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Acknowledgments

Project Director

Dr. Arthur Eisenkraft has taught high school physics for over 28 years. He is currently the Distinguished Professor of Science Education at the University of Massachusetts, Boston, where he is also an Adjunct Professor of Physics and the Director of the Center of Science and Math In Context (COSMIC). Dr. Eisenkraft is the author of numerous science and educational publications and holds a patent for a Laser Vision Testing System, which tests visual acuity for spatial frequency.

Dr. Eisenkraft has been recognized with numerous awards, including: Presidential Award for Excellence in Science Teaching, 1986, from President Ronald Reagan; the American Association of Physics Teachers (AAPT) Distinguished Service Citation for "excellent contributions to the teaching of physics," 1989, the Excellence in Pre-College Teaching Award, 1999, and the Robert A. Millikan Medal for "notable and creative contributions in physics education," 2009; Disney American Teacher Award for Science Teacher of the Year, 1991; Honorary Doctorate of Science, Rensselaer Polytechnic Institute, 1993; National Science Teachers Association (NSTA) Distinguished Service Award to Science Education, 2005, and the NSTA's most prestigious award, the Robert H. Carleton Award for "notable and creative contributions in physics education" in 2010.

In 1999, Dr. Eisenkraft was elected to a three-year cycle as the President-Elect, President, and Retiring President of the NSTA, the world's largest organization of science teachers. He has served on numerous committees of the National Academy of Sciences, including the content committee that has helped author the National Science Education Standards, and in 2003 he was elected a fellow of the American Association for the Advancement of Science (AAAS). Dr. Eisenkraft has been involved with a number of projects and chaired many notable competitions, including the Toshiba/NSTA ExploraVisions Awards (1991 to present), which he co-created; the Toyota TAPESTRY Grants (1990 to 2005); and the Duracell/NSTA Scholarship Competition (1984 to 2000). In 1993, he served as Executive Director for the XXIV International Physics Olympiad after being Academic Director for the United States Team for six years.

Dr. Eisenkraft is a frequent presenter and keynote speaker at national conventions. He has published over 100 articles and presented over 200 papers and workshops. *Quantoons*, written with L. Kirkpatrick and featuring illustrations by Tomas Bunk, led to an art exhibition at the New York Hall of Science.

Dr. Eisenkraft has been featured in articles in *The New York Times*, *Education Week*, *Physics Today*, *Scientific American*, *The American Journal of Physics*, and *The Physics Teacher*. He has testified before the United States Congress, appeared on NBC's *The Today Show*, National Public Radio, and many other radio and television broadcasts, including serving as the science consultant to ESPN's *Sports Figures*.

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Dear Student Scientists,

Imagine meeting someone who never heard of your favorite movie or music group! Now imagine how enriched they would be if they could enjoy that movie or music the way you do.

Active Physics came about as a result of a similar frustration. The usual physics course is focused on so much math and so much reading that many students miss the beauty, the excitement, and the usefulness of physics. Many more students simply refuse to take the course. *Active Physics* began when a group of physicists and physics teachers wondered how to pass on their enjoyment of physics to high school students.

Physics should be experienced and make sense to you. Each chapter of *Active Physics* begins with a challenge—develop a sport that can be played on the Moon; design a roller coaster for a target audience; persuade your parents to lend you the family car; and so on. These are tough challenges, but you will learn the physics that will allow you to be successful at every one.

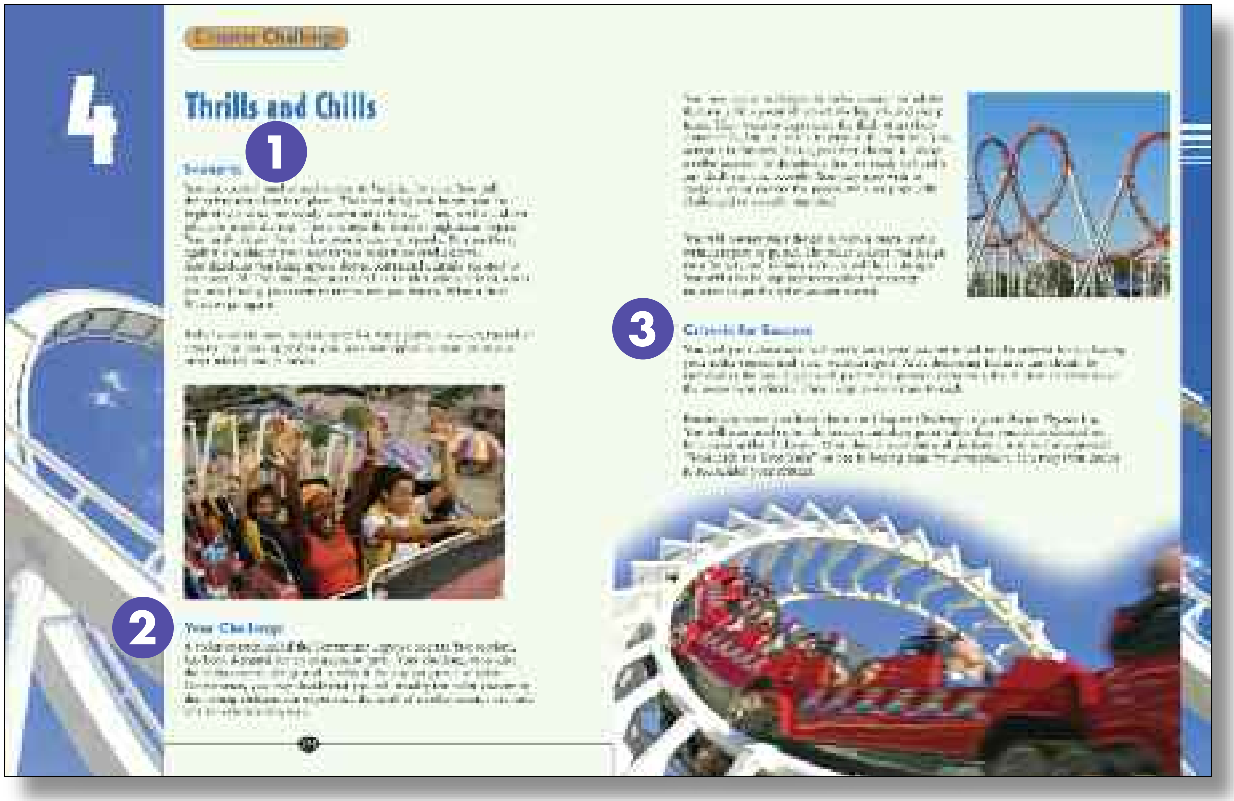
Part of your education is to learn to trust yourself and to question others. When someone tells you something, can they answer your questions: "How do you know?, Why should I believe you?, and Why should I care?" After *Active Physics*, when you describe why seat belts are important, or why sports can be played on the Moon, or why wind (or falling water) is able to generate electricity and someone asks, "How do you know?" your answer will be, "I know because I did an experiment."

Only a small number of high school students study physics. You are already a part of this select group. Physics awaits your discovery.
Enjoy the journey.

Arthur Eisenkraft

Welcome to Active Physics – Your Guide to Success

Physics is involved in every aspect of your life – from the way your body works to the things you like to do. *Active Physics* makes learning physics relevant, fun, and exciting! Here is how you are going to learn about physics in this book.



❶ Scenario

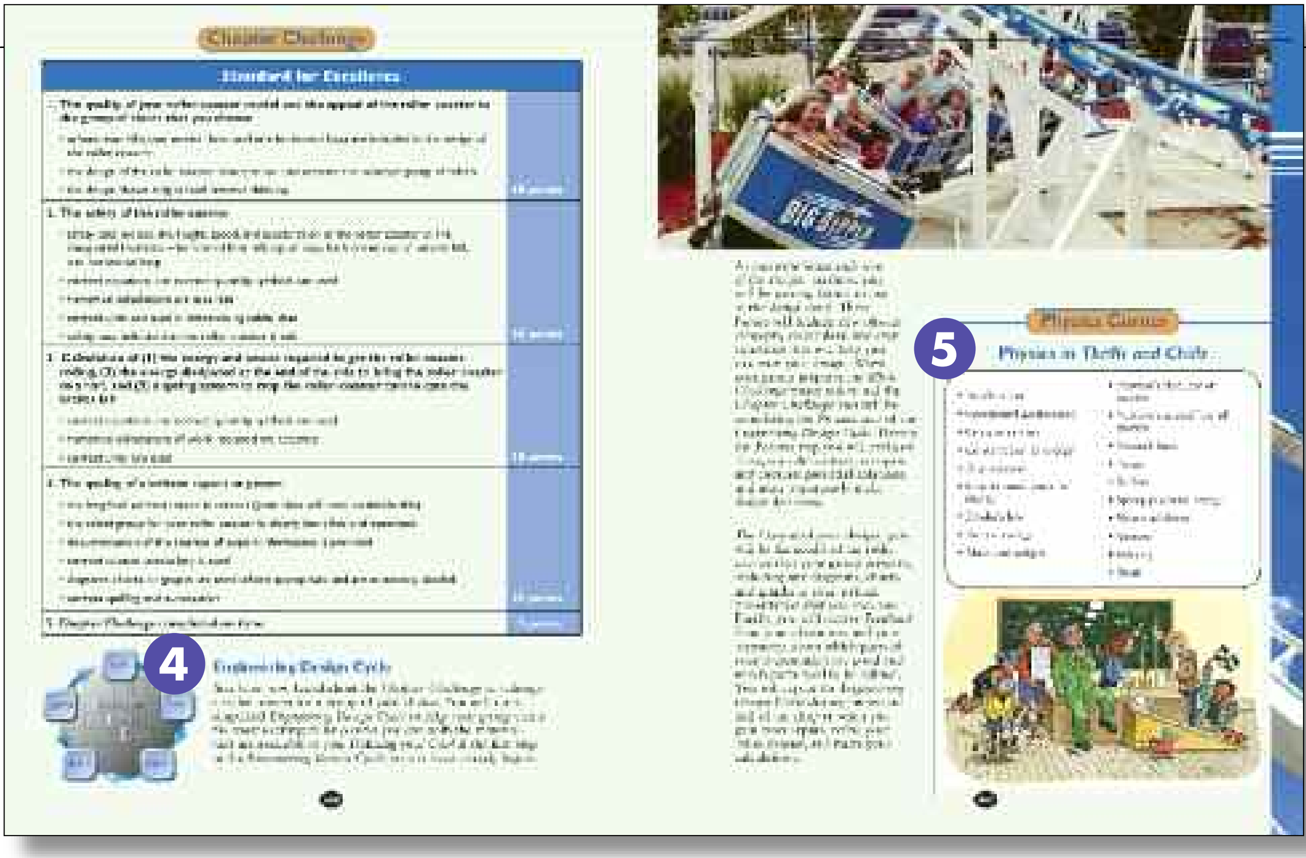
Each chapter begins with an event or situation that places physics in the context of a familiar everyday experience. Chances are that you can relate to each of these scenarios, but never thought about the physics involved! The topics involve things of interest to you and range from entertainment to driving and from sports to assisting people in developing nations.

