



国际著名物理图书

——影印版系列

2

Physics: Calculus
(Second Edition)

物理 (第2版) (上)

Eugene Hecht

以微积分为基础



清华大学出版社



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Physics: Calculus (Second Edition)

影印版序

本书是一本以微积分和矢量分析为数学基础的大学物理教材。全书共分 31 章,几乎覆盖了物理学的全部基本内容。从篇幅上看,经典物理的内容占四分之三,包括质点力学,转动,固体、液体和气体的力学性质,振动和波,热学,电磁学,几何光学和物理光学;近代物理的内容占四分之一,包括狭义相对论和量子物理,并对量子力学,量子电动力学,核物理和高能物理做了深入浅出的介绍。

本书对经典物理、狭义相对论和量子物理中的基本概念和基本原理讲解得都比较细致和深入。有些地方似乎进度较慢,但对问题论述得十分清晰。对近代和现代的内容,则主要是突出物理背景和介绍重要结果,而不是去罗列一些在大学物理层次上很难讲清楚的公式。例如,书中由相对论的能量和动量关系自然地引入反物质的概念,接着给出高能 γ 射线产生正、负电子对的径迹照片和正电子发射摄像 (PET) 的实物照片。在此基础上,通过介绍狄拉克和费曼的工作引进量子电动力学 (QED) 的概念。在介绍量子场论时,通过两个做弹性碰撞的电子在时间-空间的运动示意图,形象地引入费曼图。再利用能量和时间的不确定性关系,说明电子的弹性碰撞是交换虚光子的过程。书中还介绍了量子色动力学 (QCD),讨论了宇宙的起源等问题。

本书十分注意诸多教学要素的合理配置以及对学生学习方法的指导。书中对重要的知识点几乎都配有例题,每道例题都按示范性的五个步骤求解,并通过其他方法对所得结果做“快速核对”。每章后面都给出了内容提要和学习指导,以及讨论题、选择题和大量的习题。

本书鼓励学生课后自学,作者在序言中告诉学生:课后自学是你大部分知识的来源。随书提供的光盘,就是供学生自学和深入学习的电子教材。按照书中的提示操作光盘,可以看到对相关知识点的深入讨论和对扩展内容的介绍以及对相关习题的互动式讨论和详细解答。

本书的作者主张少用高深的数学,重点讲解基本概念和基本原理。书中用到某些数学时都预先简要地做了讲解,书后还附有简明的数学附录。因此,对正在学习微积分的学生(相当于我国的大学一年级)本书也是适用的。

本书的一个突出特点是联系实际,几乎针对所有的概念和理论都列举了有关自然现象、研究成果、技术应用和日常生活的实例,并配有数据表、曲线、示意图或实物照片。许多例题和习题都取材于实际问题,题目中的数据都是真实的数据。

近年来,国内许多院校都开展了大学物理双语教学。双语教学可以采用不同的教学模式,但都要使用原文教材。我认为,本书是一本适合我国 120 学时(两个学期)左右大学物理双语教学的优秀教材。对于使用中文教材学习大学物理的学生和讲授大学物理的教师,也有很好的参考价值。

陈信义

清华大学物理系

2004 年 10 月

PREFACE

Physics is the study of the material Universe—all there *is*. And that's a bold and wonderful agenda. The Universe is incredibly awesome and tantalizingly mysterious, and we, after all, are just beginning to understand it. Almost 3000 years in the making, physics—incomplete as it is—stands as one of the great creations of the human intellect. It has been a privilege and an unending joy to have spent much of my life studying physics, and it is out of gratitude and admiration that this book takes its form. If this work transmits a sense of the grandeur, unity, and vitality of the subject, it will have met its most important objective.

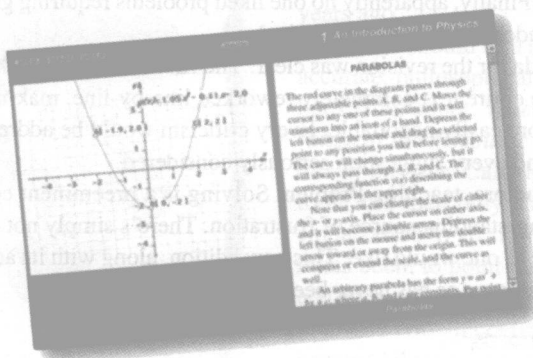
Designed for the calculus-based Introductory Physics course, this book contains the standard range of material from kinematics to quantum mechanics. It is predicated, however, on the belief that it's time to return to fundamentals; today's texts have become too mathematical and too advanced. By contrast, this work limits the associated math to basic calculus and very basic vector analysis. It omits a variety of obscure topics and instead uses its facilities to transmit a deeper understanding of the fundamentals of modern-day physics. It covers all the grand insights, but with a self-restraint that stops short of examining every possible side issue. As a result the book progresses at a slower pace and provides much more support in the process.

To the Student

The text assumes that students come with only a modest knowledge of algebra, geometry, and trigonometry. It presumes that readers are now studying or have already studied calculus, but might retain little more than a cloudy memory of that experience. Of course, the derivative of x^2 equals $2x$, even though one might not remember exactly what a derivative is. Accordingly, *whatever mathematics is required will be retaught, in place, as needed*. There's an extensive math **appendix**, and it's a good idea to review it as soon as you can.

