km above sea level. Why don't you feel the lower pressure on your entire body?
4. Water pressure at the bottom of the ocean arises from the weight of the overlying water. Does this mean that the water exerts pressure only in the downward direction? Explain.
5. The three containers in Fig. 18-37 are filled to the same level and are open to the atmosphere. How do the pressures at the bottoms of the three containers compare?

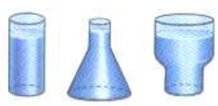


FIGURE 18-37 Question 5.

6. Municipal water systems often include tanks or reservoirs mounted on hills or towers. Besides water storage, what function might these reservoirs have?
7. Why is it easier to float in the ocean than in fresh water?
8. Figure 18-38 shows a cork suspended from the bottom of a sealed container of water. The container is on a turntable rotating about a vertical axis, as shown. Explain the position of the cork.

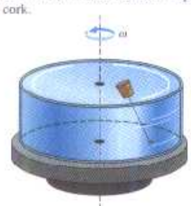


FIGURE 18-38 Question 8.

FIGURE 18-39 Why don't snorkels work at more than a meter or so of depth (Question 13)?

9. An ice cube is floating in a cup of water. Will the water level rise, fall, or remain the same when the cube melts?
10. Meteorologists in the United States usually report barometer readings in "inches." What are they talking about?
11. A mountain stream, frothy with entrained air bubbles, presents a serious hazard to hikers who fall into it, for they may sink in the stream where they would float in calm water. Why?
12. Why are dams thicker at the bottom than at the top?
13. It's not possible to breathe through a snorkel from a depth greater than a meter or so (Fig. 18-39). Why not?
14. Most humans float naturally in fresh water. Yet the body of a drowning victim generally sinks, often rising several days later after bodily decomposition has set in. What might explain this sequence of floating, sinking, and floating again?
15. A helium-filled balloon stops rising long before it reaches the "top" of the atmosphere, while a cork released from the bottom of a lake rises all the way to the surface of the water. Explain the difference between these two behaviors.
16. A barge filled with steel beams overturns in a lake, spilling its cargo. Does the water level in the lake rise, fall, or remain the same?
17. Imagine a vertical cylinder filled with water and set rotating about its axis. If pieces of wood and stone are introduced into the cylinder, where will each end up?
18. When gas in steady, subsonic flow through a tube encounters a constriction, its flow speed increases. When it flows supersonically in the same situation, flow speed decreases in the constriction. What must be happening to the gas density at the constriction in the supersonic case?
19. A ball moves horizontally through the air without spinning. Where on the ball's surface is the air pressure greatest?

An index of examples and applications appears at the beginning of the text.