❷ Your Challenge

Each chapter gives you a challenge that will be your group's responsibility for the next month or so. Physics knowledge, application, and synthesis will be necessary for the successful completion of this project. However, physics content alone is not sufficient for success. Each challenge will require imagination and creativity. Your group's challenge project will be unique and will reflect the interests and talents of the members of your group.

❸ Criteria for Success

Before you begin your *Chapter Challenge*, you will be part of an important decision-making process. You and your class will decide what constitutes an excellent project. Your teacher will help guide you through your decisions. The rubric you create will ensure that everybody knows what is required to meet the needs of the challenge and how many points each component will



be worth. After you have developed a rubric, you can take a look at the *Standard for Excellence* chart that is provided. It is worthwhile to compare your rubric with this chart.

❹ Engineering Design Cycle

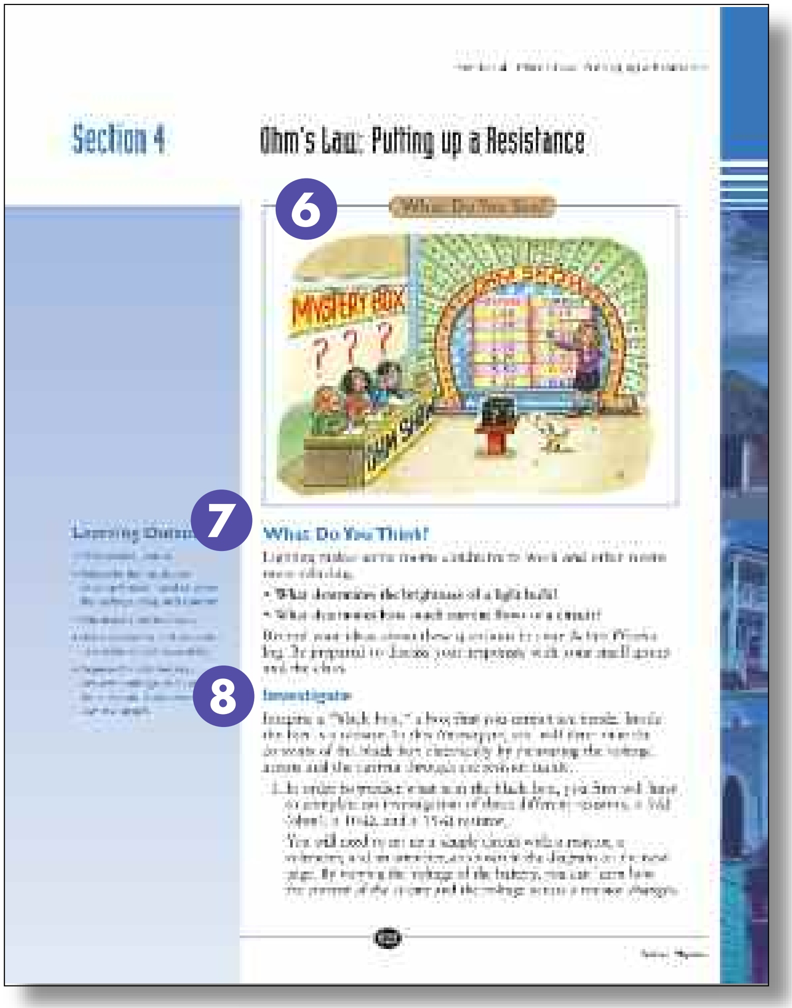
The *Chapter Challenge* is a problem that you need to solve. There are many different ways to solve problems. One sequence of steps that can be used to solve problems is called the *Engineering Design Cycle*. This cycle helps to remind you that when completing a project you have to be aware of the *Goals*. You then gather information (*Inputs*) and put this together through a design cycle. Once you have completed your work (*Output*), take a step back and provide *Feedback* for yourself and your group. You may also get feedback from other groups in your class. You are going to use a simplified *Engineering Design Cycle* as you address your challenge. You will apply it after getting halfway through the chapter.

The *Mini-Challenge* will prepare you for the requirements of the *Chapter Challenge*. It is a good way to step back and review the work done so far. At the end of the chapter, you get to use *Feedback* from the *Mini-Challenge* as well as new information to complete the *Chapter Challenge*.

❺ Physics Corner

As you enjoy learning the content necessary to develop a light and sound show, design and build an improved safety device for a car, or become a sports broadcaster, you and your teacher will be impressed by how much physics content you are learning. The *Physics Corner* previews all the physics concepts that the chapter will present. You will be actively involved and your teacher will help you keep track of all the physics concepts that you are learning.

Your Guide to Success



❻ What Do You See?

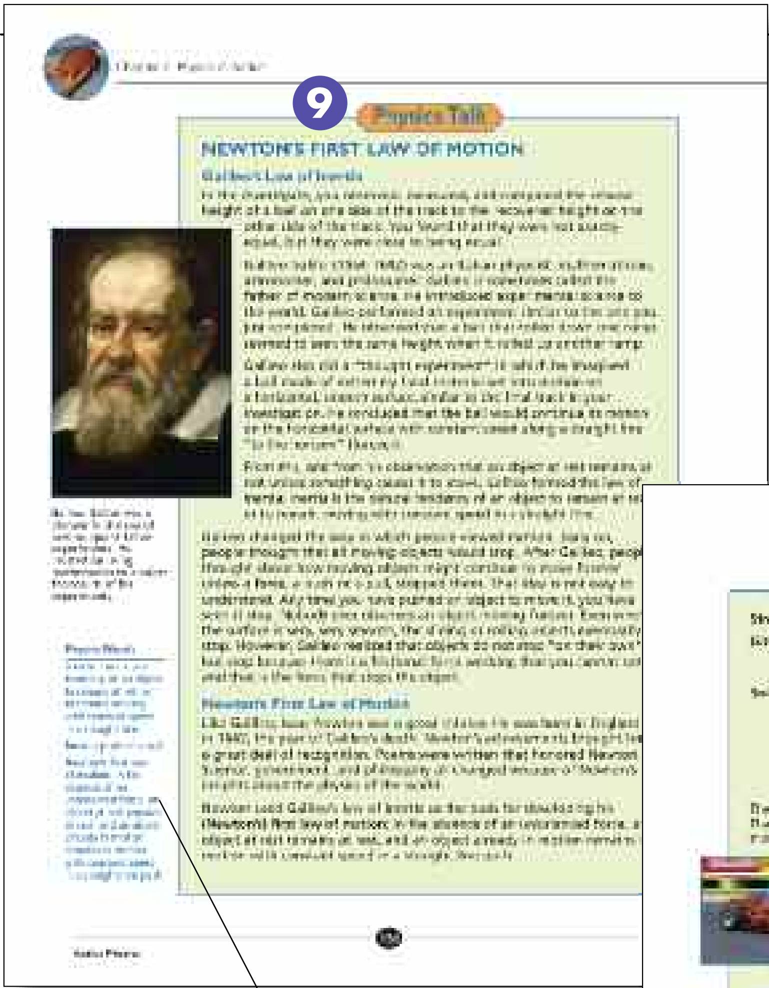
A picture is worth a thousand words. At the beginning of each section, a cartoon is shown to get you thinking about physics. Discussing what you see in the cartoon will help you reflect on what you already know about the topics in the section. This is an important step in the learning process. Tomas Bunk, a well-known illustrator of *MAD* magazine, *Quantoons*, and *Garbage Pail Kids*, created the cartoons.

❼ What Do You Think?

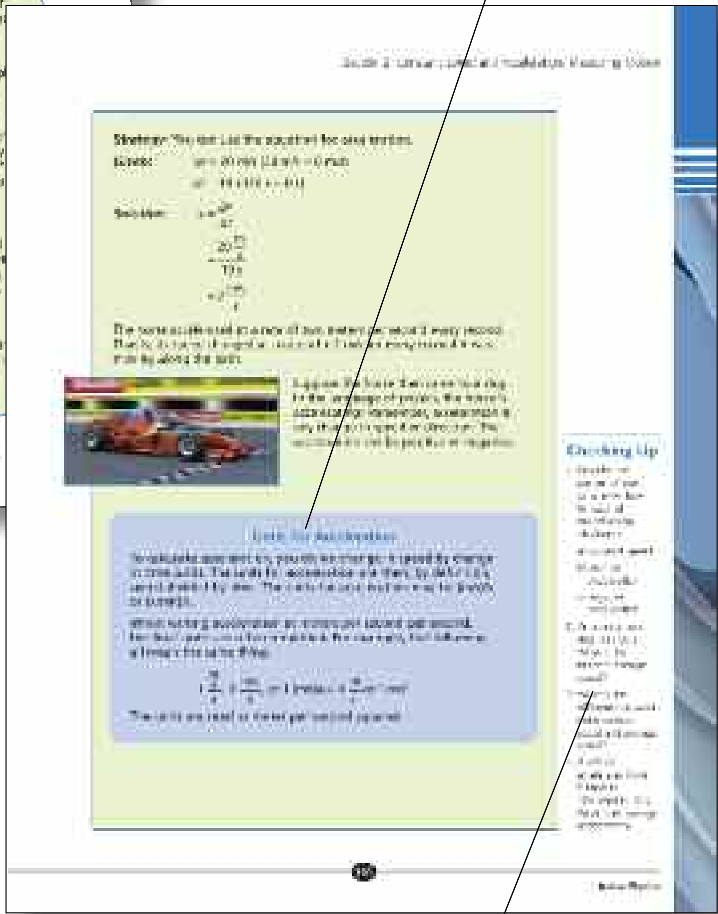
The *What Do You Think?* question gives you a chance to explore what you already know or think you know. This is sometimes called *eliciting prior understandings*. Your answers will help you become engaged and set the stage for the section. Don't worry about being "right" or "wrong." Answering the questions as well as you can is another important step in the learning process.

❽ Investigate

Everyone learns better by doing rather than by watching. You can watch someone knitting a sweater for weeks, but you won't learn to knit if you never handle the knitting needles yourself. You can watch professional athletes play basketball, but you know that you won't ever play ball like they can, unless you practice, practice, and practice. Research says that you should explore a concept in a section before your teacher tries to explain it verbally. In *Active Physics*, the *Investigate* section is your opportunity to explore the world of physics.



Science Skills — These concepts are introduced on a need-to-know basis. Metric prefixes, SI units and symbols, dimensional analysis, and so on are explained when you need to use these skills.

