COLLEGE PHYSICS

PAUL PETER URONE

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This book is dedicated to Patty, my friend, my lover, my wife.
Without her neither this book nor my heart would exist.

PREFACE

TO THE STUDENT

This book is written for you. It is based on a quarter-century of teaching college-level physics and influenced by a strong recollection of my own struggles as a student. I have spent thousands of hours in the classroom, in the laboratory, and in tutoring centers talking and *listening* to students. To the nearly three thousand students I have known over the years, I say this: You are a part of this book. Your ideas, your reactions to concepts, your needs as well as your wishes have influenced every aspect of this text. To the students now using this text: I hope the story of physics told in this book will make the subject understandable, useful, and enjoyable.

A good story is important, and physics is rich in stories. This book tells some of those stories and laces them with applications that are convincing evidence that physics is visible everywhere. Applications range from driving a car to launching a rocket, from a skater whirling on ice to a neutron star spinning in space, and from taking your temperature to taking a chest x ray. In spite of having more years behind me than most of you, I share many of your interests—a skier on the slopes is much more illuminating than a block on an incline.

But it isn't enough for you to read a story or listen to an entertaining lecture. You must take action—active inquiry, exploration, and extrapolation are the next steps to useful understanding. One activity you will undoubtedly have in your physics course is homework. At the end of each chapter in this text, you will find questions and problems your instructor may assign for homework. While that may seem burdensome at times, it is crucial to real understanding. This is where you really learn—in doing things yourself and questioning the world around you. Learning to solve physics problems is much like learning to ride a bicycle. *Your action* is necessary in addition to watching how someone else does it.

This book contains many features that are designed to help you learn the concepts of physics, use those concepts to solve problems, and also recognize how the solution fits nature (is correct). To learn more about the features in this text, consult the material titled *Special Features.* I hope you will find much in this book that interests you, helps you to succeed in your courses, and allows you to apply physics outside the classroom. The most powerful form of knowledge is that which enables you to go beyond what you are told.

TO THE INSTRUCTOR

This text is intended for one-year introductory courses requiring algebra and some trigonometry, but no calculus. It is written for both the students and instructors of today. After describing the general features of the text, I elaborate on the special features of the text designed to achieve its goals.

Goals

For a subject as sophisticated as physics and a process as complex as learning, our goals are as common as they are fundamental: to help transmit the concepts of physics and the analytical skills to apply them; to build an appreciation of the underlying simplicity and unity in nature; to impart a sense of the beauty and wonder found in the physical universe.

General Approach

Topics are introduced conceptually with a steady progression to precise definitions and analytical applications. The analytical aspect (problem solving) is tied back to the conceptual before moving on to another topic. Each chapter, for example, opens with an attractive photograph relevant to the subject of the chapter. The introduction to the chapter is made with interesting applications that are easy to visualize and that most students should have observed for themselves. The conceptual foundation of the chapter is then laid with increasing precision. Definitions and quantitative relationships follow. Worked examples not only illustrate the analytical aspects of a problem, but always tie the strategy and results back into the conceptual aspect of the topic (the *Discussion* section of each worked example). This forms a cycle: Starting with familiar applications, there is a progression from conceptual to analytical, which is tied back to the conceptual at the end.

Organization, Level, and Content

This book is innovative, yet practical for most potential users. Topics ordinarily covered in a one-year course at the algebra-trig level are included in a relatively traditional sequence. Certain highly sophisticated topics (such as the use of phasors in AC circuits) are omitted to allow sufficient treatment of the topics that remain. Thus, the length of the text has been controlled without eliminating those topics most often included in introductory courses. This does not mean that the text is written at a low level. It means that there is a uniformity of treatment that does not introduce a special technique for a single topic.

There is considerable latitude on the part of the instructor regarding level and content. By choosing the types of problems assigned (from three denoted levels of difficulty), the instructor can determine the level of sophistication required of the student. Likewise, by choosing the topics covered in depth, the instructor can determine both the level and the topical emphasis of the course.

Concepts and Calculations

In recent years there has been a growing awareness that conceptual skills need to be addressed as directly as analytical skills—that an ability to calculate does not guarantee conceptual understanding. It has always been my belief that the issues of conceptual and analytical skills should be addressed simultaneously. In order to unify conceptual, analytical, and calculational skills within the learning process, I have integrated them throughout the text. This can be seen in a series of features described in the section *Special Features*. It is particularly easy to see how this is built into the *worked examples* and *problem-solving strategies* in the text. But it is also fundamental to the general approach of conceptual to analytical tied back to conceptual described previously.

