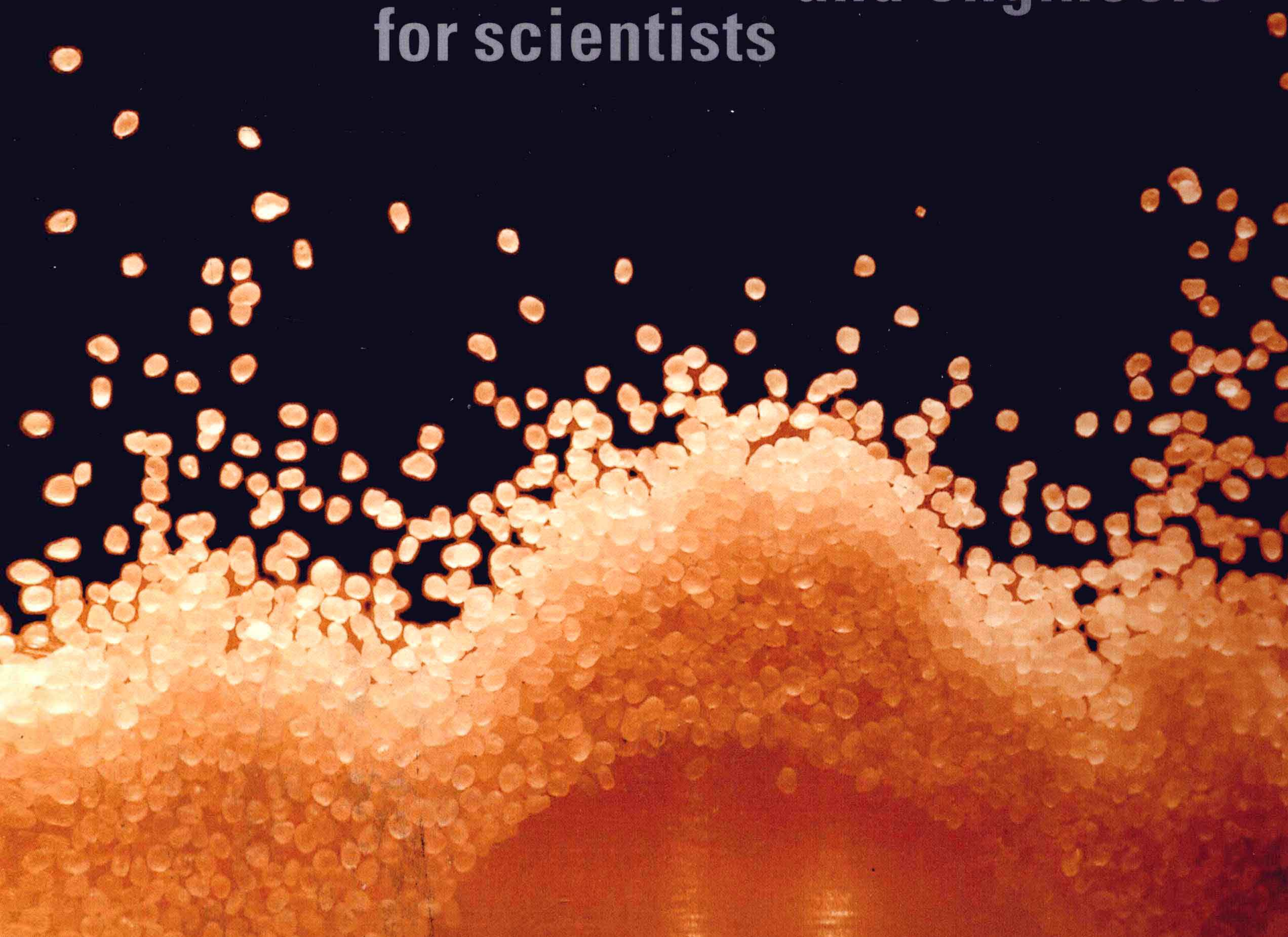
Fourth Edition

Extended Version

Paul A. Tipler

physics

for scientists and engineers



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physics for scientists and engineers

Fourth Edition

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For Claudia

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Fourth Edition
Paul A. Tipler

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physics

for scientists and engineers

preface

In this fourth edition I have worked toward four goals:

