SECTION 8

Potential and Kinetic Energy: Energy in the Pole Vault

Section Overview

Students design experiments to investigate how energy is converted from one form to another. They blast a penny in the air from the end of a ruler to measure the maximum height to which the penny flies upward. They roll balls across a ramp, which collide with a ruler attached to a pencil, at three different speeds. In each case, students record the amount the ruler deflects as it moves back to its original position. The experiments simulate factors that determine the amount of energy stored in a pole-vaulter's bar that helps to launch the vaulter up in the air. Students identify different forms of energy and solve problems to see how the total energy of a system remains constant. This section also details the concept of work and how energy relates to work.

Background Information

Concepts involving energy, introduced in this activity, include:

- energy in three forms: kinetic energy, gravitational potential energy, and spring potential energy (the energy stored in a spring),
- transformations among and conservation of the above-listed forms of energy, and
- the equivalence of *work* and *energy*.

Students are introduced first to the concept of kinetic energy, and then to how this form of energy may be transferred to other forms of energy. The kinetic energy of the runner in a pole vault is converted into the spring potential energy of the bent pole, which is then lost and converted into the gravitational potential energy of the rising pole-vaulter. These forms of energy are then related back to the basic concept of work, and it is shown that the work done by the runner accelerating is the source of the kinetic energy that undergoes all of these transformations. It is then noted that whenever work is done, the energy of the system changes. For a closed system such as the pole-vault example, energy may be transferred from one form to another without any net loss. If work is done, then the energy of the system may increase (as in the example of the runner doing work to accelerate) or it may decrease (for example, as a driver applies the brakes to a car).

The *Physics Talk* in this section confines itself to discussing the forms of energy and how to calculate the energy stored in kinetic, gravitational potential, and spring potential energy. A more formal treatment of conservation of energy is given in *Section 9*.

The treatment of the joule as the unit of energy in this activity is "soft" because groundwork for defining the joule in a mechanical context has not yet been established. At this stage without benefit of a definition of the joule, dimensional analysis can be used to satisfy yourself (and, only if it seems necessary, your students) that all of the equations given in the *Investigate* for forms of energy at least have the same unit:

- Kinetic energy $= \frac{1}{2}mv^2$, Unit:
  $(\text{kg})(\text{m/s})^2 = (\text{kg})(\text{m}^2)/(\text{s}^2)$
- Gravitational potential energy $= mgh$, Unit:
  $(\text{kg})\left[\text{m}/(\text{s})^2\right]\text{m} = (\text{kg})(\text{m}^2)/(\text{s}^2)$
- Potential energy stored in a spring $= \frac{1}{2}kx^2$ (the spring constant, k, has a unit N/m which is equivalent to kg/s^2), Unit:
  $(\text{kg/s}^2)\text{m}^2 = (\text{kg})(\text{m}^2)/(\text{s}^2)$

As shown on the previous page, all of the forms of energy defined in the activity share the same unit, $(kg)(m^2)/(s^2)$. Because 1 joule is the amount of work done when 1 newton of force is active through one meter of distance $(1 \text{ joule} = 1 \text{ newton·meter})$, and because one newton is the force that will cause 1 kg to accelerate at 1 m/s^2, one joule also can be expressed as $\left(1 \text{ kg m/s}^2 \cdot 1\text{m}\right) = \left(\text{kg}\right)\left(\text{m}^2\right)/\left(\text{s}^2\right)$. Therefore, the equations are legitimate because the unit $(kg)(m^2)/(s^2)$ is equivalent to the standard energy unit, the joule. The information above will prepare you to address questions about units, if they arise.

Crucial Physics

- Kinetic energy is energy due to motion and is given by half the mass times the square of the velocity.
- Gravitational potential energy is energy due to an object's position in Earth's gravitational field. It equals the mass of the object times *g* times the vertical height from a reference point where the gravitational potential energy has been set to zero.
- Elastic potential energy is energy due to a spring being compressed or stretched. It is equal to half the spring constant times the square of the compression or stretching distance.
- Energy can be transformed from one kind to another, and if there is no external force on a system, the total energy is conserved (does not change).
- Work occurs any time an object moves with a force parallel to the motion. Work is equal to the force parallel to the motion times the distance moved.
- Energy is "stored work." Work done on an object raises its energy. That energy later on can be converted back to work done by the object on another object.

Learning Outcomes	Location in the Section	Evidence of Understanding
Apply equations for kinetic energy, gravitational potential energy, and elastic potential energy.	***Physics Talk*** Sample Problems 1-3 ***Physics to Go*** Questions 3 and 6-12	Students apply equation of kinetic and elastic and gravitational potential energy to solve problems.
Recognize that restoring forces are active when objects are deformed.	***Investigate*** Steps 1-3 and 5-9	Students recognize that when the ruler deflects from its original position energy is stored.
Apply the equation for the force necessary to compress or stretch a spring.	***Physics Talk*** Sample Problem 2 ***Physics to Go*** Questions 9-11 and 12.d)	Students solve problems by applying equation for the force necessary to compress the spring and the energy stored in compressed spring.
Measure the transformations among the different forms of energy.	***Investigate*** Steps 1-3 and 5-9	Students recognize that the deformation of the ruler is caused by the kinetic energy of the rolling ball, and that the gravitational potential energy gained by the penny comes from the deformation of the ruler.
Conduct simulations of the transformation of energy involved in the pole vault.	***Investigate*** Steps 1-9	Students design experiments to simulate how energy is transferred from one form to another.

Section 8 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Ball, steel, 1 in. (diameter)	1 per group	
Ruler, metric, 30 cm	2 per group	
Meter stick, wood	1 per class	
C-clamp, steel, 3 in.	1 per group	
Ramp, starting, 20-degree angle	1 per group	
Pen, marking, felt tip	1 per group	
Tape, masking, 3/4 in. x 60 yds		6 per class
Cards, index, unlined, 3 in. x 5 in., pkg. of 100		1 per class
Coins (pennies, nickels)*	5 per group	

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Ball, steel, 1 in. (diameter)	1 per group	
Ruler, metric, 30 cm	2 per group	
Meter stick, wood	1 per class	
C-clamp, steel, 3 in.	1 per group	
Ramp, starting, 20-degree angle	1 per group	
Pen, marking, felt tip	1 per group	
Tape, masking, 3/4 in. x 60 yds		6 per class
Cards, index, unlined, 3 in. x 5 in., pkg. of 100		1 per class
Coins (pennies, nickels)*	5 per group	

*Additional items needed not supplied

Note: Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

Time Requirement

This *Investigate* should take approximately one class period or 40 min.

Teacher Preparation

- Assemble the required material for the *Investigate*, including the coins or washers to be flipped upward by the rulers. Try out the methods the students will use to clamp the rulers to the lab tables they will use. You may need additional "filler" blocks to allow the rulers to be clamped in the vertical orientation. The rulers or plastic strips the students will use should be very flexible, and not prone to break when bent down.

Safety Requirements

- Students should be cautioned to make certain their safety goggles are in place all during this *Investigate*. Do not use stiff plastic rulers to flip the coins upward. They may shatter into sharp pieces. Make certain the students are not above the area where the coins are being flipped as they measure the height achieved by the coin.
- Student enthusiasm for this investigation runs very high. Caution the students that this is not a contest to see who can embed coins in the ceiling!

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Understanding vocabulary	***Learning Outcomes*** ***Physics to Go*** Questions 1, 2, and 13-15	**Augmentation** • Students are expected to explain the transformations of energy. Define transformation and provide examples of different kinds of transformations. Students should also be able to provide some good examples.
Designing an experiment	***Investigate*** Steps 1 and 2	**Augmentation** • Students with attention and behavior concerns often focus better on tasks that they are motivated to complete because the task is high-interest or their idea. These students may be more successful in designing their own experiment rather than following the directions of the previously designed experiment. • When allowing students to design their own experiment, make sure that they have a sound experimental design and data-collection method before they begin.
Following directions	***Investigate*** Steps 3-9	**Augmentation** • Provide a physical model of each experiment setup. • Set time limits for each step of the *Investigate* and use a timer to keep students on task. • Make a list, presented orally and visually, of the data that should be recorded at the end of the experiment. **Accommodation** • Provide a checklist that includes each step of the experiment so that students can mark off each task as it is completed.
Understanding vocabulary	***Physics Talk*** ***Physics Essential Questions***	**Augmentation** • Provide a definition and examples for the word "conserve." Students could generate a class list of what people conserve and why.
Understanding energy transformation	***Physics Talk***	**Augmentation** • Energy transformation is difficult for students to understand because they cannot visibly see the energy "moving," instead they see the effects of energy transformation. • Provide a drawing or graphic of a ball being thrown into the air that has the types of energy along the labeled trajectory. • Ask students to think of a new situation in which energy is transferred in a similar way, sketch the situation, and label the energy transformations. • Students might find it difficult to grasp that for work to be done, the object must move over a distance. Provide examples such as pushing or pulling as hard as one can on an object without it moving. Ask students if any work has been done.
Learning many formulas at one time	***Physics Talk***	**Accommodation** • Provide a table that includes the variables, symbols, and units for each of the formulas. This graphic organizer will help students have more confidence in problem-solving. Students can identify the given values more easily when they become comfortable with the units.

Learning Issue	Reference	Augmentation and Accommodations
Finding key phrases in word problems	***Physics Talk*** ***Physics to Go*** Steps 3, 8-11	**Augmentation** • Solving word problems is a difficult skill for most students, especially ninth graders. • Ask students to highlight or underline the key phrases in word problems to emphasize what the problem is asking them to find. • Generate a class list of key phrases for problem solving, including "how much," "what is," "calculate the," "solve for the," etc. • Mastering the above skill makes it easier for students to choose the correct formula needed to solve a problem. **Accommodation** • Highlight the key phrases that students are expected to find in word problems and fade this accommodation away as they become more proficient in problem-solving.

