SECTION 3

Energy and Work: Why Air Bags?

Section Overview

Students consider how an air bag protects a passenger during an automobile accident by using an egg to simulate the head of a passenger during a collision. They investigate what occurs during a collision between an egg and a hard surface, and what occurs when the surface is covered with about 2 cm of a softer substance such as flour for various dropping heights. Then students observe a demonstration of an egg being thrown at a large sheet. Their observations provide evidence for the conclusion that when the force is spread out over a larger distance and/or area the impact on the egg is reduced. Students use the work-energy theorem to explain their observations. They then explain how an air bag protects a passenger during a collision.

Background Information

Models are very important to scientists, particularly when the phenomenon they are studying cannot be easily observed because it is too small or big, too fast or slow, or too dangerous. Automobile accidents are dangerous, happen quickly, and involve many different interactions between objects. The first modeled automobile accidents used real people. Eventually crash dummies were developed and used. Today, crash dummies with special sensors are used. These new crash dummies simulate human movement during a crash much better than previous models, and their sensors measure the amount of velocity, acceleration, force, and torque acting on them during a collision.

The forces encountered when an air bag inflates to stop a passenger can be discussed using either the work-energy theorem or impulse and momentum. In both cases, a force acts on the automobile passenger to decrease both the kinetic energy and the momentum. Using the work-energy theorem, when work is done on an object in the direction opposite to its motion, the work causes a decrease in the object's kinetic energy. If the work is done over a larger distance, a smaller force is required to achieve the same decrease in kinetic energy.

An inflated air bag will stop an occupant of the car in a distance of 0.20 m or less, depending upon impact speed. This should be compared to the passenger being stopped by the dashboard or vehicle window in a distance of less than 0.02 m or a decrease by a factor of 10 for the force required. This lowered force is the reason injuries are greatly reduced when a passenger strikes an air bag rather than an interior surface of the vehicle. In addition, air bags often spread the force over a larger area, decreasing the pressure on a given part of the passenger.

The work-energy theorem was introduced in *Chapter 2*. The work-energy theorem states that the work done by a net force acting on a rigid object to move it through a distance d is equal to the change in kinetic energy, or

$$\vec{F} \cdot \vec{d} = \Delta KE$$

Only the component of force in the direction of the displacement does work. This is written mathematically as a scalar product between the force and the displacement. In component form this equation can be expressed as

$$F_x x + F_y y + F_z z = \Delta KE$$

A more general expression of the work-energy theorem is rewritten in terms of the sum of forces acting on the object. These forces are then placed into two groups, the conservative and nonconservative forces acting on the object. A conservative force is one that changes the potential energy of the system and is path independent; for example, the gravitational force. A nonconservative force does not change the potential energy of the system and is path dependent; for example, friction. Based on this, the work-energy theorem may be written as

$$\vec{F}_c \cdot \vec{d} + \vec{F}_{nc} \cdot \vec{d} = \Delta KE$$

$$-\Delta U + \vec{F}_{nc} \cdot \vec{d} = \Delta KE$$

$$\vec{F}_{nc} \cdot \vec{d} = \Delta KE + \Delta U$$

This states that all the work done by non-conservative forces acting on the object is equal to the change in kinetic energy plus the change in potential energy.

Crucial Physics

- The net work done on an object is equal to the change in the object's kinetic energy.
- The net work done on an object moving in a straight line is equal to the net force applied in or opposite to the direction of the displacement, multiplied by the displacement.
- The force required to stop a moving object depends upon the available distance to stop the object. Stopping in a short distance requires a large force, while stopping over a longer distance requires a smaller force.

