时代教育·国外高校优秀教材精选

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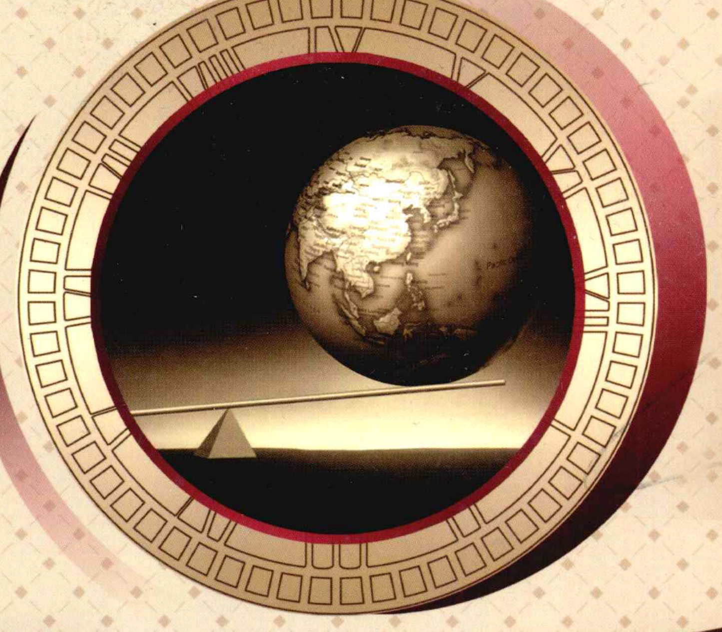
# University Physics with Modern Physics

# 现代大学物理

## （英文版）

（美） 沃尔夫冈·鲍尔 (Wolfgang Bauer)
加里 D.韦斯特福尔 (Gary D.Westfall) 著



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本书具有浓厚的现代气息，即把最新发展的科学技术纳入其中，注重介绍经典物理知识在高新技术中的应用，并与现实生产、生活紧密联系，同时将现代物理学的观点、概念和方法渗透其中，内容丰富，涉及面广，图文并茂，语言通俗易懂，既能让学生在自然清新、情趣盎然的氛围中开阔眼界，享受物理，又能让学生感受到经典物理在21世纪仍然焕发着勃勃生机，生活中到处都有物理，学习物理知识很有用，从而使物理知识的学习有的放矢。本书的这些鲜明特色对提高学生学习的积极性和主动性，培养学生科学的思维能力和创新能力具有重要作用。

本书主要内容有力学、圆周运动及转动、碰撞与波、电学、磁学、光学、相对论和量子物理等。本书部分章节（如经典部分的第12章，近代部分的第39章、第40章）与国内外许多教材相比内容偏深。

本书为高校理工科各专业学生的大学物理双语教学教材。因书中包含有丰富、实用的各类素材，所以也可作为广大物理教师非常好的教学辅助资源或参考书。

**Wolfgang Bauer & Gary Westfall**: ***University Physics with Modern Physics***
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随着我国加入WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社近期推出一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外优秀教材审定委员会。这些专家对实施双语教学作了深入细致的调查研究，对引进原版教材提出许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性严格把关，同时尽量考虑原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

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# About the Authors

**Wolfgang Bauer** was born in Germany and obtained his Ph.D. in theoretical nuclear physics from the University of Giessen in 1987. After a post-doctoral fellowship at the California Institute of Technology, he joined the faculty at Michigan State University in 1988. He has worked on a large variety of topics in computational physics, from high-temperature superconductivity to supernova explosions, but has been especially interested in relativistic nuclear collisions. He is probably best known for his work on phase transitions of nuclear matter in heavy ion collisions. In recent years, Dr. Bauer has focused much of his research and teaching on issues concerning energy, including fossil fuel resources, ways to use energy more efficiently, and, in particular, alternative and carbon-neutral energy resources. He presently serves as chairperson of the Department of Physics and Astronomy, as well as the Director of the Insitute for Cyber-Enabled Research.

**Gary D. Westfall** started his career at the Center for Nuclear Studies at the University of Texas at Austin, where he completed his Ph.D. in experimental nuclear physics in 1975. From there he went to Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California, to conduct his post-doctoral work in high-energy nuclear physics and then stayed on as a staff scientist. While he was at LBNL, Dr. Westfall became internationally known for his work on the nuclear fireball model and the use of fragmentation to produce nuclei far from stability. In 1981, Dr. Westfall joined the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) as a research professor; there he conceived, constructed, and ran the MSU $4\pi$ Detector. His research using the $4\pi$ Detector produced information concerning the response of nuclear matter as it is compressed in a supernova collapse. In 1987, Dr. Westfall joined the Department of Physics and Astronomy at MSU as an associate professor, while continuing to carry out his research at NSCL. In 1994, Dr. Westfall joined the STAR Collaboration, which is carrying out experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York.

**The Westfall/Bauer Partnership** Drs. Bauer and Westfall have collaborated on nuclear physics research and on physics education research for more than two decades. The partnership started in 1988, when both authors were speaking at the same conference and decided to go downhill skiing together after the session. On this occasion, Westfall recruited Bauer to join the faculty at Michigan State University (in part by threatening to push him off the ski lift if he declined). They obtained NSF funding to develop novel teaching and laboratory techniques, authored multimedia physics CDs for their students at the Lyman Briggs School, and co-authored a textbook on CD-ROM, called *cliXX Physik*. In 1992, they became early adopters of the Internet for teaching and learning by developing the first version of their online homework system. In subsequent years, they were instrumental in creating the Learning*Online* Network with CAPA, which is now used at more than 70 universities and colleges in the United States and around the world. Since 2008, Bauer and Westfall have been part of a team of instructors, engineers, and physicists, who investigate the use of peer-assisted learning in the introductory physics curriculum. This project has received funding from the NSF STEM Talent Expansion Program, and its best practices have been incorporated into this textbook.

**Dedication** This book is dedicated to our families. Without their patience, encouragement, and support, we could never have completed it.

# A Note from the Authors

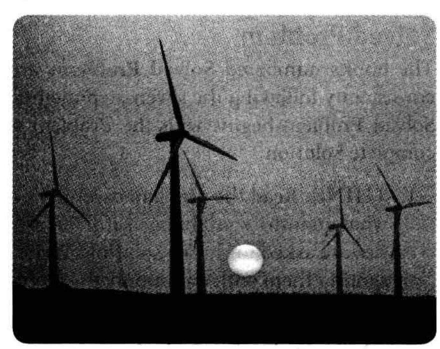
**Physics** is a thriving science, alive with intellectual challenge and presenting innumerable research problems on topics ranging from the largest galaxies to the smallest subatomic particles. Physicists have managed to bring understanding, order, consistency, and predictability to our universe and will continue that endeavor into the exciting future.

However, when we open most current introductory physics textbooks, we find that a different story is being told. Physics is painted as a completed science in which the major advances happened at the time of Newton, or perhaps early in the 20th century. Only toward the end of the standard textbooks is "modern" physics covered, and even that coverage often includes only discoveries made through the 1960s.

**Our main motivation to write this book is to change this perception by appropriately weaving exciting, contemporary physics throughout the text.** Physics is an exciting, dynamic discipline—continuously on the verge of new discoveries and life-changing applications. In order to help students see this, we need to tell the full, exciting story of our science by appropriately integrating contemporary physics into the first-year calculus-based course. Even the very first semester offers many opportunities to do this by weaving recent results from non-linear dynamics, chaos, complexity, and high-energy physics research into the introductory curriculum. Because we are actively carrying out research in these fields, we know that many of the cutting-edge results are accessible in their essence to the first-year student.