Strategies for Students with Limited English-Language Proficiency

Point out new vocabulary words in context and practice using the words as much as possible throughout the section. As you work through the section, have students write the terms in their *Active Physics* log and add the definitions in their own words.

catapult	plausible
elastic potential energy	potential energy
gravitational potential energy	release
joule	simulate
kinetic energy	work
law of conservation of energy	

Consider giving students a cloze activity when you reach the end of the section. Cloze activities are useful tools for summarizing material and for giving English-language learners opportunities to practice writing complete sentences using science vocabulary. Cloze activities are most effective when used frequently, to build students' abilities with more complex sentences.

Ask students to give you sentences describing what they did in the section, and telling what important lessons they learned. Their comments should include the vocabulary words listed above. You may wish to offer a first sentence as an example. For instance, "We investigated how much energy is stored in a pole vaulter's pole." Write simple sentences, and work them into paragraphs. Model using a topic sentence, supporting statements, and a closing sentence. Model the process of editing, in which students make corrections that improve the sentences.

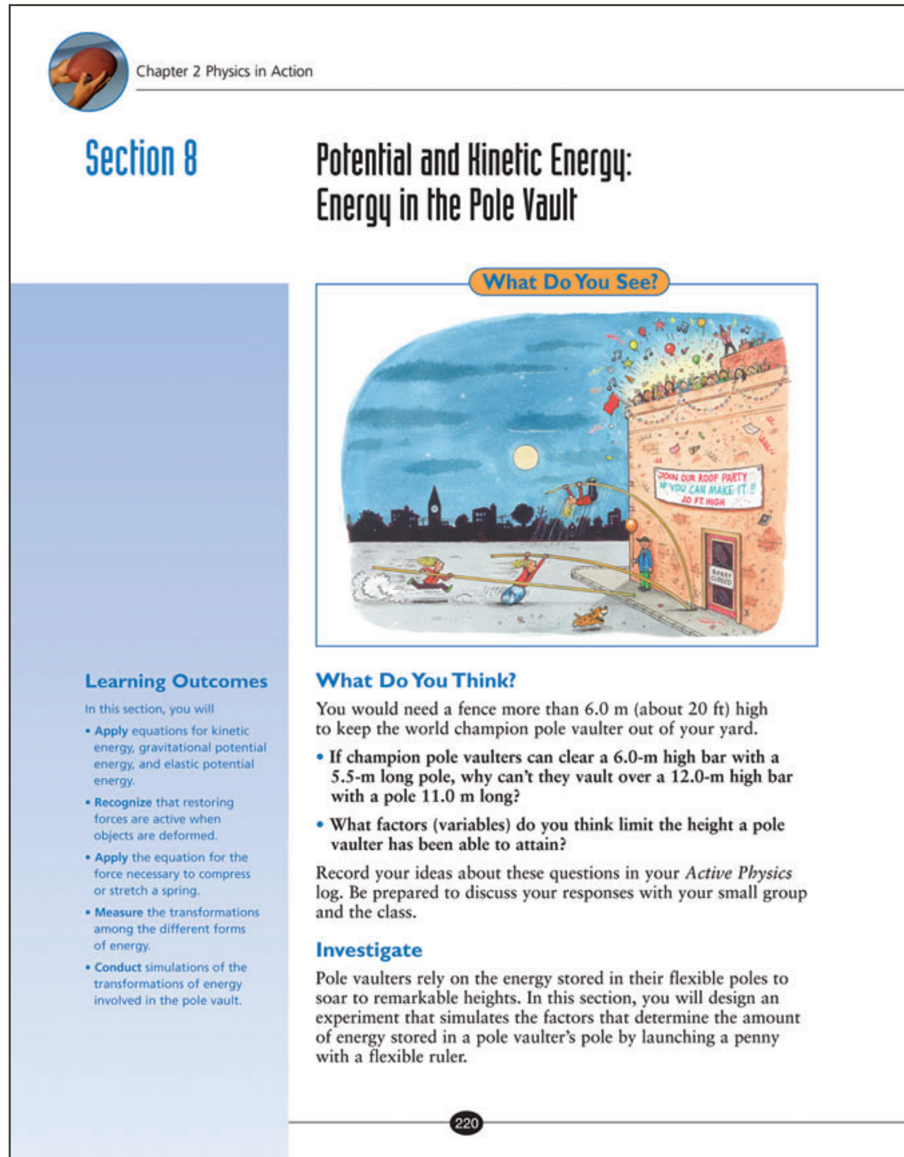
There is a lot of information in this section, so you will likely end up with a few paragraphs. Once the paragraphs are complete and students agree that they accurately summarize what they did and learned, have them copy down the paragraphs. Explain that there will be a brief quiz on the paragraphs tomorrow at the beginning of the class. The quiz will be on the same paragraphs that they wrote down, but with several blanks where some terms were. The students will need to fill in the blanks with the terms that are missing. Tell students how the quiz will be graded. Prepare this quiz by keying in the paragraphs and then going back and removing every vocabulary term and replacing it with a blank. Choose a variety of words to leave out—nouns, verbs, adjectives, etc. They can be science-content words, but they do not have to be. Score the quiz by allotting two points for every blank, one point for the correct term or word (or perhaps another word with the correct meaning), and a second point for the correct spelling of that term or word.

SECTION 8

Teaching Suggestions and Sample Answers

What Do You See?

This illustration is full of images that students can ponder and discuss with their peers. Interrelated concepts are represented by humorous sketches that stimulate curiosity. Remind students that the main purpose of the *What Do You See?* is to get them to think about motion and relate it to the title of this section. As students feel more comfortable in expressing their idea about the topic, keep them engaged by asking open-ended question that draw attention to key concepts of this section.



Chapter 2 Physics in Action

Section 8

Potential and Kinetic Energy: Energy in the Pole Vault

What Do You See?

Learning Outcomes

In this section, you will

- **Apply** equations for kinetic energy, gravitational potential energy, and elastic potential energy.
- **Recognize** that restoring forces are active when objects are deformed.
- **Apply** the equation for the force necessary to compress or stretch a spring.
- **Measure** the transformations among the different forms of energy.
- **Conduct** simulations of the transformations of energy involved in the pole vault.

What Do You Think?

You would need a fence more than 6.0 m (about 20 ft) high to keep the world champion pole vaulter out of your yard.

- **If champion pole vaulters can clear a 6.0-m high bar with a 5.5-m long pole, why can't they vault over a 12.0-m high bar with a pole 11.0 m long?**
- **What factors (variables) do you think limit the height a pole vaulter has been able to attain?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Pole vaulters rely on the energy stored in their flexible poles to soar to remarkable heights. In this section, you will design an experiment that simulates the factors that determine the amount of energy stored in a pole vaulter's pole by launching a penny with a flexible ruler.

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Students' Prior Conceptions

This section culminates in students' understanding the relationships among forces, the concept of work, and transformations of gravitational and potential energy.

1. **In general, students confuse the concepts of force, work, and energy; they may use them interchangeably.**
2. **Students associate energy only with animate objects; energy is linked with force and movement.**
3. **Preconceptions 1 and 2 may lead students to think of energy as a causal agent that can be stored in some objects as an ingredient or catalyst similar to a fuel that is used up.**
4. **If a fuel is used up, then it cannot be transferred from one form of energy to another.**

The nature of these student preconceptions makes it paramount for teachers to interview students while they are doing the investigation to encourage them to see through observations, measurements, and mathematical modeling that kinetic energy, gravitational potential energy, and spring potential energy all involve forces acting over distances to transform the different forms of energy. In the absence of friction, energy is conserved in these transformations. In the presence of friction, energy is converted to heat which is no longer available to energy transformations within the system.

What Do You Think?

Ask students to answer the question without any hesitation, even if they are not sure about their responses. Encourage them to discuss their answers and record them in their *Active Physics* log book. Reassure your students that while they may not have the right answers at this stage, they will gradually learn more as they progress in the section. At this stage, students' answers don't have to be correct. What matters most is that students think and reflect with ease. Facilitate discussions in small groups as well the whole class.

What Do You Think?

A Physicist's Response

The speed at which the athlete can run and the runner's kinetic energy determine the height a pole vaulter may attain in the pole vault. Although the arm strength of the pole vaulter may add a small amount to the height, it is the transformation of the athlete's kinetic energy to gravitational potential energy that determines the height attained, not the pole length. Because humans have a limiting speed at which they can run, they also have a limit as to the height they may reach with the pole vault. Human limitations on the kinetic energy and the amount of input work that the vaulter is able to provide limit the height much more than the length of the pole. A vaulter using an 8-m pole would not be able to reach a height any higher than if he or she used a 5.5-m pole.

In addition to the kinetic energy of the vaulter, the other factors that determine the height attained are the efficiency of the pole in converting kinetic energy into gravitational potential energy, and the work the vaulter is able to do with his arms at the top of the rise to gain a little bit of additional height.

CHAPTER 2

NOTES

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Investigate

1.a)

