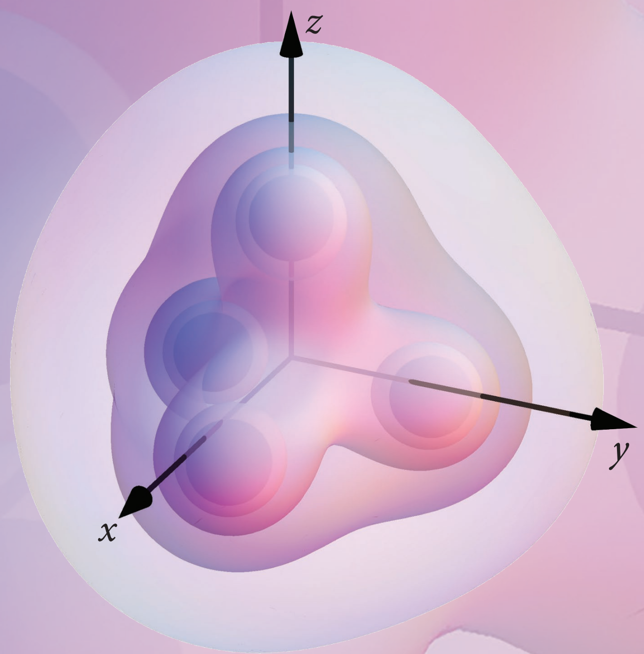
Third Edition

University Physics
with Modern Physics



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McGraw Hill

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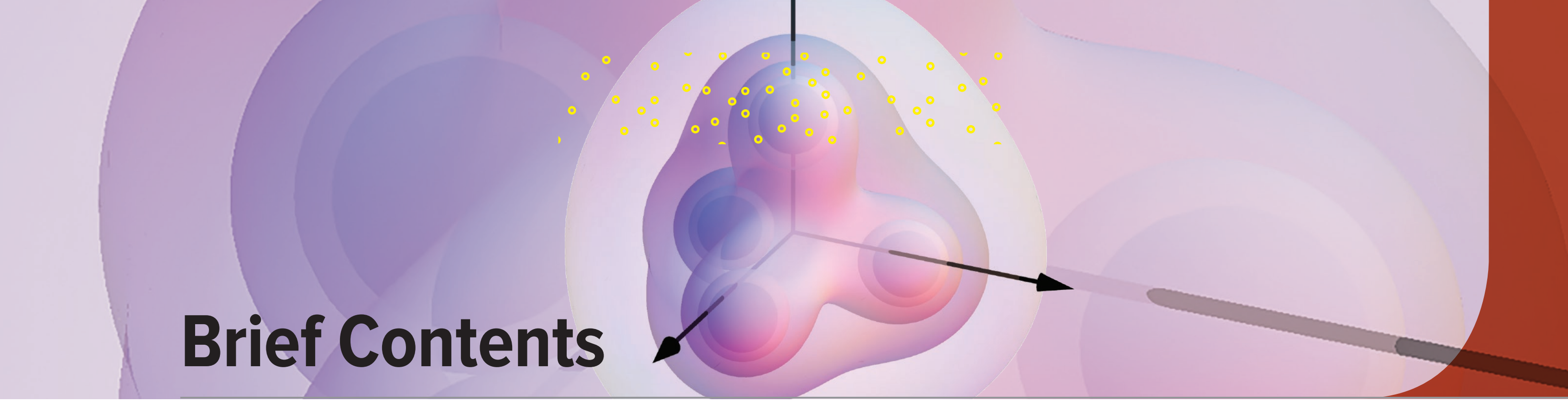


Brief Contents

About the Authors

W. Bauer and G. D. Westfall

Wolfgang Bauer was born in Germany and obtained his Ph.D. in theoretical 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, with a dual appointment at the National Superconducting Cyclotron Laboratory (NSCL). He has worked on a large variety of topics in theoretical and computational physics, from high-temperature superconductivity to supernova explosions, but has been especially interested in relativistic nuclear 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. From 2001 to 2013, he served as chairperson of the Department of Physics and Astronomy. In 2009, he founded the Institute for Cyber-Enabled Research and served as its first director until 2013. From 2013 to 2020, he was a member of MSU's executive management, as Senior Consultant and Associate Vice President for Administration. He was a coauthor of MSU's Energy Transition Plan and the lead author of the Mobility Plan. In 2020, Dr. Bauer returned to the regular faculty and holds the title of University Distinguished Professor.

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 4π Detector. His research using the 4π 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 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. Dr. Westfall is best known for his work with correlations and fluctuations of particle produced in Au+Au collisions at RHIC. In 2003, he was named University Distinguished Professor at Michigan State University. Dr. Westfall served as Chair of the RHIC Users Executive Committee and as the Chair of STAR Council. Dr. Westfall currently holds the title of University Distinguished Professor, Emeritus, at Michigan State University. Dr. Westfall received the Award for Innovative Excellence in Teaching, Learning, and Technology from the American Association of Physics Teachers, and he was a finalist for the Ernest L Boyer International Award for Innovative Excellence in Teaching, Learning, and Technology.