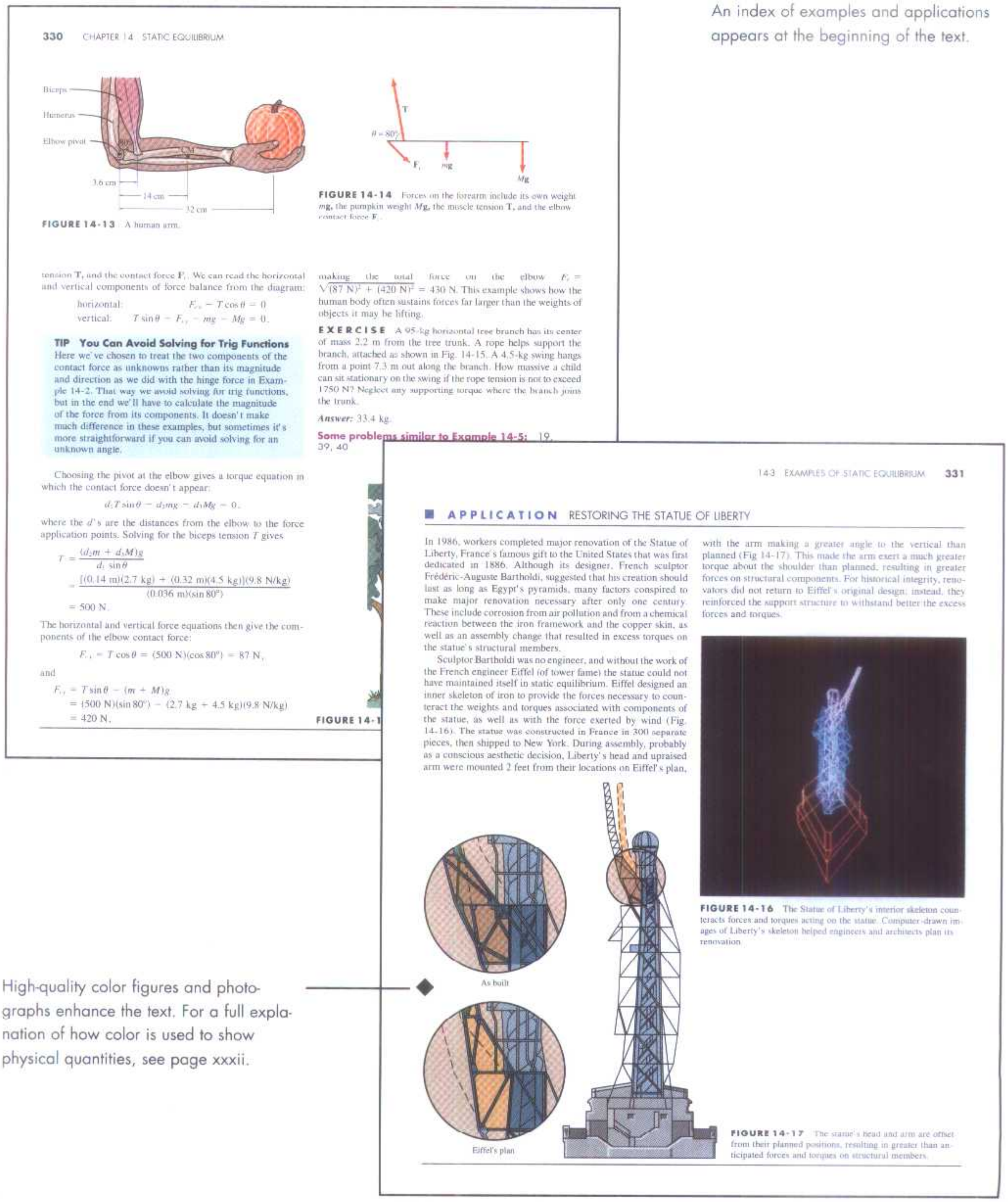


FIGURE 14-13 A human arm.

FIGURE 14-14 Forces on the forearm include its own weight **mg**, the pumpkin weight *M***g**, the muscle tension **T**, and the elbow contact force $\mathbf{F}_c$.

tension **T**, and the contact force $\mathbf{F}_c$. We can read the horizontal and vertical components of force balance from the diagram:

horizontal: $F_{cx} - T\cos\theta = 0$

vertical: $T\sin\theta - F_{cy} - mg - Mg = 0.$

TIP You Can Avoid Solving for Trig Functions Here we've chosen to treat the two components of the contact force as unknowns rather than its magnitude and direction as we did with the hinge force in Example 14-2. That way we avoid solving for trig functions, but in the end we'll have to calculate the magnitude of the force from its components. It doesn't make much difference in these examples, but sometimes it's more straightforward if you can avoid solving for an unknown angle.

Choosing the pivot at the elbow gives a torque equation in which the contact force doesn't appear:

$$d_1 T\sin\theta - d_2 mg - d_3 Mg = 0,$$

where the d's are the distances from the elbow to the force application points. Solving for the biceps tension T gives

$$T = \frac{(d_2 m + d_3 M)g}{d_1 \sin\theta} = \frac{[(0.14\text{ m})(2.7\text{ kg}) + (0.32\text{ m})(4.5\text{ kg})](9.8\text{ N/kg})}{(0.036\text{ m})(\sin 80°)} = 500\text{ N}.$$

The horizontal and vertical force equations then give the components of the elbow contact force:

$$F_{cx} = T\cos\theta = (500\text{ N})(\cos 80°) = 87\text{ N},$$

and

$$F_{cy} = T\sin\theta - (m + M)g = (500\text{ N})(\sin 80°) - (2.7\text{ kg} + 4.5\text{ kg})(9.8\text{ N/kg}) = 420\text{ N},$$

making the total force on the elbow $F_c = \sqrt{(87\text{ N})^2 + (420\text{ N})^2} = 430$ N. This example shows how the human body often sustains forces far larger than the weights of objects it may be lifting.