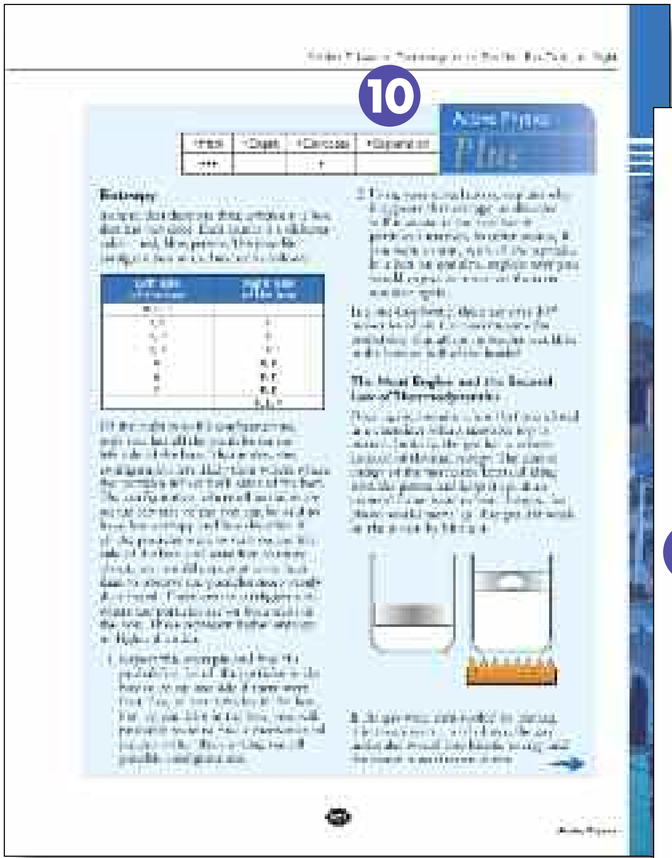


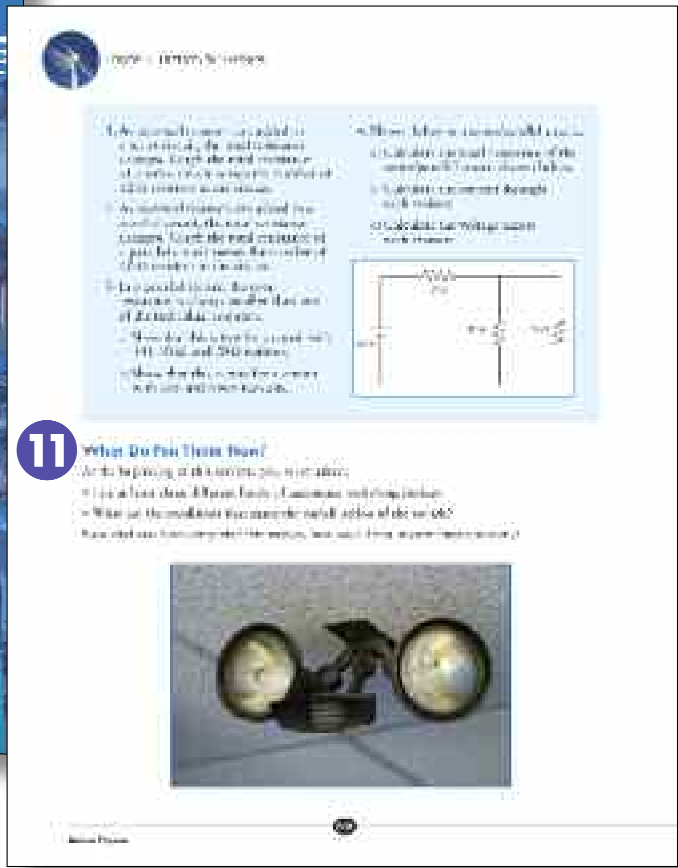
Physics Words — Concepts are often more efficiently communicated when vocabulary is introduced. *Physics Words* highlights the important terms you want to know. They are also briefly explained for you to make reading and comprehension easier.

9 Physics Talk

The *Physics Talk* will help you make better sense of the investigation you have just completed. It will introduce you to the scientific way of explaining concepts. It will provide illustrations, charts, and mathematical equations to help guide your understanding. The *Physics Talk* is chock-full of physics content.

Checking Up — These questions are great tools for evaluating your understanding of the concepts that you have learned.





10 Active Physics Plus

Active Physics Plus is an opportunity to explore physics in additional ways. It may include more math, increased depth, additional concepts, or another investigation. *Active Physics Plus* can be considered optional topics for some students in some schools. For others, your teacher may require you to complete an *Active Physics Plus*. Your teacher is familiar with your state requirements and can guide you to appropriate personal challenges so that all students extend their knowledge and skills.

Each *Active Physics Plus* component will be noted with a grid, informing you which extension categories will be covered. The diamond notation (u) indicates the level of intensity (three diamonds being the highest level).

11 What Do You Think Now?

At the beginning of each section, you were asked to think about one or two questions. At that point, you were not expected to come up with the "physics" answer. Now that you have completed the section, you will be asked to think about these questions again. Compare your initial answers to the answers you give at the end of the section.

⓬ Physics Essential Questions

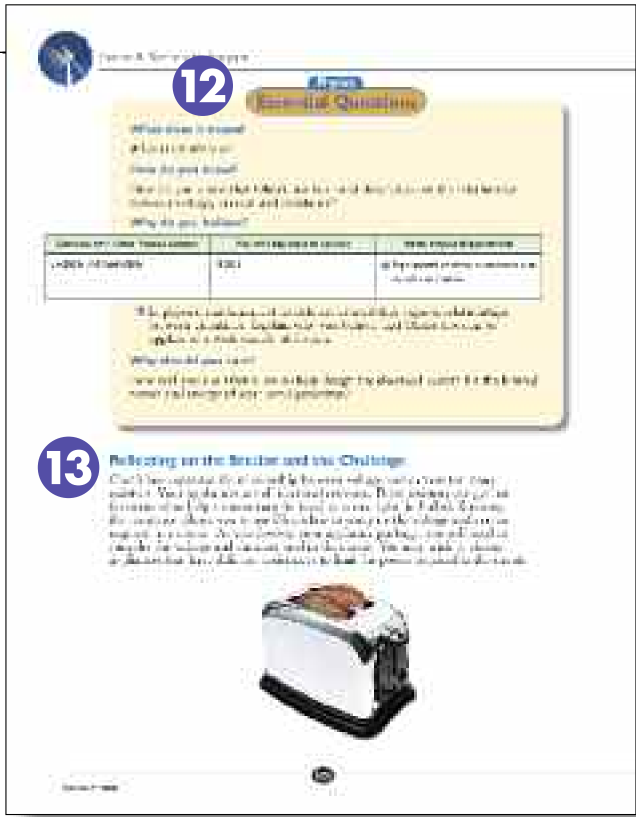
As a student physicist, you join the physics community by recognizing and understanding the organizing principles of physics. You also need to focus on the essential questions of all scientific endeavors.

- What does it mean?
- How do you know?
- Why do you believe?
- Why should you care?

The first essential question is **What does it mean?** Answering this question will help you articulate one of the physics concepts that you investigated in each section.

The second essential question is **How do you know?** You will answer this question by describing the experimental evidence that you have gathered from your investigations. You "know" because you have done an experiment.

There are different facets of interpretation to the third essential question **Why do you believe?** One of the reasons you believe things in physics is because it connects with other physics content. Physics content is often grouped into a few large ways of seeing the world. Another reason you believe in the physics is because it fits with other Big Ideas of science. These Big Ideas are often referred to as organizing principles. The third reason you believe in the new physics content and concepts is because it is supported by experiments, data, math, or can be used to explain unrelated phenomena. The **Why do you believe?** question will help you better understand the nature of science, the philosophy of science, and the organizing principles of science. Rather than having an isolated chapter entitled "What Is Science," *Active Physics* has you confront the essence of physics throughout the course with each new topic and each new explanation.



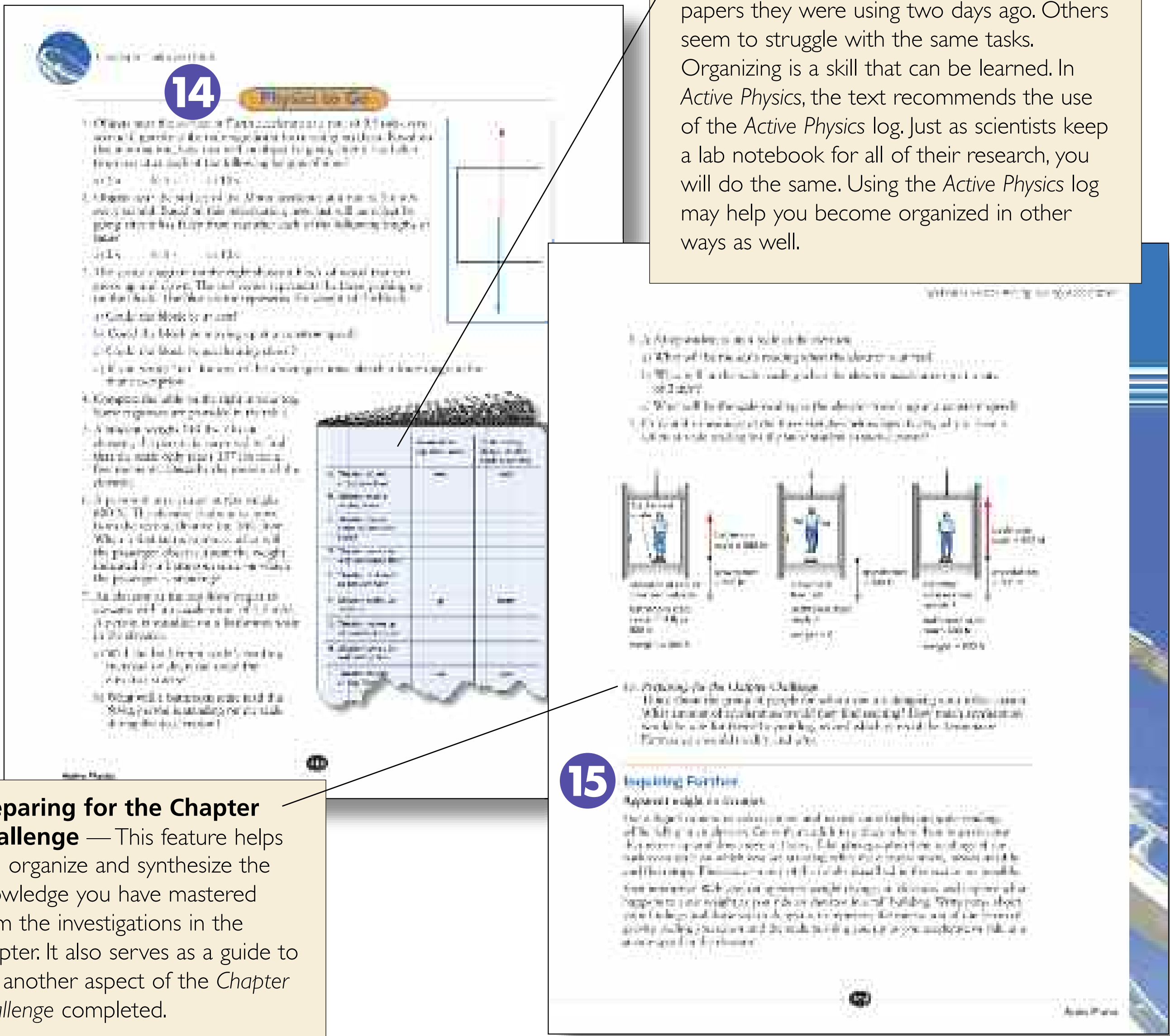
People learn better when the concepts being taught are relevant to their lives. The fourth essential question, **Why should you care?** asks you to explain how the present section relates to the *Chapter Challenge* and how you can use the content of the section in your group's project.