Once class is over for the day, you're essentially on your own and that's when much of the learning has to take place. To help that process, this second edition has been integrated with an accompanying **CD-ROM**, created by the author to be **your personal tutor**. This CD is a major extension of previous versions that have been developed over the last five years. It's the latest in an ongoing effort to create a powerful electronic tutor that will be there for you, whenever you need it.

For some, the hardest part of this course will be mastering problem solving. The CD-ROM was designed to teach you everything you need to know to get the job done. In each chapter, "play" with the simulations called **INTERACTIVE EXPLORATIONS**, making sure you understand the operative principles; go over the interactive multiple choice questions, or **WARM-UPS**, until you feel comfortable with the basics; and then study the detailed step-by-step problem analyses, the **WALK-THROUGHS**. Working at your own pace, you will learn how to approach any problem: where to begin, how to organize your thoughts, how to proceed, what the pitfalls are, and even what you should be thinking along the way. After doing all of that for a given topic, revisit the appropriate Examples in the textbook, and only then turn to the Problems. The CD-book package is an effective learning system—make use of it.



To the Instructor

The Basis of this Revision

Because the first edition of *Physics: Calculus* was very well received (e.g., see the review in *Physics Today*, April 1997), attention was soon turned to evaluating and enhancing the teaching effectiveness of the book with a second edition in mind. To that end, we began to communicate with hundreds of its users—both faculty and students.

During the next several years it became clear that the first edition had both assets and shortcomings. On the positive side: The illustrations, all conceived by the author, supported the physics in a uniquely effective way. The writing style, humor, and candor were also praised. The clarity and rigor of the exposition, as well as the error-free presentation, were all important. The Problem Sets got high grades, particularly because of the inclusion of “real-life” data and situations. The **Quick Checks** and **Selected Solutions** in the back of the book were touted by students. The **Multiple Choice Questions** proved to be a big help to those taking exams in that format (e.g., the MCAT). The vast majority of respondents agreed that the history of ideas made the physics far more approachable and the book more enjoyable. The integration of modern physics throughout the text was a necessary and welcomed advance.

On the other hand, because conceptual and motivational materials were integrated into the body of the discussion, some students had difficulty discerning what was important. The absence of \hat{i} , \hat{j} , \hat{k} unit basis vectors was frequently described by teachers as a shortcoming they had to work around. The inclusion of arrows over symbols (e.g., \vec{F}) to indicate vectors was strongly recommended. A substantial number of instructors wanted “just a bit more use of calculus.” Putting conservation of momentum before $F = ma$, although more in keeping with the modern perspective, was widely felt to be pedagogically less effective. Similarly, treating angular momentum immediately after linear momentum postponed the discussion of energy, and many preferred the more traditional sequence. The majority of instructors would have been happier with a little less Statics (formerly Chapter 6) and even less material on Solids (formerly Chapter 10). Dealing with the propagation of light—reflection and refraction—from the modern perspective of atomic scattering was appreciated, but the treatment was not as clear as it could have been. The Problem Sets were deliberately organized without overt reference to specific sections. That made the selection of homework problems by instructors a bit of a nuisance. A few problems needed to be rewritten to make sure they were unambiguous. Finally, apparently no one liked problems requiring gratuitous unit conversions (even if students do need the practice).

The basic agenda for the revision was clear: The first half of the book would have to be reorganized and the entire text completely reworked line-by-line, making it tighter, faster to the point, and more easily negotiable. Every criticism would be addressed, every shortcoming corrected and every suggestion seriously considered.

For most instructors, teaching Problem Solving is a preeminent concern and, more often than not, a long-standing source of frustration. There’s simply not enough class time to do the job as well as one would like. This new edition, along with its accompanying CD-ROM, addresses that issue as has never been done before.

Back to Basics

Over the last five decades the Introductory Physics course and the texts that support it have undergone a dramatic transformation. Prior to the Second World War a typical text dealt almost entirely with the discussion of concepts and principles; there were comparatively few equations, little analysis, and a small selection of straightforward problems. The math-

356 CHAPTER 9 SOLIDS, LIQUIDS, & GASES

Stardust & You

An adult human being is a collection of over 10^{27} atoms bound together as $\approx 5 \times 10^{13}$ cells. We are a constantly changing aggregate of atoms, themselves created thousands of millions of years ago. The living cells are recent enough, though almost without exception the atoms that form us are at least as old as the Solar System and often much older than that. They have circulated around the Earth for the last four-and-a-half thousand-million years, through air and water, and through fish and fowl and trees and Whopper burgers and dung, and back to the soil and then, for the moment, to you. Formed in the thermonuclear fires of stars long gone, the atoms you ate for breakfast extend your lineage back in time to the dawn of creation. We are stardust, borrowers in the ancient ritual of “ashes to ashes.”

ematics was algebra with a touch of trigonometry—no calculus, no vector analysis. The war brought physics into a new social prominence, and even before it ended, calculus was finding its way into the introductory course. By the mid-1950s the distinction had been established between so-called College Physics (algebra/trig.-based) and University Physics (calculus-based). Standard treatises (e.g., *University Physics* by Sears and Zemansky, 2nd edition, 1955) fully embraced calculus. The rudiments of vector analysis entered the introductory discourse only in the early 1960s.

Driven by a seemingly endless supply of high-quality students, University Physics became increasingly more sophisticated mathematically, even as it remained philosophically naive and minimally developed conceptually. The tension between competing texts (e.g., *Physics for Students of Science and Engineering* by Halliday and Resnick, 1960) and a boundless optimism in the teaching community reshaped the next generation of books and the courses that used them. By 1970 serious difficulties were already cropping up and there was a token reduction in the “level of sophistication” (*Fundamentals of Physics* by Halliday and Resnick, 1st edition), but even the revised works were doing vector calculus by Chapter 3 and ranged well beyond the once-traditional bounds of the curriculum.