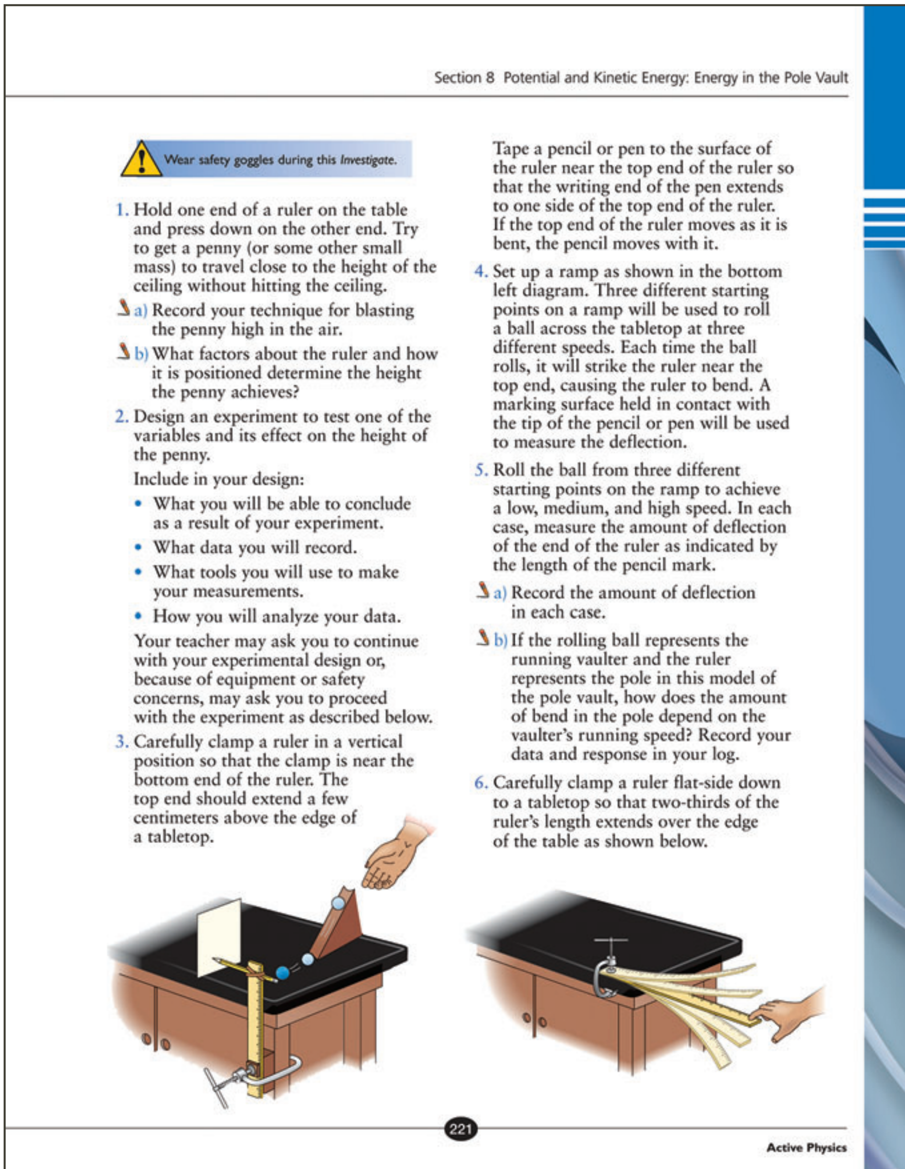
The students record that the more the ruler is deflected, the higher the penny travels.

1.b)

Students will record that if the ruler is clamped toward an end that allows most of the ruler to flex, the penny will not go as high for an equal deflection since the spring constant will be lower for a "longer" ruler.

2.

How the ruler is clamped to the table, how far it is deflected, and the mass of the coin determine how high the penny travels. The students will form conclusions about how high the coin goes as a function of one of the factors described above. The students should list the data that will be recorded in a table and list which variables are being kept constant to present their data in the form of a graph for quick analysis.



Wear safety goggles during this *Investigate*.

1. Hold one end of a ruler on the table and press down on the other end. Try to get a penny (or some other small mass) to travel close to the height of the ceiling without hitting the ceiling.
   a) Record your technique for blasting the penny high in the air.
   b) What factors about the ruler and how it is positioned determine the height the penny achieves?
2. Design an experiment to test one of the variables and its effect on the height of the penny.
   Include in your design:
   - What you will be able to conclude as a result of your experiment.
   - What data you will record.
   - What tools you will use to make your measurements.
   - How you will analyze your data.

   Your teacher may ask you to continue with your experimental design or, because of equipment or safety concerns, may ask you to proceed with the experiment as described below.
3. Carefully clamp a ruler in a vertical position so that the clamp is near the bottom end of the ruler. The top end should extend a few centimeters above the edge of a tabletop.
   Tape a pencil or pen to the surface of the ruler near the top end of the ruler so that the writing end of the pen extends to one side of the top end of the ruler. If the top end of the ruler moves as it is bent, the pencil moves with it.
4. Set up a ramp as shown in the bottom left diagram. Three different starting points on a ramp will be used to roll a ball across the tabletop at three different speeds. Each time the ball rolls, it will strike the ruler near the top end, causing the ruler to bend. A marking surface held in contact with the tip of the pencil or pen will be used to measure the deflection.
5. Roll the ball from three different starting points on the ramp to achieve a low, medium, and high speed. In each case, measure the amount of deflection of the end of the ruler as indicated by the length of the pencil mark.
   a) Record the amount of deflection in each case.
   b) If the rolling ball represents the running vaulter and the ruler represents the pole in this model of the pole vault, how does the amount of bend in the pole depend on the vaulter's running speed? Record your data and response in your log.
6. Carefully clamp a ruler flat-side down to a tabletop so that two-thirds of the ruler's length extends over the edge of the table as shown below.

A more careful analysis shows that if the distance up the ramp is doubled, the speed of the ball increases by the square root of 2. To double the speed of the ball at the bottom of the ramp, the ball must be placed four times further up the ramp. Doubling the speed should approximately double the ruler deflection.

5.a)

The students will record their data for ruler deflection depending upon starting position on the ramp.

5.b)

The students will start with a simple conception that the higher the speed, the greater the deflection of the pole. Do not discourage this view at this point.

6.

If students clamp less than the recommended amount of the ruler, the measurement of small deflection differences will become more difficult.

CHAPTER 2

3.

The student should keep all variables constant except one, and then record the height as that variable is changed. There are many variations on how the next activity can be done. Any way different speeds of the ball can be achieved is fine. Likewise, any method to determine how far the ruler deflects is also fine.

Teaching Tip

A track of some sort may be necessary to make certain the rolling ball hits the ruler.

4.

Prior to doing *Step 5*, the students may expect, as they linearly increase the distance up the ramp, to see a linear increase in the speed of the ball coming down the ramp and striking the ruler.

7.

Any coin will do but uniformity of coins for each group allows a better comparison of data between groups.

Teaching Tip

If the penny falls off the ruler easily, the students can tape a cut-down paper cup onto the ruler to hold the penny in place until it is launched.

8.

Placing a second reference ruler or straightedge next to the deflecting ruler may assist the deflection-measurement process.

8.a)

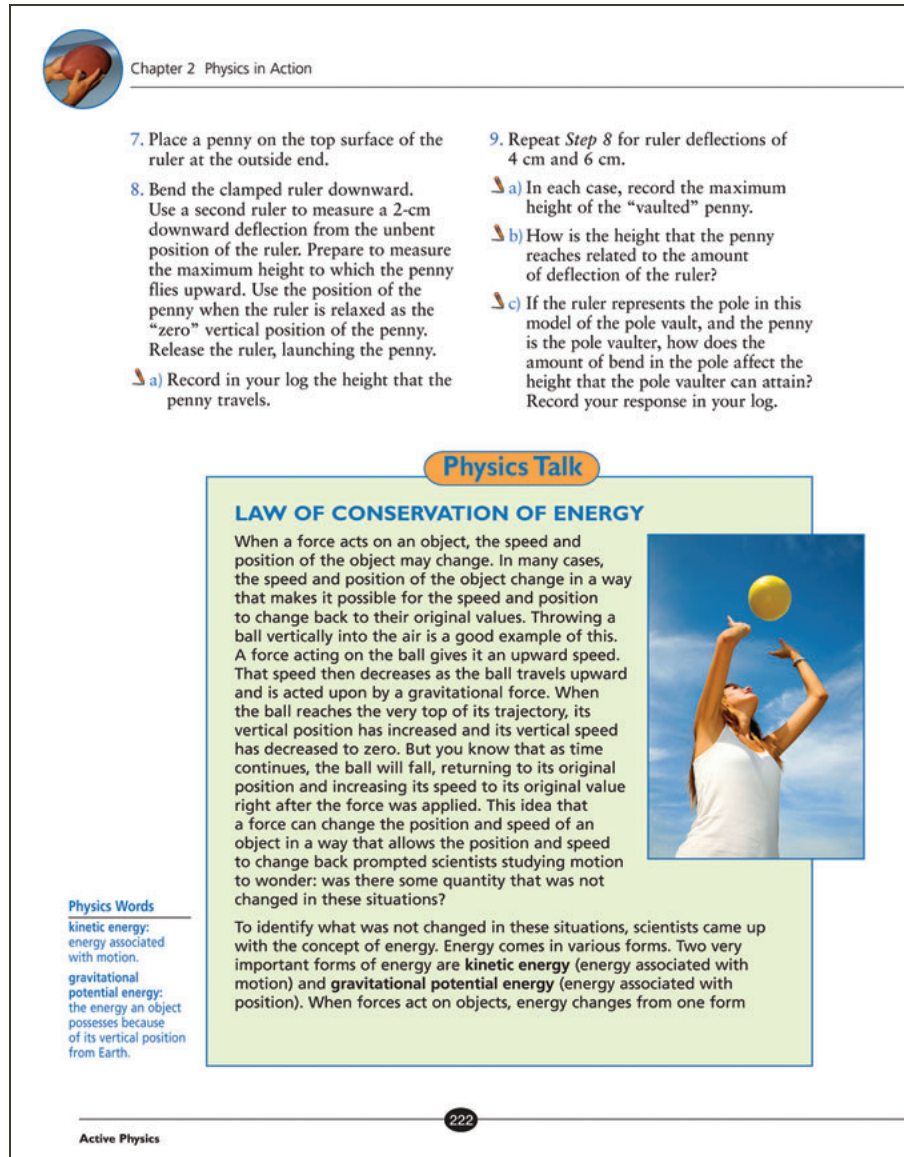
Students record the height the penny rises for the 2-cm deflection of the ruler. It might be expected that as the deflection of the ruler is doubled, the energy in the ruler increases by a factor of 4 due to the equation $SPE = \frac{1}{2}kx^2$, and thus the penny's height should increase by a factor of 4. The situation in practice is more complex, however, so the students should be expected only to see an increase of more than double.

9.a)

Encourage the students to take several trials for each ruler deflection to ensure uniform results.

9.b)

The larger the amount of deflection, the higher the coin travels. The relationship should not be expected to be linear; that is, twice the deflection may cause the coin to travel more than twice as high.


Chapter 2 Physics in Action

7. Place a penny on the top surface of the ruler at the outside end.

8. Bend the clamped ruler downward. Use a second ruler to measure a 2-cm downward deflection from the unbent position of the ruler. Prepare to measure the maximum height to which the penny flies upward. Use the position of the penny when the ruler is relaxed as the "zero" vertical position of the penny. Release the ruler, launching the penny.

a) Record in your log the height that the penny travels.