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 coauthored 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. From 2008 to 2013, Bauer and Westfall were 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

We are thrilled to introduce the third edition of our textbook, *University Physics*. 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 in writing this book is to change this perception by weaving exciting, contemporary physics throughout the text. Physics is an amazingly dynamic discipline—continuously on the verge of new discoveries and life-changing applications. To help students see this, we need to tell the full, absorbing story of our science by 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 nonlinear 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.

Recent results involving renewable energy, the environment, engineering, medicine, and technology show physics as an exciting, thriving, and intellectually alive subject motivating students, invigorating classrooms, and making the instructor's job easier and more enjoyable. In particular, 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, energy storage, alternative energy sources, and environmental effects of energy supply choices (global warming and ocean acidification, for example) 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.

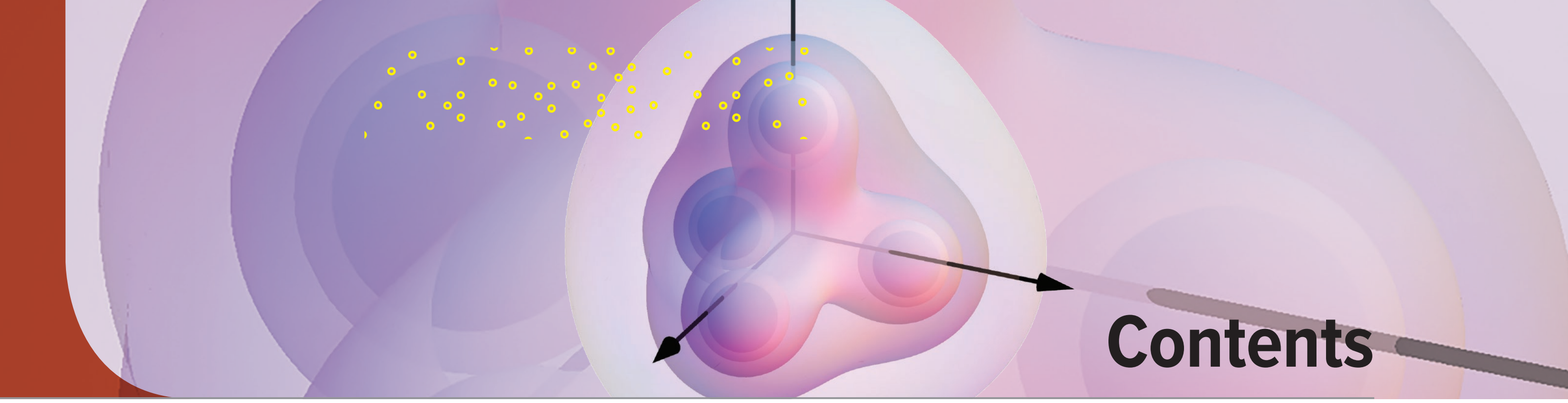
Malcolm Fife/Getty Images

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 multistep format that we have developed with students in our classes. But mastery of concepts also involves actively applying them. To this end, we have asked more than a dozen contributors from some of the leading universities across the country to share their best work in the end-of-chapter exercises. We are particularly proud of approximately 400 multi-version exercises, which allow students to address the same problem from different perspectives.

In 2012, the National Research Council published a framework for K-12 science education, which covers the essential science and engineering practices, the concepts that have application across fields, and the core ideas in four disciplinary areas (in physics, these are matter and its interactions, motion and stability, energy, and waves and their applications in information transfer). We have structured the third edition of this textbook to tie the undergraduate physics experience to this framework and have provided concept checks and self-test opportunities in each chapter. In the ebook version of this third edition, we are also providing approximately 200 apps that allow the students to watch video clips of selected lecture demonstrations, as well as perform interactive physics simulations, which hopefully will lead to deeper understanding of physics concepts.

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 we can convert at least a few students to physics majors along the way). Having feedback from more than 400 people, including a board of advisors, several contributors, manuscript reviewers, and focus group participants, assisted greatly in this enormous undertaking, as did field testing our ideas with more than 10,000 students in our introductory physics classes at Michigan State University. We thank you all!

—Wolfgang Bauer and Gary D. Westfall



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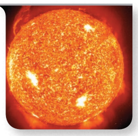
PART 6: MAGNETISM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How to Use This Book

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 that has been class-tested by the authors, which is used throughout the text. The text's problem-solving method has a multistep format.

Problem-Solving Method

Solved Problems

The book's numbered **Solved Problems** are fully worked problems, each consistently following the seven-step method described in Section 1.5. Each Solved Problem begins with the problem statement and then provides a complete solution. The seven-step method is also used in Connect Physics. The familiar seven steps are outlined in the guided solutions, with additional help where you need it.

SOLVED PROBLEM 13.2 Weighing Earth's Atmosphere

The Earth's atmosphere is composed (by volume) of 78.08% nitrogen (N_2), 20.95% oxygen (O_2), 0.93% argon (Ar), 0.25% water vapor (H_2O), and traces of other gases, most importantly, carbon dioxide (CO_2). The CO_2 content of the atmosphere is currently (year 2022) around 0.042% = 420 ppm (parts per million), but it varies with the seasons by about 6–7 ppm and has been rising since the start of the Industrial Revolution, mainly as a result of the burning of fossil fuels. Approximately 2 ppm of CO_2 are being added to the atmosphere each year.