Authors in many other fields, such as biology and chemistry, already weave contemporary research into their textbooks, recognizing the substantial changes that are affecting the foundations of their disciplines. This integration of contemporary research gives students the impression that biology and chemistry are the "hottest" research enterprises around. The foundations of physics, on the other hand, are on much firmer ground, but the new advances are just as intriguing and exciting, if not more so. We need to find a way to share the advances in physics with our students.

We believe that talking about the broad topic of energy provides a great opening gambit to capture students' interest. Concepts of energy sources (fossil, renewable, nuclear, and so forth), energy efficiency, alternative energy sources, and environmental effects of energy supply choices (global warming) are very much accessible on the introductory physics level. We find that discussions of energy spark our students' interest like no other current topic, and we have addressed different aspects of energy throughout our book.



In addition to being exposed to the exciting world of physics, students benefit greatly from gaining the ability to **problem solve and think logically about a situation.** Physics is based on a core set of ideas that is fundamental to all of science. We acknowledge this and provide a useful problem-solving method (outlined in Chapter 1) which is used throughout the entire book. This problem-solving method involves a multi-step format that both of us have developed with students in our classes.

With all of this in mind along with the desire to write a captivating textbook, we have created what we hope will be a tool to engage students' imaginations and to better prepare them for future courses in their chosen fields (admittedly, hoping that we would convert at least a few students to physics majors along the way). Having feedback from more than 300 people, including a board of advisors, several contributors, manuscript reviewers, and focus group participants, assisted greatly in this enormous undertaking, as did field testing of our ideas with approximately 4000 students in our introductory physics classes at Michigan State University. We thank you all!

—*Wolfgang Bauer and Gary D. Westfall*

# Preface

*University Physics* is intended for use in the calculus-based introductory physics sequence at universities and colleges. It can be used in either a two-semester introductory sequence or a three-semester sequence. The course is intended for students majoring in the biological sciences, the physical sciences, mathematics, and engineering.

## Problem-Solving Skills: Learning to Think Like a Scientist

Perhaps one of the greatest skills students can take from their physics course is the ability to **problem solve and think critically about a situation.** Physics is based on a core set of fundamental ideas that can be applied to various situations and problems. *University Physics* by Bauer and Westfall acknowledges this and provides a problem-solving method class tested by the authors, and used throughout the entire text. The text's problem-solving method involves a multi-step format.

> "The Problem-Solving Guidelines help students improve their problem-solving skills, by teaching them how to break a word problem down to its key components. The key steps in writing correct equations are nicely described and are very helpful for students."
>
> —*Nina Abramzon, California Polytechnic University–Pomona*

> "I often get the discouraging complaint by students, 'I don't know where to start in solving problems.' I think your systematic approach, a clearly laid-out strategy, can only help."
>
> —*Stephane Coutu, The Pennsylvania State University*

### Problem-Solving Method

#### Solved Problem

The book's numbered **Solved Problems** are fully worked problems, each consistently following the seven-step method described in Chapter 1. Each Solved Problem begins with the Problem statement and then provides a complete Solution:

1. **THINK:** Read the problem carefully. Ask what quantities are known, what quantities might be useful but are unknown, and what quantities are asked for in the solution. Write down these quantities, representing them with commonly used symbols. Convert into SI units, if necessary.
2. **SKETCH:** Make a sketch of the physical situation to help visualize the problem. For many learning styles, a visual or graphical representation is essential, and it is often necessary for defining variables.
3. **RESEARCH:** Write down the physical principles or laws that apply to the problem. Use equations that represent these principles and connect the known and unknown quantities to each other. At times, equations may have to be derived, by combining two or more known equations, to solve for the unknown.

SOLVED PROBLEM 6.6 **Power Produced by Niagara Falls**

PROBLEM

Niagara Falls pours an average of 5520 $m^3$ of water over a drop of 49.0 m every second. If all the potential energy of that water could be converted to electrical energy, how much electrical power could Niagara Falls generate?

SOLUTION

**THINK**

The mass of one cubic meter of water is 1000 kg. The work done by the falling water is equal to the change in its gravitational potential energy. The average power is the work per unit time.

**SKETCH**

A sketch of a vertical coordinate axis is superimposed on a photo of Niagara Falls in Figure 6.22.

**RESEARCH**

The average power is given by the work per unit time:

$$\bar{P} = \frac{W}{t}.$$

The work that is done by the water going over Niagara Falls is equal to the change in gravitational potential energy,

$$\Delta U = W.$$

The change in gravitational potential energy of a given mass $m$ of water falling a distance $h$ is given by

$$\Delta U = mgh.$$

**SIMPLIFY**

We can combine the preceding three equations to obtain

$$\bar{P} = \frac{W}{t} = \frac{mgh}{t} = \left(\frac{m}{t}\right)gh.$$

*Continued—*

**CALCULATE**

We first calculate the mass of water moving over the falls per unit time from the given volume of water per unit time, using the density of water:

$$\frac{m}{t}=\left(5520\,\frac{\text{m}^3}{\text{s}}\right)\left(\frac{1000\text{ kg}}{\text{m}^3}\right)=5.52\cdot 10^6\text{ kg/s}.$$

The average power is then

$$\bar{P}=\left(5.52\cdot 10^6\text{ kg/s}\right)\left(9.81\text{ m/s}^2\right)\left(49.0\text{ m}\right)=2653.4088\text{ MW}.$$

**ROUND**

We round to three significant figures:

$$\bar{P}=2.65\text{ GW}.$$

**DOUBLE-CHECK**

Our result is comparable to the output of large electrical power plants, on the order of 1000 MW (1GW). The combined power generation capability of all of the hydroelectric power stations at Niagara Falls has a peak of 4.4 GW during the high water season in the spring, which is close to our answer. However, you may ask how the water produces power by simply falling over Niagara Falls. The answer is that it doesn't. Instead, a large fraction of the water of the Niagara River is diverted upstream from the falls and sent through tunnels, where it drives power generators. The water that makes it across the falls during the daytime and in the summer tourist season is only about 50% of the flow of the Niagara River. This flow is reduced even further, down to 10%, and more water is diverted for power generation during the nighttime and in the winter.

4. **SIMPLIFY:** Simplify the result algebraically as much as possible. This step is particularly helpful when more than one quantity has to be found.
5. **CALCULATE:** Substitute numbers with units into the simplified equation and calculate. Typically, a number and a physical unit are obtained as the answer.
6. **ROUND:** Consider the number of significant figures that the result should contain. A result obtained by multiplying or dividing should be rounded to the same number of significant figures as the input quantity that had the least number of significant figures. Do not round in intermediate steps, as rounding too early might give a wrong solution. Include the proper units in the answer.
7. **DOUBLE-CHECK:** Consider the result. Does the answer (both the number and the units) seem realistic? Examine the orders of magnitude. Test your solution in limiting cases.

## Examples

Briefer, terser **Examples** (Problem statement and Solution only) focus on a specific point or concept. The briefer Examples also serve as a bridge between fully worked-out Solved Problems (with all seven steps) and the homework problems.