⓭ Reflecting on the Section and the Challenge

Research has shown that real learning takes place when people transfer their knowledge to a new domain. The physics content of each section is another puzzle piece that you can put in place to create your *Chapter Challenge* project. *Reflecting on the Section and the Challenge* provides guidance on how to transfer the knowledge and move forward on your project.

Your Guide to Success

The Active Physics Log — Some people are better organized than others. They can always find the book that they need or the papers they were using two days ago. Others seem to struggle with the same tasks. Organizing is a skill that can be learned. In *Active Physics*, the text recommends the use of the *Active Physics* log. Just as scientists keep a lab notebook for all of their research, you will do the same. Using the *Active Physics* log may help you become organized in other ways as well.



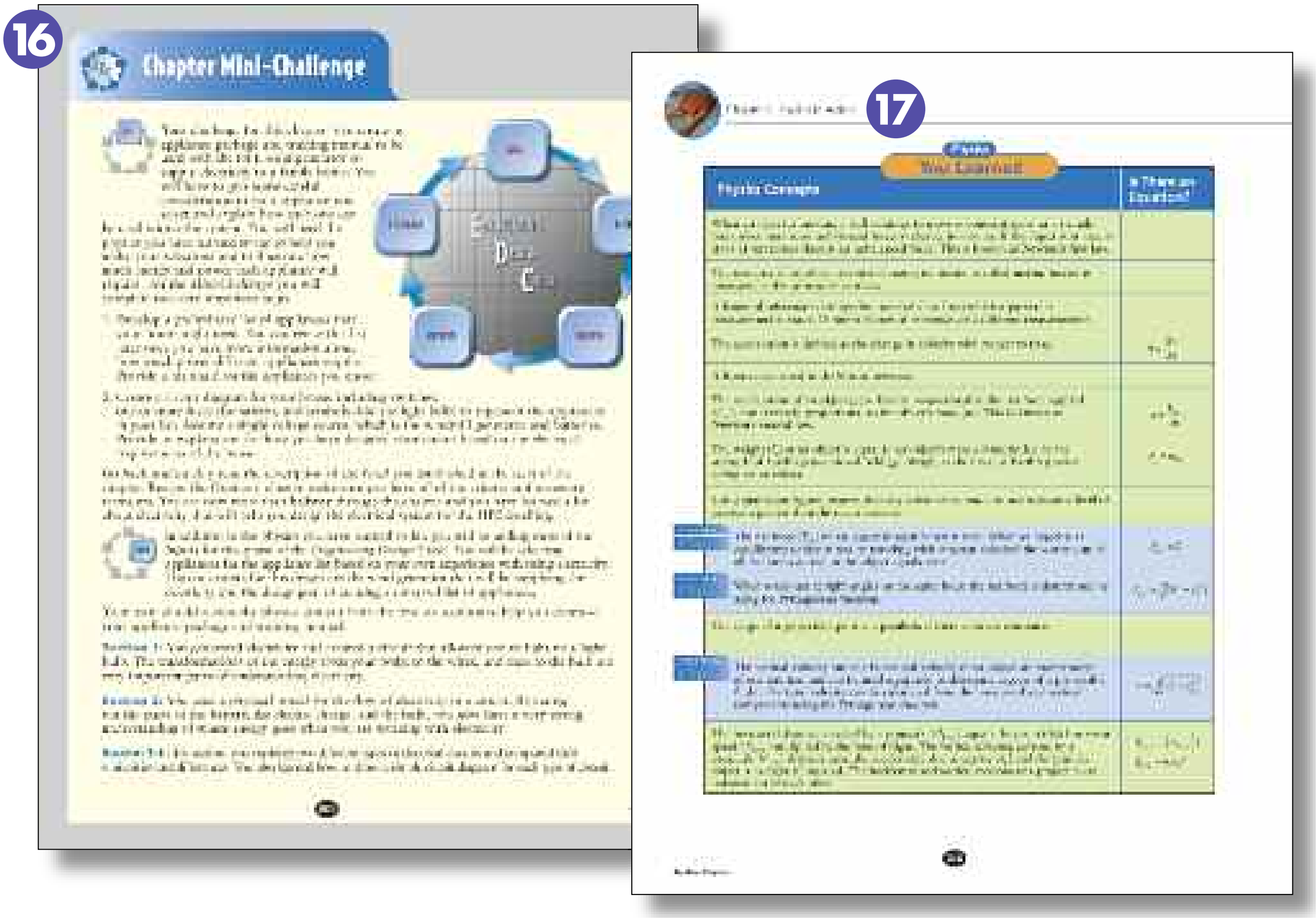
Preparing for the Chapter Challenge — This feature helps you organize and synthesize the knowledge you have mastered from the investigations in the chapter. It also serves as a guide to get another aspect of the *Chapter Challenge* completed.

⑭ Physics to Go

Often given as homework assignments, *Physics to Go* is another opportunity for you to elaborate on the physics content of the section. These are excellent study guide questions that help you to review and check your understanding.

⑮ Inquiring Further

Active Physics embraces inquiry as a way of learning. You are always involved in inquiry during the *Investigate* section. You have another opportunity for open inquiry when you are asked to inquire further. *Inquiring Further* often requires you to design your own experiment and, with teacher approval, to continue to enhance your learning. *Inquiring Further* also provides more challenging in-depth problems, questions, and exercises for extra credit.



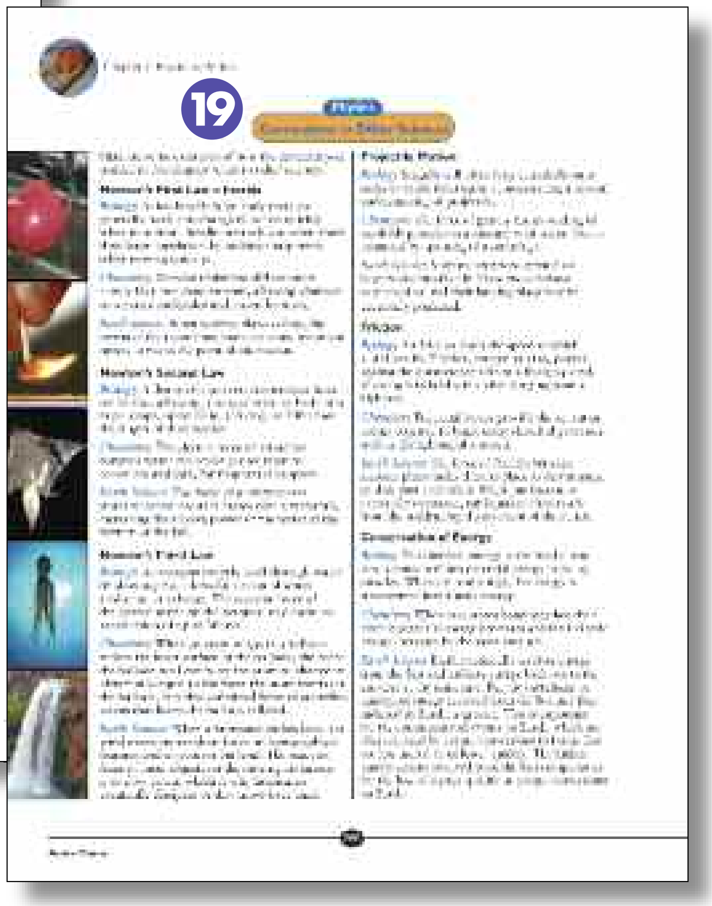
16 Chapter Mini-Challenge

When engineers design a product, they follow an *Engineering Design Cycle* with several distinct steps. The *Mini-Challenge* takes you through a first step of this cycle. As part of this process, the *Mini-Challenge* will encourage you to give your *Chapter Challenge* a first try. In this way, you are actually involved in the *Engineering Design Cycle* and not just reading about it. As you make your “product” for your *Chapter Challenge*, you will become increasingly aware of the many benefits of using the *Engineering Design Cycle*.

17 Physics You Learned

To complete your *Chapter Challenge*, you will need to use the physics principles you learned as you completed each section. For each chapter, you should review what you have learned and how you can use these concepts in your challenge. The *Physics You Learned* section lists many of the physics principles you investigated in the chapter. You can use this as a checklist to develop your own list. You may have heard it said that math is the language of nature. Physicists, in describing any phenomenon, ask themselves, “Is there an equation?” As student physicists, you will also need to ask this question. In *Physics You Learned*, you will be reminded of the equations used in this chapter.