Learning Outcomes	Location in the Section	Evidence of Understanding
Model an automobile air bag.	***Investigate*** Steps 5, 8	Students model collisions, with and without air bags, using a raw egg colliding with a countertop and on a surface covered 2-cm deep with flour, sand, or rice. Students record their observations, noting that the egg does not break when it lands on the flour. Students also observe that an egg thrown at a sheet does not break. Through these models, students obtain evidence that during a collision if the force is applied over a greater distance (and area) it does not do as much damage.
Relate the energy of a moving object to the work required to stop the object.	***Physics Talk*** ***What Do You Think Now?*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1, 4, 6	Students describe the relationship between the change of energy of an object and the work needed to stop it, using their observations. Students describe and apply the work-energy theorem to solve problems.
Demonstrate an understanding about the relationship between the force of an impact and the stopping distance.	***What Do You Think Now?*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1, 3, 4, 6, 7 ***Inquiring Further*** Question 2	Students describe how less force is needed to stop an object if it is applied over greater distances using the work-energy theorem. Students should apply the work-energy theorem to solve problems.

CHAPTER 3

Section 3 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Petri dish, sterile, disposable	1 per group	
Ruler, metric, in/cm	1 per group	
Paper clips, pkg 100		1 per class
Plastic wrap, roll		1 per class
Flour, 5 lb		1 per class
Raw egg*	2 per group	
Large bed sheet*		1 per class
Access to a smooth level surface*	1 per group	

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Petri dish, sterile, disposable	1 per group	
Ruler, metric, in/cm	1 per group	
Paper clips, pkg 100		1 per class
Plastic wrap, roll		1 per class
Flour, 5 lb		1 per class
Raw egg*	2 per group	
Large bed sheet*		1 per class
Access to a smooth level surface*	1 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

Allow one period for the students to design and run the tests. If the investigation is run over two days, students can bring in their own materials to test.

Teacher Preparation

- The raw eggs used in this section should be placed in plastic wrap to prevent spillage.
- Fasten a paper clip around the plastic wrap to keep it taut around the egg so cracks will be easily visible.
- Have students drop the egg so that it falls in the same position each time (in other words—don't let it land on its "side" once and then on one of its "ends" next).
- Conduct the investigation before class to determine what difficulties your students may have and to get an idea of the smash height for the egg colliding into the hard surface, and the depth of indentation when it is dropped onto the softer material.
- Consider ways to make cleanup efficient and easy in your classroom. You may want to have a box lid with a place cut out for the hard surface and for the dish of soft material. This way, if anything spills, it will land in the lid.
- For the demonstration, it is best to get a twin-size flat or fitted sheet. The sheet will be folded in half and two students should hold the ends of the sheet. The goal is to catch the egg in the sheet. For a fitted sheet, the egg rolling downward after hitting the sheet could get caught by the fitted part of the sheet.
- Mark a location on the sheet to indicate where the thrower should aim. In case of an accident, place the egg in a sealed bag and consider having some paper on the floor under the location where the egg should hit. If possible, try this out before class. There are videos of this demonstration on the Internet. Try the keywords "egg throw, sheet."
- Consider obtaining a video on safety to show students. Local automotive dealers have safety videos about air bags and ABS brakes. Many dealers will lend, or may even give a copy to you. You may also ask the local American Automobile Association affiliate in your area to provide safety videos; some will even send instructors to give safety talks. Some local driving companies (taxi, trucking, courier services) may also have safety supervisors who would be able to come to the classroom to talk about safety.

- The *Active Physics Transportation* content video has excellent footage showing air bags inflating. The Insurance Institute for Highway Safety has produced a wonderful video on the physics of car crashes called *Understanding Car Crashes–It's Basic Physics!* It comes with a well-written teacher's guide and is available from their Web site, which you can find by doing an Internet search for The Insurance Institute for Highway Safety.