PROBLEM

What is the mass of the Earth's atmosphere, and what is the mass of 1 ppm of atmospheric CO_2?

SOLUTION

THINK At first glance, this problem seems rather daunting because very little information is given. However, we know that the atmospheric pressure is $1.01 \cdot 10^5$ Pa and that pressure is force per area.

SKETCH The sketch in Figure 13.13 shows a column of air with weight mg above an area A of Earth's surface. This air exerts a pressure, p, on the surface.

RESEARCH We start with the relationship between pressure and force, $p = F/A$, where the area is the surface area of Earth, $A = 4\pi R^2$, and $R = 6370$ km is the radius of Earth. For the force, we can use the atmospheric weight, $F = mg$, where m is the mass of the atmosphere.

SIMPLIFY We combine the equations just mentioned

$$p = \frac{F}{A} = \frac{mg}{4\pi R^2}$$

and solve for the mass of the atmosphere

$$m = \frac{4\pi R^2 p}{g}.$$

CALCULATE We substitute the numerical values:

$$m = 4\pi(6.37 \cdot 10^6 \text{ m})^2(1.01 \cdot 10^5 \text{ Pa})/(9.81 \text{ m/s}^2) = 5.24978 \cdot 10^{18} \text{ kg}.$$

ROUND We round to three significant figures and obtain

$$m = 5.25 \cdot 10^{18} \text{ kg}.$$

DOUBLE-CHECK In order to obtain the mass of 1 ppm of CO_2 in the atmosphere, we have to realize that the molar mass of CO_2 is $12 + (2 \cdot 16) = 44$ g. The average mass of a mole of the atmosphere is approximately $0.78(2 \cdot 14) + 0.21(2 \cdot 16) + 0.01(40) = 28.96$ g. The mass of 1 ppm of CO_2 in the atmosphere is therefore

$$m_{1 \text{ ppm } CO_2} = 10^{-6} \cdot m \frac{44}{28.96} = 7.97 \cdot 10^{12} \text{ kg} = 8.0 \text{ billion tons}.$$

Humans add approximately 2 ppm of CO_2 to the atmosphere each year by burning fossil fuels, which amounts to approximately 16 billion tons of CO_2, a scary number. For comparison, the combined mass of all 8 billion humans on the planet is approximately 0.5 billion tons. Humans add more than 30 times our own weight in carbon dioxide to the atmosphere each year. It is not easy to double-check the orders of magnitude for this calculation. However, data published by the U.S. Energy Information Administration show that total carbon dioxide emissions from burning fossil fuels are currently approximately 30 billion tons per year, higher than our result by a factor of 2. Where does the other half of the CO_2 go? Mainly, it dissolves in the Earth's oceans.

Examples

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

EXAMPLE 18.9 Estimate of Earth's Internal Thermal Energy

Since Earth's core and mantle are at very high temperatures relative to its surface, there must be a lot of thermal energy available inside Earth.

PROBLEM

What is the thermal energy stored in Earth's interior?

SOLUTION

Obviously, we can make only a rough estimate, because the exact radial temperature profile of Earth is not known. Let's assume an average temperature of 3000 K, which is approximately half of the difference between the surface and core temperatures.

The specific heats (see Table 18.1) for the materials in the Earth's interior range from 0.45 kJ/(kg K) for iron to 0.92 kJ/(kg K) for rocks in the crust. In order to make our estimate, we will use an average value of 0.7 kJ/(kg K). The total mass of Earth is (see Table 12.1) $5.97 \cdot 10^{24}$ kg.

Inserting the numbers into equation 18.12, we find

$$Q_{\text{Earth}} = m_{\text{Earth}} c \Delta T = (6 \cdot 10^{24}\,\text{kg})[0.7\text{kJ/(kg K)}](3000\,\text{K}) = 10^{31}\,\text{J}.$$

Does it matter that some part of Earth's core is liquid and not solid? Should we account for the latent heat of fusion in our estimate? The answer is yes, in principle, but since the latent heat of fusion for metals is typically on the order of a few hundred kilojoules per kilogram, it would contribute only 10–20% of what the specific heat does in this case. For our order-of-magnitude estimate, we can safely neglect this contribution.

Problem-Solving Guidelines

Located before the end-of-chapter exercise sets, **Problem-Solving Guidelines** summarize important skills or techniques that can help you solve problems related to the material in the chapter. Acknowledging that physics is based on a core set of fundamental ideas that can be applied to various situations and problems, *University Physics* emphasizes that there is no single way to solve every problem and helps you think critically about the most effective problem-solving method before beginning to work on a solution.

PROBLEM-SOLVING GUIDELINES: NEWTON'S LAWS

Analyzing a situation in terms of forces and motion is a vital skill in physics. One of the most important techniques is the proper application of Newton's laws. The following guidelines can help you solve mechanics problems in terms of Newton's three laws. These are part of the seven-step strategy for solving all types of physics problems and are most relevant to the Sketch, Think, and Research steps.