Your Guide to Success

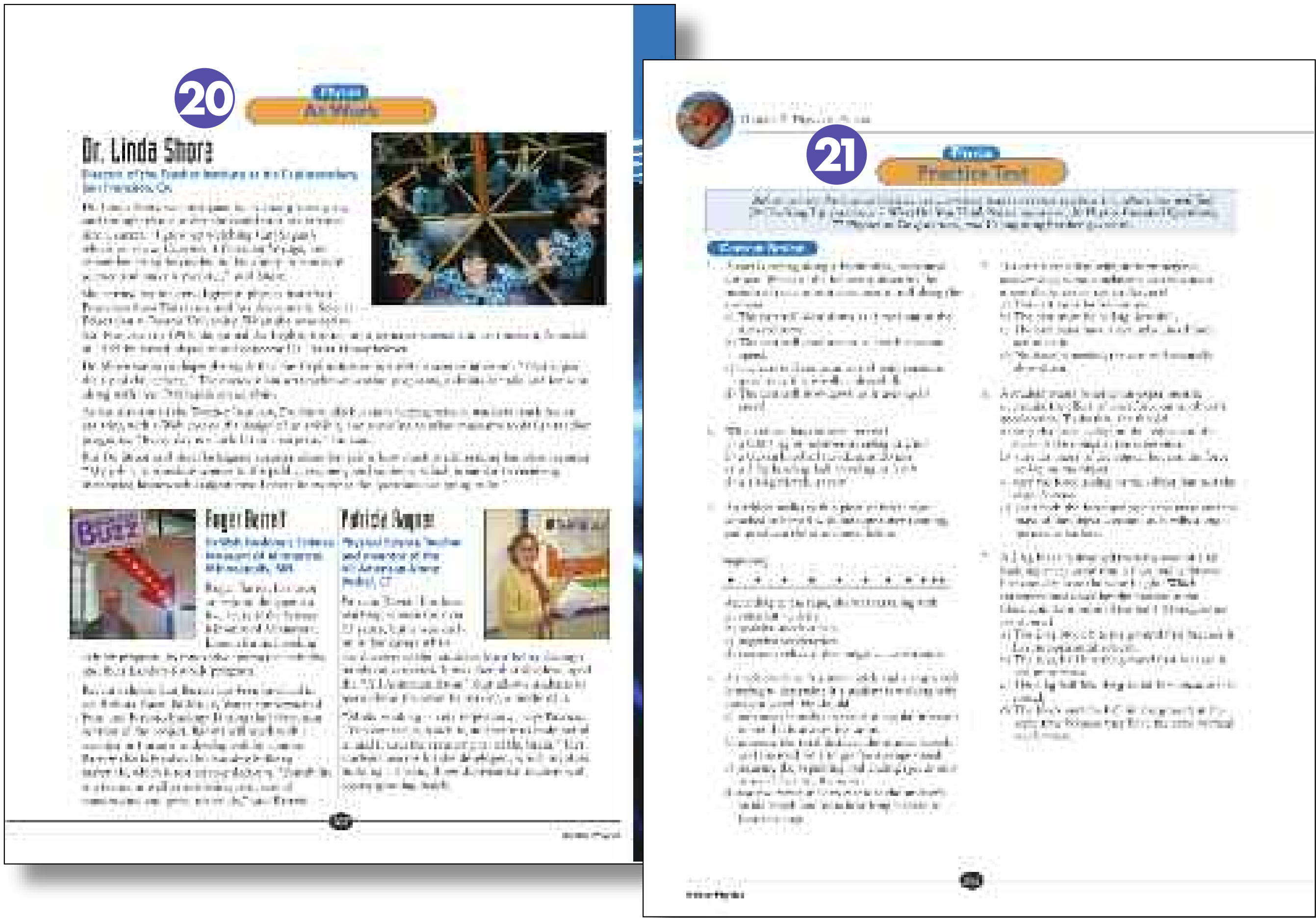


⑱ Physics Chapter Challenge

Business leaders want to hire people who know how to work effectively in groups and how to complete projects. The *Chapter Challenge* provides guidance on how to begin your work on the *Chapter Challenge* project, set deadlines, meet all the requirements, and combine the contributions of all members of the group. This section guides you without restricting you. Your group's creativity and imagination will be a major factor in your enjoyment and success. The best projects will reflect the diverse interests, backgrounds, and cultures of your group members. Once again, you will visit the *Engineering Design Cycle* as a way to help organize your work.

⑲ Physics Connections to Other Sciences

The fundamental ideas you have studied in this chapter are also basic to many other sciences that you will study in the future. Appreciating the connections among science disciplines helps scientists achieve a richer understanding of nature. Science research in the twenty-first century depends heavily upon the way these different disciplines interact, with disciplines such as biophysics and geophysics becoming major areas of study.



20 Physics at Work

The projects that you complete for the *Chapter Challenges* are often the actual jobs of real people. *Physics at Work* introduces you to people who use the physics of the chapter as part of their career. Reading about their lives may get you thinking about careers that interest you and help you make a difference in the world.

21 Physics Practice Test

You have been checking up on your own understanding of the physics concepts throughout each chapter. You have been asking yourself all sorts of questions as you complete the investigations and other parts of each section. High achievers learn to check for understanding and to recognize when they have to do a bit more work to fully understand something. The *Physics Practice Test* is a way in which you can find out how well you have learned the physics in this chapter. Before taking the *Physics Practice Test*, it makes sense to review each section's *Checking Up*, *Physics to Go*, *What Do You Think Now?*, and *Physics Essential Questions*. Reviewing the cartoons and illustrations of the investigations in the chapter may help you to remember all that you have learned.

How to Use Your Active Physics Log

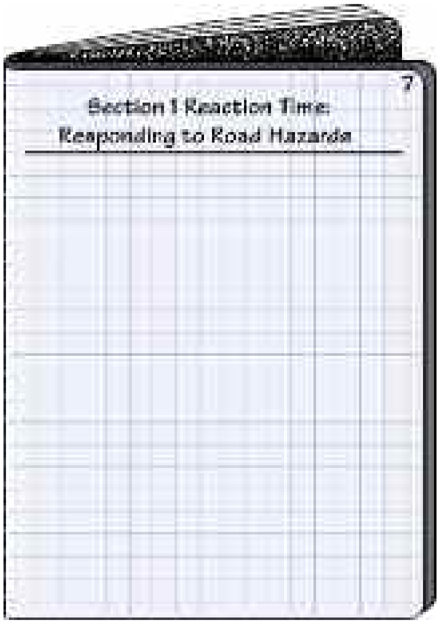
Scientists must keep a record of all of their work. The scientist's notebook is a legal document that can be used as evidence in court to determine the time, description, and breadth of a discovery. As student scientists, you will be keeping an *Active Physics* log. This log or notebook will be a record of all that you learn and accomplish as well as a way to organize all your notes, lab investigations, homework, and conversations.

At the end of the first few months of school, what will your excellent student log look like? It will have each page numbered. The first few pages will be a table of Contents where you will list each chapter and each section of each chapter as you go along. The sections will all be in order (for example, *Section 1* will be followed by *Section 2*, which will be followed by *Section 3*, and so on). Your *Active Physics* log will have a complete record of all of your work including notes, lab procedures, data, graphs, and homework. For example, your teacher will be able to review your progress by turning to the table of Contents, finding the page for *Section 6* of a chapter and all the work for that section will be on those pages. Some of that work will be written in the log while other work will be glued into the log. It will be a log that brings you pride and respect.

How will you create such a log?

Scientists usually have a bound notebook. This insures that pages are not added to or removed from the log as can easily be done in a loose-leaf binder. Your first step in getting your bound or spiral notebook ready for use as a log is to number all the pages in the upper right-hand corner. The first page has a "1" and the back of the first page has a "2." It won't take long. If your notebook has 150 pages, this will probably take between 150 and 300 seconds. That amounts to at most 5 minutes. If you get tired, you can number the first 50 pages now and number the rest later.

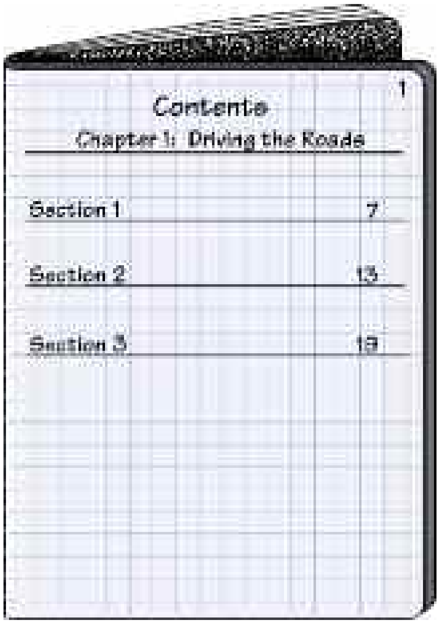
The second step is to write your name on the cover of the log and/or on the inside front cover. The third step is to write at the top of page 1, "Contents." You should begin your notes on page 5. This will allow you to use pages 1 to 4 as a table of contents for the entire book.



When you begin your first chapter, you should write at the top of page 5 the name of the chapter. For example, if you start with *Chapter 1*, you would write *"Chapter 1: Driving the Roads."* As you begin the chapter, you will record notes about the *Chapter Challenge*. When it is time to begin *Section 1*, you should begin a new page. Every time you start a new section, you should begin a new page.

Everything goes into this log. If you complete a homework that your teacher collects, the returned homework should be glued into the log. If your log has pages made of graph paper, you can make graphs directly in the log. If you use sheets of graph paper to make graphs, these sheets of paper will be glued into the log. If your teacher collects some homework, you must remember to skip a page or two to glue that homework into your log when it is returned. In this way, the homework assignments from *Section 4* will be with *Section 4*, even if it is not returned after you have begun *Section 5* or even *Section 6*. Because some of these items may be an entire page, you may fold them in half and glue them into the log sideways.

What do I do if I am absent from school?



If you miss a day of school, you should find out from one of the members of your group how many pages should be left blank in your log for the work that took place while you were absent. When you do make up that work, you can place it in the appropriate place. This works whether your teacher asks you to make up the work or to get the notes and information from someone else on in your group.

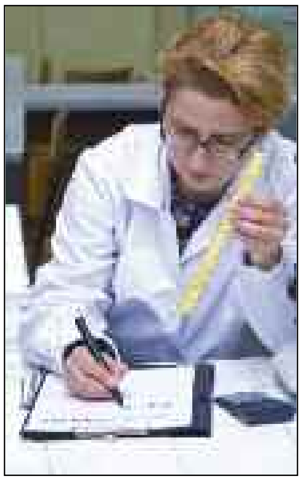
Each time you complete a section, you create a link in the table of Contents. On the left side of the new line, you may write *Section 3*. On the right-hand side of the line, you record the page on which the beginning of all of the information for *Section 3* is located. Because you begin each section on a new page, this will make it easier to locate each section for a given chapter.

When you begin a new chapter, place the name of the chapter in your notebook and record the page reference for that chapter in the table of Contents. Skip a line between the end of one chapter and the beginning of a new chapter. The chapter title may also be written in capital letters or underlined in the table of contents to help with readability.

That should do it. The most difficult part will be remembering to skip pages for work that is to be returned or work that you will make up. Another difficult part will be keeping the table of Contents up to date. Try to remind yourself of these potential pitfalls.

If you have a question about your log or its format, ask your group members. If everyone seems confused, ask your teacher. With care and commitment, you will create a high-quality log.

Scientists keep logs. You, as a student scientist, will keep one as well.



Chapter 1: Driving the Roads

Chapter Challenge

The challenge for this chapter is to demonstrate your knowledge of the physics of driving by making a presentation to a board of driving instructors. The instructors will evaluate your knowledge in both an oral and written presentation on the physics of braking distances, friction and curves, safe following distances, and yellow-light intersections.