9. Repeat *Step 8* for ruler deflections of 4 cm and 6 cm.

a) In each case, record the maximum height of the "vaulted" penny.

b) How is the height that the penny reaches related to the amount of deflection of the ruler?

c) If the ruler represents the pole in this model of the pole vault, and the penny is the pole vaulter, how does the amount of bend in the pole affect the height that the pole vaulter can attain? Record your response in your log.

Physics Talk

LAW OF CONSERVATION OF ENERGY

When a force acts on an object, the speed and position of the object may change. In many cases, the speed and position of the object change in a way that makes it possible for the speed and position to change back to their original values. Throwing a ball vertically into the air is a good example of this. A force acting on the ball gives it an upward speed. That speed then decreases as the ball travels upward and is acted upon by a gravitational force. When the ball reaches the very top of its trajectory, its vertical position has increased and its vertical speed has decreased to zero. But you know that as time continues, the ball will fall, returning to its original position and increasing its speed to its original value right after the force was applied. This idea that a force can change the position and speed of an object in a way that allows the position and speed to change back prompted scientists studying motion to wonder: was there some quantity that was not changed in these situations?

To identify what was not changed in these situations, scientists came up with the concept of energy. Energy comes in various forms. Two very important forms of energy are **kinetic energy** (energy associated with motion) and **gravitational potential energy** (energy associated with position). When forces act on objects, energy changes from one form

Physics Words

kinetic energy: energy associated with motion.

gravitational potential energy: the energy an object possesses because of its vertical position from Earth.

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9.c)

The more bend in the pole, the higher in the air the pole vaulter can go.

Physics Talk

As students read about the law of conservation of energy, have them focus on the example of a ball that travels upward and then is acted upon by a gravitational force. Emphasize that the velocity decreasing to zero means that the kinetic energy is also zero but the ball now has maximum potential energy due to gravity. Point out that when the transformation of energy takes place the energy is not being lost, but transformed to a different form. Consider drawing two columns for the gravitational potential energy and kinetic energy on the board to show what happens at different stages of a ball's trajectory. Calculations may be

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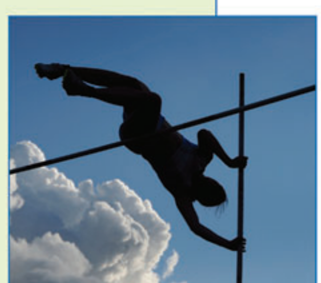
to another, but the sum of the kinetic and **potential energy** (the total energy) remains constant. That is why it is often possible for the objects to reverse the transformation of one form of energy to the other and return to their past positions and speeds. The concept that the total energy remains constant is referred to as the **law of conservation of energy**.

Energy and Work

While a ball is rising or falling, the sum of the gravitational potential energy and the kinetic energy remains constant. For the ball to start to rise, a force had to be applied to the ball over a distance. In the case of throwing a ball up in the air, the force acting on the ball is the force of your hand acting over a distance in an upward direction. For the ball to stop, another force had to be applied to the ball over another distance. In this case, it is gravitational force acting in a downward direction as the ball rises over a distance into the air. Whenever a force is applied to an object over a distance (in the same direction or opposite direction of the force), **work** is done. Work is a precisely defined physics quantity that equals the force multiplied by the distance. Whenever work is done, the energy of an object changes. Therefore, one very appropriate way to think about energy is to consider it "stored work."

Conservation of Energy in the Pole Vault

The coin in the investigation is a good example of work and conservation of energy. You applied a force to the ruler to bend it a certain distance. This was the work done on the ruler to add energy. After that, the ruler had **elastic potential energy**. When you released the ruler, that energy was transferred to the coin as the ruler applied a force to the coin over a certain distance. The coin now had kinetic energy. It traveled up in the air and the kinetic energy became gravitational potential energy as the coin rose. At its peak, the coin stopped momentarily. It now had no kinetic energy, but did have gravitational potential energy. As the coin began to fall, it gained kinetic energy as it lost gravitational potential energy. At all points during the rise and fall, the sum of the kinetic energy and gravitational energy of the coin was constant.



The pole vault is another wonderful example of the law of conservation of energy. The forms of energy are changed, or transformed, from one to another during a vault, but, in principle, the total amount of energy in the system of the vaulter and the pole remains constant.

Physics Words

potential energy: energy associated with position.

law of conservation of energy: energy cannot be created or destroyed; it can be transformed from one form to another, but the total amount of energy remains constant.

work: the product of the displacement and the force in the direction of the displacement.

elastic potential energy (also called spring potential energy): the energy of a spring due to its compression or stretch.

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used to show that as the ball's gravitational energy is increasing, its kinetic energy is decreasing. Encourage students to think about the concept of energy remaining constant, regardless of its transformations. You could reemphasize the question, "Was there some quantity that was not changed in these situations?"

Have students distinguish between the different forces that propel the ball, either upward or downward. Discuss the definition of work and ask students to write down the definition of work in their *Active Physics* log. To help relate the concept of work to energy, explain to the students that the work done by the thrower's hand while it was in contact with the ball is equal to the ball's increase in kinetic energy as it starts to rise. As students read about the conservation of energy, ask them to provide examples of situations where work is stored as elastic potential energy and then changes into kinetic energy. Discuss examples of different forms of energy transformations that an object goes through and have students take a short quiz to gauge their understanding. Concentrate on the general idea of energy being conserved as it passes through the various transformations between work and the different forms of energy. The *Physics Talk* provides several examples of calculating different forms of energy. It does not specifically provide numerical examples of using the conservation of energy principle to determine the energy at various stages when transformations occur. This aspect of conservation of energy will be dealt with more explicitly in the following section.

CHAPTER 2

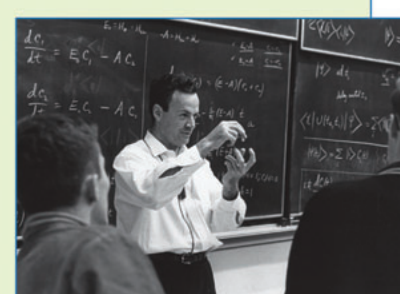
Chapter 2 Physics in Action

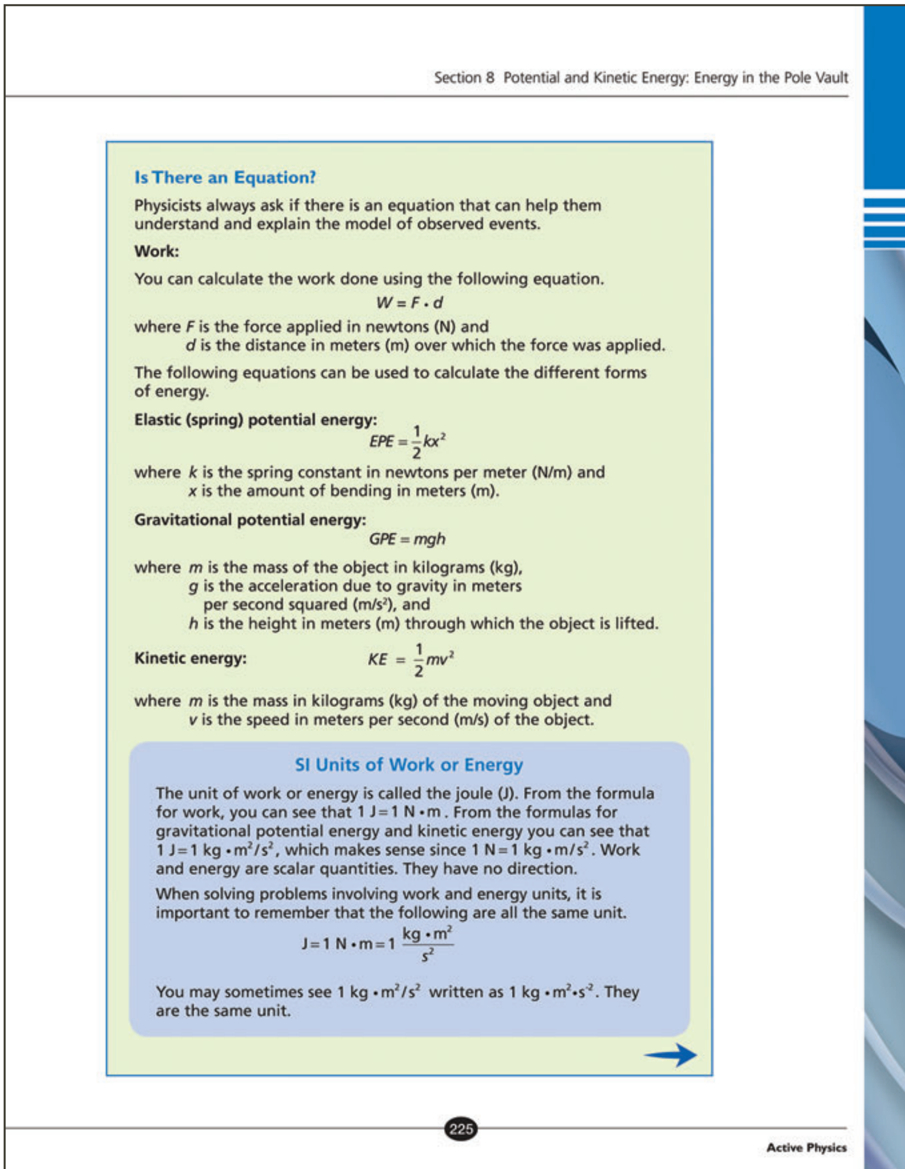
Food energy provides muscular energy for the vaulter to run, gaining an amount of kinetic energy. Some of the vaulter's kinetic energy is used to catapult the vaulter with an initial speed upward and the remaining kinetic energy is converted into an amount of elastic potential energy as the vaulter does work on the pole as it bends. As the bent pole straightens, its elastic potential energy is transferred to the vaulter to increase the vaulter's gravitational potential energy as the vaulter's height increases.

Richard Feynman's Explanation of the Conservation of Energy

In making measurements of the ruler's deflection and the height of the coin, you were investigating conservation of energy — one of the most important principles of science. Richard Feynman, an American physics giant of the twentieth century, provides a story that may help you to understand energy conservation.