1. To help students increase their experience and ability in problem solving
2. To make the reading of the text easier and more fun for students
3. To bring the presentation of physics up to date to reflect the importance of the role of quantum theory
4. To make the text more flexible for the instructor in a wide variety of course formats

Enhanced Problem Solving

To help students learn how to solve problems, the number of worked *Examples* that correspond to intermediate-level problems has been greatly increased. Especially notable is a new two-column side-by-side example format that has been developed to better display the text and equations in worked examples. Care has been taken to show the students a logical method of solving problems. Examples begin with strategies, and often diagrams, in a *Picture the Problem* prologue. When possible, the first step gives an equation relating the quantity asked for to other quantities. This is usually followed by a statement of the general physical principle that applies. For example, this step may be "Apply Newton's second law" or "Use conservation of energy." Examples usually conclude with *Remarks* that discuss the problem and solution, and in many cases there are additional *Check the Result* sections that teach the student how to check the answer, as well as *Exercises* that present additional related problems, which students can solve on their own.

Also new are innovative, interactive types of examples, each labeled *Try it yourself*. In these, students are told in the left column how to proceed with each step of the problem-solving process, but in the right column are given only the answer. Thus, students are guided through the problem, but must independently work through the actual derivations and calculations.

A *Problem-Solving Guide* appears at the end of each chapter in the form of a summary of the worked examples in the chapter. The Problem-Solving Guide is designed to help students recognize types of problems and find the right conceptual strategy for solving them. Here again, general principles such as applying Newton's second law or the conservation of energy are emphasized.

Concluding each chapter is a selection of approximately one hundred *Problems*. The problems are grouped by type, which may or may not coincide with the section titles in the chapter. Each problem is designated easy, intermediate, or challenging. Qualitative questions and problems are integrated with quantitative problems within each group, in the hope that this organization will elevate the stature of qualitative problems in the minds of students (and instructors). At the back of the book, *Answers* are given to the odd-numbered problems. Preceding the answers for each chapter is a *Problem Map* that charts which odd-numbered intermediate-level problems correspond with worked examples in the text. Complete solutions to every other odd-numbered problem, worked out in the two-column example format, are available in the *Solutions Manual for Students.*

I do not believe that students can be given too much help in solving problems. Students learn best when they are successful at the tasks they are given. The hierarchy of worked examples, "Try it yourself" examples, Problem-Solving Guide, and Problem Map gives the student and the instructor maximum flexibility by leading the student through progressive levels of independence. "Try it yourself" problems take students step by step through a problem without doing the math for them. The Problem-Solving Guide gives an overview of the techniques that have been demonstrated in the chapter. The Problem Map shows students who are having difficulty where help may lie in the chapter but gives no other assistance.

Student Interest

Much effort has gone into making the written text more lively and informal. Students build their understanding of physics on the physics they've already learned, each concept serving as a building block that will provide the foundation for further inquiry. Over one hundred enthusiastic student reviews indicate that the changes in the fourth edition will successfully reach the widest range of students and will help them to enjoy learning and doing physics rather than focusing on the difficulty of the subject. To further stimulate the interest of students, supplemental, brief *"Exploring ..."* sections offer essays on various topics of interest to science and engineering undergraduates.

Modern Physics in the Introductory Course

Although quantum theory revolutionized the way we describe the physical world more than 70 years ago, we have been slow to integrate it into our introductory physics courses. To make physics more relevant to today's students, the mass–energy relationship and energy quantization sections are included in the conservation of energy chapter, and the quantization of angular momentum is discussed in the chapter on the conservation of angular momentum. These ideas are then used throughout the text, for example, in Chapter 19 to explain the failure of the equipartition theorem.