1. An overall sketch can help you visualize the situation and identify the concepts involved, but you also need a separate free-body diagram for each object to identify which forces act on that particular object and no others. Drawing correct free-body diagrams is the key to solving all problems in mechanics, whether they involve static (nonmoving) objects or kinetic (moving) ones. Remember that the $m\vec{a}$ from Newton's Second Law should not be included as a force in any free-body diagram.

2. Choosing the coordinate system is important—often the choice of coordinate system makes the difference between very simple equations and very difficult ones. Placing an axis along the same direction as an object's acceleration, if there is any, is often very helpful. In a statics problem, orienting an axis along a surface, whether horizontal or inclined, is often useful. Choosing the most advantageous coordinate system is an acquired skill gained through experience as you work many problems.

End-of-Chapter Questions and Exercise Sets

Along with providing problem-solving guidelines, examples, and strategies, *University Physics* also offers a **wide variety of end-of-chapter Questions and Exercises.** Included in each chapter are Multiple-Choice Questions, Conceptual Questions, Exercises (by section), Additional Exercises (no section "clue"), and Multi-Version Exercises. One bullet identifies slightly more challenging Exercises, and two bullets identify the most challenging Exercises.

Calculus Primer

Since this course is typically taken in the first year of study at universities, this book assumes knowledge of high school physics and mathematics. It is preferable that students have had a course in calculus before they start this course, 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 Conceptual Understanding

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, you will 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.

WHAT WE WILL LEARN

- An electric field represents the electric force at different points in space.
- Electric field lines represent the net force vectors exerted on a unit positive electric charge. They originate on positive charges and terminate on negative charges.
- The electric field of a point charge is radial, proportional to the charge, and inversely proportional to the square of the distance from the charge.
- An electric dipole consists of a positive charge and a negative charge of equal magnitude.
- The electric flux is the electric field component normal to an area times the area.
- Gauss's Law states that the electric flux through a closed surface is proportional to the net electric charge enclosed within the surface. This law provides simple ways to solve seemingly complicated electric field problems.
- The electric field inside a conductor is zero.
- The magnitude of the electric field due to a uniformly charged, infinitely long wire varies as the inverse of the perpendicular distance from the wire.
- The electric field due to an infinite sheet of charge does not depend on the distance from the sheet.
- The electric field outside a spherical distribution of charge is the same as the field of a point charge with the same total charge located at the sphere's center.

Conceptual Introductions

Conceptual explanations are provided in the text prior to any mathematical explanations, formulas, or derivations in order to establish why the concept or 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.

Self-Test Opportunity 5.3

A block is hanging vertically from a spring at the equilibrium displacement. The block is then pulled down a bit and released from rest. Draw the free-body diagram for the block in each of the following cases:

a) The block is at the equilibrium displacement.

b) The block is at its highest vertical point.

c) The block is at its lowest vertical point.

Self-Test Opportunities

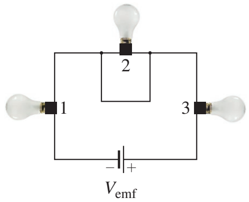
In each chapter, a series of questions focus on major concepts within the text to encourage students to develop an internal dialogue. These questions will help students think critically about what they have just read, decide whether they have a grasp of the concept, and develop a list of follow-up questions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

Concept Checks

Concept Checks are designed to be used with personal response system technology. They will appear in the text so that you may begin contemplating the concepts. Answers will only be available to instructors.

Concept Check 25.8

Three light bulbs are connected in series with a battery that delivers a constant potential difference, V_{emf}. When a wire is connected across light bulb 2 as shown in the figure, light bulbs 1 and 3



a) burn just as brightly as they did before the wire was connected.

b) burn more brightly than they did before the wire was connected.

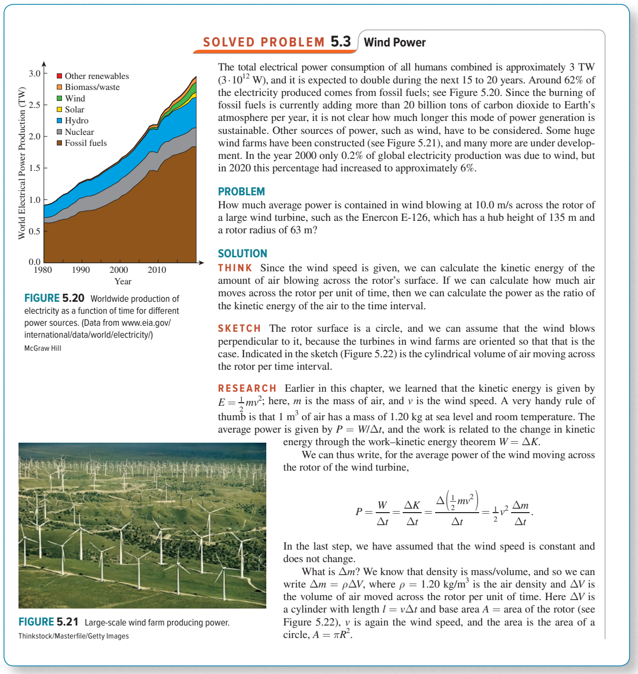
c) burn less brightly than they did before the wire was connected.

d) go out.