Safety Requirements

- Check to see if any students have egg allergies or flour allergies. If so, let students know that the eggs will be contained in plastic. If an egg allergy is severe, you may want to find an alternative activity for the student to do. If students have a flour allergy, fine dry sand can be used as a substitute.
- Students holding the sheet during the egg throw should wear goggles.
- If an egg is broken and leaks out of the plastic, clean the residue immediately and wash the area with soap and water.
- When the students are throwing the egg into the bed sheet, have all the students except those holding the sheet stand behind the thrower. Make certain the area behind the sheet is clear of all obstructions for several meters. If the investigation is done in a hall, make certain no one is in the hall on the side of the sheet opposite the thrower.
- If the egg bounces out of the sheet and falls on the floor, use the cleanup procedures described previously.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Measuring the indentation	***Investigate*** Step 6	**Augmentation** • As noted in *Step 6*, measuring the indentation left in the landing material is a challenging task for most students. This step provides an opportunity for differentiation. • Some students will be able to independently measure the indentation. • Some students will need the teacher to quickly model a method or two for measuring the indentation. • A few students may need a small group or one-on-one assistance to measure the indentation. **Accommodation** • Use hand-over-hand techniques (physical guidance) to assist students in measuring the indentation.
Conceptualizing an equation	***Physics Talk*** Kinetic Energy ***Physics to Go*** Question 3	**Augmentation** • The equation for kinetic energy is more complex than most of the equations students have learned so far and may require more instruction than previous equations. Students often understand how to square a number but are confused by what v^2 represents. Also, they do not know how to input $\frac{1}{2}$ into their calculators to perform the required computation. • Show students that $KE = 0.5 \cdot m \cdot v \cdot v$ is the same equation. This can lead into lessons about fractions and decimals, using the calculator for computation, and squaring a number. • The conceptual understanding of this equation is explained further in *Physics Talk, Speed and Kinetic Energy* with an example that includes values for comparison.
Understanding dimensional analysis	***Physics Talk*** Science Skills	**Augmentation** • Some students are not developmentally ready to understand this abstract concept. If students are just beginning to learn algebra and their number sense is weak, they will have a difficult time understanding what the letters for units represent. If a student struggles to understand what a unit represents, he or she will really struggle to derive units. • For these students, it may be better to have them memorize the units associated with different variables for the purpose of problem-solving and to do more work on dimensional analysis when their skills are more developed.
Solving problems	***Sample Problems*** ***Physics to Go*** Questions 4, 6, 8	**Augmentation** • Students need opportunities to practice problem-solving with new equations and receive timely feedback to make sure they learn correct procedures. • Give pairs of students the same problem to solve on a whiteboard or using a whole sheet of paper. Ask them to solve the problem individually and then compare their results with their partner to check their answers. • Remind students to draw problem-solving boxes as introduced in *Chapter 1* or to carefully show all of the steps used to solve the problem. • Provide many opportunities for students to practice identifying which variable the problems are asking students to solve for and which equation to use. **Accommodation** • Provide students with a blank sheet of problem-solving boxes. • Highlight the important information in a word problem to assist students. Withdraw this accommodation as students become more independent.