In addition, two optional chapters, "Wave–Particle Duality and Quantum Physics" (Chapter 17) and "The Microscopic Theory of Electrical Conduction" (Chapter 27), have been written so that instructors who choose to do so can integrate them into a two-semester course along with the usual topics in classical physics. These chapters offer something completely new—support for professors who choose to introduce quantum physics earlier in the course. Chapter 17 on the wave–particle duality of nature is the concluding chapter in Part II, immediately following the chapter on superposition and standing waves. This chapter introduces the idea of the wave–particle duality of light and matter and uses the frequency quantization of standing waves, just studied in the previous chapter, to introduce energy quantization of confined systems. Many students have heard of quantum theory and are curious about it. Having just studied frequency quantization that arises in standing waves, students can easily grasp energy quantization from standing electron waves, once they have seen from diffraction and interference patterns that electrons have wave properties. Because there is little time to cover even the usual material in the introductory course, some instructors are reluctant to consider adding even one more chapter such as Chapter 17. I would argue that quantum physics is at least as important as many of the other topics we teach.

Chapter 27 on the quantum explanation for electrical conduction is positioned so that it can be covered immediately after the discussion of electric current and dc circuits. The classical model of conduction is developed, concluding with the relation between resistivity and the average speed v_{av} and mean free path λ of electrons. The classical and quantum interpretations of v_{av} and λ are then discussed using the particle-in-a-box problem, discussed in the optional Chapter 17, to introduce the Fermi energy. Simple band theory is discussed to show why materials are conductors, insulators, or semiconductors. My hope in offering these optional chapters is that, given the choice, instructors will take advantage of the means to incorporate simple quantum theory into their elementary physics course.

Flexibility

To accommodate professors in a wide variety of course formats and to respond to the preferences of previous users of this text, there has been some revision in the order of material. With this new edition, instructors can give their students a brief exposure to modern physics integrated with the classical topics, or they can choose to skip the optional chapters on quantum physics entirely, perhaps returning to them in the final part of the course when this material is traditionally taught. To make room for these optional quantum chapters, some traditional material may be deleted from the course. To aid the instructor, material that can be skipped without jeopardizing coverage in other sections has been placed in optional sections. There are also two optional chapters in addition to Chapters 17 and 27. Chapter 12, "Static Equilibrium and Elasticity," and Chapter 21, "Thermal Properties and Processes," gather material that instructors sometimes choose to skip over or offer as added reading. The "optional" labeling of sections and chapters enables the instructor to pick and choose among topics with confidence that no material in nonoptional sections depends on previous coverage of an optional topic. Optional sections and chapters are clearly marked by gray borders down the side of the page. Some optional material, such as numerical methods and the use of complex numbers to solve the driven oscillator equation, is presented in "Exploring ..." essays.

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Many people have contributed to this edition. I would like to thank everyone who used the earlier editions and offered comments and suggestions.

Gene Mosca, James Garland, Robert Lieberman, and Murray Scureman provided detailed reviews of nearly every chapter. Gene Mosca also wrote the student study guide along with Ron Gautreau. Robert Leiberman and Brooke Pridmore class-tested parts of the book, and assisted in obtaining student reviews and feedback. Howard McAllister was instrumental in the development of a standard approach to problem solving in the examples.

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Boris Korsunsky, *Northfield Mt. Hermon School*
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Jay D. Strieb, *Villanova University*
Martin Tiersten, *City College of New York*
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Fred Watts, *College of Charleston*
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David Gordon Wilson, *MIT*
David Winter, *Columbia University*
Frank L. H. Wolfe, *University of Rochester*
Roy C. Wood, *New Mexico State University*
Yuriy Zhestkov, *Columbia University*

Focus Group Participants

Cherry Hill, New Jersey, July 15, 1997

John DiNardo, *Drexel University*
Eduardo Flores, *Rowan College*
Jeff Martoff, *Temple University*
Anthony Novaco, *Lafayette College*
Jay Strieb, *Villanova University*
Edward Whittaker, *Stevens Institute of Technology*

Denver, Colorado, August 15, 1997

Edward Adelson, *Ohio State University*
David Bartlett, *University of Colorado at Boulder*
David Elmore, *Purdue University*
Colonel Rolf Enger, *United States Air Force Academy*
Kendal Mallory, *University of Northern Colorado*
Samuel Milazzo, *University of Colorado at Colorado Springs*
Anders Schenstrom, *Milwaukee School of Engineering*
Daniel Schroeder, *Weber State University*
Ashley Schultz, *Fort Lewis College*

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Berkeley, California
December 1997

Paul Tipler

supplements

For Students

Study Guide

Volume 1 (Chapters 1–21) ISBN: 1-57259-511-6
Volumes 2 and 3 (Chapters 22–41) ISBN: 1-57259-512-4

Each chapter contains a description of key ideas, potential pitfalls, true-false questions that test essential definitions and relations, questions and answers that require qualitative reasoning, and problems and solutions.