Seeing the Big Picture

Contemporary Examples

The authors have included recent physics research results throughout the text. Results involving renewable energy, the environment, aerospace, engineering, medicine, and technology demonstrate that physics is an exciting, thriving, and intellectually stimulating field. Available in Connect, the student resource center provides a number of items to enhance your understanding and help you prepare for lectures, labs, and tests.



SOLVED PROBLEM 5.3 Wind Power

The total electrical power consumption of all humans combined is approximately 3 TW ($3 \cdot 10^{12}$ W), and it is expected to double during the next 15 to 20 years. Around 62% of the electricity produced comes from fossil fuels; see Figure 5.20. Since the burning of fossil fuels is currently adding more than 20 billion tons of carbon dioxide to Earth's atmosphere per year, it is not clear how much longer this mode of power generation is sustainable. Other sources of power, such as wind, have to be considered. Some huge wind farms have been constructed (see Figure 5.21), and many more are under development. In the year 2000 only 0.2% of global electricity production was due to wind, but in 2020 this percentage had increased to approximately 6%.

PROBLEM

How much average power is contained in wind blowing at 10.0 m/s across the rotor of a large wind turbine, such as the Enercon E-126, which has a hub height of 135 m and a rotor radius of 63 m?

SOLUTION

THINK Since the wind speed is given, we can calculate the kinetic energy of the amount of air blowing across the rotor's surface. If we can calculate how much air moves across the rotor per unit of time, then we can calculate the power as the ratio of the kinetic energy of the air to the time interval.

SKETCH The rotor surface is a circle, and we can assume that the wind blows perpendicular to it, because the turbines in wind farms are oriented so that that is the case. Indicated in the sketch (Figure 5.22) is the cylindrical volume of air moving across the rotor per time interval.

RESEARCH Earlier in this chapter, we learned that the kinetic energy is given by $E = \frac{1}{2}mv^2$; here, m is the mass of air, and v is the wind speed. A very handy rule of thumb is that 1 m^3 of air has a mass of 1.20 kg at sea level and room temperature. The average power is given by $P = W/\Delta t$, and the work is related to the change in kinetic energy through the work–kinetic energy theorem $W = \Delta K$.

We can thus write, for the average power of the wind moving across the rotor of the wind turbine,

$$P = \frac{W}{\Delta t} = \frac{\Delta K}{\Delta t} = \frac{\Delta\left(\frac{1}{2}mv^2\right)}{\Delta t} = \frac{1}{2}v^2\frac{\Delta m}{\Delta t}.$$

In the last step, we have assumed that the wind speed is constant and does not change.

What is Δm? We know that density is mass/volume, and so we can write $\Delta m = \rho\Delta V$, where $\rho = 1.20$ kg/m^3 is the air density and ΔV is the volume of air moved across the rotor per unit of time. Here ΔV is a cylinder with length $l = v\Delta t$ and base area A = area of the rotor (see Figure 5.22), v is again the wind speed, and the area is the area of a circle, $A = \pi R^2$.

FIGURE 5.20 Worldwide production of electricity as a function of time for different power sources. (Data from www.eia.gov/international/data/world/electricity/)
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FIGURE 5.21 Large-scale wind farm producing power.
Thinkstock/Masterfile/Getty Images

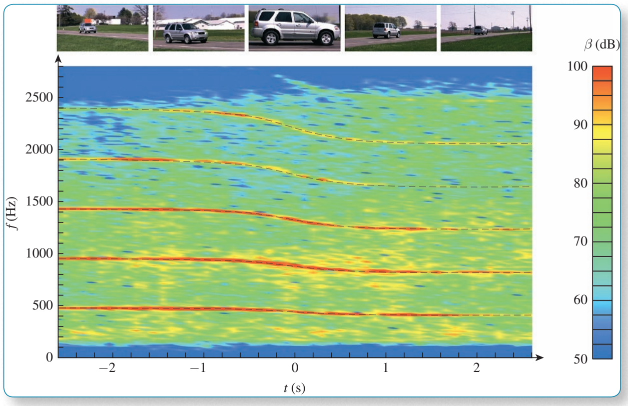
eBook

Linked to multimedia assets—including author videos, applets that allow you to explore fundamental physics principles, and images—the eBook allows you to take notes, highlight, and even search for specific words or phrases. All of the textbook figures, videos, and interactive content are also listed in line and by chapter, so you can navigate directly to the resource you need. Links to the eBook are included in the online homework and SmartBook 2.0. assignments, so if you are having trouble with an exercise or concept, you can navigate directly to the relevant portion of the text.

Visual Program

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

- Line drawings are superimposed on photographs to 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 as well as a visually appealing style.