Section Summaries	Physics Principles
Section 1 Reaction Time: Responding to Road Hazards Using various reaction timers, students explore the time it takes them to react to a situation. This section introduces students to the process of first beginning with their own ideas and predictions, then implementing an investigation that results in both qualitative and quantitative data.	Reaction time
Section 2 Measurement: Errors, Accuracy, and Precision Students count the number of strides it takes them to cover a selected distance in an area away from traffic. Students measure the length of their stride using a meter stick and calculate the entire distance by multiplying the total number of strides with the length of each stride. The measurements are then compared by each group. By comparing measurements students arrive at an understanding of error and the different kinds of errors present in a measurement.	Errors in measurement Accuracy Precision
Section 3 Average Speed: Following Distance and Models of Motion Strobe or multiple-exposure photos of a moving vehicle are used to illustrate speed and acceleration. Students then use a motion detector to measure their walking speed and obtain a computer-generated graph of their motion. Information about speed and velocity is then connected to reaction distance with a discussion on tailgating.	Average speed Instantaneous speed Velocity Reaction distance Doppler effect
Section 4 Graphing Motion: Distance, Velocity, and Acceleration Students use sloped tracks to investigate the speed and distance an automobile travels before stopping. They then examine data on time and distance required to stop a vehicle moving at various speeds. This is connected to the total time required to react to a hazard, apply force to the brake, and slow the motion of the vehicle to a complete stop.	Acceleration Positive acceleration Negative acceleration Vector quantity
Section 5 Negative Acceleration: Braking Your Automobile The students investigate the relationship between an automobile's speed and the distance required to bring it to a stop. Students draw graphs to study the change in velocity with respect to time. The concept of negative acceleration is explored in this context.	Negative acceleration Braking distance
Section 6 Using Models: Intersections with a Yellow Light Using a spreadsheet model of an intersection, students explore how reaction time, speed, and stopping distance affect what they should do at a yellow light. This also introduces them to how transportation engineers use a computer simulation to model various factors affecting decisions about speed limits and traffic-light cycles. Students now have the opportunity to apply their understanding of reaction time, distance vs. velocity, and braking distance to identify the STOP, GO, and Dilemma Zones at intersections when they see a yellow light.	Speed Negative acceleration Distance vs. time relationships
Section 7 Centripetal Force: Driving on Curves Students' perceptions and prior learning about the force needed to change the direction of a moving object are challenged in this section. After performing investigations, they reflect on the discrepancy between their perceptions and observed results. Students then read for more information on how forces change the direction of motion.	Force Centripetal force Centripetal acceleration

Chapter 2: Physics in Action

Chapter Challenge

The challenge for this section is to develop a 2–3 minute voice-over for a sports clip explaining the physics involved in the sport. The voice-over should be entertaining, as well as explain how a number of physics principles determine what is occurring during the sport. In addition, a written script will be submitted.

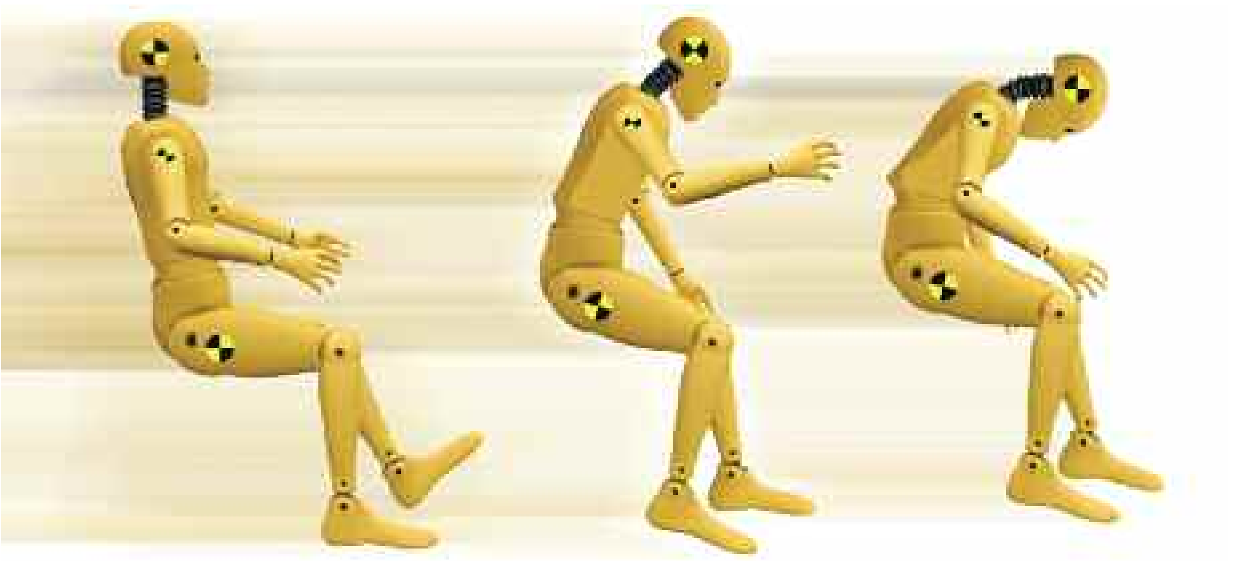
Section Summaries	Physics Principles
Section 1 Newton's First Law: A Running Start Students release a ball to roll down and then up the sides of a track. They first record its starting height and then the recovered height. From this, they are introduced to the concept of inertia.	Inertia and mass, Newton's first law of motion, Force, Velocity and speed, Acceleration, Frames of reference
Section 2 Constant Speed and Acceleration: Measuring Motion A timer and paper tape are used to record the motion of various objects. Distance, time, instantaneous and average velocities, and accelerations are calculated from the data.	Instantaneous speed Average speed Positive acceleration Negative acceleration
Section 3 Newton's Second Law: Push or Pull Students calibrate and use a simple force meter to explore the variables involved in the acceleration of an object. They then connect their observations and data to a study of Newton's second law of motion.	Newton's second law of motion Weight Free-body diagram Gravitational attraction between masses
Section 4 Projectile Motion: Launching Things into the Air Students explore the motion of objects that are projected in a gravitational field. Differences between objects being dropped, launched horizontally, and launched at an angle are explored in relation to the landing position of objects dropped straight down to those with projected motion.	Gravity, Independence of right-angle components, Trajectory of a projectile
Section 5 The Range of Projectiles: The Shot Put Students compare mathematical and physical models of projectile motion to that of a shot put. They apply this to describe the vertical and horizontal motion of the projected object and predict its trajectory.	Acceleration due to gravity, Range of a projectile, Mathematical versus physical models
Section 6 Newton's Third Law: Run and Jump Thinking about the direction in which they apply force to move in a desired way introduces students to the concept that every force has an equal and opposite force. They test this concept and then apply it to a variety of motions observed in sports.	Normal force Newton's third law Action-reaction pair forces Free-body diagrams Center of mass
Section 7 Frictional Forces: The Mu of the Shoe Students measure the amount of force necessary to slide athletic shoes on a variety of surfaces. From this and the weight of the shoe, they learn to calculate friction coefficients. They then consider the effect of friction on an athlete's performance.	Friction Coefficient of friction Normal force Weight
Section 8 Potential and Kinetic Energy: Energy in the Pole Vault Students use a penny launched from a ruler to model motion during the pole vault. They connect their observations to the concept of energy conservation.	Gravitational potential energy, Kinetic energy, Energy conversion, Law of conservation of energy, Work, Spring potential energy
Section 9 Conservation of Energy: Defy Gravity Students learn to measure hang time and analyze vertical jumps of athletes using slow-motion videos. This introduces the concept that work when jumping is force applied against gravity.	Gravitational potential energy, Kinetic energy, Energy conversions, Force and weight, Law of conservation of energy, Work, Spring potential energy

Chapter 3: Safety

Chapter Challenge

Your design team will develop a safety system for protecting automobile, airplane, bicycle, motorcycle, or train passengers during a collision. To illustrate this safety system, you will design and build a prototype safety system to protect an egg in a moving cart that undergoes a collision. This prototype will then be tested to see how effectively it protects the egg.

Section Summaries	Physics Principles
Section 1 Accidents Students identify and evaluate safety features in automobiles. Students then consider what safety features they could use for various vehicles and for their design of a safety system.	**Identifying criteria for building a safety feature**
Section 2 Newton's First Law of Motion: Life and Death before and after Seat Belts Students explain what occurs to passengers during a collision using Newton's first law. They read about the concept of pressure and apply this concept while designing and testing a seat belt to safely secure a clay passenger in a cart undergoing a collision.	**Newton's first law** **Pressure**
Section 3 Energy and Work: Why Air Bags? Students investigate and observe how spreading the force of an impact over a greater distance reduces the amount of damage done to an egg during a collision. They describe and explain their observations using the work-energy theorem.	**Average velocity** **Newton's second law** **Work** **Kinetic energy** **Work-energy theorem**
Section 4 Newton's Second Law of Motion: The Rear-End Collision Students explore the effects of rear-end collisions on passengers, focusing on whiplash. They use Newton's laws to describe how whiplash occurs. They also describe, analyze, and explain situations involving collisions using Newton's first and second laws.	**Newton's first law** **Newton's second law**
Section 5 Momentum: Concentrating on Collisions After observing various collisions, students are introduced to the concept of momentum. Through measurements taken during various collisions they determine the mass of a cart. Students then calculate and consider the momentum of various objects.	**Linear motion** **Momentum**
Section 6 Conservation of Momentum Students investigate the law of conservation of momentum by measuring the masses and velocities of objects before and after collisions. Students then analyze various collisions by applying the law of conservation of momentum.	**Newton's second law** **Newton's third law** **Momentum** **Conservation of momentum**
Section 7 Impulse and Changes in Momentum: Crumple Zone Students design a device on the outside of a cart to absorb energy during a collision to assist in reducing the net force acting on passengers inside the vehicle. Students use probes to measure the velocity of the vehicle and the force acting on the vehicle during impact, and then describe the relationship between impulse ($F\Delta t$) and change in momentum ($m\Delta v$).	**Newton's second law** **Impulse** **Momentum** **Work-energy theorem**



Chapter 4: Thrills and Chills

Chapter Challenge

The *Chapter Challenge* is to modify the design of a roller coaster to meet the needs of a specific group of riders who would not normally ride the roller coaster. The design should include calculations to insure the safety of the ride and the energy needed for the ride to operate. A written report and a class presentation of a model of the roller coaster are necessary to complete the assignment.