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The *Solutions Manual for Students* provides answers to every other odd end-of-chapter problem, presented in the same format and with the same level of detail as the *Instructor's Solutions Manual* (see below).

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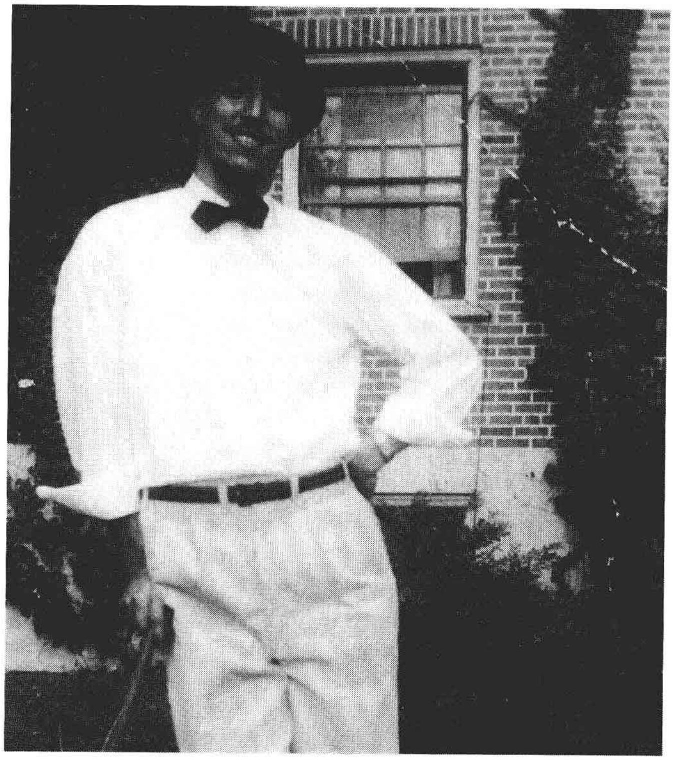
about the author

Paul Tipler was born in the small farming town of Antigo, Wisconsin, in 1933. He graduated from high school in Oshkosh, Wisconsin, where his father was superintendent of the Public Schools. He received his B.S. from Purdue University in 1955 and his Ph.D. at the University of Illinois in 1962, where he studied the structure of nuclei. He taught for one year at Wesleyan University in Connecticut while writing his thesis, then moved to Oakland University in Michigan, where he was one of the original members of the physics department, playing a major role in developing the physics curriculum. During the next 20 years, he taught nearly all the physics courses and wrote the first and second editions of his widely used textbooks *Modern Physics* (1969, 1978) and *Physics* (1976, 1982). In 1982, he moved to Berkeley, California, where he now resides, and where he wrote *College Physics* (1987) and the third edition of *Physics* (1991). In addition to physics, his interests include music, hiking, and camping, and he is an accomplished jazz pianist and poker player.



The author as a student, 1954

Example 2-15

A car is speeding at 25 m/s (≈ 90 km/h ≈ 56 mi/h) in a school zone. A police car starts from rest just as the speeder passes and accelerates at a constant rate of 5 m/s². (*a*) When does the police car catch the speeding car? (*b*) How fast is the police car traveling when it catches up with the speeder?

Picture the Problem To determine when the two cars will be at the same position, we write the positions x_s of the speeder and x_p of the police car as functions of time and solve for the time t when $x_s = x_p$.

(*a*) 1. Write the position functions for the speeder and the police car: $x_s = v_s t$ and $x_p = \frac{1}{2}a_p t^2$

2. Set $x_s = x_p$ and solve for the time t: $v_s t = \frac{1}{2}a_p t^2;\quad t = 0$ (initial condition)

$$t = \frac{2v_s}{a_p} = \frac{2(25\ \text{m/s})}{5\ \text{m/s}^2} = 10\ \text{s}$$

(*b*) The velocity of the police car is given by $v = v_0 + at$ with $v_0 = 0$: $v_p = a_p t = (5\ \text{m/s}^2)(10\ \text{s}) = 50\ \text{m/s}$

Remark The final speed of the police car in (*b*) is exactly twice that of the speeder. Since the two cars covered the same distance in the same time, they must have had the same average speed. The speeder's average speed, of course, is 25 m/s. For the police car to start from rest and have an average speed of 25 m/s, it must reach a final speed of 50 m/s.