EXERCISE A 95-kg horizontal tree branch has its center of mass 2.2 m from the tree trunk. A rope helps support the branch, attached as shown in Fig. 14-15. A 4.5-kg swing hangs from a point 7.3 m out along the branch. How massive a child can sit stationary on the swing if the rope tension is not to exceed 1750 N? Neglect any supporting torque where the branch joins the trunk.

Answer: 33.4 kg.

Some problems similar to Example 14-5: 19, 39, 40

FIGURE 14-1

■ **APPLICATION** RESTORING THE STATUE OF LIBERTY

In 1986, workers completed major renovation of the Statue of Liberty, France's famous gift to the United States that was first dedicated in 1886. Although its designer, French sculptor Frédéric-Auguste Bartholdi, suggested that his creation should last as long as Egypt's pyramids, many factors conspired to make major renovation necessary after only one century. These include corrosion from air pollution and from a chemical reaction between the iron framework and the copper skin, as well as an assembly change that resulted in excess torques on the statue's structural members.

Sculptor Bartholdi was no engineer, and without the work of the French engineer Eiffel (of tower fame) the statue could not have maintained itself in static equilibrium. Eiffel designed an inner skeleton of iron to provide the forces necessary to counteract the weights and torques associated with components of the statue, as well as with the force exerted by wind (Fig. 14-16). The statue was constructed in France in 300 separate pieces, then shipped to New York. During assembly, probably as a conscious aesthetic decision, Liberty's head and upraised arm were mounted 2 feet from their locations on Eiffel's plan, with the arm making a greater angle to the vertical than planned (Fig 14-17). This made the arm exert a much greater torque about the shoulder than planned, resulting in greater forces on structural components. For historical integrity, renovators did not return to Eiffel's original design; instead, they reinforced the support structure to withstand better the excess forces and torques.

FIGURE 14-16 The Statue of Liberty's interior skeleton counteracts forces and torques acting on the statue. Computer-drawn images of Liberty's skeleton helped engineers and architects plan its renovation.

FIGURE 14-17 The statue's head and arm are offset from their planned positions, resulting in greater than anticipated forces and torques on structural members.

High-quality color figures and photographs enhance the text. For a full explanation of how color is used to show physical quantities, see page xxxii.

A rich array of practical applications is presented—from the workings of a compact disc to skyscraper engineering, biomedical technology, antilock brakes, global warming, and microelectronics.

166 CHAPTER 7 WORK, ENERGY, AND POWER

EXAMPLE 7-12 CLIMBING MOUNT WASHINGTON

A 55 kg hiker ascends New Hampshire's Mount Washington, a vertical rise of 1300 m from the base elevation. The hike takes 2 hours. A 1500-kg car drives up the Mount Washington Auto Road, the same vertical rise, in half an hour. What is the average power output in each case? Assume the hiker and car maintain constant speed and neglect friction, so each does work only against the gravitational force.

Solution

In Example 7-9, we found that the work done by gravity depends only on the overall change in vertical position. Here the hiker and car do positive work $\Delta W = mgh$ to overcome the negative work $-mgh$ done by gravity. So the average power outputs are

$$\bar{P}_{hiker} = \frac{\Delta W}{\Delta t} = \frac{(55\ \text{kg})(9.8\ \text{m/s}^2)(1300\ \text{m})}{(2.0\ \text{h})(3600\ \text{s/h})} = 97\ \text{W}$$

and

$$\bar{P}_{car} = \frac{\Delta W}{\Delta t} = \frac{(1500\ \text{kg})(9.8\ \text{m/s}^2)(1300\ \text{m})}{(0.50\ \text{h})(3600\ \text{s/h})} = 1.1\times 10^4\ \text{W}.$$