In his story, a child plays with 28 blocks. Every day the child's mother counts the blocks and always finds the total to be 28. On one occasion, she only finds 27 blocks, but then realizes that one block is hidden in a box. On another day, she finds only 25 blocks, but can see that the water in a pail is higher than expected. By measuring the height difference, and knowing something about the original height of the water and the volume of a block, she determines that 3 blocks are below the surface of the water. Feynman equates counting the blocks with measuring the total energy. There were 28 blocks and there will always be 28 blocks. If there are 28 units of energy, then there will always be 28 units of energy.





Section 8 Potential and Kinetic Energy: Energy in the Pole Vault

Is There an Equation?

Physicists always ask if there is an equation that can help them understand and explain the model of observed events.

Work:

You can calculate the work done using the following equation.

$$W = F \cdot d$$

where F is the force applied in newtons (N) and
d is the distance in meters (m) over which the force was applied.

The following equations can be used to calculate the different forms of energy.

Elastic (spring) potential energy:

$$EPE = \frac{1}{2}kx^2$$

where k is the spring constant in newtons per meter (N/m) and
x is the amount of bending in meters (m).

Gravitational potential energy:

$$GPE = mgh$$

where m is the mass of the object in kilograms (kg),
g is the acceleration due to gravity in meters per second squared (m/s²), and
h is the height in meters (m) through which the object is lifted.

Kinetic energy:

$$KE = \frac{1}{2}mv^2$$

where m is the mass in kilograms (kg) of the moving object and
v is the speed in meters per second (m/s) of the object.

SI Units of Work or Energy

The unit of work or energy is called the joule (J). From the formula for work, you can see that $1\ \text{J} = 1\ \text{N} \cdot \text{m}$. From the formulas for gravitational potential energy and kinetic energy you can see that $1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2$, which makes sense since $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$. Work and energy are scalar quantities. They have no direction.

When solving problems involving work and energy units, it is important to remember that the following are all the same unit.

$$\text{J} = 1\ \text{N} \cdot \text{m} = 1\ \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$$

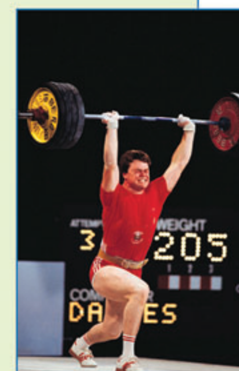
You may sometimes see $1\ \text{kg} \cdot \text{m}^2/\text{s}^2$ written as $1\ \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$. They are the same unit.

CHAPTER 2

Chapter 2 Physics in Action

Sample Problem 1

A weightlifter uses a force of 325 N to lift a set of weights 2.00 m off the ground. How much work did the weightlifter do?



Strategy: You can use the following equation for calculating work:

$$W = F \cdot d$$

Given:

$$F = 325 \text{ N}$$
$$d = 2.00 \text{ m}$$

Solution:

$$\begin{aligned} W &= F \cdot d \\ &= 325 \text{ N} \times 2.00 \text{ m} \\ &= 650 \text{ N} \cdot \text{m or } 650 \text{ J} \end{aligned}$$

Work done by the weightlifter is 650 J.

Sample Problem 2

How much energy is stored in a pole with a spring constant of 15 N/m if it is deflected 1.6 m?

Strategy: You can use the following equation for calculating elastic potential energy:

$$EPE = \frac{1}{2}kx^2$$

Given:

$$k = 15 \text{ N/m}$$
$$x = 1.6$$

Solution:

$$\begin{aligned} EPE &= \frac{1}{2}kx^2 \\ &= \frac{1}{2} \cdot 15 \frac{\text{N}}{\cancel{\text{m}}} \cdot (1.6 \text{ m})^{\cancel{2}} \\ &= 19.2 \text{ N} \cdot \text{m or } 19 \text{ J} \end{aligned}$$

Elastic potential energy in the pole is 19 J.

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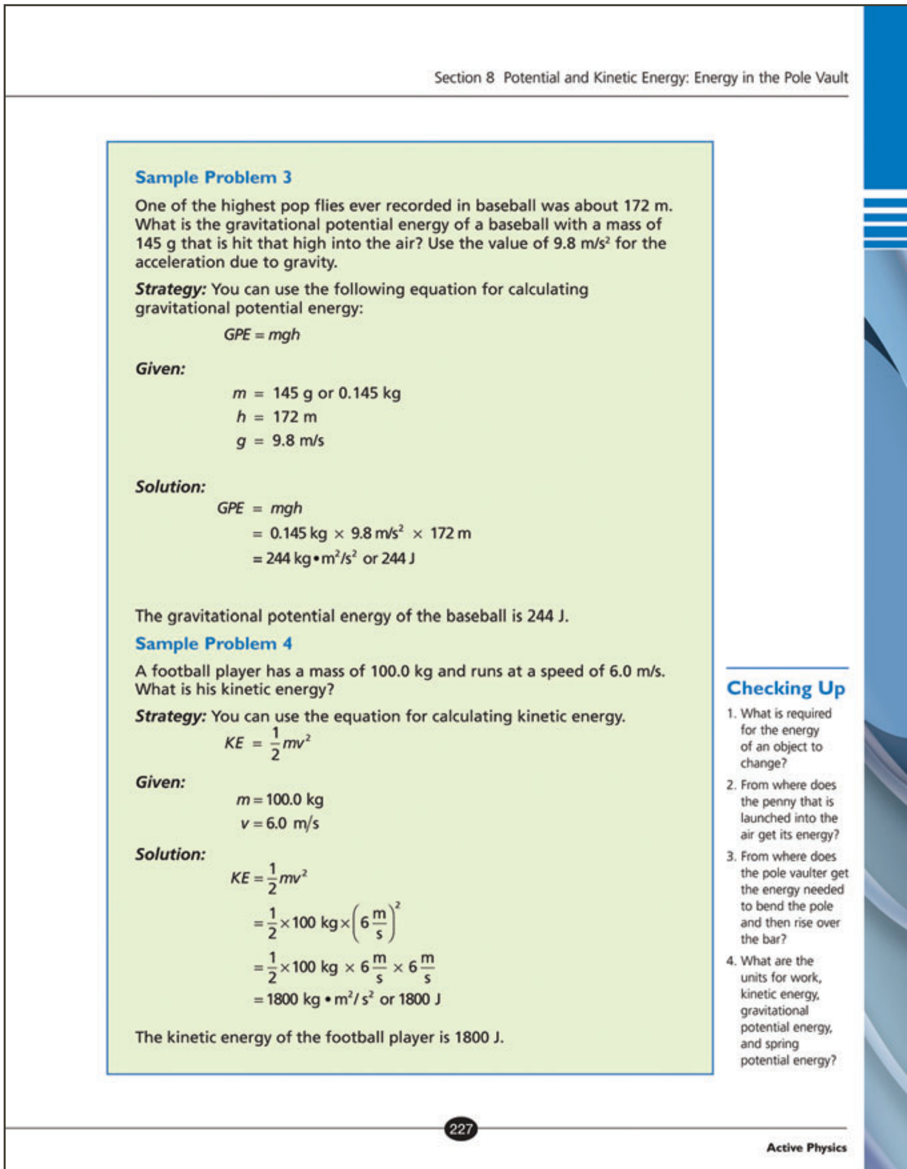
Active Physics



Sample Problem 3

One of the highest pop flies ever recorded in baseball was about 172 m. What is the gravitational potential energy of a baseball with a mass of 145 g that is hit that high into the air? Use the value of 9.8 m/s² for the acceleration due to gravity.

Strategy: You can use the following equation for calculating gravitational potential energy:

$$GPE = mgh$$

Given:

m = 145 g or 0.145 kg
h = 172 m
g = 9.8 m/s

Solution:

$$\begin{aligned} GPE &= mgh \\ &= 0.145\ \text{kg} \times 9.8\ \text{m/s}^2 \times 172\ \text{m} \\ &= 244\ \text{kg}\bullet\text{m}^2/\text{s}^2 \text{ or } 244\ \text{J} \end{aligned}$$

The gravitational potential energy of the baseball is 244 J.

Sample Problem 4

A football player has a mass of 100.0 kg and runs at a speed of 6.0 m/s. What is his kinetic energy?

Strategy: You can use the equation for calculating kinetic energy.

$$KE = \frac{1}{2}mv^2$$

Given:

m = 100.0 kg
v = 6.0 m/s

Solution:

$$\begin{aligned} KE &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 100\ \text{kg} \times \left(6\frac{\text{m}}{\text{s}}\right)^2 \\ &= \frac{1}{2} \times 100\ \text{kg} \times 6\frac{\text{m}}{\text{s}} \times 6\frac{\text{m}}{\text{s}} \\ &= 1800\ \text{kg}\bullet\text{m}^2/\text{s}^2 \text{ or } 1800\ \text{J} \end{aligned}$$

The kinetic energy of the football player is 1800 J.

Checking Up

1. What is required for the energy of an object to change?
2. From where does the penny that is launched into the air get its energy?
3. From where does the pole vaulter get the energy needed to bend the pole and then rise over the bar?
4. What are the units for work, kinetic energy, gravitational potential energy, and spring potential energy?

Checking Up

1.

Work must be done on an object to change its total energy.

2.

The penny gets kinetic energy from the elastic potential energy of the ruler.

3.

The energy to bend the pole comes from the kinetic energy of the running pole vaulter, and the energy to go over the bar comes from the stored energy in the pole and the work done by the pole vaulter's muscles.