Exercise How far have the cars traveled when the police car catches the speeder? (*Answer* 250 m)

Remark In Figure 2-13 the solid lines depict the speeder and the police car in this example. The dashed lines are variations on the example. The smaller acceleration depicted by the lower dashed line means the police car takes longer to reach the speeder. In the higher dashed line, the acceleration is the same as in the example, but the police car does not start accelerating until 4 s after the speeder passes by.

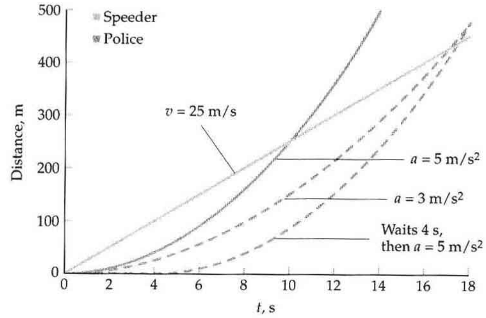


Figure 2-13

- Instructive illustrations accompany nearly all examples.
- Students are involved in every step of the complete solution for each example.

"TRY IT YOURSELF" EXAMPLES

- **"Try it yourself"** examples follow the same format as regular examples, except that the student is given only brief instructions on the left side, and only the relevant formulas and the answer on the right side, without being shown the mathematical steps in between.
- **"Try it yourself"** examples test understanding, identify weaknesses, and reinforce proper problem-solving procedures.

Example 6-7 *try it yourself*

A particle is given a displacement $\vec{\Delta s} = 2\ \text{m}\ \hat{i} - 5\ \text{m}\ \hat{j}$ along a straight line. During the displacement, a constant force $\vec{F} = 3\ \text{N}\ \hat{i} + 4\ \text{N}\ \hat{j}$ acts on the particle (Figure 6-14). Find (*a*) the work done by the force, and (*b*) the component of the force in the direction of the displacement.

Picture the Problem The work W is found by computing $W = \vec{F}\cdot\vec{\Delta s} = F_x\Delta x + F_y\Delta y + F_z\Delta z$. Since $\vec{F}\cdot\vec{\Delta s} = F\cos\phi|\vec{\Delta s}|$, we can find the component of $\vec{F}$ in the direction of the displacement from

$$F\cos\phi = \frac{(\vec{F}\cdot\vec{\Delta s})}{|\vec{\Delta s}|} = \frac{W}{|\vec{\Delta s}|}$$

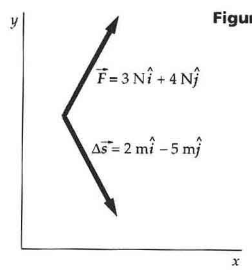


Figure 6-14

Cover the column to the right and try these on your own before looking at the answers.

Steps	*Answers*
(*a*) Compute the work done W.	$W = -14\ \text{N}\cdot\text{m}$
(*b*) 1. Compute $\vec{\Delta s}\cdot\vec{\Delta s}$ and use your result to find the distance $\lvert\vec{\Delta s}\rvert$.	$\lvert\vec{\Delta s}\rvert = \sqrt{29}\ \text{m}$
2. Compute $F\cos\phi = W/\lvert\vec{\Delta s}\rvert$.	$F\cos\phi = -2.60\ \text{N}$

Remark The component of the force in the direction of the displacement is negative, so the work done is negative.

Exercise Find the magnitude of $\vec{F}$, and the angle ϕ between $\vec{F}$ and $\vec{\Delta s}$. (*Answer* $F = 5\ \text{N}$, $\phi = 121°$)

"EXPLORING" ESSAYS

- "Exploring" essays enrich students by covering topics that are outside the core part of the course—but are too interesting to pass over completely.