These values correspond to 0.13 hp and 14 hp, respectively. The figure of 97 W is typical of the sustained long term power output of the human body. Remember that next time you leave a 100-W light bulb burning! The power plant supplying the electricity is doing work at about the rate your body can (actually, it's doing work about three times this rate, for reasons we will examine in Chapter 22). You may be surprised at the low output of the car, given that it probably has an engine rated at several hundred horsepower. Actually, only a small fraction of a car engine's rated horsepower is available in mechanical power to the wheels. The rest is lost in friction and heating.

Some problems similar to Example 7-12: 58, 60, 62

When power is constant, so the average and instantaneous power are the same, then Equation 7-17 shows that the amount of work W done in a time Δt is just

$$W = P\Delta t. \qquad (7\text{-}19)$$

When the power is not constant, we can consider small amounts of work ΔW, each taken over so small a time interval Δt that the power is nearly constant. Adding all these amounts of work, and taking the limit as Δt becomes arbitrarily small, we have

$$W = \lim_{\Delta t \to 0} \sum P\Delta t = \int_{t_1}^{t_2} P\,dt, \qquad (7\text{-}20)$$

where t_1 and t_2 are the beginning and end of the time interval over which we calculate the power.

EXAMPLE 7-13 AN ELECTRIC BILL: YANKEE STADIUM

Each of the 500 floodlights at Yankee Stadium uses electrical energy at the rate of 1.0 kW. How much does it cost to run these lights during a 4-hour night game, if electricity costs 9.5¢/kWh (see Fig. 7-19)?

Solution

The total power consumption of the 500 lights is 500 kW. Since the power is constant, the total work done to run the lamps is given by Equation 7-19:

$$W = P\Delta t = (500\ \text{kW})(4.0\ \text{h}) = 2000\ \text{kWh}.$$

The cost is then (2000 kWh)(9.5¢/kWh) = \$190.

Note in this example that energy in kilowatt-hours is simply the product of power in kilowatts and time in hours.

EXERCISE New Hampshire's Seabrook nuclear power plant produces electrical energy at the rate of 1150 MW. (a) How much energy does it produce in a year? (b) At a wholesale price of 2¢/kWh, how much is this energy worth?

Answers: (a) 10^{10} kWh; (b) \$200 million

Some problems similar to Example 7-13: 67, 70, 74

APPLICATION ENERGY AND SOCIETY

We hear a great deal about today's energy-intensive industrial societies and about environmental and other negative consequences of our energy use. Just how much energy do we use, and what does it mean for a society to be energy intensive?

Example 7-12 showed that the average power output of the human body is about 100 W. Before our species harnessed fire and domesticated animals, that 100 W was all the power available to the average human being. At what rate, on the average, do *you* use energy? There's the 100 W associated with your own body. Then there's that 100-W light bulb you keep on several hours a day. Maybe your car burns an average of a gallon of gasoline a day; that gallon is equivalent to about 40 kWh (Appendix C lists this and many other fuel equivalents). On average, that's 40 kWh/24 h or about 1.7 kW. In the winter, your share of the heat may account for several kilowatts. The energy to cook your meals adds further. And what about the energy used to plow the fields that grew your food or to produce the fertilizers and pesticides used in agriculture? Or to manufacture all the goods you consume? In all, you use energy at a substantial rate. In the United States at the end of the twentieth century, in fact, the average energy consumption rate is just about 10 kW per person (see Fig. 7-20). Other industrial nations are within a factor of two of this value, most of them lower.

This quantity, 10 kW, is 10,000 W, or 100 times the average power output of the human body. If our energy were supplied by human labor, instead of gasoline engines and nuclear power plants, each of us would need about 100 laborers working around the clock. What do our 100 "energy workers" do? Figure 7-21 shows that 36 of them work in the industries that supply us with goods; 27 are in transportation, moving us and our goods

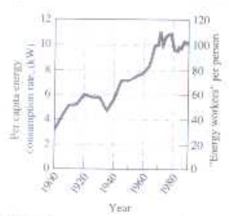


FIGURE 7-20 Per-capita energy consumption rate in the United States through the twentieth century. One "energy worker" is 100 W, about the average power output of the human body.