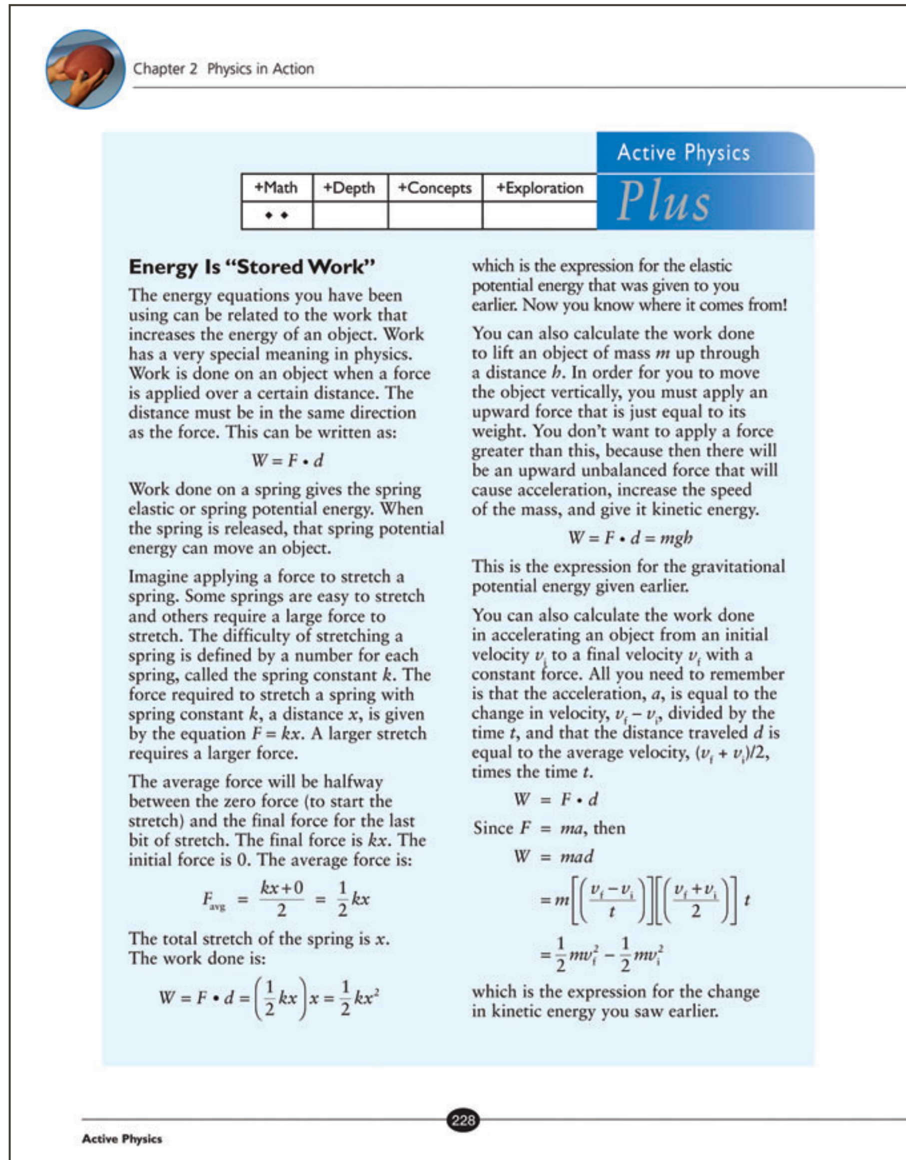
4.

The unit for all kinds of energy and work is joules, which means they are all equivalent forms.

CHAPTER 2

Active Physics Plus

Students explore the change in energy due to work done by learning the strategies of solving sample problems. As students solve each problem, ask them to focus on how one type of energy is equated to another to solve a variable comprising the energy equation. Draw their attention to the statement "energy is stored work," and have them explain how this concept is shown by sample problems.



Active Physics **Plus**

+Math	+Depth	+Concepts	+Exploration
• •			

Energy Is "Stored Work"

The energy equations you have been using can be related to the work that increases the energy of an object. Work has a very special meaning in physics. Work is done on an object when a force is applied over a certain distance. The distance must be in the same direction as the force. This can be written as:

$$W = F \cdot d$$

Work done on a spring gives the spring elastic or spring potential energy. When the spring is released, that spring potential energy can move an object.

Imagine applying a force to stretch a spring. Some springs are easy to stretch and others require a large force to stretch. The difficulty of stretching a spring is defined by a number for each spring, called the spring constant k. The force required to stretch a spring with spring constant k, a distance x, is given by the equation $F = kx$. A larger stretch requires a larger force.

The average force will be halfway between the zero force (to start the stretch) and the final force for the last bit of stretch. The final force is kx. The initial force is 0. The average force is:

$$F_{avg} = \frac{kx+0}{2} = \frac{1}{2}kx$$

The total stretch of the spring is x. The work done is:

$$W = F \cdot d = \left(\frac{1}{2}kx\right)x = \frac{1}{2}kx^2$$

which is the expression for the elastic potential energy that was given to you earlier. Now you know where it comes from!

You can also calculate the work done to lift an object of mass m up through a distance h. In order for you to move the object vertically, you must apply an upward force that is just equal to its weight. You don't want to apply a force greater than this, because then there will be an upward unbalanced force that will cause acceleration, increase the speed of the mass, and give it kinetic energy.

$$W = F \cdot d = mgh$$

This is the expression for the gravitational potential energy given earlier.

You can also calculate the work done in accelerating an object from an initial velocity v_i to a final velocity v_f with a constant force. All you need to remember is that the acceleration, a, is equal to the change in velocity, $v_f - v_i$, divided by the time t, and that the distance traveled d is equal to the average velocity, $(v_f + v_i)/2$, times the time t.

$$W = F \cdot d$$

Since $F = ma$, then

$$W = mad$$

$$= m\left[\left(\frac{v_f - v_i}{t}\right)\right]\left[\left(\frac{v_f + v_i}{2}\right)\right]t$$

$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

which is the expression for the change in kinetic energy you saw earlier.

Although the energy equations were stated first, notice that they result from the idea that whenever work is done, energies change. The energy equations simply reflect the amount of work done. This is where the statement "energy is stored work" originates.

Sample Problem I

Your teacher gives you a pop-up toy. When you push down on it, it sticks to the desk for a moment and then pops into the air.

a) If the toy has a mass of 100.0 g and leaps 1.20 m off the table, how much potential energy does it have at its point of maximum height? (Use $g = 9.80\ \text{m/s}^2$.)

Strategy:

The toy at its peak has a type of energy that depends on its position in Earth's gravitational field. So you need to use the formula for gravitational potential energy.

Given:

$$m = 100.0\ \text{g or } 0.100\ \text{kg}$$
$$h = 1.20\ \text{m}$$

Solution:

$$GPE = mgh$$
$$= (0.100\ \text{kg})(9.8\ \frac{\text{m}}{\text{s}^2})(1.20\text{m})$$
$$= 1.18\ \text{kg}\cdot\text{m}^2/\text{s}^2 \text{ or } 1.18\ \text{J}$$

b) When the toy jumps off the desk, with what speed does it leave?

Strategy: At the point where it jumps off the desk, the toy has maximum amount of kinetic energy. This is what becomes the potential energy at the peak of its trajectory.

Because energy is conserved, these two values will be equal—kinetic energy at the bottom equals the potential energy at the peak.

Given:

$$GPE = 1.18\ \text{J}$$

Solution:

$$GPE = KE$$
$$KE = \frac{1}{2}mv^2$$

Since you know that the KE must be equal to 1.18 J and you know the mass is 0.100 kg, you can use your calculator to find a value for v such that $\frac{1}{2}mv^2 = 1.18\ \text{J}$.

Alternatively, you can practice your algebra skills and find the value directly.

You can use algebra to rearrange the equation to solve for v.

$$v = \sqrt{\frac{KE}{\frac{1}{2}\text{m}}}$$
$$= \sqrt{\frac{1.18\text{J}}{\frac{1}{2}(0.100\ \text{kg})}}$$
$$= 4.90\ \text{m/s}$$

c) If you push the toy down 2.0 cm to make it stick to the desk, what is the spring constant of the spring in the toy?

Strategy: The kinetic energy to make the toy leap off the desk came from doing work on the spring and storing it as elastic potential energy. Using the conservation of energy, this energy was then transformed into kinetic energy.

CHAPTER 2

Given:

$x = 2.0 \text{ cm} = 0.020 \text{ m}$

Solution:

$EPE = 1.18 \text{ J}$

You can use your calculator to find a value for k, such that:

$$\frac{1}{2}kx^2 = 1.18 \text{ J}$$

or you can use algebra again to rearrange the equation to solve for k.

$$k = \frac{1.18 \text{ N} \cdot \text{m}}{\frac{1}{2}(0.020 \text{ m})(0.020 \text{ m})} \quad (1 \text{ J} = 1 \text{ N} \cdot \text{m})$$

$$= 5900 \ \frac{\text{N}}{\text{m}}$$

d) What force was needed to compress the spring the 2.00 cm?

Strategy: Now that you know the compression and the spring constant, it is possible to find the amount of force required to press down on the spring.

Given:

$k = 5900 \text{ N/m}$

$x = 0.0200 \text{ m}$

Solution:

$$F = kx$$

$$= \left(5900 \frac{\text{N}}{\text{m}}\right)(0.0200 \text{ m})$$

$$= 118 \text{ N or } 120 \text{ N}$$

Sample Problem 2

At what height, above the ground, could a tennis ball ($m = 57$ g) be dropped to give it the same kinetic energy it has when traveling at 45 m/s? (Neglect air resistance.)

Strategy: Assume that you are looking for the vertical position that will yield a speed of 45 m/s the instant before the ball touches the ground. The problem can be solved in one step using conservation of energy.