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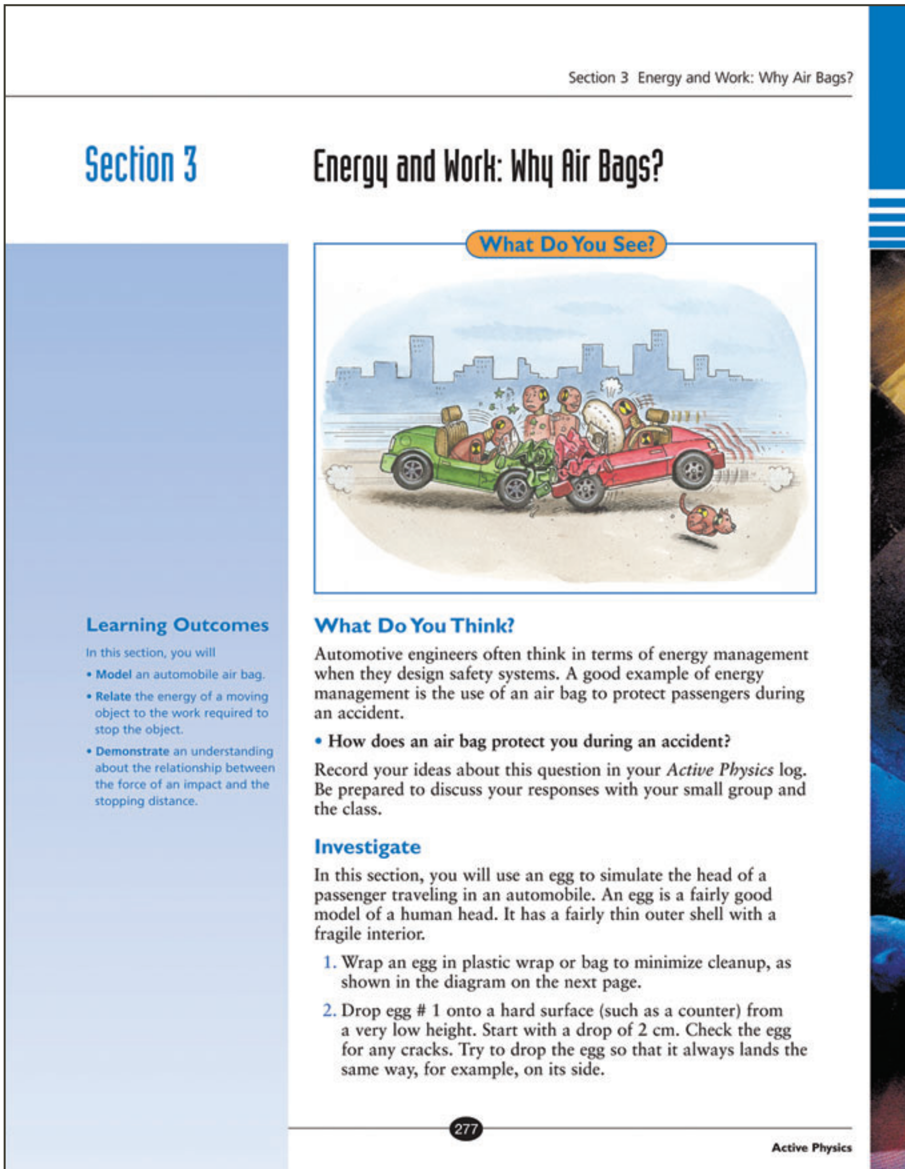
Sketching a graph	***Active Physics Plus*** Steps 1-3	**Augmentation** • These graphs may support students' understanding of the relationships between work, kinetic energy, speed, and mass. However, some students will struggle to sketch these graphs independently or to understand the derivation. • Ask for volunteers who were able to create accurate graphs to share their graphs with the class and explain what they have learned from the graphs. • Design teacher-made graphs and ask students to use the *Physics Talk* section and apply their understanding of the new equations to explain the concepts that the graphs represent.
Understanding essential concepts	***Physics Essential Questions*** ***Physics to Go*** Questions 1, 7	**Augmentation** • Students have been asked to read, solve problems, and interpret graphs related to work and change in kinetic energy. Now they are being asked to synthesize the essential concepts based on the work they have completed. • Allow students to Think-Pair-Share to answer the *Physics Essential Questions*, and then ask them to answer the *Physics to Go* questions independently. • Think-Pair-Share means that students think for a couple of minutes about a question. Then students talk to a partner about the question and formulate an answer. Lastly, the pairs share their answers with the whole class. This strategy allows students to discuss their understandings and rethink their misconceptions. **Accommodation** • Provide direct instruction to teach these essential concepts.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Understanding concepts Vocabulary comprehension	***What Do You Think?***	The concept of energy management is crucial to automotive engineers, and it will be crucial to your students when they design their prototype safety system. Hold a class discussion about what energy management means in the context of automobile accidents. Ask why engineers manage the energy instead of getting rid of some of the energy. Students may need some guidance to remember the law of conservation of energy. Help students understand that energy management here means designing automobiles to control or direct the flow of energy during a collision.
Vocabulary comprehension	***Investigate*** Step 7	Help students infer the meaning of "dissipated" in context. Guide them to think about what happens when a force is applied over a distance. They should be able to discern that the energy, like the force, is also spread out, or dissipated, over a distance. Some students may have encountered the term in the context of a crowd dissipating after a ball game, or fumes spreading out after a toxic spill.
Understanding concepts Vocabulary comprehension	***Dimensional Analysis***	"Dimensional analysis" is a big term for a simple concept: making sure that you are comparing apples to apples. To help students understand, share with them the following anecdote: The *Climate Observer*, a spacecraft sent to explore Mars, was lost during a 1999 mission. NASA and other teams of scientists had planned the mission together. It was determined that one team used standard units (feet, inches) to make its calculations and another team used metric units (centimeters, meters). As a result, the *Observer's* on-board computer received incorrect numerical data when establishing its course. It went slightly off course, but the error added up to 100 km by the time the probe reached Mars. The mission was ruined in part because of inconsistent use of units.
Understanding concepts Vocabulary comprehension	***Active Physics Plus***	In dimensional analysis, checking that each term has the same dimension may require deriving, or determining, equations and the fundamental quantities (mass, length, time) from other equations. The math can be quite involved, but the concept is basic. When you work through *Deriving the Equation for the Relationship Between Work and Change in Kinetic Energy*, be sure students are able to follow the derivation in the example. Pay close attention to their graphs, as they are another tool with which you can check student understanding.
Understanding concepts Vocabulary comprehension	***Inquiring Further*** Step 2	When students design their landing pad, they need to understand the constraints, or limits, under which they have to work. Hold a class discussion to elicit ideas students have about the constraints for building a landing pad. Point out to students that they will have to recognize the constraints when they design their prototype safety system as well.