Modern Perspective

Professional study groups and surveys have identified a need for expanded emphasis of modern physics. This is met in this text by the early incorporation of familiar ideas from modern physics, such as the existence of atoms and the conversion of mass into energy. The chapters on modern physics are more complete than most, with an entire chapter devoted to applications of nuclear physics and another to particle physics. The final chapter of the text, *Frontiers of Physics,* is devoted to the most current and exciting endeavors in physics. It ends with a section titled *Questions We Know to Ask*.

Accuracy

Every effort has been made not only to keep the text free from error but to have it accurately portray the physical universe. My goal has always been to produce a first edition text of second edition quality. Thorough peer reviews performed at many stages of the writing and editing of the text have been carefully taken into account. Also considered were the results of selected student reviews and extensive classroom testing. During the final stages of production, every equation, calculation, and number in the text was checked yet again by the author and by another qualified physicist for accuracy and consistency in significant figures. Two physicists each solved all of the end-of-chapter problems in detail. Many of those problems have been solved by other individuals as well. This has eliminated ambiguities in the statements of problems, ensured that the situations posed were reasonable, and made the number of significant figures used consistent with the simple rules elaborated in the text. The answers to odd-numbered problems that appear at the end of the book are thus felt to be nearly error free, as are the solutions to problems found in the *Instructor's Solution Manual*. The art program was rendered with the advice of a physicist and was checked for accuracy and effectiveness by the author and other individuals during production.

SUPPLEMENTS

The text is supported by a complete package of text supplements:

Student's Solutions Manual, prepared by Steven Yount of the United States Patent Office and Gary Shoemaker of California State University, Sacramento. Provides carefully worked-out solutions to the odd-numbered problems, answers to which appear in the back of the book.

Instructor's Solutions Manual, also by Steven Yount and Gary Shoemaker. This manual includes detailed solutions for all problems in the end-of-chapter sections.

Instructor's Solutions Disk, a computer disk version of the *Instructor's Solutions Manual*. This is available to instructors in Microsoft Word for Windows and Macintosh.

Test Item File, by Frank D. Stekel of University of Wisconsin–Whitewater. The test bank contains more than 1600 questions of varying formats and level of difficulty.

Computerized Testing A computerized version of the printed test items is available to DOS, Windows, and Macintosh platforms.

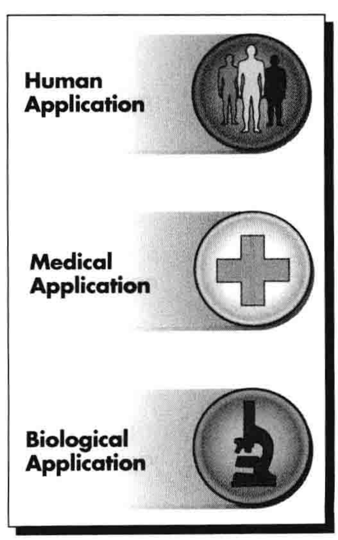
Transparencies Approximately 115 four-color transparency acetates of key figures from the text are included in this package.

CNN Physics Today This 50 minute video contains numerous segments highlighting everyday physics—from spiderwebs to Cirque du Soleil. Available to adopters of the text.

SPECIAL FEATURES

The following briefly describe special features of this text.

Applications *Applications of physics relevant* and *visible* to students are an integral part of making the physics interesting. I revel in finding physics everywhere and have incorporated that passion in this text. This is present in the body of each chapter and continues in the worked examples and end-of-chapter conceptual questions and problems. There is a discernible point to most of what the students read and do. When the results of an application of physics give a new insight, the physics sings as it does to those of us who have always found it inherently interesting.



Throughout the book, you will find icons for significant instances of *human, medical,* and *biological applications*. Many students in algebra-trig based physics courses are majoring in related disciplines and find these applications stimulating. *Human, medical,* and *biological* applications are an integral part of the prose of the text and are found in worked examples and in end-of-chapter conceptual questions and problems, but those that obscure the exposition of the physics are avoided. Certain sections are devoted to human, medical, and biological topics, including: forces and torques in muscles and joints (Section 5.7), fluids and pressures in the human body (Section 10.8), nerve conduction (Section 19.7), color and color vision (Section 24.10), and biological effects of ionizing radiation (Section 30.5). The table of contents includes many others.