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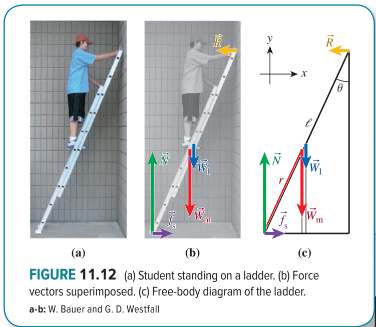
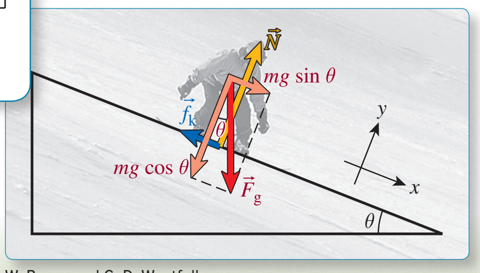


FIGURE 11.12 (a) Student standing on a ladder. (b) Force vectors superimposed. (c) Free-body diagram of the ladder.
a-b: W. Bauer and G. D. Westfall



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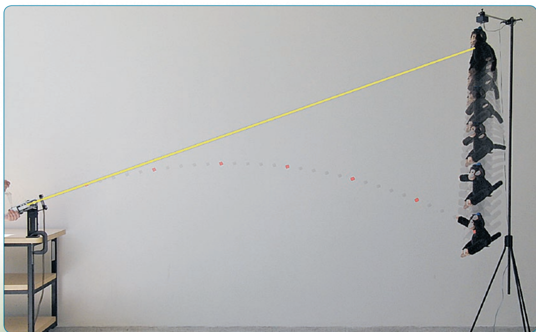

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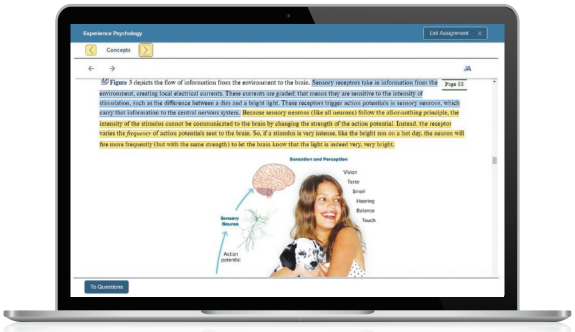

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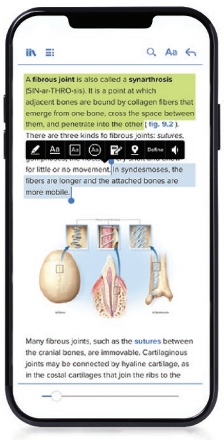

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The Connect library also provides a number of author-provided applets to help you visualize physics concepts that are presented throughout the book—from vectors and kinematics to quantum and nuclear physics. Interactive simulations allow you to simulate real experiments, while viewing data in real time, thereby linking concepts and principles you have just learned to real, quantifiable results.

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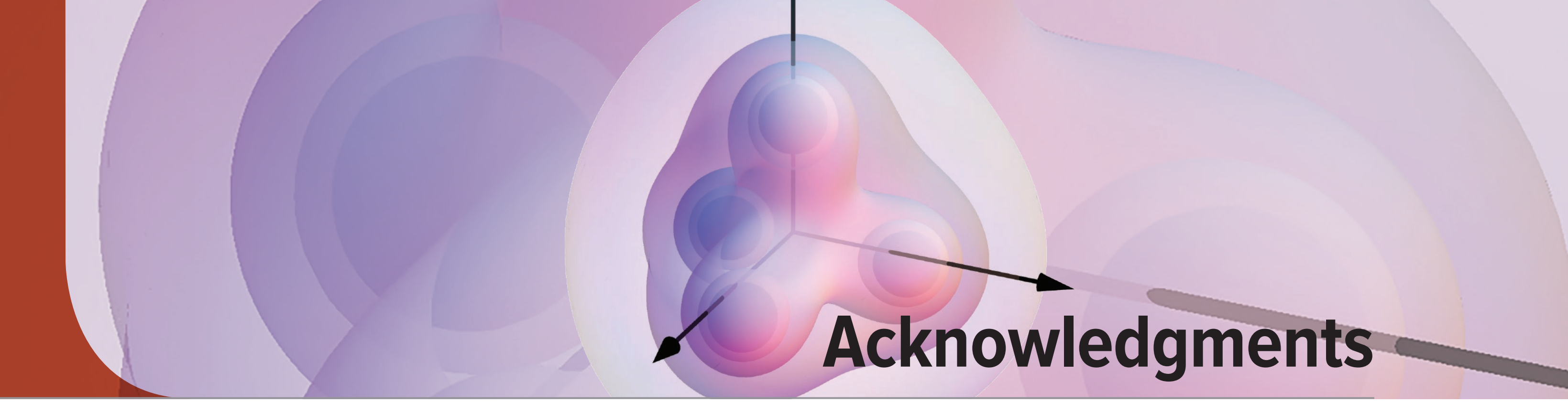

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—Wolfgang Bauer

—Gary D. Westfall

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Changes Since the Second Edition

In all chapters we added apps to perform interactive Concept Checks, a total number of 306, distributed over all 40 chapters.