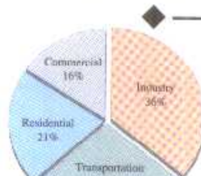


FIGURE 7-21 Energy use in the United States for the late Twentieth Century.

We chose to integrate many shorter applications into the text, where they are more likely to be read, rather than present a few as guest essays.

A VISUAL GUIDE TO THE BOOK

5-7 ADDING FORCES

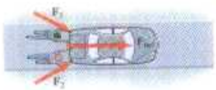


FIGURE 5-13 When two people push a stalled car, the force they exert is the vector sum of their individual forces.

So far we've considered only situations where a single force acts on an object. But often there are several forces acting, as suggested in Fig. 5-13. Airplane flight involves the forces associated with engine thrust, air flowing over the wings and body of the plane, and the force of gravity (Fig. 5-14).

How are we to apply Newton's law in these multiple-force cases? The answer is given ultimately by experiment: We add vectorially the individual forces to find the **net force** on an object. Newton's second law then relates the object's mass and acceleration to this net force. As long as that net force is not zero, the object must be accelerating.

The *net* force is all-important! There may be all sorts of forces acting on a body, but it's their vector sum alone that determines the net force and therefore the acceleration. We've written Newton's law $\mathbf{F}_{net} = m\mathbf{a}$ to emphasize this point; some authors write $\Sigma\mathbf{F} = m\mathbf{a}$ for the same reason.

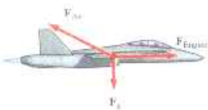


FIGURE 5-14 Forces on a jet include the force of the engines, the force of the air that provides both lift and drag, and the force of gravity. When the plane moves with constant velocity, these forces sum to zero.

TIP **Trust Newton** Newton's second law really does relate acceleration to the net force in all inertial frames. In particular, if you see an object at rest or moving with constant velocity, with respect to an inertial frame, then $\mathbf{a} = \mathbf{0}$ and Newton says the net force on that object must be zero. If you find a nonzero net force, look again; there *must* be additional forces acting (see Fig. 5-15).

Tips point out strategies for helping students to solve problems.

In this introductory chapter on Newton's laws, we'll consider the addition of forces in one dimension only. But forces are vectors, and vector addition is generally necessary to get the net force. In the next chapter we'll deal with Newton's laws in two and three dim…

FIGURE 5-15 The gravitational force F… acceleration is zero, the net force must be ze… case, it is the upward contact force F, provid… electrical force involving interactions betwee…

EXAMPLE 5-7 AN ELEVATOR

A 740-kg elevator is accelerating upward at 1.1 m/s², pulled by a cable of negligible mass, as shown in Fig. 5-16. What is the tension force in the elevator cable?

Solution

This is an important example, and understanding it thoroughly will help you apply Newton's second law correctly in more complicated situations. We're given the acceleration and mass and asked for the force in the cable. Can't we just write $\mathbf{F} = m\mathbf{a}$ for that force? No! $\mathbf{F} = m\mathbf{a}$ is true only for the *net force*, and here the cable tension is *not* the only force acting. There is also the force of gravity, which has magnitude mg and points downward. We've shown both forces in Fig. 5-16*b*.

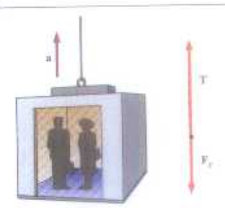


FIGURE 5-16 Forces on the elevator include the cable tension $\mathbf{T}$ and the gravitational force $\mathbf{F}_g$; the net force is their vector sum. Since the elevator is accelerating upward, this net force must be upward.

TIP **Identify the Forces** A key step in solving any Newton's law problem is to identify the forces acting on the object or objects of interest. There's no sense proceeding unless you know the *net* force– and that requires identifying *all* the individual forces acting.