**EXAMPLE 17.4** **Rise in Sea Level Due to Thermal Expansion of Water**

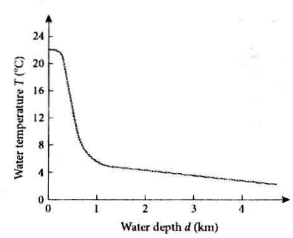



**FIGURE 17.22** Average ocean water temperature as a function of depth below the surface.

The rise in the level of the Earth's oceans is of current concern. Oceans cover $3.6\cdot 10^8$ km$^2$, slightly more than 70% of Earth's surface area. The average ocean depth is 3700 m. The surface ocean temperature varies widely, between 35 °C in the summer in the Persian Gulf and –2 °C in the Arctic and Antarctic regions. However, even if the ocean surface temperature exceeds 20 °C, the water temperature rapidly falls off as a function of depth and reaches 4 °C at a depth of 1000 m (Figure 17.22). The global average temperature of all seawater is approximately 3 °C. Table 17.3 lists a volume expansion coefficient of zero for water at a temperature of 4 °C. Thus, it is safe to assume that the volume of ocean water changes very little at a depth greater than 1000 m. For the top 1000 m of ocean water, let's assume a global average temperature of 10.0 °C and calculate the effect of thermal expansion.

**PROBLEM**

By how much would sea level change, solely as a result of the thermal expansion of water, if the water temperature of all the oceans increased by $\Delta T = 1.0$ °C?

**SOLUTION**

The volume expansion coefficient of water at 10.0 °C is $\beta = 87.5\cdot 10^{-6}$ °C$^{-1}$ (from Table 17.3), and the volume change of the oceans is given by equation 17.9, $\Delta V = \beta V\Delta T$, or

$$\frac{\Delta V}{V}=\beta\Delta T. \qquad \text{(i)}$$

We can express the total surface area of the oceans as $A=(0.7)4\pi R^2$, where $R$ is the radius of Earth and the factor 0.7 reflects the fact that about 70% of the surface of the sphere is

## Problem-Solving Practice

**Problem-Solving Practice** provides **Additional Solved Problems,** again following the full seven-step format. This section is found immediately before the end-of-chapter problems to provide a review and to emphasize the fundamental concepts of the chapter. Additional **Problem-Solving Strategies and Guidelines** are also presented here.

> "They provide a useful tool for students to improve their problem-solving skills. The authors did a good job in addressing, for each chapter, the most important steps to approach the solution of the end-of-chapter problems. Students that never had physics before will find this guideline quite beneficial. I liked in particular the connection between the guideline and the solved problem. The detailed description on how to solve these problems will certainly help the students to understand the concepts better."
>
> —*Luca Bertello, University of California–Los Angeles*

**PROBLEM-SOLVING PRACTICE**

**Problem-Solving Guidelines: Kinetic Energy, Work, and Power**

1. In all problems involving energy, the first step is to clearly identify the system and the changes in its conditions. If an object undergoes a displacement, check that the displacement is always measured from the same point on the object, such as the front edge or the center of the object. If the speed of the object changes, identify the initial and final speeds at specific points. A diagram is often helpful to show the position and the speed of the object at two different times of interest.
2. Be careful to identify the force that is doing work. Also note whether forces doing work are constant forces or variable forces, because they need to be treated differently.
3. You can calculate the sum of the work done by individual forces acting on an object or the work done by the net force acting on an object; the result should be the same. (You can use this as a way to check your calculations.)
4. Remember that the direction of the restoring force exerted by a spring is always opposite the direction of the displacement of the spring from its equilibrium point.
5. The formula for power, $P = \vec{F}\bullet\vec{v}$, is very useful, but applies only for a constant force. When using the more general definition of power, be sure to distinguish between the average power, $\bar{P}=\frac{W}{\Delta t}$, and the instantaneous value of the power, $P=\frac{dW}{dt}$.

**SOLVED PROBLEM 5.2** **Lifting Bricks**

**PROBLEM**

A load of bricks at a construction site has a mass of 85.0 kg. A crane raises this load from the ground to a height of 50.0 m in 60.0 s at a low constant speed. What is the average power of the crane?

**SOLUTION**

**THINK**

Raising the bricks at a low constant speed means that the kinetic energy is negligible, so the work in this situation is done against gravity only. There is no acceleration, and friction is negligible. The average power then is just the work done against gravity divided by the time it takes to raise the load of bricks to the stated height.

**SKETCH**

A free-body diagram of the load of bricks is shown in Figure 5.20. Here we have defined a coordinate system in which the $y$-axis is vertical and positive is upward. The tension, $T$, exerted by the cable of the crane is a force in the upward direction, and the weight, $mg$, of the load of bricks is a force downward. Because the load is moving at a constant speed, the sum of the tension and the weight is zero. The load is moved vertically a distance $h$, as shown in Figure 5.21.

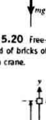



**FIGURE 5.20** Free-body diagram of the load of bricks of mass $m$ being lifted by a crane.

**RESEARCH**

The work, $W$, done by the crane is given by

$$W = mgh.$$

The average power, $\bar{P}$, required to lift the load in the given time $\Delta t$ is

$$\bar{P}=\frac{W}{\Delta t}.$$

**SIMPLIFY**

Combining the above two equations gives

$$\bar{P}=\frac{mgh}{\Delta t}.$$

**CALCULATE**

Now we put in the numbers and get

$$\bar{P}=\frac{(85.0\text{ kg})(9.81\text{ m/s}^2)(50.0\text{ m})}{60.0\text{ s}}=694.875\text{ W}.$$

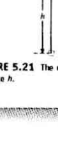



**FIGURE 5.21** The mass $m$ is lifted a distance $h$.

*Continued*—

## End-of-Chapter Questions and Problem Sets

Along with providing problem-solving guidelines, examples, and strategies, *University Physics* also offers a **wide variety of end-of-chapter Questions and Problems.** Often professors say, "I don't need a lot of problems, just a handful of really good problems." *University Physics* has both. The end-of-chapter Questions and Problems were developed with the idea of making them interesting to the reader. The authors, along with a panel of excellent writers (who, perhaps more importantly, are also experienced physics instructors) wrote Questions and Problems for each chapter, being sure to provide wide variety in level, content, and style. Included in each chapter are a set of Multiple-Choice Questions, Questions, Problems (by section), and Additional Problems (no section "clue"). One bullet identifies slightly more challenging Problems, and two bullets identify the most challenging Problems. The problem-solving theme from the text is also carried through to the Test Bank: The same group that wrote the end-of-chapter questions and problems also wrote the Test Bank questions, providing consistency in style and coverage.

### MULTIPLE-CHOICE QUESTIONS

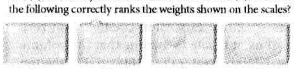
**13.1** Salt water has a greater density than freshwater. A boat floats in both freshwater and salt water. The buoyant force on the boat in salt water is ______ that in freshwater.

a) equal to  b) smaller than  c) larger than

**13.2** You fill a tall glass with ice and then add water to the level of the glass's rim, so some fraction of the ice floats above the rim. When the ice melts, what happens to the water level? (Neglect evaporation, and assume that the ice and water remain at 0 °C during the melting process.)

a) The water overflows the rim.
b) The water level drops below the rim.
c) The water level stays at the top of the rim.
d) It depends on the difference in density between water and ice.