Today’s established texts are the end product of that rush toward analytic prowess that rolled on, untempered and unchallenged, across the 1970s and 1980s. A glance through any of these works will reveal a splendid but unintegrated mini-compendium of physics. Scattered among the foundational concepts (and undifferentiated from them) one can find a plethora of such unlikely items as the gradient operator in all its glory, a derivation of the partial differential wave equation, the relativistic Doppler effect, an analysis of forced oscillations, and the quantum mechanical treatment of a particle in a well. Any first-year graduate student should be pleased to have mastered the scope and depth of the material now proffered as Introductory Physics.

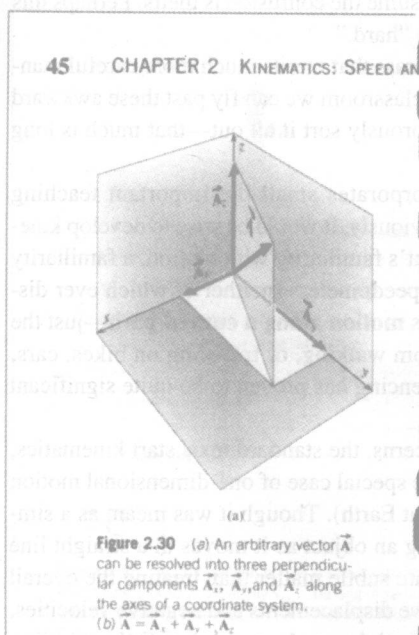
This state of affairs is only acceptable for a core cadre of highly motivated gifted students of the physical sciences. The clientele at the beginning of the twenty-first century is much broader than that, and these people are not at all well served by the standard texts of the day. Indeed, for many, these books are simply overwhelming, and that puts inordinate demands on the professor. From their earliest chapters these texts require a familiarity with vector analysis and calculus, something few undergraduates have at the time.

Consequently, at the very beginning of the experience, when students are most vulnerable, and when they should be concentrating on learning *how* to learn physics, they are asked to master mathematical machinery, albeit elegant machinery, that can easily be postponed until later on. Moreover, the standard texts seem to make the assumption that someone who is taking, or has taken, a course in calculus has learned calculus. With little or no additional preparation, they swiftly go on to incorporate vector calculus—something quite unheard of, even for physics majors, thirty or forty years ago.

There should be a realistic alternative, especially one that is thoroughly modern, accurate, philosophically mature, and pedagogically effective. And that’s what *this* book is all about. *Where appropriate, it restrains the mathematics and limits the range of the discourse so that it can focus on, elaborate, and teach the fundamentals of physics.* Calculus and vector analysis are both painstakingly developed as tools and then only used insofar as they illuminate the physics. This text is not embarrassed to go slowly; to justify where it is going; to stop to take stock of where it has been; to point out the marvelous unity of the subject; to skip obscure topics; and above all, to seem simple, indeed occasionally *to be* simple. Informed by an integrated twentieth century perspective and guided by a commitment to providing a conceptual overview of the discipline, *this book is a return to basics.*

Pedagogy

The present work has assimilated the important educational research findings of the last several decades. Its many innovations (e.g., in notation, graphics, topic order,



problem handling, and photography) have been extensively tested in classrooms throughout the world.

This text is rich in small but important teaching advances that are difficult to notice without actually using the book. For example, most textbooks write the scalar components of a two-dimensional vector $\vec{A} = \vec{A}_x + \vec{A}_y$, as

$$A_y = A \sin \theta \quad \text{and} \quad A_x = A \cos \theta$$

p. 35 where A is the always positive *magnitude* of \vec{A} . That's fine—we usually make sure to tell students that lightface symbols are the magnitudes of the corresponding vectors. Here, however, A_x and A_y can be positive or negative (depending on θ) and are *not* the magnitudes of the component vectors \vec{A}_x and \vec{A}_y , all of which is rather clumsy and confusing. In fact it's so confusing that one of the leading introductory physics texts defines A_x and A_y as is done above, and yet on the facing page actually calls them “magnitudes.” Just think of what must be going on in the mind of a student reading this for the first time.

p. 44 The problem only gets worse in kinematics. After all, **speed** (v) is the magnitude of the **velocity** (\vec{v}), which is a vector quantity. One cannot have a negative speed, and so what shall we call -10 m/s? And what symbol shall we give it? It isn't v , and by definition, without an explicit direction it certainly isn't \vec{v} . Surely, -10 s is a scalar, just as -10 m/s is a scalar. The majority of books deliberately ignore the issue, but inevitably write the equations of constant acceleration and present formulas such as $v = v_0 + at$. Here v , which can be positive or negative, isn't the *speed* despite the fact that it's a lightfaced letter (and therefore supposedly the magnitude of \vec{v}). At this point without addressing, or even acknowledging, the problem, texts simply call v the “velocity.” The student, who is new to all of this, may well conclude that since vectors are boldfaced, “velocity” is now a scalar.