Calling the tension force $\mathbf{T}$ and the gravitational force $\mathbf{F}_g$, Newton's second law becomes

$$\mathbf{F} = \mathbf{T} + \mathbf{F}_g = m\mathbf{a}. \qquad (5\text{-}5)$$

TIP **Vectors Tell it All** You might be tempted to put minus signs in Equation 5-5. But not yet! This is a *vector* equation, and information about signs is built into the directional nature of the vectors. Skipping the step of writing Newton's law in vector form will often get you into trouble. And in writing the vector equation, you never need to worry about signs.

Having written the vector form of Newton's second law for our problem, we next choose a coordinate system and write the components of Newton's law in that system. Here all the forces are vertical, so we choose our y axis pointing vertically upward. Now we write the components of our vector equation 5-5. In this one-dimensional problem only the y equation is interesting; formally, it reads

$$T_y + F_{gy} = ma_y. \qquad (5\text{-}6)$$

Now the tension force $\mathbf{T}$ points upward, or in the $+y$ direction; its vertical component T_y is positive and is equal to the magnitude T of $\mathbf{T}$. The gravitational force $\mathbf{F}_g$ has magnitude mg and points vertically downward, in the $-y$ direction. Its vertical component F_{gy} is therefore $-mg$. Then Equation 5-6 is

$$T - mg = ma_y,$$

so

$$T = ma_y + mg = m(a_y + g). \qquad (5\text{-}7)$$

Before putting in specific numbers, let's see if this result makes sense. Suppose the acceleration a_y were zero. Then the net force on the elevator would have to be zero. In this case, Equation 5-7 tells us that $T = mg$, showing that the tension force and gravity have the same magnitude. Since they point in opposite directions, they indeed sum to zero.

If, on the other hand, the elevator is accelerating upward, so a_y is positive, then Equation 5-7 requires that the magnitude of the tension force exceed that of the gravitational force by an amount ma_y. Why is this? Because in this case the cable not only supports the elevator against gravity, but also provides the upward acceleration. For the numbers of this example, we have

$$T = m(a_y + g) = (740\ \text{kg})(1.1\ \text{m/s}^2 + 9.8\ \text{m/s}^2)$$
$$= 8100\ \text{N}.$$

What if the elevator were accelerating downward? Then a_y is negative and Equation 5-7 shows that the tension force is less than mg. Does this make sense? Yes. For a downward acceleration, the net force must be downward so that the magnitude of the downward gravitational force exceeds that of the upward tension force. Were the elevator in free fall, so $a_y = -g$, the tension force would be exactly zero.

You probably could have reasoned out the answer to this problem in your head. But by applying the steps illustrated here– specifically, writing Newton's second law as a vector equation and then breaking it into components– you will be able to handle more complicated situations without confusion. We will outline the steps in solving a Newton's law problem more formally in the next chapter.

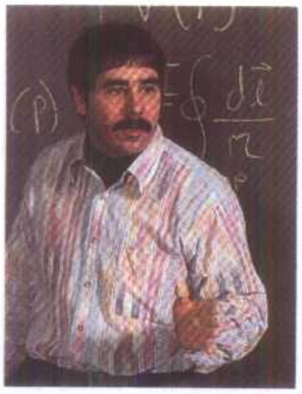
EXERCISE A 270-kg rocket accelerates straight upward from Earth at 51 m/s². What is the thrust (force) provided by the rocket's engine?

Answer: 1.6×10^4 N

Some problems similar to Example 5-7: 27±30

Worked examples are followed by exercises to reinforce concepts. A **Similar Problems** line after the exercise indicates the relevant end-of-chapter problems.

ABOUT THE AUTHORS



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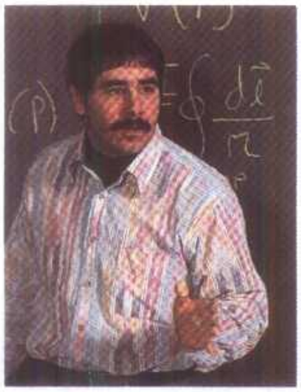

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BRIEF CONTENTS