Chapter 1

We added interactive apps to study logarithmic scales of length, mass, and time. We also provided interactive apps for vector addition, scalar vector products, and vector products in Cartesian and spherical coordinates. The definition of the kilogram base unit was updated.

Chapter 2

We added an interactive app to study logarithmic scales of speed, an app to illustrate the relationship between position, velocity, and acceleration, a video demonstration of weightlessness during free fall, two apps to illustrate motion with constant acceleration visualized with a moving car, and an app that shows the convergence of difference ratios to derivatives. We also added two Concept Checks.

Chapter 3

We added apps to illustrate projectile motion trajectories with and without a drag force, two gaming apps to study relative motion, and an app to study Cartesian velocity components during projectile motion. We include three video demonstrations of a basketball free throw, the independence of motion in the x- and y-directions, and the "shoot-the-monkey" lecture demonstration.

Chapter 4

We added two video demonstrations of dropping objects that reach terminal speed and on acceleration on an inclined plane. We supplied an app with which the student can study the Atwood machine, and we included seven different apps with which the student can practice drawing free-body diagrams. We added three new Concept Checks.

Chapter 5

We added interactive apps to study logarithmic scales of energy and power. We also included apps to study wind turbine power production, overall U.S. electricity production, visualization of the work done by gravity, and studying motion on an inclined plane during snowboarding. Video demonstrations included were lifting of a chain, lifting of a weight, and dropping of a vase. To introduce the spring force, we included an app to show the force vector and another app to portray the work done against the spring force. Figures 5.6 and 5.20 were updated with recent data, and the discussion of renewable electricity production was revised.

Chapter 6

We added video demonstrations for potential energy stored in deformation, for the potential energy of a waterfall, and for races between two identical balls on different paths. Apps illustrating the difference in work done by gravity and the friction force and for motion on an inclined plane with friction were also added. Three additional Concept Checks were included.

Chapter 7

We added video demonstrations for the ballistic pendulum, collision of a basketball and tennis ball, totally elastic air track collisions with equal and unequal masses, pendulum collisions, a pile driver, totally inelastic collisions, and collisions with two different coefficients of restitution. Apps to simulate totally elastic and totally inelastic collisions were provided. One additional Concept Check was included.

Chapter 8

Apps to illustrate vectors in cylindrical and spherical coordinate systems were provided. Two videos showing launches of toy rockets were included. Example 8.2 was revised. One additional Concept Check was inserted.

Chapter 9

We added centripetal force video illustrations for chips on a table, with and without banking, a roller-coaster loop, and a ball on circular motion in a vertical plane. We also provided a video of a wind turbine / wind farm. Two apps to illustrate polar coordinates were included, and four Concept Checks were added. Two examples referring to outdated technologies were removed.

Chapter 10

One Concept Check was added and another one removed. A total of 25 video demonstrations for the angular momentum chair, for angular momentum conservation, for torque, for a yo-yo, for rolling motion through a loop, for a gyroscope, for precession, for races between round objects with different moments of inertia, and for falling hinged rods were produced. We included an app to study the Atwood machine including the rotation of the pulley.

Chapter 11

Four different apps to practice drawing of free-body diagrams were added. A gaming app for stacking blocks was included as well.

Chapter 12

We revised Example 12.4, including Figure 12.21, with recent data on the black hole in the center of our galaxy, and discussed the Nobel Prize–winning work leading to the production of this figure. Example 12.5, which quantitatively discusses evidence for dark matter in the Andromeda galaxy was added. We updated Figure 12.23 with satellite positions as of December 2021. One additional Concept Check was inserted. We added apps to study Kepler's Laws, satellite orbits, and kinetic and potential energy in orbits. Videos illustrating planetary orbits in geo-centric and helio-centric frames were produced.

Chapter 13

We added interactive apps to study logarithmic scales of pressure. A total of 12 video demonstrations showing a wind farm, a swimmer in paint thinner and water, the Bernoulli Effect, buoyancy, and the effects of air pressure were produced. We also included an additional app to study the continuity equation.

Chapter 14

Apps to enable the student to study the similarities between circular motion and harmonic oscillations, pendulum motion, a mass on a spring in undamped harmonic motion, a mass on a spring in damped oscillation, and a mass on a spring with forced damped oscillations were added. Six video demonstrations of oscillating systems were produced.

Chapter 15

We produced 12 video demonstrations of coupled oscillations, wave propagation, wave addition, standing waves, and resonance. We also included apps to simulate and study eigenmodes in coupled oscillations, wave interference in one dimension and in two dimension. We updated Section 15.9 to reflect the advances made in gravitational wave detection.

Chapter 16

We inserted a new Concept Check. We included videos on wave tanks, resonance pipes, the Doppler effect, and beats. We also produced apps to enable the student to study beats, the Doppler effect, and the creation of Mach cones.

Chapter 17

We added interactive apps to study logarithmic scales of temperature. An app to illustrate temperature conversion was also included. We also produced video demonstrations of bimetal bending, as well as thermal expansion. Section 17.5, on the surface temperature of Earth, was updated with the most recent data. Section 17.6, on the temperature of the Universe, was updated with the most recent findings from the Planck observatory.