Problem-solving strategies *Problem-solving strategies* are first presented in a special section and subsequently appear at crucial points in the text where students can benefit most from them. Problem-solving strategies have a logical structure that is reinforced in the *worked examples* and supported in certain places by line drawings that illustrate various steps. There are three types of problem-solving strategies. The largest number are found in the main body of the text. The other two types are those for the *integrated concepts* problems and those for the *unreasonable results* problems. These help the student to accomplish the goals of those two different types of problems. All problem-solving strategies contain conceptual elements as well as analytical.

PROBLEM-SOLVING STRATEGY

FOR NEWTON'S LAWS OF MOTION

Step 1. As usual, it is first necessary to identify the physical principles involved. *Once it is determined that Newton's laws of motion are involved, it is particularly important to draw a careful sketch of the situation.* Such a sketch is shown in Figure 4.17(a). Then, as in Figure 4.17(b), use arrows to represent all forces, label them carefully, and make their lengths and directions correspond to the forces they represent whenever sufficient information exists.

Step 2. Identify what needs to be determined and what is known or can be inferred from the problem as stated. That is, make a list of knowns and unknowns. *Then carefully determine the system of interest.* This is a crucial step, since Newton's second law involves only external forces. Once the system of interest has been identified, it becomes possible to determine which forces are external and which are internal, a necessary step to employ Newton's second law. (See Figure 4.17(c).) (Newton's third

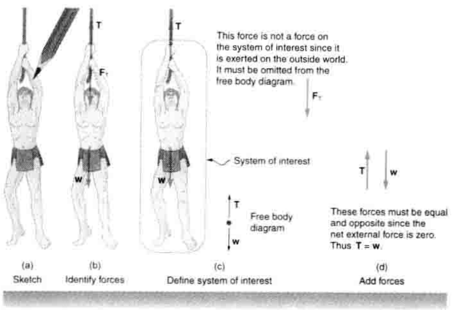


Figure 4.17 (a) A sketch of Tarzan hanging from a vine. (b) Arrows are used to represent all forces. **T** is the tension in the vine above Tarzan, $\mathbf{F}_T$ is the force he exerts on the vine, and **w** is his weight. All other forces, such as the nudge of a breeze, are assumed negligible. (c) Suppose we are given the ape man's mass and asked to find the tension in the vine. We then define the system of interest as shown. $\mathbf{F}_T$ is no longer shown, because it is not a force acting on the system of interest; rather, $\mathbf{F}_T$ acts on the outside world. This is a free body diagram. (d) Showing only the arrows, the head-to-tail method of addition is used. It is apparent that **T** = **w**, if Tarzan is stationary.

Worked examples *Worked examples have four distinct parts* to promote both analytical and conceptual skills. Worked examples are *introduced in words*, always using some application that should be of interest. This is followed by a clearly labeled *Strategy* section that emphasizes the concepts involved and how solving the problem relates to those concepts. Next comes the mathematical *Solution* to the problem. Finally, there is a *Discussion* section. This last step ties the analytical back to the conceptual by discussing the answer of the worked example—its meaning, magnitude, further implications, and so on are used to give the analytical process conceptual meaning and to link topics together.

Many worked examples contain *multiple-part problems* to help the students learn how to approach normal situations, in which problems tend to have multiple parts. Finally, worked examples *employ the techniques of the problem-solving strategies* so that students can see how those strategies succeed in practice as well as in theory.

EXAMPLE 3.8 VELOCITY RELATIVE TO . . .?

An airline passenger drops a quarter in change while the plane is moving at 260 m/s in level flight. What is the velocity of the quarter when it strikes the floor 1.50 m below its point of release: (a) Measured relative to the plane? (b) Measured relative to the earth?

Strategy Both problems can be solved with the techniques for falling objects and projectiles. In part (a), the initial velocity of the quarter is zero relative to the plane, making the motion that of a falling object (one-dimensional). In part (b), the initial velocity is 260 m/s horizontal relative to the earth and gravity is vertical, making this a projectile motion. In both parts it is best to use a coordinate system with vertical and horizontal axes.