The muddle continues with angular velocity. Another leading text in the field rightly tells the reader that ω “can be either positive or negative,” but five pages later it calls v , in the seminal equation $v = r\omega$, “the linear speed (the magnitude of the linear velocity).” Obviously, v is *not* linear *speed*! Ah, but by the time we get to wave motion, where we traditionally write $y = f(x \pm vt)$, all is well because now v is linear *speed*! Remember that the original rationale for calling v “velocity” was that the motion was one-dimensional. Well, it's one-dimensional here where v is speed. What the student will make of this logical conundrum is anyone's guess; most will quietly assume the confusion is theirs. Perhaps this is partly why physics has a reputation for being so “hard.”

Clearly this whole matter is a pedagogical morass that merits much more careful management than it's gotten thus far. Although in the classroom we can fly past these awkward little moments, a textbook must patiently and rigorously sort it all out—that much is long overdue!

As another example of how this book incorporates small but important teaching advances, consider a related kinematical issue. Obviously, it would be wise to develop kinematics in a way that takes advantage of the student's familiarity with motion, a familiarity predicated on automobiles with odometers and speedometers (neither of which ever displays a negative value). Thus Chapter 2 first treats **motion along a curved path**—just the kind of motion we all know about intimately from walking, or traveling on bikes, cars, trains, boats, and planes. This small shift in sequencing has proven to be quite significant pedagogically.

By contrast, out of purely mathematical concerns, the standard texts start kinematics, *as they have for well over half a century*, with the special case of one-dimensional motion (something that would be unrealistic even on a flat Earth). Though it was meant as a simplification, it turns out to be a poor idea. Locating an object as it moves in a straight line using its *displacement* from the origin is a far more subtle matter than treating the overall *distance* it traveled. That approach leads to negative displacements and negative velocities, which, to the modern traveler, are counterexperiential—students do very little traveling backwards and never use displacement or velocity meters. As we've seen, because they're

treating one-dimensional motion, these texts go on to completely blur the difference between speed and velocity. In the effort to immediately develop a sophisticated vector description, much of the physics often gets lost. Far better and more intuitive to begin with two-dimensional motion specified by the scalar path-length along a curve (using distance and speed), and once that's mastered, to move on to the vector notions of displacement and velocity.

Another important pedagogical improvement is in **notation**. Consider the needless confusion engendered by the choice of symbols in most introductory texts. How many different symbols are used for force— F , f , w , W , N , T , R —in any one book? How could that not be confusing to the uninitiated? This text uses one symbol for force, F . There are tensile forces F_T , normal forces F_N , reaction forces F_R , weight forces F_w , friction forces F_f , elastic forces F_e , electrical forces F_E , and so on. When a student sees F representing a physical quantity anywhere in this book, it is force. In the same way, W is work, nothing else.

This small list only touches on some of the important pedagogical concerns dealt with in this edition; there are dozens more. For example, what's the surprising problem with the Work-Energy Theorem as it's usually applied in contemporary textbooks? When you jump, does the floor do work on you to change your KE? If work is force times displacement, is zero work done against friction when you drag a load back to where you started and $s = 0$? If planes fly via Bernoulli, how do they fly upside down? How does the E -field manage to propel an electric current through bends in a wire? Why is most of the sky really blue? If photons can only exist at c , what is the index of refraction? Is mass still a function of speed? And so on.

Pacing & Support

The Introductory Physics course makes a wide range of demands on the student, and the experienced instructor knows that the first few weeks of the semester can be crucial. With that in mind, the material of kinematics has been rearranged to introduce the physics more gradually and allow time for the ideas to be assimilated. Consequently, Chapter 2 deals only with the physical concepts of speed, displacement, and velocity. The explanations are elaborate, and there are many examples, graphs, and illustrations. Acceleration comes later, in Chapter 3.

Anticipating that a successful development of calculus requires a substantial mathematical foundation, Chapter 1 contains a preparatory section (p. 16) on graphs and functions. And that's backed up on the companion CD-ROM with a great interactive simulation called **PARABOLAS & STRAIGHT LINES**, and a set of **WARM-UPS** called **GRAPHS & FUNCTIONS**.

The basic idea of differentiation is introduced in Chapter 2 (pp. 33–34) and methodically developed. A selection of problems (pp. 64–65) and an extensive appendix (p. A-13) assist the effort. Further support is provided on the CD-ROM by a group of basic interactive multiple choice questions; just click on **WARM-UPS** in **CHAPTER 2** and select **DIFFERENTIATION**.

The concept of vectors appears for the first time as it relates to displacement (pp. 35–38). It is justified, made logically appealing, and illustrated with explanatory diagrams you'll see nowhere else (pp. 53 and 57). To help establish a basic working knowledge, the CD-ROM contains two sets of **WARM-UPS**, one entitled **VECTORS** and the other **UNIT VECTORS**. Moreover, there are two especially helpful interactive simulations—**VECTOR COMPONENTS** and **VECTOR ADDITION**—on the CD.

Only after the student has presumably worked out dozens of problems and has begun to learn how to learn physics, do we turn to Chapter 3 and acceleration. By the time the equations of uniform acceleration are reached, the typical reader is much better able to deal with what's involved. In con-

57 CHAPTER 2 KINEMATICS: SPEED AND VELOCITY

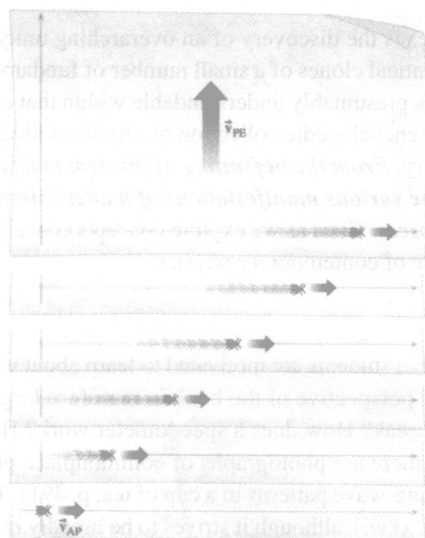


Figure 2.45 An ant walking across a sheet of paper that is itself being moved at a velocity \vec{v}_{PB} . The bug is carried along with the paper so that it moves northeast with respect to the Earth at a velocity \vec{v}_{AB} .