Exploring

Numerical Methods: Euler's Method

If a particle moves under the influence of a *constant* force, its acceleration is constant and we can find its velocity and position from the constant-acceleration formulas in Chapter 2. But consider a particle moving through space where the force on it, and therefore its acceleration, depends on its position and velocity. The velocity and acceleration of the particle at one instant determine its position and velocity at the next instant, which then determines its acceleration at that instant. The actual position, velocity, and acceleration of an object all change continuously with time. We can approximate this by replacing the continuous time variations with small time steps of duration Δt. The simplest approximation is to assume constant acceleration during each step. This approximation is called **Euler's method**. If the time interval is sufficiently short, the change in acceleration during the interval will be small and can be neglected.

Let x_0, v_0, and a_0 be the known position, veloc-

$$x_2 = x_1 + v_1\Delta t$$

In general, the connection between the position and velocity at time t_n and time $t_{n+1} = t_n + \Delta t$ is given by

$$v_{n+1} = v_n + a_n\Delta t \qquad 3$$

and

$$x_{n+1} = x_n + v_n\Delta t \qquad 4$$

To find the velocity and position at some time t, we therefore divide the time interval $t - t_0$ into a large number of smaller intervals Δt and apply Equations 3 and 4, beginning at the initial time t_0. This involves a large number of simple, repetitive calculations that are easily done on a computer. The technique of breaking the time interval into small steps and computing the acceleration, velocity, and position at each step using the values from the previous step is called numerical integration.

Drag Forces

To illustrate the use of numerical methods, let us consider a problem in which a sky diver is dropped from rest at some height under the influences of gravity and a drag force that is proportional to the square of the speed. We will find the velocity v and the distance traveled x as functions of time.

The equation describing the motion of an object of mass m dropped from rest is Equation 5-7 with $n = 2$:

$$\sum F_y = mg - bv^n = ma_y$$

SUMMARY

- Detailed **Summary** sections reinforce the lessons of the chapter. The summary is not a substitute for attentive study of the text, but a skeletal outline to help students organize what they have learned.

Summary

1. Work, kinetic energy, potential energy, and power are important derived dynamic quantities.
2. The work–kinetic energy theorem is an important relation derived from Newton's laws applied to a particle.
3. The dot product of vectors is a mathematical definition that is useful throughout physics.

Topic	Remarks and Relevant Equations	
1. Work		
Constant force	The work done by a constant force is the product of the component of the force in the direction of motion and the displacement of the force: $W = F\cos\theta\,\Delta x = F_x\,\Delta x$	6-1
Variable force	$W = \int_{x_1}^{x_2} F_x\,dx$ = area under the F_x-versus-x curve	6-9
Force in three dimensions	$W = \int_1^2 \vec{F}\cdot d\vec{s}$	6-14
Units	The SI unit of work and energy is the joule (J): $1\text{ J} = 1\text{ N}\cdot\text{m}$	6-2
2. Kinetic Energy	$K = \frac{1}{2}mv^2$	6-6

PROBLEMS

- Types of problems are denoted by color swatches: **yellow** denotes conceptual problems and a **gray** band indicates optional or exploring sections.
- The difficulty level is denoted by bullets.
- Qualitative problems are included in context with related quantitative problems.

Problems

In a few problems, you are given more data than you actually need; in a few other problems, you are required to supply data from your general knowledge, outside sources, or informed estimates.

Conceptual Problems

Problems from Optional and Exploring sections

- • Single-concept, single-step, relatively easy
- •• Intermediate-level, may require synthesis of concepts
- ••• Challenging, for advanced students

Conditions for Equilibrium

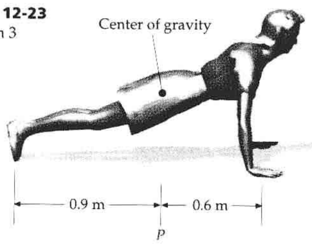
1 • True or false:

(*a*) $\Sigma\vec{F} = 0$ is sufficient for static equilibrium to exist.
(*b*) $\Sigma\vec{F} = 0$ is necessary for static equilibrium to exist.
(*c*) In static equilibrium, the net torque about any point is zero.
(*d*) An object is in equilibrium only when there are no forces acting on it.