Solution for (a) With the given information, we note that the initial velocity and position are zero, and the final position is −1.50 m. The final velocity can be found using Equation 3.10d:

$$v^2 = v_0^2 - 2gy$$

Substituting known values, we get

$$v^2 = 0 - 2(9.8\ \text{m/s}^2)(-1.50\ \text{m}) = 29.4\ \text{m}^2/\text{s}^2$$

yielding

$$v = -5.42\ \text{m/s}$$

The minus sign is *chosen* when the square root is taken; it means the velocity is downward. There is no initial horizontal velocity relative to the plane and no horizontal acceleration, and so the motion is straight down relative to the plane.

Solution for (b) Since the initial vertical velocity is zero relative to the ground and since vertical motion is independent of horizontal motion, the final vertical velocity for the quarter relative to the ground is $v_y = -5.42$ m/s, the same as found in part (a). There is no horizontal acceleration, and so the initial and final horizontal velocities are the same and $v_x = 260$ m/s. The x- and y-components of velocity can be combined, using Equation 3.16, to find the magnitude of the final velocity:

$$v = \sqrt{v_x^2 + v_y^2}$$

Thus,

$$v = \sqrt{(260\ \text{m/s})^2 + (-5.42\ \text{m/s})^2}$$

yielding

$$v = 260.06\ \text{m/s}$$

The direction is given by Equation 3.17:

$$\theta = \tan^{-1}(v_y/v_x) = \tan^{-1}(-5.42/260)$$

so that

$$\theta = \tan^{-1}(-0.0208) = -1.19^\circ$$

Discussion In part (a), the final velocity relative to the plane is the same as it would be if the quarter were dropped from rest on earth and fell 1.50 m. This fits our experience; objects fall the same way when the plane is flying horizontally as when it is at rest on the ground. This is also true in moving cars. In part (b), an observer on the ground sees a much

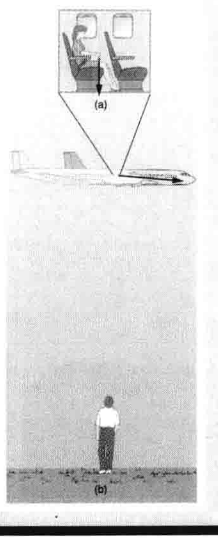


Figure 3.19 More classical relativity. The motion of a quarter dropped inside an airplane as viewed by two different observers. (a) An observer in the plane sees the quarter fall straight down. (b) An observer on the ground sees the quarter move almost horizontally.

(continued)

Integrated concept problems Many would say that a central tenet of physics is its underlying unity and connections. Although topics are necessarily introduced separately, I have written numerous *integrated concept problems*, to encourage students to apply principles broadly. In many chapters, there are *integrated concept worked examples* that guide the student in approaching situations that have more than one physical principle involved. These are augmented by *integrated concept problem-solving strategies* that explicitly help the student draw ideas from more than one area and apply them conceptually and analytically to solving a problem. While some texts contain problems drawing from many areas, very few aid students in mastering such problems. In this text, such problem-solving support has been a central idea in the development of these problems.

INTEGRATED CONCEPTS

These problems involve physical principles from more than one chapter. Integrated knowledge from a broad range of topics is much more powerful than a narrow application of physics. Energy, for example, is involved in kinematics, whence the relevance of Chapter 2. The following topics are involved in some or all of the problems in this section:

Topics	*Location*
Kinematics	Chapter 2
Two-dimensional kinematics	Chapter 3
Dynamics	Chapter 4
Statics, elasticity	Chapter 5

PROBLEM-SOLVING STRATEGY

Use the following strategy to solve integrated concept problems.

Step 1. *Identify which physical principles are involved.* This is done by following the problem-solving strategies found in this and previous chapters (see the table of contents or look in the index). Listing the givens and the quantities to be calculated will allow you to identify the principles involved.

Step 2. *Solve the problem using strategies outlined in the text.* If these are available for the specific topic, you should refer to them. You should also refer to the sections of the text that deal with a particular topic.

CONNECTIONS

Newton's universal law of gravitation is modified by Einstein's general theory of relativity, as we shall see in Chapter 32. Newton's gravity is not seriously in error—it was and still is an extremely good approximation for most situations. Einstein's modification is most noticeable in extremely large gravitational fields, such as near black holes. However, general relativity also explains such things as small but long-known deviations of the orbit of the planet Mercury from classical predictions.