Section 3 Energy and Work: Why Air Bags?

Section 3 Energy and Work: Why Air Bags?

What Do You See?

Learning Outcomes

In this section, you will

- **Model** an automobile air bag.
- **Relate** the energy of a moving object to the work required to stop the object.
- **Demonstrate** an understanding about the relationship between the force of an impact and the stopping distance.

What Do You Think?

Automotive engineers often think in terms of energy management when they design safety systems. A good example of energy management is the use of an air bag to protect passengers during an accident.

- **How does an air bag protect you during an accident?**

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

Investigate

In this section, you will use an egg to simulate the head of a passenger traveling in an automobile. An egg is a fairly good model of a human head. It has a fairly thin outer shell with a fragile interior.

1. Wrap an egg in plastic wrap or bag to minimize cleanup, as shown in the diagram on the next page.
2. Drop egg # 1 onto a hard surface (such as a counter) from a very low height. Start with a drop of 2 cm. Check the egg for any cracks. Try to drop the egg so that it always lands the same way, for example, on its side.

277

Active Physics

SECTION 3

Teaching Suggestions and Sample Answers

What Do You See?

Have students consider the illustration and the title of the section. Ask them what they think the illustration depicts and record their responses. When students discuss the air bag, ask them to compare the drivers in the illustration, and what difference the air bag may have made. This elicitation of students' initial ideas provides a focus for the science content. Encourage students to comment on how they perceive the image in context of the title of this section. Remind them that they will get a chance to return to this illustration later during this section.

CHAPTER 3

Students' Prior Conceptions

Students' understanding of the relationship between the force of the impact and the distance through which this force acts is crucial to the connections they make among the conservation of momentum, the energy involved in collisions due to mass and velocity, and the work involved in transferring energy to and from the system. This sets the stage for subsequent investigations within this chapter.

1. **Students believe that traveling at low velocities does not cause extensive or severe impact damage during collisions.** Students tend to overlook the kinetic energies involved in collisions. They recognize the transfer of energy from one object to another and realize that an object must absorb energy upon impact, but mathematical modeling forms the basis for them to alter their perception that driving at a slow speed does not cause damage during a collision. Analysis gives students the confidence to reorganize their ideas. As they calculate the energies involved in stopping a large mass moving at a slow velocity and then compare the work needed to bring a small mass moving with a large velocity to rest, they change their disregard of the physical impact of collisions with low speeds.

What Do You Think?