**13.3** The figure shows four identical open-top tanks filled to the brim with water and sitting on a scale. Balls float in tanks (2) and (3), but an object sinks to the bottom in tank (4). Which of the following correctly ranks the weights shown on the scales?

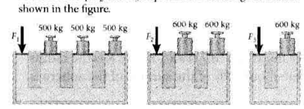



a) (1) < (2) < (3) < (4)  c) (1) < (2) = (3) = (4)
b) (1) < (2) = (3) < (4)  d) (1) = (2) = (3) < (4)

**13.4** You are in a boat filled with large rocks in the middle of a small pond. You begin to drop the rocks into the water. What happens to the water level of the pond?

a) It rises.
b) It falls.
c) It doesn't change.
d) It rises momentarily and then falls when the rocks hit bottom.
e) There is not enough information to say.

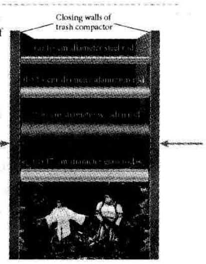
**13.5** Rank in order, from largest to smallest, the magnitudes of the forces $F_1$, $F_2$, and $F_3$ required for balancing the masses shown in the figure.




**13.6** In a horizontal water pipe that narrows to a smaller radius, the velocity of the water in the section with the smaller radius will be larger. What happens to the pressure?

a) The pressure will be the same in both the wider and narrower sections of the pipe.
b) The pressure will be higher in the narrower section of the pipe.
c) The pressure will be higher in the wider section of the pipe.
d) It is impossible to tell.

**13.7** In one of the *Star Wars*™ movies, four of the heroes are trapped in a trash compactor on the Death Star. The compactor's walls begin to close in, and the heroes need to pick an object from the trash to place between the closing walls to stop them. All the objects are the same length and have a circular cross section, but their diameters and compositions are different. Assume that each object is oriented horizontally and does not bend. They have the time and strength to hold up only one object between the walls. Which of the objects shown in the figure will work best—that is, will withstand the greatest force per unit of compression?




**13.8** Many altimeters determine altitude changes by measuring changes in the air pressure. An altimeter that is designed to be able to detect altitude changes of 100 m near sea level should be able to detect pressure changes of

a) approximately 1 Pa.
b) approximately 10 Pa.
c) approximately 100 Pa.
d) approximately 1 kPa.
e) approximately 10 kPa.

**13.9** Which of the following assumptions is *not* made in the derivation of Bernoulli's Equation?

a) Streamlines do not cross.
b) There is negligible viscosity.
c) There is negligible friction.
d) There is no turbulence.
e) There is negligible gravity.

**13.10** A beaker is filled with water to the rim. Gently placing a plastic toy duck in the beaker causes some of the water to spill out. The weight of the beaker with the duck floating in it is

a) greater than the weight before adding the duck.
b) less than the weight before adding the duck.
c) the same as the weight before adding the duck.
d) greater or less than the weight before the duck was added, depending on the weight of the duck.

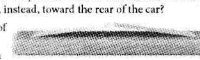
**13.11** A piece of cork (density = 0.33 g/cm³) with a mass of 10 g is held in place under water by a string, as shown in the figure. What is the tension, *T*, in the string?


a) 0.10 N  c) 0.30 N  e) 200 N
b) 0.20 N  d) 100 N  f) 300 N

### QUESTIONS

**13.12** You know from experience that if a car you are riding in suddenly stops, heavy objects in the rear of the car move toward the front. Why does a helium-filled balloon in such a situation move, instead, toward the rear of the car?

**13.13** A piece of paper is folded in half and then opened up and placed on a flat table so that it "peaks" up in the middle as shown in the figure. If you blow air between the paper and the table, will the paper move up or down? Explain.



**13.14** In what direction does a force due to water flowing from a showerhead act on a shower curtain, inward toward the shower or outward? Explain.

**13.15** Point out and discuss any flaws in the following statement: *The hydraulic car lift is a device that operates on the basis of Pascal's Principle. Such a device can produce large output forces with small input forces. Thus, with a small amount of work done by the input force, a much larger amount of work is produced by the output force, and the heavy weight of a car can be lifted.*

**13.16** Given two springs of identical size and shape, one made of steel and the other made of aluminum, which has the higher spring constant? Why? Does the difference depend more on the shear modulus or the bulk modulus of the material?

**13.17** One material has a higher density than another. Are the individual atoms or molecules of the first material necessarily more massive than those of the second?

**13.18** Analytic balances are calibrated to give correct mass values for such items as steel objects of density $\rho_s$ = 8000.00 kg/m³. The calibration compensates for the buoyant force arising because the measurements are made in air, of density $\rho_a$ = 1.205 kg/m³. What compensation must be made to measure the masses of objects of a different material, of density $\rho$? Does the buoyant force of air matter?

**13.19** If you turn on the faucet in the bathroom sink, you will observe that the stream seems to narrow from the point at which it leaves the spigot to the point at which it hits the bottom of the sink. Why does this occur?

**13.20** In many problems involving application of Newton's Second Law to the motion of solid objects, friction is neglected for the sake of making the solution easier. The counterpart of friction between solids is viscosity of liquids. Do problems involving fluid flow become simpler if viscosity is neglected? Explain.

**13.21** You have two identical silver spheres and two unknown fluids, A and B. You place one sphere in fluid A, and it sinks; you place the other sphere in fluid B, and it floats. What can you conclude about the buoyant force of fluid A versus that of fluid B?

**13.22** Water flows from a circular faucet opening of radius $r_0$, directed vertically downward, at speed $v_0$. As the stream of water falls, it narrows. Find an expression for the radius of the stream as a function of distance fallen, $r(y)$, where $y$ is measured downward from the opening. Neglect the eventual breakup of the stream into droplets, and any resistance due to drag or viscosity.

### PROBLEMS

A blue problem number indicates a worked-out solution is available in the Student Solutions Manual. One • and two •• indicate increasing level of problem difficulty.

#### Sections 13.1 and 13.2

**13.23** Air consists of molecules of several types, with an average molar mass of 28.95 g. An adult who inhales 0.50 L of air at sea level takes in about how many molecules?

**•13.24** Ordinary table salt (NaCl) consists of sodium and chloride ions arranged in a *face-centered cubic crystal lattice*. That is, a sodium chloride crystal consists of cubic unit cells with a sodium ion on each corner and at the center of each face, and a chloride ion at the center of the cube and at the midpoint of each edge. The density of sodium chloride is $2.165 \cdot 10^3$ kg/m³. Calculate the spacing between adjacent sodium and chloride ions in the crystal.

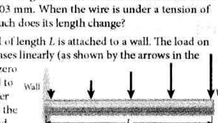
#### Section 13.3

**13.25** A 20-kg chandelier is suspended from the ceiling by four vertical steel wires. Each wire has an unloaded length of 1 m and a diameter of 2 mm, and each bears an equal load. When the chandelier is hung, how far do the wires stretch?

**13.26** Find the minimum diameter of a 50-m-long nylon string that will stretch no more than 1 cm when a load of 70 kg is suspended from its lower end. Assume that $Y_{nylon} = 3.51 \cdot 10^8$ N/m².

**13.27** A 2.0-m-long steel wire in a musical instrument has a radius of 0.03 mm. When the wire is under a tension of 90 N, how much does its length change?