Connections boxes To illustrate the underlying unity of apparently different topics, *Connections boxes* are placed in the margin where appropriate. They contain brief discussions of conceptual connections not necessarily obvious at the introductory level. Connections boxes augment the integrated concepts problems and their supporting materials, adding emphasis to the most powerful aspects of physics—its underlying unity, breadth of applicability, and fundamental simplicity.

Unreasonable results *Unreasonable result problems* are unique to this text. They are designed to further emphasize that properly applied physics must describe nature accurately and is not simply the process of solving equations. These problems contain a premise that produces an unreasonable answer. For example, if the heat generated by metabolizing an average day's food is retained, a person's body temperature will rise to a lethal level. Thus, physics correctly applied produces in this case a result that is never observed—the student must recognize that the premise of complete heat retention is at fault. These problems are clearly labeled and are found at the very end of the end-of-chapter problems—all other problems in the text produce reasonable results and often contain discussion to emphasize that physics must fit nature. Taken with the careful accuracy of the text and the discussions at the end of *worked examples*, unreasonable results problems can help students examine the concepts of a problem as well as the mechanics of solving it.

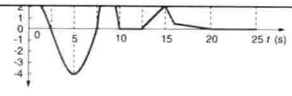


Figure 2.22 (a) Graph of displacement versus time for a jogger who starts on a run, stops, and goes back to pick up his keys at 2.5 m before continuing. (b) Graph of velocity versus time produced by finding the slope of the displacement graph. (c) Graph of acceleration versus time produced by finding the slope of the velocity graph. Problems 54 and 55.

UNREASONABLE RESULTS

Physics must describe nature accurately. The following problems have results that are unreasonable because one premise is unreasonable or because certain of its premises are inconsistent with one another. The physical principle applied correctly then produces an unreasonable result. For example, if a person starting a foot race accelerates at 0.40 m/s^2 for 100 s, his final speed will be 40 m/s (about 90 miles per hour)—clearly unreasonable because the time of 100 s is an unreasonable premise. The physics is correct in a sense, but there is more to describing nature than just manipulating equations correctly. Checking the result of a problem to see if it is reasonable does more than help uncover errors in problem solving—it also builds intuition in judging whether nature is being accurately described.

PROBLEM-SOLVING STRATEGIES

Use the following strategies to determine if an answer is reasonable and, if it is not, to determine what is the cause.

Step 1. *Solve the problem using strategies as outlined in Section 2.5 and in the format followed in the worked examples in the text.* In the example given in the preceding paragraph, you would identify the givens as the acceleration and time and use Equation 2.9 to find the unknown final velocity. That is,

$$v = v_0 + at = 0 + (0.40\ \text{m/s}^2)(100\ \text{s}) = 40\ \text{m/s}$$

Step 2. *Check to see if the answer is reasonable.* Is it too large or too small, or does it have the wrong sign, improper units, . . .? In the present case, the velocity is about four times higher than a person can run—so it is too large.

Step 3. *If the answer is unreasonable, look for what specifically could cause the identified difficulty.* In the example of the runner, there are only two assumptions that are suspect. The acceleration could be too great or the time too long. People can easily accelerate at 0.40 m/s^2; thus, the time must be too long.

2.58 Suppose you drop a rock from a cliff and you observe that it falls 39.2 m in 2.00 s. (a) What is the acceleration of the rock? (b) What is unreasonable about the result? (c) Which premise is unreasonable, or are the premises inconsistent?

2.59 An advertisement claims that a certain automobile can stop from a speed of 35.0 m/s in a distance of 20.0 m. (a) What is the average deceleration? (b) What is unreasonable about the result? (c) Which premise is unreasonable?

Things Great and Small In these special topic essays, Macroscopic Phenomena (such as air pressure) are explained with Submicroscopic Phenomena (such as atoms bouncing off walls). These essays support the modern perspective by describing aspects of modern physics before they are formally treated in later chapters. Connections are also made between apparently disparate phenomena.

THINGS GREAT AND SMALL

Submicroscopic Collisions and Momentum

The conservation of momentum principle not only applies to the macroscopic world, it is also essential to our explorations of the substructure of matter. Giant machines hurl submicroscopic particles at one another and evaluate the results by assuming conservation of momentum (among other things). Figure 7.A shows a detector used in such experiments.