Section Summaries	Physics Principles
Section 1 Velocity and Acceleration: The Big Thrill Students investigate methods of making mechanical drawings. Observing motion in class, they determine at which points changes that they associate with roller coasters occur. The velocity and acceleration of a steel ball are determined as it rolls along different tracks using a velocity meter.	Velocity Acceleration Acceleration due to gravity
Section 2 Gravitational Potential Energy and Kinetic Energy: What Goes Up and What Comes Down Students discover what determines the speed of a ball as it rolls on an incline. This result is compared with the velocity of a pendulum swinging from different heights by graphing velocity squared versus height. Gravitational potential energy and kinetic energy are used to explain the similarity of results. Conservation of energy is explored in the transformation of energy forms.	Velocity versus distance Gravitational potential energy Kinetic energy Law of conservation of energy
Section 3 Spring Potential Energy: More Energy Students use a spring "pop-up" toy to investigate spring potential energy stored in a compressed spring. Using the concepts of kinetic and gravitational potential energy, they explore the law of conservation of mechanical energy that includes the energy stored when springs are compressed or stretched.	Stoichiometry Gravitational potential energy Kinetic energy Spring potential energy Law of conservation of energy
Section 4 Newton's Law of Universal Gravitation: The Ups and Downs of a Roller Coaster Students investigate how the force of gravity varies with distance from the center of Earth using data for the acceleration due to gravity at various points. Using a graph, they determine the inverse square relationship between gravitational force and distance. The shape of Earth's gravitational field is noted. Newton's derivation of the gravitational force and the shape of celestial orbits are discussed.	Acceleration due to gravity The force of gravity Inverse square relationships Earth's gravitational field
Section 5 Hooke's Law: Your "At Rest" Weight Students explore the difference between mass and weight, and how the weight of an object depends upon the acceleration due to gravity. They determine how the stretch of a spring relates to the force applied to stretch or compress. By graphing their data, the students determine Hooke's law and calculate a spring constant. A spring is used to determine the size of an unknown mass. Equilibrium of forces is discussed.	Weight versus mass Force due to springs Hooke's law Equilibrium and Newton's laws
Section 6 Forces Acting During Acceleration: Apparent Weight on a Roller Coaster Students use a spring scale to investigate the net force required for an object to travel upward and downward, first at a constant velocity, then for upward and downward acceleration. Newton's second law for net forces is used to analyze a free-body diagram for objects undergoing accelerations. The apparent weight change in an elevator is related to its acceleration and the acting net force. Why the force of gravity accelerates all objects at the same rate is discussed.	Newton's second law Free-body diagrams Apparent weight Acceleration due to gravity
Section 7 Circular Motion: Riding on the Curves Students investigate centripetal force. They identify the direction of the centripetal force, acceleration, and velocity for objects moving in circles. The students investigate the relationship between centripetal force and the object's mass, speed, and the radius of the circle for both horizontal and vertical circles. The changing force required for a vertical circle is explored in depth in relation to Newton's second law.	Tangential velocity Centripetal force Centripetal acceleration Apparent weight Net force Free-body diagrams Normal force
Section 8 Work and Power: Getting to the Top Students pull up a fixed height by various paths to demonstrate the independence of the path on the work being done. The definition of work is then developed from the students' data and then related to gravitational potential energy. Uncertainty in measurement and the development of scientific principles from data is discussed. The relationship between work and power is discussed, and the formula for power is introduced.	Work Work and energy transformations Power Horsepower Measuring uncertainty
Section 9 Force and Energy: Different Insights Students develop concept maps on forces and energy relationships to organize their knowledge. The relationship between force and energy (work) is explored. Explicit examples of the principle of conservation of energy are explored for various points on the roller coaster. Analysis using energy considerations is explored, as well as situations where energy is insufficient information and force considerations are appropriate. The students do an exercise using vectors to locate the position of an object.	Gravitational potential energy Spring potential energy Kinetic energy Work Vectors and scalars Vector addition Forces
Section 10 Safety Is Required but Thrills Are Desired Students investigate parameters that determine what limits are placed on their design. Students calculate centripetal force, apparent weight, normal force, and the net force acting on the roller coaster cars at various points to determine the forces acting on the coaster car.	Force, Newton's second law, Centripetal force, Centripetal acceleration, Normal force, Apparent weight, Net force

Chapter 5: Let Us Entertain You

Chapter Challenge

The *Chapter Challenge* is to design a sound and light show to entertain students your age. The sounds must come from musical instruments, human voices, or sound makers you build and the light from a laser or conventional lamps. An explanation of the physics principles involved in your show will also be required.

Section Summaries	Physics Principles
Section 1 Sounds in Vibrating Strings To connect vibrations and waves to sound, the students observe the vibration of a plucked string and investigate how the pitch varies with the length of the string. They then explore how the tension of the string affects the vibration rate and the pitch.	**Sound and vibration** **Vibrations on strings** **Sound and tension** **Sound and string length** **Pitch and frequency**
Section 2 Making Waves By making waves with coiled springs, students observe transverse and longitudinal waves, periodic wave pulses, and standing waves. The students investigate the relationship between wave speed and amplitude, the effect of a medium on wave speed, and when waves meet, wave addition (or the principle of superposition). Using standing waves, the students develop the relationship between wave speed, frequency, and velocity.	**Periodic waves** **Wave pulse** **Transverse waves** **Longitudinal waves** **Standing waves** **Principle of superposition**
Section 3 Sounds in Strings Revisited Students return to vibrating strings, interpreting what they observed in *Section 1* in terms of standing waves, wavelength, and the frequency of a vibrating string. The students then apply the wave equation to human motion, where speed equals stride length times frequency.	**Wavelength** **Frequency** **Wave speed**
Section 4 Sounds from Vibrating Air Drinking straws and test tubes partially filled with water are used to model wind instruments that use columns of vibrating air to produce sounds. The students investigate the relationship of pitch to the length of the vibrating column of air in longitudinal waves. Diffraction of waves is investigated as a method to transmit sound from the vibrating air column to its surroundings.	**Longitudinal waves** **Frequency** **Wavelength** **Diffractiony** **Absolute zero**
Section 5 Shadows In this section, students investigate how shadows are produced. The rectilinear nature of light rays is used to investigate how to produce the umbra and penumbra shadows of extended light sources.	**Light travels in straight lines** **Shadows** **Umbra** **Penumbra**
Section 6 Reflected Light Students explore how plane mirrors reflect light rays. First investigating how changing the angle of incidence affects the angle of reflection, the students use this to build up a model of how images are formed by plane mirrors.	**Angle of incidence** **Angle of reflection** **Normal** **Virtual images** **Transverse waves**
Section 7 Curved Mirrors Students explore how light rays reflect from convex and concave mirrors using a laser pointer. They investigate how a convex mirror is able to focus light, and how this property allows convex mirrors to focus light rays to produce real images. The relationship between the distance of the real image formed from the mirror, the object distance, and the mirrors' focal length is discovered. Virtual images formed by both the convex and concave mirror are also discussed.	**Concave mirror** **Convex mirror** **Real image** **Virtual image** **Focal point** **Light rays**
Section 8 Refraction of Light Using a laser pointer, the students send a ray of light through an acrylic block to explore how light refracts as it passes from one transparent medium to another. By measuring the angle of incidence and the angle of refraction, the students develop the concept of the index of refraction. As the angle of incidence approaches the critical angle, total internal reflection in a prism is explored.	**Angle of incidence** **Angle of refraction** **Normal** **Index of refraction** **Snell's law** **Total internal reflection** **Critical angle**
Section 9 Effect of Lenses on Light By shining light through a convex lens and locating the image formed at different positions of the light source, the students develop an understanding of how real images are formed by convex lenses. By projecting different sizes of images of the light source onto a surface, the students explore how images are formed and used in everyday equipment. Ray diagrams, as a method to predict image size and location are discussed, while *Active Physics Plus* further develops the lens equation.	**Convex lens** **Real images** **Virtual images** **Ray diagrams** **Focal point** **Lens equation**
Section 10 Color Students investigate colored shadows formed by multiple light sources using additive primary colors. By carefully tracing the light rays from different sources, the students investigate the colored shadows that are formed and how added light produces different colors. Subtractive primaries are also investigated.	**Light rays** **Primary colors** **Color addition**

Chapter 6: Electricity for Everyone

Chapter Challenge

The *Chapter Challenge* is to design an appliance package for a family that is powered by a wind-driven generator. The constraints are that no part of the package can draw more than 2400 W and the average daily consumption should not exceed 3 kWh. In addition, you will construct a training manual explaining the basic principles of electricity for the family, including a wiring diagram with the locations of outlets and switches.

Section Summaries — Physics Principles

Section 1 Generating Electricity

With a simple hand generator, wires, and light bulbs, students investigate electric circuits and electrical energy. Using the hand generator introduces them to the concept that electricity is the result of converting one form of energy into another. The operation of a light bulb is also investigated.

Electricity
Generator
Closed circuit
Energy sources

Section 2 Modeling Electricity: The Electron Shuffle

Students develop a qualitative model of electricity, including how current flows in series and parallel circuits, and how electrical energy is delivered to devices by playing the part of electric charges as they move through a circuit.

Electric charge (coulomb),
Electric energy,
Electric current,
Resistance,
Series circuit, Circuit symbols

Section 3 Series and Parallel Circuits: Lighten Up

The Electron Shuffle model is used again to investigate current, resistance, and how electrical energy behaves in a parallel circuit. Comparisons between series and parallel circuits are investigated. Fundamental charges are also discussed.

Series circuit
Parallel circuit
Electric energy
Electric current
Resistance
Fundamental charges

Section 4 Ohm's Law: Putting Up a Resistance

Students design an experiment to determine the resistance of an unknown resistor. Proper use of a voltmeter and ammeter are discussed, and the students set up a series circuit to determine the current for a series of voltages applied to the resistor. Graphing the relationship between voltage and current for a resistor demonstrates Ohm's law. The process is repeated for other resistors, and then for an unknown.

Voltage
Current
Resistance
Voltmeter
Ammeter
Black box

Section 5 Electric Power: Load Limit

Students create a simple fuse to see how fuses work. The teacher then connects a group of appliances to a power strip until a fuse in the circuit blows. The students then calculate the load limit of a household circuit and the watts required by appliances, comparing these to the limits given in the challenge. This also introduces the use of terms and equations for calculating power.

Voltage
Current
Power
Power rating
Load limit

Section 6 Current, Voltage, and Resistance in Parallel and Series Circuits: Who's in Control?

Students assemble a parallel circuit to explore how switches control the flow of electricity through various sections of the circuit. They then use a voltmeter and ammeter to determine the voltage and current for the elements of a parallel circuit, as well as the circuit as a whole. Finally, they mathematically examine voltage, current flow, and total resistance in series and parallel circuits, while being introduced to circuit diagrams.

Switches
Parallel circuit
Series circuit
Voltage equations
Current equations
Resistance equations
Power equations
Circuit analysis

Section 7 Laws of Thermodynamics: Too Hot, Too Cold, Just Right

Students investigate the laws of heat transfer by mixing hot and cold water in different proportions. The concept of specific heat is developed as the students use hot metal to warm cold water. Conservation of energy is then discussed as the students calculate energy transfers between various materials. The difference between heat and temperature is emphasized while the laws of thermodynamics and entropy are discussed.

Heat transfer
Temperature
Specific heat
Zeroth law of thermodynamics
First law of thermodynamics
Entropy
Second law of thermodynamics
Heat engines

Section 8 Energy Consumption: Cold Shower

Electricity used by water heaters is the focus of this activity, which also reinforces concepts of energy transfer. Students investigate the amount of energy in joules needed to raise the temperature of water, and then calculate the efficiency of different water heaters. They also consider alternate solutions to the expectation of hot water in a home.

Heat transfer
Electric energy
Voltage
Current
Power, Efficiency

Section 9 Comparing Energy Consumption: More for Your Money

Students conduct an experiment in which they determine and compare the power consumption and efficiency of three systems that could be used to heat water. They apply collected data to confirm their response to the challenge in which they recommend appliances for the universal home. Methods of heat transfer are discussed, including convection, conduction, and radiation.