Given:

$m = 57 \text{ g} = 0.057 \text{ kg}$

$v = 45 \text{ m/s}$

$g = 9.8 \text{ m/s}^2$

Solution:

$$GPE = KE$$

$$mgh = \frac{1}{2}mv^2$$

Notice that you do not have to take into account the mass of the ball.

$$h = \frac{v^2}{2g}$$

$$= \frac{\left(45 \ \frac{\text{m}}{\text{s}}\right)^2}{2\left(9.8 \ \frac{\text{m}}{\text{s}^2}\right)}$$

$$= \frac{2025 \ \frac{\text{m}^2}{\text{s}^2}}{19.6 \ \frac{\text{m}}{\text{s}^2}}$$

$$= 103.3 \text{ m or } 100 \text{ m}$$

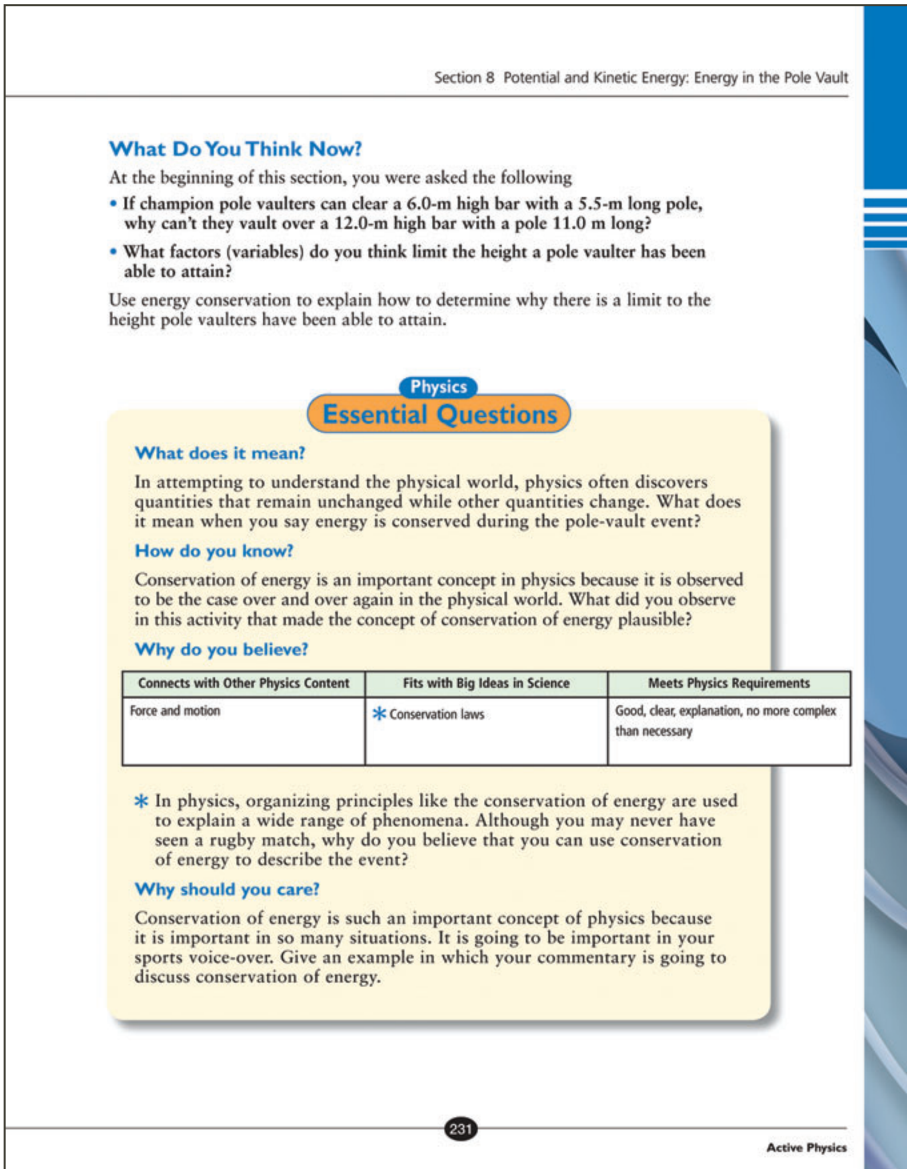
When the ball is traveling at 45 m/s, it has a kinetic energy of 58 J. You can calculate this:

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(0.57 \text{ kg})(45 \text{ m/s})^2 = 58 \text{ J}$$

If the tennis ball were positioned at a location 103 m above Earth, the gravitational potential energy of the ball would also equal 58 J.

$$GPE = mgh = (0.57 \text{ kg})(9.8 \text{ m/s}^2)(103 \text{ m})$$

$$= 58 \text{ J}$$



What Do You Think Now?

At the beginning of this section, you were asked the following

- **If champion pole vaulters can clear a 6.0-m high bar with a 5.5-m long pole, why can't they vault over a 12.0-m high bar with a pole 11.0 m long?**
- **What factors (variables) do you think limit the height a pole vaulter has been able to attain?**

Use energy conservation to explain how to determine why there is a limit to the height pole vaulters have been able to attain.

Physics

Essential Questions

What does it mean?

In attempting to understand the physical world, physics often discovers quantities that remain unchanged while other quantities change. What does it mean when you say energy is conserved during the pole-vault event?

How do you know?

Conservation of energy is an important concept in physics because it is observed to be the case over and over again in the physical world. What did you observe in this activity that made the concept of conservation of energy plausible?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Force and motion	* Conservation laws	Good, clear, explanation, no more complex than necessary

* In physics, organizing principles like the conservation of energy are used to explain a wide range of phenomena. Although you may never have seen a rugby match, why do you believe that you can use conservation of energy to describe the event?

Why should you care?

Conservation of energy is such an important concept of physics because it is important in so many situations. It is going to be important in your sports voice-over. Give an example in which your commentary is going to discuss conservation of energy.

What Do You Think Now?

Have students review their answers in light of what they have learned so far in this section. Ask them questions that lead students to answer the *What Do You Think Now?* questions. Share the *Physicist's Response* with them. Invite students to discuss their answers. Remind them that at this stage they should review and revise their original responses. While students are revising their responses, emphasize how they can use their knowledge of energy conservation to determine the maximum height pole vaulters can attain.

CHAPTER 2

Physics Essential Questions

What does it mean?

Although the height and the speed of the vaulter change, the sum of the gravitational potential energy, *GPE*, and the kinetic energy, *KE*, remains constant.

How do you know?

The spring toy had kinetic energy at one point and then had an equal amount of gravitational potential energy at another point.

Why do you believe?

Conservation of energy holds for all events, including all sports.

Why should you care?

When a pop fly is hit in baseball, the ball first has kinetic energy. There is a loss in kinetic energy as the ball rises and an equal gain in gravitational potential energy.

Reflecting on the Section and the Challenge

This is the time for students to reflect on what their commentary could cover if they were sports-casting a pole-vault event. They should be able to describe the law of conservation of energy in relation to other sports and include it in their voice-over narration. Have the students write a short summary of their sportscast, so that they can discuss it with their peers and incorporate physics concepts that apply to the sport they want to include in their *Chapter Challenge*. Point out that their work will be evaluated on the basis of how clearly they explain the transformation of energy in a system after force is applied. Use the terms *force*, *work*, and *energy* frequently in your discussion so that students can relate to each term in context.

Chapter 2 Physics in Action

Reflecting on the Section and the Challenge

In this section, you were told that throughout the event of pole vaulting, energy changes from one form to another, but the total amount of energy in the system at all instants remains the same. (A small amount of energy may be transformed into internal energy by making a dent in the end of the pit that stops the pole or by raising the temperature of the pole as it bends.) Therefore, a sportscaster covering the pole vault event has many opportunities to explain what is happening in terms of the law of conservation of energy.

As a sportscaster, you can also describe the law of conservation of energy as it applies to a baseball rising in the air. In soccer, when you kick the ball, you do work on the ball and compress it. This elastic potential energy becomes kinetic energy. If the ball rises, some of that kinetic energy becomes gravitational potential energy. From a physics perspective, the behavior of a golf ball or a tennis ball is identical. High-speed photographs can show the compression of the balls. Since conservation of energy is one of the organizing principles of all science, you may want to include this in your voice-over.

Physics to Go

1. Describe the energy transformations in the shot put.
2. Describe the energy transformations in golf.
3. Assume that a vaulter is able to carry a vaulting pole while running as fast as Carl Lewis in his world record 100-m dash (around 12 m/s). Also assume that all of the vaulter's kinetic energy is transformed into gravitational potential energy. What vaulting height could that person attain? (Hint: Use the equation $\frac{1}{2}mv^2 = mgh$.)
4. Why does the length of the pole alone not determine the limit of vaulting height?
5. The temperature of some poles increases slightly as they flex. Use the law of conservation of energy to explain how this would affect performance.
6. The women's pole vault world record as of spring 1997 was 4.55 m, set by Emma George. What do you estimate was Emma's speed prior to planting the pole? Use conservation of energy for your prediction.
7. Sergei Bubka held the world record for the pole vault as of spring 1997 at 6.14 m. How did Sergei's speed compare with Emma George's speed? (See *Question 6*.)
8. A 2.0-kg rock is dropped off a 100-m high cliff.

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Active Physics

Physics to Go

1.

The shot putter imparts a launching speed to the projectile, which is kinetic energy. By giving the shot two speeds in the same direction, the speeds add together. One of the motions is provided by the spinning motion of the shot putter before release, and the other is provided by the thrusting action of the shot putter's arm. In both cases, the athlete does work that is transformed into the kinetic energy that the ball has upon release. The horizontal component of the shot's speed is maintained while the projectile is in the air. The vertical component of the speed can be used to calculate the part of the kinetic energy, which will be transformed into gravitational potential energy, allowing prediction of the height to which the shot will rise at the peak of its flight. Students are more likely to write that the athlete uses muscles to transfer kinetic energy to the shot. Some of this energy makes the shot rise, converting kinetic energy into potential energy. Then the shot falls as potential energy is converted back to kinetic energy. When the shot hits the ground, the kinetic energy transforms into internal energy as the temperature of the shot and ground increases slightly.

2.

In golf, the golfer does work on the golf club to give the end of the club a great deal of kinetic energy. Upon impact, the end of the golf club does work on the golf ball, giving the golf ball kinetic energy. As with the shot after release, the golf ball has both horizontal and vertical speed components. The energy transformations are therefore the same as with the shot.

3.

Lewis' maximum speed in the dash = 12 m/s. Solving for h in the equation given in the problem: $h = v^2/2g = 7.3\text{ m}$.

4.

The vaulter's kinetic energy is determined by the running speed and the amount of work he or she does using their arms to lift their body. This energy, which includes the work done, determines the maximum height the pole vaulter can reach, regardless of the length of the vaulting pole. The pole could, however, have an effect if it is either too short or too long.

5.

The amount of internal energy (due to the temperature rise) generated during the bending of the pole would "rob" part of the potential energy that can be stored in the pole by causing it to bend less than it would if no internal energy were generated and by causing the pole to straighten with less "straightening" speed than if no internal energy were generated; overall, heating of the pole would reduce the vaulter's height.