On the small scale, we find that particles and details of their properties invisible to the naked eye can be measured with our instruments, and models of the submicroscopic world can be constructed to describe the results. Momentum is found to be a property of all submicroscopic particles *including massless particles*, such as photons composing light. This hints that momentum may have an identity beyond mass times velocity. Furthermore, we find that the conservation of momentum principle is valid. We use it to analyze the mass and other properties of previously undetected particles, such as the nucleus of the atom and theexistence of quarks inside the nucleus itself. Figure 7.B illustrates how a particle scattering backward from another implies that its target is massive and dense. Experiments seeking evidence of quarks inside nuclei scattered high-energy electrons from protons (nuclei of hydrogen atoms). Occasionally, electrons scattered straight backward in a manner that implied a very small and very dense particle *inside* the proton—this is considered nearly direct evidence of quarks. The analysis, again, was based partly on the same conservation of momentum principle that works so well on the large scale.

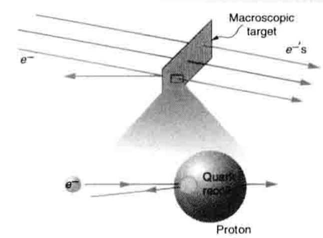


Figure 7.B A submicroscopic particle scatters straight backward from a target particle. In experiments seeking evidence for quarks, electrons were observed to occasionally scatter straight backward from a proton.

Figure 7.A A huge accelerator hurls tiny particles at one another to explore the submicroscopic world. The results of the collisions are measured with huge detectors such as this, and they are analyzed with the conservation of momentum principle, among others.

Summary *Chapter summaries* are thorough and functional and present all important definitions and numbered equations. Students are able to find the definitions of all terms and symbols as well as their physical relationships. The structure of the summary makes plain the fundamental principles of the chapter and will serve as useful study guides.

Index The *index* of this book is unique. It is more detailed and sophisticated, yet easier to use, than any other. There is significant cross-referencing, making it easy for readers to find what they seek. Index entries often tell a small story—for example, the name of a famous scientist is listed with a sublisting of what he or she is known for.

Glossary The *glossary* contains all relevant symbols, their meaning, and where they are defined in the text. The glossary thus enables students to take the first step in organizing their material by defining symbols and tracing their first use to help locate basic definitions.

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It is a pleasure to acknowledge the contributions of those who have helped shape this book. As mentioned earlier, the influence of my students has been profound. I have also benefited from interactions with many colleagues over many years. I thank all of you for the very important role you have played in the development of this book.

Most of the writing process is incredibly solitary, but there are junctures at which the direct input and work of others is not only enjoyed but absolutely crucial. There were many rounds of reviews during the writing of this book, producing invaluable advice ranging from general comments on organization to specific aspects of physics and modern teaching theory. A partial list of those who reviewed part or all of this text includes:

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To all of you I give my sincere thanks. Those errors that remain are entirely my own responsibility, and I will be happy to be informed about them.

Certain individuals merit special mention. Steve Yount solved almost every problem in the text, starting as a motivated student and finishing some years later as a physicist. Professor Gary Shoemaker of my own department also solved all of these problems giving them an added degree of accuracy. Also in my department, Professor Duane Aston classroom-tested part of the manuscript. The support and influence of my former editor, Rick Mixter, contributed to the successful completion of this text.

My deepest debt of gratitude is to my friends and family. All of them tolerated me and my preoccupation with this project over many years, gave me support in times of despair, and shared the moments of joy. In ways they may not realize, my parents, my wife's parents, and my children have carried me along. But my wife, Patty, has done more than anyone should expect or hope. I will be forever grateful.