2 • A seesaw consists of a 4-m board pivoted at the center. A 28-kg child sits on one end of the board. Where should a 40-kg child sit to balance the seesaw?

3 • In Figure 12-23, Misako is about to do a push-up. Her center of gravity lies directly above point *P* on the floor, which is 0.9 m from her feet and 0.6 m from her hands. If her mass is 54 kg, what is the force exerted by the floor on her hands?

Figure 12-23 Problem 3



4 • Juan and Bettina are carrying a 60-kg block on a 4-m board as shown in Figure 12-24. The mass of the board is 10 kg. Since Juan spends most of his time reading cookbooks, whereas Bettina regularly does push-ups, they place the block 2.5 m from Juan and 1.5 m from Bettina. Find the force in newtons exerted by each to carry the block.

Figure 12-24 Problem 4

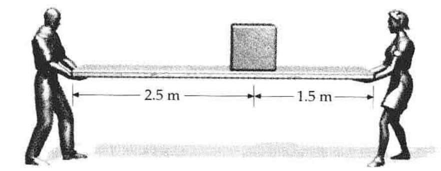
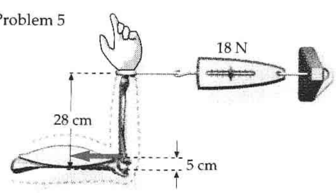


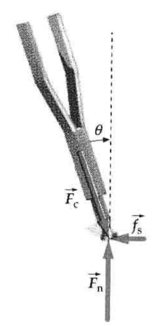
Figure 12-25 Problem 5



the pivot point. If the scale reads 18 N when she exerts her maximum force, what force is exerted by the biceps muscle?

6 • A crutch is pressed against the sidewalk with a force $\vec{F}_c$ along its own direction as in Figure 12-26. This force is balanced by a normal force $\vec{F}_n$ and a frictional force $\vec{f}_s$. (*a*) Show that when the force of friction is at its maximum value, the coefficient of friction is related to the angle θ by $\mu_s = \tan\theta$. (*b*) Explain how this result applies to the forces on your foot when you are not using a crutch. (*c*) Why is it advantageous to take short steps when walking on ice?

Figure 12-26 Problem 6



The Center of Gravity

7 • True or false: The center of gravity is always at the geometric center of a body.

8 • Must there be any material at the center of gravity of an object?

9 • If the acceleration of gravity is not constant over an object, is it the center of mass or the center of gravity that is the pivot point when the object is balanced?

10 • Two spheres of radius *R* rest on a horizontal table with their centers a distance 4*R* apart. One sphere has twice the weight of the other sphere. Where is the center of gravity of this system?

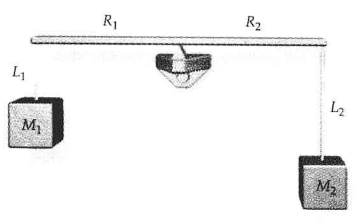
11 • An automobile has 58% of its weight on the front wheels. The front and back wheels are separated by 2 m.

General Problems

66 • If the net torque about some point is zero, must it be zero about any other point? Explain.

67 • The horizontal bar in Figure 12-52 will remain horizontal if

(*a*) $L_1 = L_2$ and $R_1 = R_2$. (*b*) $L_1 = L_2$ and $M_1 = M_2$.
(*c*) $R_1 = R_2$ and $M_1 = M_2$. (*d*) $L_1M_1 = L_2M_2$.
(*e*) $R_1L_1 = R_2L_2$.



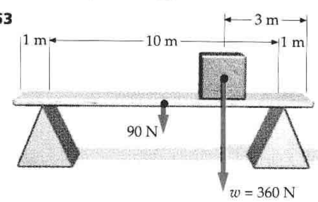
68 • Which of the following could not have units of N/m^2?

(*a*) Young's modulus (*b*) Shear modulus
(*c*) Stress (*d*) Strain

69 •• Sit in a chair with your back straight. Now try to stand up without leaning forward. Explain why you cannot do it.

70 • A 90-N board 12 m long rests on two supports, each 1 m from the end of the board. A 360-N block is placed on the board 3 m from one end as shown in Figure 12-53. Find the force exerted by each support on the board.

Figure 12-53 Problem 70



physics

for scientists and engineers