- p. 76
p. 83
p. 96
p. 102

trast to standard treatments that roar through integral calculus in the first fifty pages or so, *this book derives the equations of constant acceleration without recourse to calculus and then leisurely introduces integration after the student has had ample opportunity to assimilate the physics.*

With the mathematics of trigonometry, vector algebra, and calculus in place, and with a more realistic understanding of the demands of the experience, the serious student is then ready to move ahead more rapidly.

The Utility of History

Historical materials are incorporated in the book for a variety of reasons. For instance, when details of the lives of any of the great scientists are given, it is with an eye toward making these larger-than-life figures less intimidating (e.g., p. 84 on Galileo, or p. 116 on Newton) and their work a little more approachable. In a similar vein, *the book is responsive to the significant contribution made by women in physics.* It highlights the accomplishments of such outstanding twentieth-century scientists as Amalie Noether, Maria Goeppert Mayer, and Lise Meitner, among many others.

Most importantly, the text follows a historical approach whenever doing so allows the physics to unfold more clearly. The **history of ideas** is examined in order to make those ideas more immediately accessible. Once the student learns what Buridan (1330) was thinking about when he conceived the notion of momentum, the concept instantly becomes understandable: mv makes sense. The brilliant idea of *Conservation of Momentum* came out of Descartes's metaphysical musings in a way that's perfectly reasonable, though no one would call it physics. Having

read why Huygens was unhappy with Descartes's momentum, and why he squared the v as an alternative (thereby discovering a new conserved quantity), the concept of kinetic energy comes alive.

A Modern Approach

The central glory of twentieth-century physics is the discovery of an overarching unity in Nature. All matter is composed of myriad identical clones of a small number of fundamental interacting particles. Everything physical is presumably understandable within that context. Thus, to treat the subject as if it were an encyclopedic collection of unrelated ideas is to miss the whole point of the twentieth century. *From the beginning of this text to its end we study the unity of natural phenomena, the various manifestations of matter interacting with matter via the fundamental Four Forces.* Even as we explore concepts conceived centuries ago, we bring to bear the perspective of contemporary physics.

Practical Emphasis

A driving force shaping this text is the belief that students are motivated to learn about what directly affects their lives and concerns. The perspective of the book is therefore largely practical: How do we walk? Why do bones break? How does a speedometer work? How can we make a battery? Throughout the text there are photographs of commonplace phenomena that usually go unnoticed (e.g., standing-wave patterns in a cup of tea, p. 491). The work is rich in life-science applications (see p. xxvii), although it strives to be broadly interdisciplinary. If the textbook does its job in this regard, the instructor should never even hear that forlorn and exasperating question, "Why do I have to take this course?"

A new feature called **EXPLORING PHYSICS ON YOUR OWN** consists of easy-to-do home experiments that can be performed without any special equipment (e.g., adiabatic cooling

126 CHAPTER 4 NEWTON'S THREE LAWS: MOMENTUM

Momentum

The realization that speed alone fails to give us some essential aspect of the motion of an object goes back to Jean Buridan, working around 1330. He was trying to understand why an iron ball of the same size as a wooden one would travel much farther when both were launched at the same speed. Or, equivalently, why you would rather be hit by a firefly traveling at 60 km/h than by a fire engine at the same speed. Buridan reasoned that the crucial concept was the product of the mass (Section 1.4) and the speed. The "drive" that a moving body has—that ability to plow along—cannot be attributed to its speed alone (the firefly has the same speed as the fire engine). The "true measure of motion" was a new basic quantity, the product of *mass* (m) and *speed*. The more mass a body has the greater its inertia, and the more difficult it is to alter the way it's moving; it's a lot harder to change the motion of a fire engine than a firefly.

The idea, though somewhat muddled, was picked up by Galileo who called it *momentum*.

p. 236



Standing waves revealed by particles aligned in rows at the bottom of a cup of tea.

319 CHAPTER 8 ROTATIONAL MOTION



EXPLORING PHYSICS ON YOUR OWN

Your Center-of-Gravity: (a) Sit back upright in a straight chair with your legs touching the floor just in front of the chair. Where is your $c.g.$? Without shifting your position, can you stand up? Explain. How do you get up from a chair? Note that if the seat is too low, your legs will be bent and that decreases the strength of the muscles, making it seem harder to raise your $c.g.$ (b) Now stand, feet flat on the ground, with your back and heels against a wall. Try to touch your toes. Explain why you cannot do it. (c) Face the edge of an open door. Place one foot on each side of the door so that both feet extend somewhat beyond the edge against which you are resting your nose. Try to stand up on your toes. Explain what's happening. (d) To crudely locate your $c.g.$, stand rigid, hands at sides, and slowly lean forward until the upward normal force can just pass through your $c.g.$ —any farther and you fall over. Now do it again leaning right or left. Your $c.g.$ is where the lines-of-action of the normal forces intersect.

using a rubber band, p. 582, or the effect of air drag on a projectile, p. 99). These allow students to personally experience how the physical concepts under study relate to everyday phenomena.