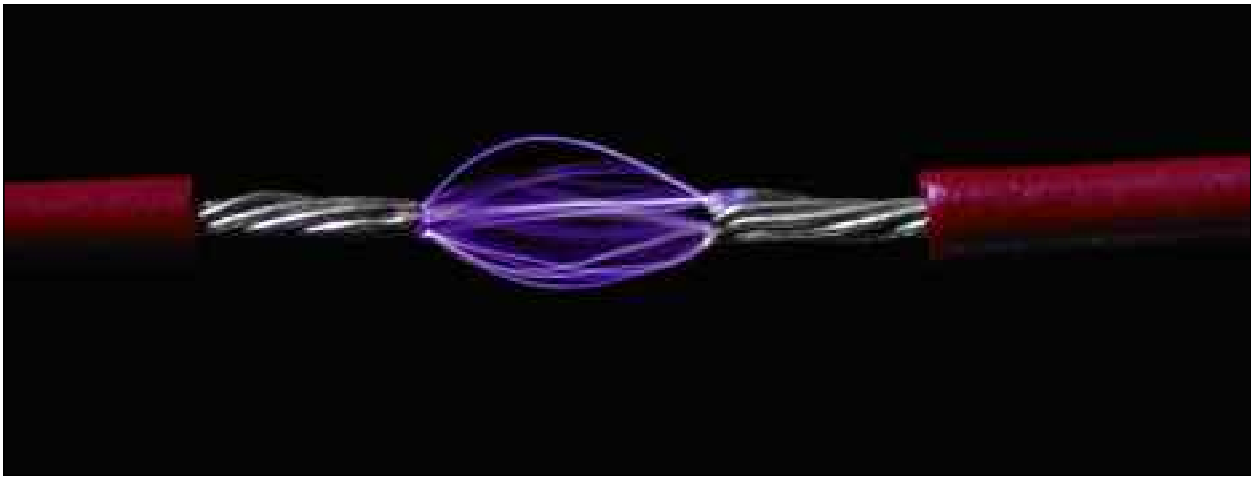
Heat transfer
Electric energy
Power
Efficiency
Convection
Conduction
Radiation

Chapter 7: Toys for Understanding

Chapter Challenge

The *Chapter Challenge* is to design a toy that employs either a motor or a generator as a fun device to teach children about how generators and electric motors work. An instruction manual should be developed that explains how to assemble the toy and the basic physics principles of how and why it works.

Section Summaries	Physics Principles
Section 1 The Electricity and Magnetism Connection Students explore the forces of magnetic attraction and repulsion as well as the magnetic properties of ferrous materials. They then plot the magnetic field of a bar magnet using a compass and iron filings. Students investigate the relationship between electricity and magnetism by using a compass to test for the magnetic field produced by a current-carrying wire. A method to predict the direction of the magnetic field around a current-carrying wire using the left hand is discussed.	**Magnetic field** **Magnet** **Compass** **Left-hand rule**
Section 2 Electromagnets Using a hand generator to power an electromagnet is the first step in a continuing investigation into the relationship between electricity and magnetism. Students test the strength and find the polarity of electromagnets made with different core materials and different currents.	**Solenoid** **Magnetic polarity** **Core material**
Section 3 Building an Electric Motor Students construct and operate a DC motor. They also read about how a DC motor works, and how a commutator is necessary to operate a DC motor.	**DC motor** **Commutator** **Force on a current-carrying conductor**
Section 4 Detect and Induce Currents Students construct a galvanometer by using the fact that a compass can detect the presence of a magnetic field. They will use a permanent magnet and a solenoid to create an induced current by manually alternating the motion of a magnet in a fashion similar to the process used by Faraday and Henry. Using the galvanometer to detect the induced current, they will explore the need for relative motion between magnetic fields and wires.	**Galvanometer** **Induced voltage** **Lenz's law** **Field lines**
Section 5 AC and DC Currents Producing an electric generator by rotating a coil of wire in a magnetic field is explored. Students learn the difference between how AC and DC currents are generated by considering both types of electric generators and analyzing the induced currents in their rotating coils. Students read about how a commutator changes AC electricity into DC electricity. Students also learn how to sketch output waveforms.	**Electric generator** **AC electricity** **DC electricity** **Commutator** **Waveforms**
Section 6 Electromagnetic Spectrum: Maxwell's Great Synthesis Students start by classifying groups as a way to identify patterns. The students look at the relationships between electricity and magnetism they have studied and try to find a pattern. A discussion of the pattern discovered by Maxwell and his discovery that all electromagnetic waves travel at the speed of light is discussed. Several experiments that attempted to calculate the speed of light are also discussed. The students conclude by reading about the electromagnetic spectrum.	**Maxwell's equations** **Speed of light** **Electromagnetic spectrum**



Chapter 8: Atoms on Display

Chapter Challenge

The *Chapter Challenge* is to develop a museum exhibit to acquaint visitors with aspects of the atom that they will see throughout the museum. An introductory and concluding poster about the exhibits, as well as written matter about the exhibit you designed, should be included.

Section Summaries	Physics Principles
Section 1 Static Electricity and Coulomb's Law: Opposites Attract Using transparent cellophane tape, students investigate the static electricity of charged objects. Inductive electric forces are explored and the students read about conservation of charge and Coulomb's law to prepare them to understand the forces holding an atom together.	Electric fields Charge Conservation of charge Coulomb's law Grounding, Induction
Section 2 The Nature of Charge: Tiny and Indivisible In a simulation of Millikan's oil-drop experiment, students use inquiry to find the number of coins enclosed in a film canister. They then learn how related techniques were used to determine that electric charge is quantized. The process of inference to obtain information about systems that cannot be directly measured is used.	Quantization of charge Charge on the electron Millikan experiment
Section 3 The Size of a Nucleus: How Big Is Small? Using statistical measurements, students estimate the size of a penny. They then compare their statistical approach with direct measurement. Finally, they compare their experiment with Rutherford's experiment to determine the size of a nucleus in relation to an atom and the evidence we have to verify that knowledge.	Atomic models Atomic nucleus Atomic forces Atom as mostly empty space
Section 4 Hydrogen Spectra and Bohr's Model of the Hydrogen Atom Students investigate spectral lines by using a spectrometer to measure the wavelengths of light emitted by three gases. The unique spectra of atoms are discussed and the students then learn about the Bohr model of the atom. Using this model, they calculate the wavelengths of light emitted as electrons jump from one quantized orbit to another. The discovery of helium from its spectrum is discussed. In the *Active Physics Plus*, the formula for the energy of a photon is also discussed.	Bohr model Quantized electron orbits Atomic spectra Electron energy levels Balmer series
Section 5 Wave-Particle Model of Light: Two Models Are Better Than One! The wave and particle nature of light is explored by investigating two-slit interference and the photoelectric effect. By drawing an analogy to standing waves on a string, a new interpretation of the Bohr orbit as standing waves of electrons is introduced, with a nonmathematical introduction of the Schrödinger wave equation. The dual wave and particle nature of electrons is also discussed.	Interference of waves Photoelectric effect Work function Photon energy Photon model of light Schrödinger wave equation DeBroglie waves
Section 6 The Strong Force: Inside the Nucleus The proton-neutron model of the nucleus is introduced and explored. With a huge Coulomb repulsion pushing protons apart, the need for a strong attractive force in the nucleus is investigated. Students are then introduced to Feynman diagrams as a means of understanding how forces are transmitted.	Proton-neutron model Strong force Feynman diagram Action at a distance Virtual particles
Section 7 Radioactive Decay and the Nucleus Students investigate the statistical properties of randomly tossing marked cubes. They then relate these results to the statistics of radioactive decay. The concept of half-life is introduced as a clock for measuring radioactive decay. Students are then introduced to complete nuclear equations for alpha, beta, and gamma decays.	Radioactive decay Half-life Atomic mass Atomic number Nuclear transmutation
Section 8 Energy Stored within the Nucleus Students are introduced to Einstein's famous equation $E = mc^2$ and use it to calculate the energy liberated by the conversion of mass to energy. After calculating the mass defect of the nucleus, the equation is used to calculate nuclear binding energies.	Atomic mass unit Conservation of mass energy Nuclear mass defect Nuclear binding energy Particle-antiparticle annihilation
Section 9 Nuclear Fission and Fusion: Breaking Up Is Hard to Do Students start by calculating the nuclear binding energy of various elements and then graph the binding energy per nucleon versus the element's atomic number. Students explore nuclear fission and fusion reactions. How a fission chain reaction works is also studied.	Binding energy per nucleon Nuclear fission Nuclear fusion

Chapter 9: Sports on the Moon

Chapter Challenge

The *Chapter Challenge* is to develop a proposal for NASA by either adapting or inventing a sport that can be played on the surface of the Moon with its reduced gravity. Writing a local newspaper article describing the championship match for your sport is also required.

Section Summaries	Physics Principles
Section 1 Identifying and Classifying: What Is a Sport? Students apply their knowledge of sports to identify attributes that define an activity as a sport. From this, they begin to consider how differences between Earth and the Moon can affect sports.	**Pattern identification**
Section 2 Acceleration Due to Gravity: Free Fall on the Moon Students compare the free fall of different objects. They then calculate acceleration with respect to gravity on the Moon using measurements obtained from a slow-motion video of an astronaut in space dropping objects.	**Gravity** **Acceleration** **Distance covered by accelerating objects**
Section 3 Mass, Weight, and Gravity Using a simulation that allows for the comparison of mass and weight between Earth and the Moon, students investigate the ratio of gravity on Earth to that on the Moon. After determining that an object's inertia does not change, the forces needed to overcome weight and inertia on the Moon are discussed.	**Inertia** **Weight** **Universal law of gravitation** **Newton's second law**
Section 4 Projectile Motion on the Moon Beginning with scale drawings, students calculate the distances that projected objects will travel on the Moon. These distances are then compared to projectiles launched on Earth with the same velocity to determine how sports that use projectiles would be changed on the Moon.	**Projectile motion** **Gravity**
Section 5 Gravity, Work, and Energy: Jumping on the Moon Students measure vertical distances when jumping and then analyze their motion in terms of work and conservation of energy. Applying what they know about gravity on the Moon, they predict vertical distances they could jump on the Moon.	**Work** **Gravitational potential energy** **Kinetic energy** **Conservation of energy**
Section 6 Momentum and Gravity: Golf on the Moon Using a variety of balls, students measure the height each bounces when dropped and when projected by a collision. They use this data to infer a golf ball's speed when hit on Earth and on the Moon. The interaction of different golf clubs and golf balls with varying degrees of mass is also investigated.	**Gravitational potential energy** **Kinetic energy**
Section 7 Friction: Sliding on the Moon Students investigate the force necessary to overcome the friction between objects and the surfaces on which they move. They then relate this to gravity and predict the force needed to overcome the friction against a sliding motion made on the Moon.	**Weight** **Friction** **Coefficient of friction** **Normal force** **Newton's second law**
Section 8 Modeling Human Motion: Bounding on the Moon Using cylinders of different lengths and weights, students explore pendulum motion. They then compare the motion of the pendulums to the swinging motion of human legs when walking, finally predicting how walking on the Moon and on Earth is different.	**Gravitational field strength** **Simple harmonic motion** **Period of a pendulum**
Section 9 Air Resistance and Terminal Velocity: "Airy" Indoor Sports on the Moon Students start by investigating how mass and terminal velocity are related. They then use badminton shuttlecocks to investigate how air resistance affects motion. They then apply what they know about the ratio of gravity on Earth to that of the Moon to predict the air resistance to motion on the Moon.	**Air resistance** **Terminal velocity**