Discuss how automotive engineers use energy considerations in designing automobiles and their safety features. Then ask students to consider the *What Do You Think?* question. Record students' responses and encourage them to ask questions to clarify and support their ideas. Consider asking students what they think energy has to do with the air bag. Then emphasize to students that the physics they learn in this section will help them to answer this question and to solve the challenge.

Investigate

Ask students why models are used. During the discussion point out the importance of models in studying phenomena that are too big, small, fast, slow, or dangerous. Describe the model students will be using and how the egg represents a person's head. Discuss the procedure for the *Investigate* and the cleanup. Emphasize to the students that the eggs should be completely covered in plastic wrap, and that they should drop their eggs so that they land the same way every time.

Teaching Tip

Surfaces upon which it is easy to measure indentation are often ones that are quite messy. Flour seems to work well, but it scatters over a large area when the egg strikes. Place the flour or sand in a container such as a Petri dish or a tuna can. The sides of the container help to contain the flour or sand.

What Do You Think?

A Physicist's Response

An air bag can protect passengers in many ways in an accident, but it can also harm a child or small adult. When an automobile undergoes a collision, it has a large deceleration, however, the driver and passengers still move at about the speed of the vehicle until they collide with something. Colliding with a rigid object, such as a dashboard, can cause severe injury because it stops the passenger in a short distance and time, which requires great force. If a passenger can be slowed down over a greater distance and time, the force acting on the passenger to stop him or her is reduced. Reducing the force acting on a passenger reduces the severity of the passenger's injury during a collision.

As an automobile undergoes a collision, a sensor in the vehicle releases the air bags when it senses the vehicle decelerating above a certain amount. A chemical reaction transpires that releases nitrogen gas (commonly found in air) into the air bag. The gas fills the bag at about 200 mi/h (322 km/h). All of this happens in about 1/25 of a second. The back of the air bag has vents or holes through which the gas dissipates after the crash, so when a passenger collides with the air bag, he or she does not hit a rigid object but rather hits this bag that releases the nitrogen gas out of the vents in the back of the bag. This slows down the persons involved in a collision to a halt over a distance, and considerably absorbs their energy of motion, so the collision does not cause them to have such a rapid deceleration (or a great force acting on them).

Air bags can also cause injury. One problem that occurs with air bags is when the passenger is too close to the air bag as it deploys, for instance, two to three inches. A safe distance is about ten inches from the air bag.

Air bags can be fatal for children. Different types of air bags can cause different problems. It is best to read the manufacturers' warnings about the air bags in a vehicle and how they pertain to children. In general, children under the age of 13 years should ride buckled up in a properly installed, age-appropriate seat in the back seat of the vehicle.

1.

Students should make sure the eggs are covered in plastic wrap and sealed with a paper clip.

2.

Eggs should be dropped so that they always land the same way, for example, on their side.

Teaching Tip

If the students are having difficulty measuring the depression made by the egg, several methods may help. A few are listed below:

- If using flour in a tuna can, fill the can to the rim. The students can then place a ruler across the top of the rim, and measure down to the bottom of the depression.
- An alternative method would be to mark the edge of the egg that is even with the top of the surface with a marking pen. Removing the egg and placing it on a flat surface should allow the students to get a fairly accurate depression measurement.

NOTES

3.a)

Students should observe that as the distance increases, the likelihood of the shell cracking increases. A distance of 5 cm is usually more than sufficient to crack the egg.

4.a)

After the first crack appears, subsequent cracks will be created more easily and increasing the drop height by only a few additional centimeters should cause the contents of the egg to leak.

5.a)

Students should observe that the egg leaves an indentation in the surface.

6.

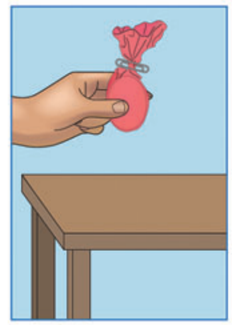
One method to measure the indentation is to draw a line using a felt-tipped pen around the surface of the egg that is just at the level of the sand. Removing the egg from the sand and placing it on a hard surface such as a table will then allow the students to measure the distance between the bottom of the egg and the position of the line. This is the depth of the indentation made in the sand.