The careful reader will likely detect that the author, who earned an undergraduate degree in engineering physics and was a practicing engineer for several years, still takes endless delight in exploring how things work. The text has a subtle engineering sensibility (e.g., Table 4.6, p. 159 or p. 435) that also embraces bioengineering concerns (e.g., p. 153 or p. 420).

Problem Solving

Every physicist who has ever taught this course has heard the universal student lament, “I understand everything; I just can’t do the problems.” Nonetheless, most instructors believe that “doing” problems is the culmination of the entire experience. This edition (along with its CD-ROM) goes considerably further than any other text has ever gone in systematically addressing this challenge.

Five-Step Approach to Problem Solving Every worked **EXAMPLE** in the book and every **WALK-THROUGH** on the CD now follows the same Five-Step Approach that is based on contemporary pedagogical research and discussions with hundreds of teachers. (It’s described in detail on page 24.) For instance, the first step is the **TRANSLATION** in which the problem is restated in generic scientific prose. This forces students to read the problem carefully and organize their thoughts before jumping in. It strips off the extraneous and trains students to extract the essential aspects of the problems. It overcomes the “same-problem syndrome” in which the same question, written once in terms of a running chicken, and then again in terms of a speeding locomotive, is perceived as two totally different problems. All such variations have the same translation. Finally, it allows for the easy transition to a symbolic representation in step two: **GIVEN & FIND**.

The Five-Step Approach carries students from one necessary phase of the analysis to the next, providing the organizational framework that so many desperately need. Classroom testing during the last five years has proven the efficacy of the method and shown that it is tremendously helpful for the book to approach every solution in the same systematic way.

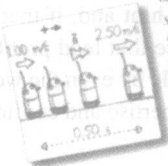
To encourage students to draw diagrams and, indeed, to teach them how to do it, the text and the CD-ROM contain hundreds of pieces of new “sticker art.” These illustrate how to transform a verbal statement into a simple visual one.

More than 500 new problems have been added to the book. Additionally, there are several hundred more new problems on the CD-ROM, all of which are provided with complete solutions.

Quick Checks All of the **EXAMPLES** in the text and the **WALK-THROUGHS** on the CD end with a **QUICK CHECK**. This teaches a wide variety of verification methods and establishes the habit of checking one’s work.

73 CHAPTER 3 KINEMATICS: ACCELERATION

Example 3.1 (1) A yellow messenger robot is traveling at 1.00 m/s in a straight line along a ramp in a spaceship. If it speeds up to 2.50 m/s in a time of 0.50 s, what is the magnitude of its average acceleration?



Solution: (1) **TRANSLATION:** An object changes from an initial to a final speed over a known time interval; determine its average acceleration. (2) **GIVEN:** $v_i = 1.00 \text{ m/s}$, $v_f = 2.50 \text{ m/s}$, and $\Delta t = 0.50 \text{ s}$. **FIND:** a_{avg} . (3) **PROBLEM TYPE:** Average acceleration; straight-line motion.

(4) **PROCEEDING:** We have v_i , v_f , and Δt and must find a_{avg} , the definition of a_{avg} . Eq. (3.2), relates all four quantities. (5) **CALCULATION:**

$$a_{\text{avg}} = \frac{\Delta v}{\Delta t} = \frac{2.50 \text{ m/s} - 1.00 \text{ m/s}}{0.50 \text{ s}}$$

and

$$a_{\text{avg}} = 3.0 \text{ m/s}^2$$

Quick Check: Put $a_{\text{avg}} = 3.0 \text{ m/s}^2$ back in Eq. (3.2) whereupon $\Delta v = a_{\text{avg}} \Delta t = (3.0 \text{ m/s}^2)(0.50 \text{ s}) = 1.5 \text{ m/s}$ and that checks out.

(For more worked problems check out **WALK-THROUGHS** on the CD.)

Problem-Solving Aids Every chapter includes a section called **Suggestions on Problem Solving** that explores techniques applicable to those particular problems. It may also contain approximation methods as well as discussions of the pitfalls and common errors specific to the material at hand. For example, a common error in kinematics is to compute the average speed of a uniformly accelerating object using $v_{av} = \frac{1}{2}(v - v_0)$ rather than $v_{av} = \frac{1}{2}(v + v_0)$; students are appropriately cautioned.

Core Material & Study Guide Each chapter ends with a section called **CORE MATERIAL & STUDY GUIDE**. This is an in-depth summary of what's important if one is to be able to do the problems: it outlines what should be studied and reread, which **EXAMPLES** should be given special attention, and so forth.

Discussion Questions All chapters contain a selection of discussion questions designed to develop and extend the conceptual understanding of the material.

Multiple Choice Questions A group of roughly 20 multiple choice questions similar to those found on national medical (MCAT) and optometry (OATP) school entrance exams is included in each chapter. Among other types, these comprise single-concept calculational questions as well as probing conceptual questions. In addition to those, the CD-ROM contains hundreds of interactive multiple choice questions designed to establish a base level of competence—just click on **WARM-UPS** in any chapter. More and more universities are using multiple choice questions on examinations, and *this is the only text at this level that provides the student with a sample of the genre.*

Problem Level An extensive selection of problems, most built on real data and referring to actual situations, is provided at the end of each chapter. An instructor will find a wealth of choices from which to assign homework. The Problem Sets are arranged in three levels of increasing difficulty (indicated by the symbols [I], [II], and [III], respectively) and always include a large selection of single-concept problems that explore one idea at a time (from several perspectives) to help students establish a strong foundation of competence and confidence with the basics.