**•13.28** A rod of length *L* is attached to a wall. The load on the rod increases linearly (as shown by the arrows in the figure) from zero at the left end to *W* newtons per unit length at the right end. Find the shear force at




a) the right end,  b) the center, and  c) the left end.

**•13.29** Challenger Deep in the Marianas Trench of the Pacific Ocean is the deepest known spot in the Earth's oceans, at 10.922 km below sea level. Taking density of seawater at atmospheric pressure ($p_0$ = 101.3 kPa) to be 1024 kg/m³ and its bulk modulus to be $B(p) = B_0 + 6.67(p - p_0)$, with $B_0 = 2.19 \cdot 10^9$ Pa, calculate the pressure and the density of the seawater at the

"The problem-solving technique, to borrow a phrase from my students, 'doesn't suck.' I'm a skeptic when it comes to anybody else's one-size-fits-all approach to problem solving—I've seen too many that just don't work, pedagogically. The approach used by the authors, however, is one in which students are really forced to tap their intuition before they start, to reflect on the relevant first principles. . . .

Wow! There are some really nice problems at the end of the chapter. My compliments to the authors. There was a nice diversity of problems, and most of them required a lot more than simple plug-and-chug. I found many problems I'd be inclined to assign."

—*Brent Corbin, University of California–Los Angeles*

"The text strikes a very good balance of providing mathematical details and rigor together with a clear, intuitive presentation of physics concepts. The balance and variety of problems provided, both as worked-out examples and as end-of-chapter problems, are outstanding. Many features are found in this book that are difficult to find in other standard texts, including proper use of vector notation, explicit evaluation of multiple integrals, e.g., in moment of inertia calculations, and intriguing connections to modern physics."

—*Lisa Everett, University of Wisconsin–Madison*

## Contemporary Topics: Capturing Students' Imaginations

*University Physics* incorporates a wide variety of contemporary topics as well as research-based discussions designed to help students appreciate the beauty of physics and see how physics concepts are related to the development of new technologies in the fields of engineering, medicine, astronomy and more. The "Big Picture" section at the beginning of the text is designed to introduce students to some of the amazing new frontiers of research that are being explored in various fields of physics and the results that have been obtained during the last few years. The authors return to these topics at various points within the book for more in-depth exploration.

The authors of *University Physics* also repeatedly discuss different aspects of the broad topic of energy, by addressing concepts of energy sources (fossil, nuclear, renewable, alternative, and so forth), energy efficiency, and environmental effects of energy supply choices. Alternative energy sources and renewable resources are discussed within the framework of possible solutions to the energy crisis. These discussions provide a great opportunity to capture students' interest and are accessible on the introductory physics level.

The following contemporary physics research topics and topical energy discussions (in green) are found in the text:

**Chapter 1**
Section 1.3 has a subsection called "Metrology" that mentions the new definition of the kilogram and the optical clock at NIST
Section 1.4 mentions the authors' research on heavy-ion collisions

**Chapter 4**
Section 4.2 has a subsection on the Higgs particle
Section 4.7 has a subsection on tribology

**Chapter 5**
Section 5.1 Energy in Our Daily Lives
Section 5.7 Power and Fuel-Efficiency of U.S. Cars

**Chapter 6**
Section 6.8 has a subsection titled "Preview: Atomic Physics" that discusses tunneling of particles
Solved Problem 6.6 Power Produced by Niagara Falls

**Chapter 7**
Example 7.5 Particle Physics
Section 7.8 discusses Sinai billiards and chaotic motion

**Chapter 8**
Example 8.3 mentions electromagnetic propulsion and radiation shielding in context of sending astronauts to Mars

**Chapter 10**
Example 10.7 Death of a Star
Example 10.8 Hybrid

**Chapter 12**
Section 12.1 has a subsection titled "Solar System" that mentions research on objects in Kuiper Belt
Section 12.7 Dark Matter

**Chapter 13**
Section 13.1 briefly discusses nanotubes and nanotechnology
Section 13.2 briefly discusses plasmas and Bose-Einstein condensates
Section 13.6 has a subsection titled "Applications of Bernoulli's Equation" that discusses lift and design of aircraft wings
Section 13.8 Turbulence and Research Frontiers in Fluid Flow

**Chapter 14**
Section 14.7 Chaos

**Chapter 15**
Section 15.5 has a subsection titled "Seismic Waves" that mentions reflection seismology
Figure 15.11b shows nanoscale guitar
Section 15.8 includes Self-Test Opportunity 15.4 on nanoscale guitar string
Section 15.9 Research on Waves

**Chapter 16**
Section 16.4 has a subsection titled "Mach Cone" that mentions creation of shock waves by collisions of nuclei in particle accelerators and has a paragraph on Cherenkov radiation

**Chapter 17**
Section 17.2 has subsections titled "Research at the Low-Temperature Frontier" and "Research at the High-Temperature Frontier"
Section 17.5 Surface Temperature of Earth
Section 17.6 Temperature of the Universe
Example 17.4 Rise in Sea Level Due to Thermal Expansion of Water

**Chapter 18**
Example 18.7 Roof Insulation
Solved Problem 18.2 Warming Costs for Winter
Solved Problem 18.3 Power Carried by the Gulf Stream
Example 18.8 Earth as a Blackbody
Section 18.8 Modes of Thermal Energy Transfer/Global Warming
Section 18.8 has a subsection titled "Heat in Computers"

**Chapter 19**
Example 19.5 The Quark-Gluon Plasma

**Chapter 20**
Example 20.2 Warming a House with a Heat Pump
Example 20.4 Maximum Efficiency of an Electrical Power Plant
Solved Problem 20.1 Efficiency of an Automobile Engine
Section 20.4 Real Engines and Efficiency/Hybrid Cars
Section 20.4 Real Engines and Efficiency/Efficiency and the Energy Crisis
Solved Problem 20.2 Cost to Operate an Electrical Plant
Section 20.7 Entropy Death

**Chapter 21**
Section 21.3 Superconductors
Section 21.5 Electrostatic Force—Coulomb's Law/Electrostatic Precipitator

**Chapter 22**
Example 22.4 Time Projection Chamber (STAR TPC)
Section 22.6 discusses noninvasive imaging of brain electric fields and the brain-computer interface

**Chapter 23**
Section 23.2 describes new batteries
Example 23.2 Battery-Powered Cars

**Chapter 24**
Example 24.4 The National Ignition Facility
Section 24.9 Supercapacitors

**Chapter 25**
Example 25.1 Iontophoresis
Section 25.3 Temperature Dependence, and Superconductivity
Solved Problem 25.2 Brain Probe (ECoG)
Section 25.7 Energy and Power in Electric Circuits discusses high-voltage electric power transmission
Section 25.8 Diodes: One-Way Streets in Circuits
Solved Problem 25.4 Size of Wire for Power Line

**Chapter 27**
Section 27.3 and Example 27.1 STAR TPC
Section 27.3 has a subsection on magnetic levitation
Example 27.3 Cyclotron

**Chapter 28**
Solved Problem 28.1 Electromagnetic Rail Accelerator
Section 28.7 discusses superconducting magnets and the Meissner effect

**Chapter 29**
Section 29.4 Generators and Motors discusses regenerative braking
Section 29.10 discusses computer hard drives and giant magnetoresistance