Chapter 18

We created a simple app to visualize different countries' contributions to the discovery of elements during the last few centuries. We also included apps to show the phase transition temperature of the individual elements, and the heat required to change the temperature of ice/water/steam. We updated the section on global warming and Figure 18.28 to reflect the most recent data on the CO_2 concentration in the atmosphere. A discussion of the 2021 Nobel Prize, awarded to Syukuro Manabe, was included.

Chapter 19

We included three video demonstrations of the thermal expansion and contraction of gases. Two apps on three-dimensional gases and gas law allow the student to study the behavior of gases at different temperatures, pressures, and volumes.

Chapter 20

We included video demonstrations of a heat pump and a Sterling engine. We also provided an app that allows the student to visualize the free expansion of a gas in three dimensions, and an app to study the Carnot process.

Chapter 21

We produced two video demonstrations of electrostatic attraction. We added an app that allows students to visualize the Coulomb interaction between point charges.

Chapter 22

We added video demonstrations of the Faraday cage, a visualization of a dipole field, and video demonstrations of electrostatic deflection, as well as shielding. We also included an app to let students study electric field in three dimensions.

Chapter 23

Two video demonstrations of a Van de Graaf generator are included. We also added an app to help the student visualize electric potential. A new Example 23.8 was added, and a new Conceptual Question 23.16 was constructed.

Chapter 24

We added two video demonstrations of capacitor discharges. We provided an app to allow the student to experiment with the equivalent capacitance of several configurations of individual capacitors in series and/or in parallel. We updated the discussion of the National Ignition Facility with the most recent performance data.

Chapter 25

We added an interactive app to study logarithmic scales of current. The video demonstrations added to this chapter are about drift velocity and on conduction in heated glass. We created two apps to enable the student to visualize the potential and currents in a circuit with resistors in parallel and in series. Another app allows the student to experiment with the equivalent resistance of several configurations of individual resistors in series and/or in parallel.

Chapter 26

We added a video showing the time dependence of the current in an RC circuit. Two apps allow the student to experiment with charging and discharging of capacitors in RC circuits. Another app lets the student change parameters in a multi-loop circuit of resistors and batteries to study Kirchhoff's rules. A figure discussing an EEG taken with an Apple Watch was added.

Chapter 27

We added six video demonstrations that show magnetic forces on current-carrying wires and bending of electron beams in magnetic fields. We also included an app that allows the student to study and visualize the Lorentz force.

Chapter 28

New video demonstrations include torque on a compass needle, an electromagnet in action, forces between current-carrying wires, and the Curie temperature. We added an app to illustrate the definition of Ampere's Law.

Chapter 29

We added 12 video demonstrations on induction and eddy currents. A new induction app allows the student to explore induced currents in a loop due to moving magnets.

Chapter 30

We added three new apps that allow detailed visualization of RLC circuits, including frequency dependence of impedance and phasors.

Chapter 31

We updated the discussion of assigned frequency bands in the electromagnetic spectrum. We also updated Example 31.1 to reflect battery performance in modern electric cars. We added five new video demonstrations about polarization and radiation pressure. We included a new app on linear polarizers that allows the student to study polarized light.

Chapter 32

We added eight new apps to allow the student to interactively explore image construction with plane mirrors, parabolic mirrors, converging mirrors, diverging mirrors, dispersion in prisms, and Snell's Law.

Chapter 33

We added new apps for image construction with converging lenses and diverging lenses.

Chapter 34

One new video demonstration and four new apps allow detailed interactive exploration of diffraction.

Chapter 35

We rewrote the discussion of gravitational waves in Section 35.5 following their discovery in 2015, which led to the 2017 Nobel Prize in Physics. Video demonstrations for the equivalence principle and particle-antiparticle creation at RHIC are now included. We also added an app that interactively explores the twin paradox.

Chapter 36

We updated the discussion of cosmic microwave background with new results. The discussion of fundamental constants was updated to reflect the most recent changes in the standards. An app to explore blackbody radiation, Planck's Radiation Law, and Wien's Law was added.

Chapter 37

We added an app for the student to study energy levels and wave functions for a quantum particle in a box. We updated the discussion of quantum computing to reflect the most recent achievements.

Chapter 38

We updated the periodic table with the names of recently named elements 113, 115, 117, and 118. We updated the discussion of high-powered lasers with the newest performance data. Three new apps allow the student to explore the Bohr model of the atom, the quantum mechanical wave functions of the hydrogen atom, and the filling of electron shells in the periodic table.

Chapter 39

Additive and subtractive color mixer apps were added to illustrate the ideas behind quark and gluon confinement. Discussions of masses and lifetimes of elementary particles were updated to conform with the most recent research results. The Planck results replace the WMAP results for the measurements of the cosmic microwave background.

Chapter 40

We added video demonstrations for a chain reaction (with corks and mousetraps) and a heavy ion collision. New interactive apps allow the student to explore chain reactions, MRIs, and decays. Two additional apps that were added explore isotopes and their half-lives. We updated Figure 40.5 with the newly discovered isotopes.