The type and level of the calculus-based problems are indicated via the designations [c], [cc], or [ccc], respectively. *The student is carefully guided through some of the more demanding problems by a variety of Hints.* This is an important and unique feature of this book. It allows someone who is less well prepared to nonetheless experience the methodology of calculus.

Solutions *Approximately 15 percent of the end-of-chapter problems are worked out succinctly at the back of the book in order to encourage and strengthen independent study.* (These problems are indicated by a boldface numeral.) Another 10 percent of the solutions are provided in a student solutions manual, which is available at the instructor's request to the bookstore. (These problems are indicated by an italic numeral.)

Confidence Builders The end-of-the-chapter Problem Sets now contain special groupings, each consisting of three very similar problems, which are set off in color. The first in each such group has an elaborate hint and, if that's not enough, there's a solution in the back of the book. Once that lead problem is mastered, the next two in the group should be manageable by even the weakest student. This is yet another mechanism to help build expertise and confidence.

The CD-ROM: Your Personal Tutor


Every text has limited resources; there are just so many pages. Discussions must be cut short and topics have to be excluded. Although it would be won-

- ($4.00\hat{i} + 7.21\hat{j}$) in SI units. What is the net external force acting on the particle at $t = 2.00$ s?
17. [II] A youngster having a mass of 50.0 kg steps off a 1.00-m-high platform. If she keeps her legs fairly rigid and comes to rest in 10.0 ms, what is her momentum just as she hits the floor? What average force acts on her during the subsequent deceleration? [Hint: Use the fact that she falls with a constant acceleration to compute her impact speed.]
18. [III] A 20.0-kg ball of wet clay drops off a workman's scaffold and falls for 4.0 s before hitting the ground. If it comes to rest in 5.0 ms, what average force did the floor exert on the clay? Use momentum considerations to solve the problem.
19. [III] A 47-g golf ball is hit into the air at 60 m/s. It lands in sand at the same elevation and comes to rest in 10 ms. Ignoring air friction, what was the average force the sand exerted on the ball?
20. [III] A golf ball with a mass of 47.0 g can be blasted from rest to a speed of 70.0 m/s during the impact with a clubhead. Taking that impact to last only about

derful if the book could take all students by the hand and walk them through the analysis of two or three hundred additional problems—exploring the logic and pointing out the pitfalls in each—that’s simply not possible in the textbook format. Ergo, the CD-ROM.

This second edition comes with a free CD that complements and extends the book. If you’d like to see an in-depth discussion of the gyroscope, or read a complete derivation of the Thin Lens Equation, or learn how a refrigerator works (and a great deal more) it’s there, fully illustrated; just click on **FURTHER DISCUSSIONS** on the CD.

Even more importantly, the CD continues the problem-solving system with hundreds of interactive multiple choice questions (with complete solutions), the **WARM-UPS**, that establish the basic foundation of knowledge. These are followed by hundreds of completely worked out substantial problems, called **WALK-THROUGHS**. Students are taught how to “read” a problem, how to draw an appropriate diagram, and how to analyze that problem.

The CD-ROM also contains over forty marvelous simulations of key phenomena. These **INTERACTIVE EXPLORATIONS** are like having an elementary lab at your disposal. Students are encouraged to “play” with the simulations until they understand the principles involved. All references to the CD in the text are marked with a  icon.

Additional Changes and New Features

Boxed Material Discussions (philosophical insights, humorous anecdotes, etc.) that are not part of the main body of required material are now set off in green boxes. This allows for better readability and more direct access to the central discourse.

Integrated CD-ROM The text and CD-ROM form an effective synergistic whole. The student is advised to consult the CD at appropriate places throughout the book. Over forty wonderful simulations allow the reader to interactively explore many of the key physical principles.

Unit Basis Vectors $\hat{i}, \hat{j}, \hat{k}$ unit vectors are now used wherever appropriate.

Arrows over Vectors All vectors are now designated by boldface letters topped with a small arrow. That makes it much easier for students to work between their notes and the text.

More Calculus Without appreciably raising the mathematical level of the treatment, the use of calculus has been cautiously extended.

Biomedical & Bioengineering Material By popular request the range of applications of physics to other disciplines has been enriched, especially when it comes to the life sciences and bioengineering.

Margin Call-Outs To help the student immediately recognize the key points and definitions within the discussion, the book now has margin call-outs (with arrows leading back to the appropriate text) where the idea is restated in a succinct summary fashion.

New Drawings & Photographs There are dozens of new drawings and photographs.

A Complete Ancillary Package


The following comprehensive teaching and learning package accompanies this book.

For the Student

Student Solutions Manual Written by Jerry Shi and Eugene Hecht, this manual includes answers to selected odd-numbered discussion questions, answers to odd-num-

13.1 Heat and Temp

In previous chapters, we c
object that moved or inte
dealing with organized, or
ordinated motions to the i
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sessed by the group of pa

If we throw an apple
will have an increased ar
apple will show no change
whole in an ordered fashi
some of that organized KE
{For the origins of this in
CD.) 