**Chapter 30**
Section 30.7 Transformers

**Chapter 31**
Example 31.1 Using Solar Panels to Charge an Electric Car

**Chapter 32**
Section 32.2 discusses perfect mirrors and laser surgery

**Chapter 33**
Section 33.8 Laser Tweezers

**Chapter 35**
Example 35.2 discusses the possibility of a muon collider
Section 35.6 discusses particle accelerators
Section 35.8 discusses the Hubble Space Telescope and gravitational lensing, Black holes, LIGO, and LISA
Section 35.9 Relativity in Our Daily Life: GPS

**Chapter 36**
Section 36.2 Blackbody Radiation describes cosmic background radiation
Section 36.3 discusses night-vision devices
Section 36.8 has a subsection on "Bose-Einstein Condensate"

**Chapter 37**
Introduction on quantum computing, nanoscience, and nanotechnology
Section 37.9 discusses two-fermion wave function and computer modeling of physical systems, as well as quantum computing

**Chapter 38**
Section 38.4 has a subsection titled "X-Ray Production" that discusses X-rays in medicine
Section 38.5 discusses the use of lasers in surgery, weapons, measurement, chemical bonds, free-electron lasers, and the NIF laser system

**Chapter 39**
Section 39.1 discusses CERN, LHC, complex atomic-level systems, protein folding, DNA, and the origin of life
Section 39.3 discusses elementary particles and Higgs bosons
Section 39.4 has a subsection titled "Supersymmetry and String Theory"

**Chapter 40**
Section 40.2 discusses neutrino-less double-beta decays
Section 40.3 describes the nuclear shell model and models of nuclear collisions
Section 40.4 Nuclear Energy: Fission and Fusion discusses the use of controlled fusion for energy production, as well as ITER and NIF
Section 40.5 describes core-collapse supernova explosions
Section 40.6 discusses gamma knives (in brain surgery), heavy-ion beam treatments for cancer, and technetium diagnostic scans

"I think this idea is great! It would help the instructor show the students that physics is a live and exciting subject. . . . because it shows that physics is a happening subject, relevant for discovering how the universe works, that it is necessary for developing new technologies, and how it can benefit humanity . . . . The [chapters] contain a lot of interesting modern topics and explain them very clearly."

—*Joseph Kapusta, University of Minnesota*

"Section 17.5 on the surface temperature of the Earth is excellent and is an example of what is *missing* from so many introductory textbooks: examples that are relevant and compelling for the students."

—*John William Gary, University of California-Riverside*

"I think the approach to include modern or contemporary physics throughout the text is great. Students often approach physics as a science of concepts which were discovered long ago. They view engineering as the science which has given them the advances in technology which they see today. It would be great to show students just where these advances do start, with physics."

—*Donna W. Stokes, University of Houston*

## Enhanced Content: Flexibility for Your Student and Course Needs

To instructors who are looking for additional coverage of certain topics and mathematical support for those topics, *University Physics* also offers flexibility. This book includes some topics and some calculus that do not appear in many other texts. However, these topics have been presented in such a way that their exclusion will not affect the overall course. The text as a whole is written at a level appropriate for the typical introductory student. Below is a list of flex-coverage content as well as additional mathematical support:

### Chapter 2

Section 2.3 The concept of the derivative is developed using an approach that is both conceptual and graphical. Examples using the derivative are provided, and students are referred to an appendix for other "refreshers." This is a more extensive approach than is taken in some other texts.

Section 2.4 Acceleration as the time derivative of velocity is introduced by analogy, and the discussion includes an example.

Section 2.6 Integration as the inverse to differentiation is introduced for finding the area under a curve. This more extensive presentation than in many texts is spread over two sections with multiple examples.

Section 2.7 Examples using differentiation are included.

Section 2.8 A derivation on minimum time arguments is shown to lead to a solution that is equivalent to Snell's Law.

End-of-chapter exercises related to this coverage include Questions 20, 22, and 23 and multiple Problems using calculus.

### Chapter 3

Section 3.1 The component-wise derivative of a three-dimensional position vector into three-dimensional velocity and then into three-dimensional acceleration is presented.

Section 3.3 The tangetiality of the velocity vector to the trajectory is covered.

Section 3.4 The maximum height and range of a projectile are found by setting the derivative equal to zero.

Section 3.5 Relative motion is covered (equation 3.27).

End-of-chapter Problem 3.38 covers the derivative.

### Chapter 4

Section 4.8 Example 4.10 on the best angle to pull a sled is a maximum-minimum problem.

### Chapter 5

Section 5.5 Work done by a variable force is covered using definite integrals and the derivation of equation 5.20. The chain rule is also covered.

Section 5.6 Work done by spring force is discussed (equation 5.24).

Section 5.7 Power as the time derivative of work is covered (equation 5.26).

A number of end-of-chapter Problems supplement this coverage, such as Problems 5.34 through 5.37.

### Chapter 6

Section 6.3 Finding the work done by a force includes use of integrals.

Section 6.4 Obtaining force from the potential includes the use of derivatives; partial derivatives and the gradient are also introduced (for example, the Lennard-Jones potential).

A number of end-of-chapter Questions and Problems supplement this coverage, such as Questions 6.24 and 6.25 and Problems 6.34, 6.35, and 6.36.

### Chapter 8

The text introduces volume integrals so that the volume of a sphere and the center of mass of a half sphere can be determined in a worked example.

### Chapter 9

Explicit derivatives of the radical and tangential unit vectors are provided. The text derives the equations of motion for constant angular acceleration, repeating the customary derivation of equations of motion for constant linear acceleration presented in Chapter 2.

### Chapter 10

The volume integral introduced in Chapter 8 is utilized in finding the moment of inertia for different objects. The text derives the expression for angular momentum to determine the relationship between the angular momentum of a system of particles and the torque.

### Chapter 11

Section 11.3 The stability condition is utilized, and the second derivative of potential energy is examined to determine the type of equilibrium through graphical interpretation of the functions.

### Chapter 12

Section 12.1 Unique coverage is provided of the derivation of the gravitational force from a sphere and inside a sphere.

### Chapter 14

Section 14.4 The subsection titled "Small Damping" applies the student's knowledge of simple harmonic oscillators to derive the small damping equation through differentiation. For the case of large damping, the student is again referred to the solution to the differential equation. Example 14.6 walks the student through an example of a damped harmonic oscillator. The solution to this equation is stated explicitly, but the text utilizes calculus to reach the answer. The subsection "Energy Loss in Damped Oscillations" includes a calculation of the rate of energy loss that uses the differential definition of power.

Section 14.5 A thorough discussion of forced harmonic motion takes advantage of the student's understanding of differential equations, graphically analyzes the solution, and then analyzes the outcome.

A number of end-of-chapter Problems supplement this coverage, such as Problems 14.55 and 14.73.

### Chapter 15

Section 15.4 This entire section is unique among introductory physics texts as it utilizes partial differential equations to derive the wave equation.

Several of the end-of-chapter Questions and Problems related to the content of Section 15.4 require an understanding of the calculus used in this section, particularly 15.30 and 15.31.

### Chapter 16

Section 16.4 Covers the Doppler effect as a function of the perpendicular distance.

### Chapter 22

Section 22.9 Solved Problem 22.3 covers the electric field for a nonuniform spherical charge distribution

### Chapter 25

Section 25.5 Solved Problem 25.2, "Brain Probe" covers a case of nonconstant cross-sectional area.