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Paul Peter Urone

ABOUT THE AUTHOR

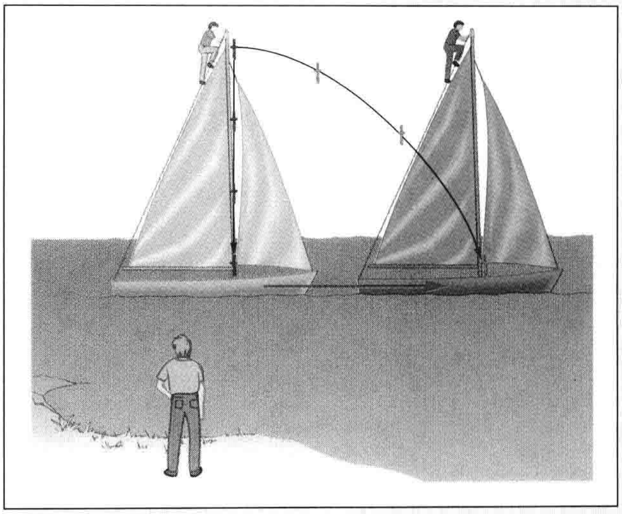
Paul Peter Urone (Peter, as he calls himself) is a professor of physics at California State University, Sacramento. Peter is a product of the Sputnik era, being in ninth grade when the space race began. Encouraged by the rush toward high technology, he received a bachelor's degree in physics from the University of Colorado in Boulder, where he later went on to earn his Ph.D. Following graduate school, he performed basic research in nuclear physics in The Netherlands, England, and at Stony Brook in New York before joining the faculty at CSU, Sacramento in 1973. After some years there he turned his attention to medical and biological applications of physics and authored the text *Physics with Health Science Applications*, now in its sixteenth printing.

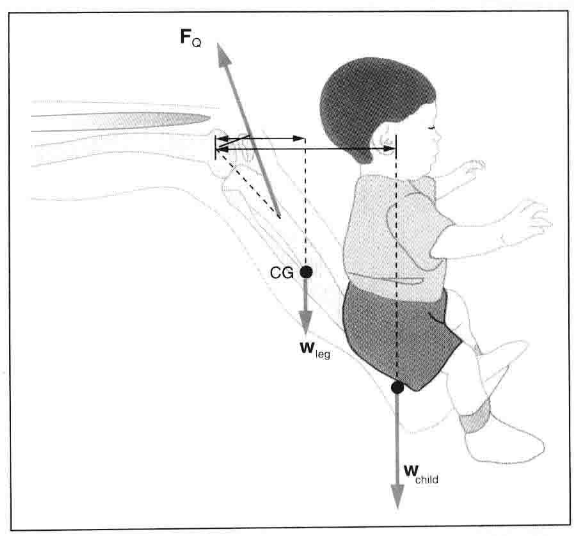
A dedicated teacher, Peter receives high marks from his students and considers himself a compulsive story teller. He firmly believes that the role of an educator is to inspire, motivate, and guide as well as to explain. Peter's greatest intellectual joy is in the beauty of physics and especially in being able to communicate that appreciation to others in a manner they find useful.

When not writing or teaching, Peter pursues his interests in ancient Greek coins, folk art, and Native American art. His true passion, however, is spending as much time as possible with his wife, Patty, and their two sons, Chris and Dustin.

BRIEF CONTENTS

CONTENTS





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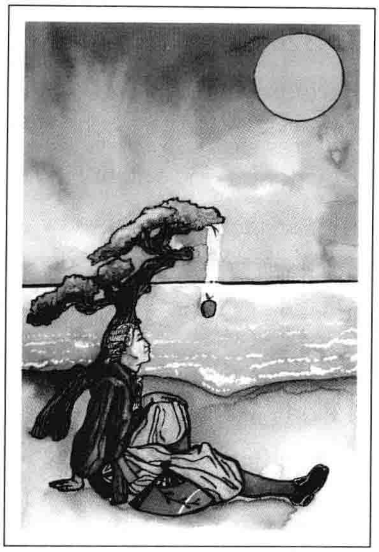

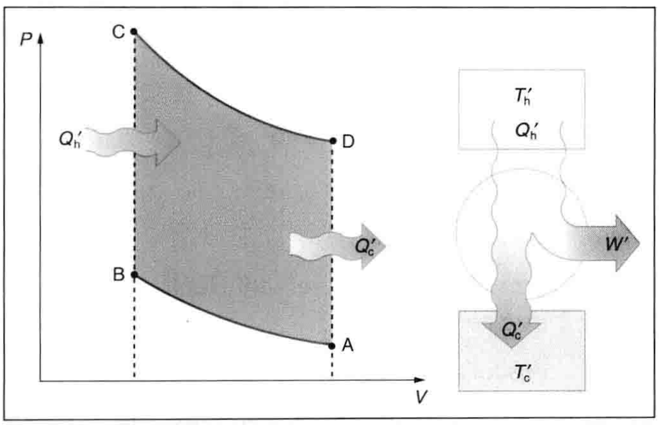
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