6.

$v = \sqrt{2gh} = \sqrt{2\left(10\text{ m/s}^2\right)\left(4.6\text{ m}\right)} = \sqrt{92\text{ m}^2/\text{s}^2} = 9.6\text{ m/s}$. Notice that Emma's height was rounded to two significant figures in the above substitution.

7.

$v = \sqrt{2gh} = \sqrt{2\left(10\text{ m/s}^2\right)\left(6.1\text{ m}\right)} = \sqrt{120\text{ m}^2/\text{s}^2} = 11\text{ m/s}$. Therefore, Sergei's speed was greater than Emma's. Notice that while Sergei's speed was only about 15% greater than Emma's, his vault height (6.1 m compared to Emma's 4.6 m) was about 32% higher. This is due to the squared effect of speed on kinetic energy; squaring the ratio of speeds verifies that the ratio of heights should be 1.32:1.00, as shown below:

$$\left(\frac{6.1\text{ m/s}}{4.6\text{ m/s}}\right)^2 = (1.33)^2 = 1.76$$

NOTES

CHAPTER 2

NOTES

8.a)

Using the law of conservation of energy, the gravitational potential energy (*GPE*) at the top of the cliff is equal to the kinetic energy (*KE*) at the bottom.

$$GPE_i + KE_i = GPE_f + KE_f$$

$$mgh + 0 = 0 + \tfrac{1}{2}mv^2$$

$$v = \sqrt{2gh}$$

$$v = \sqrt{2\left(9.8\text{ m/s}^2\right)\left(100\text{ m}\right)} =$$

44 m/s

8.b)

Yes, the speed is independent of the mass. All objects fall at the same rate as long as air resistance is small enough to ignore. In the energy equations, you can see that the mass drops out.

9.a)

$$W = \tfrac{1}{2}kx^2 =$$

$$\tfrac{1}{2}(1500\text{ N/m})(0.25\text{ m})^2 = 47\text{ J}$$

9.b)

The work becomes spring potential energy (*SPE*). This *SPE* becomes kinetic energy (*KE*) of the arrow.

$$KE = \tfrac{1}{2}mv^2$$

$$47\text{ J} = \tfrac{1}{2}(0.1\text{ kg})v^2$$

$$v = \sqrt{\frac{2(47\text{ J})}{0.1\text{ kg}}} = 30.7\text{ m/s}$$

10.a)

$$W = \tfrac{1}{2}kx^2 =$$

$$\tfrac{1}{2}(315\text{ N/m})(0.30\text{ m})^2 = 14.2\text{ J}$$

10.b)

$$F = kx = (315\text{ N/m})(0.30\text{ m}) = 95\text{ N}$$

11.

The gravitational potential energy (*GPE*) of the car will become kinetic energy (*KE*) of the car. This *KE* will then do work on the spring and compress it. The compression of the spring will store this energy as spring potential energy (*SPE*). You can therefore compare the *GPE* to the *SPE* and not concern yourself with the *KE*.

$$mgh = \tfrac{1}{2}kx^2$$

$$x = \sqrt{\frac{2mgh}{k}}$$

$$x = \sqrt{\frac{2\left(0.04\text{ kg}\right)\left(9.8\text{ m/s}^2\right)\left(1\text{ m}\right)}{\left(18\text{ N/m}\right)}} =$$

0.21 m

12.a)

$$F(\text{in newtons}) = ma =$$

$$\left(1\text{ kg}\right)\left(1\text{ m/s}^2\right) = 1\text{ N} = 1\left(\text{kg}\cdot\text{m}\right)/\text{s}^2$$

12.b)

$$GPE = mgh = \left(1\text{ kg}\right)\left(1\text{ m/s}^2\right)\left(1\text{ m}\right) =$$

$$\left(1\text{ N}\right)\left(1\text{ m}\right) = 1\text{ J}$$

a) Using energy considerations only, calculate the speed the rock is going when it gets to the bottom of the cliff.

b) Can you do this calculation if you do not know the mass of the rock? What does this imply for the speeds of falling objects when friction is not considered?

9. Active Physics Plus A bow is strung with a bowstring that has a spring constant, k, of 1500 N/m.

a) If you pull the bowstring back 25 cm, how much work have you done on it?

b) If the string is pushing against an arrow that has a mass of 0.10 kg, how fast is the arrow going when it leaves the bow?

10. Active Physics Plus An exercise spring has a spring constant of 315 N/m.

a) How much work is required to stretch the spring 30 cm?

b) What force is needed to stretch the spring 30 cm?

11. A toy car ($m = 0.04$ kg) is released from rest and slides down a frictionless track 1 m high. At the bottom of the track it slides along a horizontal portion until it hits a spring ($k = 18$ N/m). The spring is attached to an immovable object. What is the maximum compression of the spring?

12. The unit for energy is the joule. It is also the unit of work. One joule is the work done by a force of one newton over a distance of one meter ($1\text{ J} = 1\text{ N} \cdot 1\text{ m}$).

a) Using $F = ma$, show that $1\text{ N} = 1\text{ kg} \cdot 1\text{ m/s}^2$.

b) Using $GPE = mgh$, show that GPE is measured in joules.

c) Using $KE = \frac{1}{2}mv^2$, show that KE is measured in joules.

d) Using $EPE = \frac{1}{2}kx^2$ and $GPE = \frac{1}{2}kx^2$, show that EPE is measured in joules.

(The spring constant k has units of N/m, as you can see from the equation $F = kx$.)

13. A high diver jumps off the diving board, travels up and then down twirling her body. Explain high diving in terms of energy transformations among *EPE*, *GPE*, and *KE*.

14. A volleyball player is setting the ball by hitting it directly up with her hands. Describe the energy transformations in the volleyball play.

15. A long fly ball in baseball can be described in terms of energy transformations. Can you make your descriptions entertaining so that it can be used in a sports announcer's voice-over?

16. ***Preparing for the Chapter Challenge***
Describe how the law of conservation of energy applies to the sport you are going to describe in your voice-over. Include a specific example you might be able to use in your voice-over.

12.c)

$$KE = \tfrac{1}{2}mv^2 = \tfrac{1}{2}(1\text{ kg})(1\text{ m/s})^2$$

$$(1\text{ kg})(1\text{ m/s})^2 = (1\text{ kg})(1\text{ m}^2/\text{s}^2) =$$

$$(1\text{ kg}\cdot\text{m/s}^2)(\text{m}) = 1\text{ J}$$

13.

When the diver walks onto the diving board, she first does work jumping in the air to increase her potential energy. When she falls back to the springboard, the potential energy turns to kinetic energy, which turns to spring potential energy as the board bends. The stored potential energy in the diving board then imparts kinetic energy to the diver causing her to rise off the board and gain *GPE* equal to the stored *SPE* that was in the diving board. The gravitational potential energy turns into kinetic energy as the diver falls to the water. When the diver strikes the water, her kinetic energy is lost and converted to thermal energy, increasing the energy and temperature of the water.

14.

When the volleyball player "sets" a ball for another player to spike, she is doing work on the ball to give it kinetic energy. This causes the ball to rise and gain potential energy. If timed correctly, a second player will jump up and strike the ball at the highest point of the ball's rise (maximum *GPE*), doing work on the ball to give it kinetic energy. The ball will also gain kinetic energy as it falls back to the court, with the final kinetic energy being equal to the work done by the "spiker" plus the *GPE* that the ball had at the peak of its rise just before being struck.

15.

The student's voice-over should include a description of the energy changes the ball undergoes similar to the descriptions in the answers to Questions 14 and 15. It should also include an exciting description of what the outfielder should do to catch the ball, and the work done on the mitt and the temperature change as the ball lands in the player's mitt.

16.

Preparing for the Chapter Challenge

The students should choose a sport and describe the energy changes. A sport with numerous changes would be more appropriate than a simpler one. The voice-over should include a discussion of how the energy changes form between work, *GPE*, *KE*, and possibly *SPE* and thermal energy to be complete.

CHAPTER 2

SECTION 8 QUIZ

2-8a **Blackline Master**

1. In an emergency stop, a 1500-kg vehicle loses 300,000 joules of energy as it comes to rest. What was the speed of the vehicle the moment the brakes were applied?

   a) 10 m/s
   b) 14 m/s
   c) 20 m/s
   d) 25 m/s

2. If the kinetic energy of an object is 16 J when its speed is 4 m/s, what is the object's mass?

   a) 0.5 kg
   b) 2.0 kg
   c) 8 kg
   d) 19.6 kg

3. If a 5-kg mass is raised two meters vertically from the surface of Earth, its gain in potential energy will be

   a) 5 J.
   b) 10 J.
   c) 20 J.
   d) 100 J.

4. A spring has a spring constant of 120 N/m. How much energy is stored in the spring as it is stretched a distance of 0.20 meter?

   a) 2.4 J
   b) 4.8 J
   c) 12 J
   d) 24 J

5. A 0.50-kg ball is thrown vertically upward with an initial velocity of 35 m/s. Approximately, how high will the ball rise?

   a) 35 m
   b) 60 m
   c) 85 m
   d) 120 m

SECTION 8 QUIZ ANSWERS

1 c) $KE = \frac{1}{2}mv^2 \quad v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2(300{,}000\ \text{J})}{(1500\ \text{kg})}} = 20\ \text{m/s}$

2 b) $KE = \frac{1}{2}mv^2 \quad m = \frac{2KE}{v^2} = \frac{2(16\ \text{J})}{(4\ \text{m/s})^2} = 2.0\ \text{kg}$

3 d) $GPE = mgh = (5\ \text{kg})(9.8\ \text{m/s}^2)(2\ \text{m}) = 100\ \text{J}$

4 a) $SPE = \frac{1}{2}kx^2 = \frac{1}{2}(120\ \text{N/m})(0.20\ \text{m})^2 = 2.4\ \text{J}$

5 b) $KE = GPE$ gives $\frac{1}{2}mv^2 = mgh$

Solving for h we have

$$h = \frac{v^2}{2g} = \frac{(35\ \text{m/s})^2}{2(10\ \text{m/s}^2)} = 61\ \text{m}$$

NOTES

CHAPTER 2