### Chapter 32

Section 32.3 This textbook goes deeper into calculus than many others by demonstrating how calculus can be used in deducing from Newton's Laws of Motion the necessarily parabolic shape of liquid surfaces that have a net circular motion.

Some end-of-chapter Problems, such as Problem 32.43, also use calculus to solve a minimization problem.

### Chapter 34

Section 34.10 This section discusses the quality of diffraction gratings using the concept of dispersion. In many similar physics textbooks, the formula for dispersion is simply given. This textbook, however, uses calculus to derive dispersion in a straightforward manner.

### Chapter 35

Section 35.2 This section has a very instructive and intuitive derivation of light cone variables that goes beyond what is found in most standard textbooks.

Section 35.6 The text features calculus-based derivations for velocity transformation and energy (based on integrating the distance dependence of work). While the energy derivation follows standard integration techniques and is used in most books, the velocity transformation derivation is unique and very instructive.

### Chapter 36

Section 36.2 The level of detail that characterizes the derivation of several radiation laws (Wien, Planck, Boltzmann, Raleigh-Jeans) is not found in many other textbooks.

Section 36.8 The introduction to Bose-Einstein and Fermi-Dirac statistics is important and unique to this textbook. The connection to radiation laws is especially relevant. The end-of-chapter Problems related to Section 36.8, in particular Problems 36.53 through 36.55, are challenging and utilize the relevant mathematics.

### Chapter 37

Most standard textbooks teach quantum mechanics with minimal usage of calculus, using mostly a conceptual approach. This book takes a more formal approach, from Section 35.1 on wave functions. The students are exposed to derivations that are unique to modern physics, starting from the normalization condition of the wave function over operators for momentum and kinetic energy and continuing to solutions for infinite and finite potentials. Hamiltonians are introduced and applied to Schrödinger and Dirac equations. The many-particle wave function is then covered in Section 37.9. The end-of-chapter Problems that utilize calculus include Problems 37.28 through 37.39.

### Chapter 38

This textbook derives the full solution of the hydrogen electron wave function and breaks it down into radial and angular parts. This complete solution allows the student to derive the degeneracy of the quantum levels rather than simply learning a simple formula for calculating the levels without understanding their physical origin.

Section 38.3 The solution of the Schrödinger equation in Section 38.3. is based on the derivations in Chapter 37, and the text further explores the full solution of the hydrogen electron wave function considered earlier in the chapter. The end-of-chapter Problems 38.35, 38.36, and 38.37 use the calculus from the chapter.

### Chapter 39

The definition of the differential scattering cross section is defined in equations 39.3 and 39.4, based on classical (Rutherford) physics. (Many other texts simply show and describe graphs.) The differential cross section from quantum considerations is given in equation 39.6, and the form factor (deviation from Rutherford and deviation from point particle) is given in equations 39.7 and 39.8. Form factors are not often described in other texts. While this discussion adds to the mathematical detail, it could be easily omitted to fit the needs of the course. End-of-chapter Problem 39.32 makes use of calculus to calculate the fraction of particles scattered into a range of angles.

### Chapter 40

The text presents a slightly more detailed discussion than is usually seen in deriving the Fermi energy while covering Fermi's model of the nucleus in Section 40.3. Some end-of-chapter problems could involve simple integration of the exponential function: 40.31, 40.33, 40.52, 40.53, and 40.61.

"Strongest feature . . . The use of real mathematics, especially calculus, to derive kinematic relations, the relations between quantities in circular motion, the direction of the gravitational force, the magnitude of the tidal force, the maximum extension of a set of piled blocks. Solved problems are always addressed symbolically first. Too often textbooks don't let the math do the work for them."

—*Kieran Mullen, University of Oklahoma*

DERIVATION 5.1

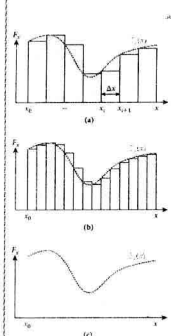



FIGURE 5.14 (a) A series of rectangles approximates the area under the curve obtained by plotting the force as a function of the displacement; (b) a better approximation using rectangles of smaller width; (c) the exact area under the curve.

If you have already taken integral calculus, you can skip this section. If equation 5.20 is your first exposure to integrals, the following derivation is a useful introduction. We'll derive the one-dimensional case and use our result for the constant force as a starting point.

In the case of a constant force, we can think of the work as the area under the horizontal line that plots the value of the constant force in the interval between $x_0$ and $x$. For a variable force, the work is the area under the curve $F_x(x)$, but that area is no longer a simple rectangle. In the case of a variable force, we need to divide the interval from $x_0$ to $x$ into many small equal intervals. Then we approximate the area under the curve $F_x(x)$ by a series of rectangles and add their areas to approximate the work. As you can see from Figure 5.14a, the area of the rectangle between $x_i$ and $x_{i+1}$ is given by $F_x(x_i)\cdot(x_{i+1}-x_i) = F_x(x_i)\cdot\Delta x$. We obtain an approximation for the work by summing over all rectangles:

$$W \approx \sum_i W_i = \sum_i F_x(x_i)\cdot\Delta x.$$

Now we space the points $x_i$ closer and closer by using more and more of them. This method makes $\Delta x$ smaller and causes the total area of the series of rectangles to be a better approximation of the area under the curve $F_x(x)$ as in Figure 5.14b. In the limit as $\Delta x \to 0$, the sum approaches the exact expression for the work:

$$W = \lim_{\Delta x\to 0}\left[\sum_i F_x(x_i)\cdot\Delta x\right].$$

This limit of the sum of the areas is exactly how the integral is defined:

$$W = \int_{x_0}^{x} F_x(x')dx'.$$

We have derived this result for the case of on… tion of the three-dimensional case proceeds alon… in terms of algebra.

## Derivations

Detailed derivations are provided in the text as examples for students, who will eventually need to develop their own derivations as they review Solved Problems, work through Examples, and solve end-of-chapter Problems. The Derivations are identified in the text with numbered headings so that instructors can include these detailed features as necessary to fit the needs of their courses.

"Again the derivation resulting in equation 6.15 is outstanding. Few books that I have seen will show students even once all the math steps in derivations. This is a strength of this book. Also, in the next section, I like very much the generalization of the relation between force and potential energy to three dimensions. It is something that I always do in lecture although most books do not get close."

—*James Stone, Boston University*

# Appendix A

*Mathematics Primer*



## Calculus Primer

A Calculus Primer can be found in the appendices. Since this course sequence is typically given in the first year of study at universities, it assumes knowledge of high school physics and mathematics. It is preferable that students have had a course in calculus before they start this course sequence, but calculus can also be taken in parallel. To facilitate this, the text contains a short calculus primer in an appendix, giving the main results of calculus without the rigorous derivations.

# Building Knowledge: The Text's Learning System

## Chapter Opening Outline

At the beginning of each chapter is an outline presenting the section heads within the chapter. The outline also includes the titles of the Examples and Solved Problems found in the chapter. At a quick glance, students or instructors know if a desired topic, example, or problem is in the chapter.

## What We Will Learn / What We Have Learned

Each chapter of *University Physics* is organized like a good research seminar. It was once said, "Tell them what you will tell them, then tell them, and then tell them what you told them!" Each chapter starts with **What We Will Learn**—a quick summary of the main points, without any equations. And at the end of each chapter, **What We Have Learned/Exam Study Guide** contains key concepts, including major equations, symbols, and key terms. All symbols used in the chapter's formulas are also listed.