Thermal energy is the internal KE
associated with the random motion of
the submicroscopic particles (atoms,
molecules, ions, and free electrons)
that constitute a system.

bered multiple choice questions, and solutions to selected odd-numbered problems (approximately 10%) not already solved in the book.

Study Guide with Additional Calculus Problems This student guide provides step-by-step strategies for solving calculus-based physics problems, as well as an extensive collection of exercises, solutions, and answers.

Your Personal Tutor for PHYSICS: Calculus This interactive CD-ROM, fully integrated with the text, teaches vital problem-solving skills. **WARM-UPS** get students started by reviewing key ideas and establishing basic knowledge; **INTERACTIVE EXPLORATIONS** help students visualize and learn physical concepts; **WALK-THROUGHS** expertly guide students through typical problems found on examinations; and **FURTHER DISCUSSIONS** enrich understanding of the material.

Media Resource

Brooks/Cole Physics Resource Center This is Brooks/Cole's Web site for physics, which contains a homepage for *PHYSICS: Calculus, 2nd edition*. Students can access supplementary practice and conceptual problems, practice quizzes for every chapter, and hyperlinks that relate to each chapter's contents.

For the Instructor

Complete Solutions Manual Written by Jerry Shi and Eugene Hecht, this manual contains answers to all discussion questions, answers to all multiple choice questions, and solutions to all end-of-chapter problems in the text.

Test Items This feature includes more than 1,000 multiple choice and short-answer questions. The notation of the test items carefully follows that of the main text.

Instructor's Manual This manual contains suggested demonstrations, homework, chapter/lecture outlines, teaching hints, and a correlation chart of problems mapped to those in the first edition.

Thomson Learning™ Testing Tools This aid is a fully integrated suite of test creation, delivery, and classroom management tools on a cross-platform CD. It consists of three software programs—Test, Test Online, and Manager—that enable instructors to assess quickly and easily student performance. Instructors can design their own tests and tutorial feedback from the test items provided. Tests, practice tests, and quizzes created in Test can be delivered via paper, diskette or local hard drive, LAN (Local Area Network), or the Internet. All testing results can then be integrated into a multifaceted classroom management tool with scoring, gradebook, and reporting capabilities.

World Class Course Now you can quickly and easily create and update a World Wide Web page specifically for a course or class. Post your own course information, office hours, lesson information, assignments, sample tests and link to rich Web content.

Presentation Tools and Online Resources

Transparencies Acetate transparencies in full color include over 200 illustrations from the text, enlarged for use in the classroom and lecture halls.

CNN Physics Videos These videos, produced by Turner Learning, can stimulate and engage your students by launching a lecture, sparking a discussion, or demonstrating an

application. Each physics-related segment from recent CNN broadcasts clearly demonstrates the relevancy of physics to everyday life.

Brooks/Cole's PhysicsLink Creating lectures has never been easier with this cross-platform CD-ROM containing art from the text as well as that from other Brooks/Cole physics titles. Using multitiered indexing, search capabilities, and a comprehensive resource bank that includes glossary, graphs, tables, illustrations, and animations, instructors can conduct a quick search to incorporate these materials into presentations and tests. And any PhysicsLink file can be posted to the Web for easy student reference.

WebAssignOnline Homework This versatile, Web-based homework delivery system saves time grading and recording homework assignments and provides students with individual practice and instant feedback on their work. It delivers, collects, grades, and records text-specific customized homework assignments over the Internet. Assignments can be customized so that each student can receive a unique question to solve. Access to WebAssign is secured by passwords, and each student has access only to his or her record. WebAssign © 1998–99 by North Carolina State University.

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If you have any comments about this edition, suggestions for the next edition, or favorite problems you'd like to share, send them to E. Hecht, Adelphi University, Physics Department, Garden City, N.Y. 11530 (or genehecht@aol.com).

Eugene Hecht
Freeport, N.Y.

BRIEF CONTENTS

Volume 1

1	AN INTRODUCTION TO PHYSICS	1
2	KINEMATICS: SPEED & VELOCITY	25
3	KINEMATICS: ACCELERATION	71
4	NEWTON'S THREE LAWS: MOMENTUM	116
5	CENTRIPETAL FORCE & GRAVITY	181
6	ENERGY	222
7	MOMENTUM & COLLISIONS	269
8	ROTATIONAL MOTION	298
9	SOLIDS, LIQUIDS, & GASES	355
10	ELASTICITY & OSCILLATIONS	407
11	WAVES & SOUND	448
12	THERMAL PROPERTIES OF MATTER	503
13	HEAT & THERMAL ENERGY	535

14	THERMODYNAMICS	570
----	----------------	-----

Volume 2

15	ELECTROSTATICS: FORCES	609
16	ELECTROSTATICS: ENERGY	654
17	DIRECT CURRENT	698
18	CIRCUITS	727
19	MAGNETISM	758
20	ELECTROMAGNETIC INDUCTION	805
21	AC AND ELECTRONICS	841
22	RADIANT ENERGY: LIGHT	881
23	THE PROPAGATION OF LIGHT: SCATTERING	912
24	GEOMETRICAL OPTICS AND INSTRUMENTS	946
25	PHYSICAL OPTICS	993
26	SPECIAL RELATIVITY	1038
27	THE ORIGINS OF MODERN PHYSICS	1076
28	THE EVOLUTION OF QUANTUM THEORY	1104
29	QUANTUM MECHANICS	1136
30	NUCLEAR PHYSICS	1165
31	HIGH-ENERGY PHYSICS	1206