WHAT WE WILL LEARN

- A force is a vector quantity that is a measure of how an object interacts with other objects.
- Fundamental forces include gravitational attraction and electromagnetic attraction and repulsion. In daily experience, important forces include tension and normal, friction, and spring forces.
- Multiple forces acting on an object sum to a net force.
- Free-body diagrams are valuable aids in working problems.
- Newton's three laws of motion govern the motion of objects under the influence of forces.
  - a) The first law deals with objects for which external forces are balanced.
  - b) The second law describes those cases for which external forces are not balanced.
  - c) The third law addresses equal (in magnitude) and opposite (in direction) forces that two bodies exert on each other.
- The gravitational mass and the inertial mass of an object are equivalent.
- Kinetic friction opposes the motion of moving objects; static friction opposes the impending motion of objects at rest.
- Friction is important to the unde… world motion, but its causes and … are still under investigation.
- Applications of Newton's laws of … multiple objects, multiple forces, … applying the laws to analyze a situ… the most important problem-solv… physics.

WHAT WE HAVE LEARNED | EXAM STUDY GUIDE

- The net force on an object is the vector sum of the forces acting on the object: $\vec{F}_{net} = \sum_{i=1}^{n} \vec{F}_i$.
- Mass is an intrinsic quality of an object that quantifies both the object's ability to resist acceleration and the gravitational force on the object.
- A free-body diagram is an abstraction showing all forces acting on an isolated object.
- Newton's three laws are as follows:

  Newton's First Law. In the absence of a net force on an object, the object will remain at rest, if it was at rest. If it was moving, it will remain in motion in a straight line with the same velocity.

  Newton's Second Law. If a net external force, $\vec{F}_{net}$, acts on an object with mass $m$, the force will cause an acceleration, $\vec{a}$, in the same direction as the force: $\vec{F}_{net} = m\vec{a}$.

  Newton's Third Law. The forces that two interacting objects exert on each other are always exactly equal in magnitude and opposite in direction: $\vec{F}_{1\to 2} = -\vec{F}_{2\to 1}$.
- Two types of friction occur: static and kinetic friction. Both types of friction are proportional to the normal force, $N$.

  Static friction describes the force of friction between an object at rest on a surface in terms of the coefficient of static friction, $\mu_s$. The static friction force, $f_s$, opposes a force trying to move an object and has a maximum value, $f_{s,max}$, such that $f_s \le \mu_s N = f_{s,max}$.

  Kinetic friction describes the force of friction between a moving object and a surface in terms of the coefficient of kinetic friction, $\mu_k$. Kinetic friction is given by $f_k = \mu_k N$.

  In general, $\mu_s > \mu_k$.

## Conceptual Introductions

Conceptual explanations are provided in the text prior to any mathematical explanations, formulas, or derivations in order to establish for students why the quantity is needed, why it is useful, and why it must be defined accurately. The authors then move from the conceptual explanation and definition to a formula and exact terms.

> "The section on thermal expansion is outstanding and the supporting example problems are very well done. This section can be put up against any text on the market and come out ahead. The authors do very well on basic concepts."
>
> —*Marllin Simon, Auburn University*

## Self-Test Opportunities

Sets of questions follow the coverage of major concepts within the text to encourage students to develop an internal dialogue. These questions will help students think critically about what they have just read, decide whether they have a grasp of the concept, and develop a list of follow-up questions to ask in lecture. The answers to the Self-Tests are found at the end of each chapter.

> "The Self-Test Opportunities are effective for encouraging students to place what they have learned in this chapter in the context of the broader conceptual understanding they have been developing throughout the earlier chapters."
>
> — *Nina Abramzon, California Polytechnic University–Pomona*

**6.3 Self-Test Opportunity**

Why does the lighter-colored ball arrive at the bottom in Figure 6.10 before the other ball?

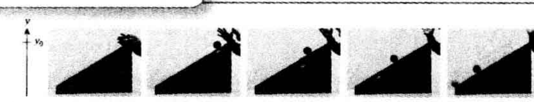


**FIGURE 6.10** Race of two balls down different inclines of the same height.

6.3 The lighter-colored ball descends to a lower elevation earlier in its motion and thus converts more of its potential energy to kinetic energy early on. Greater kinetic energy means higher speed. Thus, the lighter-colored ball reaches higher speeds earlier and is able to move to the bottom of the track faster, even though its path length is greater.

## In-Class Exercises

In-Class Exercises are designed to be used with personal response system technology. They will appear in the text so that students may begin contemplating the concepts. Answers will only be available to instructors. (Questions and answers are formatted in PowerPoint for universal use with personal response systems.)

**2.2 In-Class Exercise**

Throwing a ball straight up into the air provides an example of free-fall motion. At the instant the ball reaches its maximum height, which of the following statements is true?

a) The ball's acceleration points down, and its velocity points up.

b) The ball's acceleration is zero, and its velocity points up.

c) The ball's acceleration points up, and its velocity points up.

d) The ball's acceleration points down, and its velocity is zero.

e) The ball's acceleration points up, and its velocity is zero.

f) The ball's acceleration is zero, and its velocity points down.

## Visual Program

Familiarity with graphic artwork on the Internet and in video games has raised the bar for the graphical presentations within textbooks, which must now be more sophisticated to excite both students and faculty. Here are some examples of techniques and ideas implemented in the *University Physics:*

- Overlays of line drawings over photographs connect sometimes very abstract physics concepts to students' realities and everyday experiences.
- A three-dimensional look for line drawings adds plasticity to the presentations. Mathematically accurate graphs and plots were created by the authors in software programs such as Mathematica and then used by the graphic artists to ensure complete accuracy along with a visually appealing style.

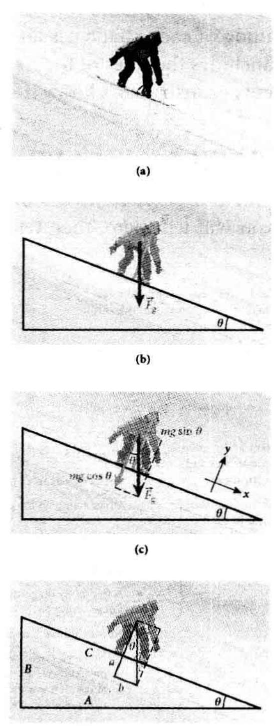



**FIGURE 4.16** (a) Snowboarding as an example of motion on an inclined plane. (b) Free-body diagram of the snowboarder on the inclined plane. (c) Free-body diagram of the snowboarder, with a coordinate system added. (d) Similar triangles in the inclined-plane problem.

## McGraw-Hill Connect™ Physics


With Connect Physics, instructors can deliver assignments, quizzes, and tests online. The problems directly from the end-of-chapter material in Bauer/Westfall's *University Physics* are presented in an auto-gradable format. The online homework system incorporates new and exciting interactive tools and problem types: a graphing tool; a free-body diagram drawing tool; symbolic entry; a math palette; and multi-part problems. The seven-step problem-solving method from the text is also reflected in Connect Physics: Students will find the familiar seven steps outlined in the guided solutions, with additional detailed help with the math where they need it most. Over 2300 multiple-choice Test Bank questions (written by the authors and the same contributors who provided the text's end-of-chapter problems) are also included.

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