7.a)

Students should observe that the damage to egg # 1 is much greater because the stopping distance (indentation) is much smaller for this egg. Egg # 2 stops over a greater distance, requiring a smaller force to bring it to rest, and therefore, less damage occurs.

Chapter 3 Safety

For best results, hold the egg with your thumb and index finger as shown in the diagram below.



3. Gradually increase the height of the drop in increments of 2 cm until you get a crack in the shell.

a) Record this as crack height in your log.

4. Continue dropping from greater heights until you get a full break in the shell and the yolk spills out.

a) Record this as smash height # 1.

5. Now create a softer surface for a second egg to fall on. Try a bed of flour, sand, or rice about 2 cm thick. Drop egg # 2 from smash height # 1. Try to drop the egg so that it lands in the same way as your first egg.

a) Record your observations.

6. Measure the depth of the indentation left in the landing material for the drop at smash height # 1. This can be challenging. Try measuring how much of the egg is still sticking out above the original level of the landing material. Then take the difference between the amount above the surface and the total height of the egg. This should be what remains below the surface, or the indentation depth.

a) Record your measurement.

7. Compare the damage of egg # 1 and egg # 2 when dropped from the smash height # 1. When dropped from the same height, egg # 1 and egg # 2 have the same speed just before hitting the landing material. The material must supply a force over a distance (that is, the indentation of the material) for the energy to be dissipated.

a) Compare the force (damage) and distance (indentation) of egg # 1 and egg # 2 when dropped from smash height # 1.

8. The next part of the *Investigate* is best done as a class demonstration. Take a large bed sheet to an area with a clear throwing area. Choose a volunteer that has a good throwing arm, such as a pitcher from the softball or baseball team. Have two other students be the "catchers." They should design a target for the egg-thrower by stretching the sheet out, holding the top two corners of the bed sheet over their heads and the lower two corners a little lower than their waists. The goal for the catchers is to catch the egg in the sheet by creating a cup or scoop at the bottom, which will prevent the egg from rolling off the sheet. Have the pitcher throw the egg as hard as she or he can at the center of the sheet. The pitcher should try to break the egg when it hits the sheet. Everyone else should observe the motion of the sheet when the egg hits it. Have the egg in a plastic bag. It will be a bit harder to throw, but much easier to clean up.

a) Explain why the sheet cannot exert a force large enough to break the egg.

278

Active Physics

8.a)

It is likely that no matter how hard the thrower throws the egg, it will not break because the sheet "gives" or cushions the stopping motion of the egg. In comparison with dropping the egg on a hard surface, this stopping distance is very large.

Have a class discussion on students' observations and record them to refer to later during the chapter.

Physics Talk

ENERGY AND WORK

In this section, you observed the damage to an egg from collisions. This is similar to the damage to a person's skull during collisions.

When egg # 1 was dropped from smash height # 1, the shell broke. In contrast, egg # 2 dropped from the same height probably did not experience the same damage because the new surface was softer. How can you describe "softer" in terms of physics concepts?

Kinetic Energy

An automobile traveling down a highway at 100 km/h (about 60 mph) represents a considerable amount of energy. This kind of energy is called **kinetic energy**. Kinetic energy is the energy an object has because of its motion. The adjective "kinetic" comes from the Greek word for motion, "*kinesis*."

Physics Words

kinetic energy: the energy possessed by a moving body is called kinetic energy. $KE = \frac{1}{2}mv^2$

Kinetic energy depends on the mass and the velocity of the object. The following equation shows this relationship.

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

where KE stands for kinetic energy,
m represents the mass of the vehicle and its occupants, and
v represent the velocity of the vehicle.

In your investigation, the falling eggs had kinetic energy and approximately the same mass. Both eggs also had the same velocity at the moment before hitting the surface because they were both dropped from the same height (smash height # 1). Both eggs, therefore, had the same kinetic energy (KE).

Physics Talk

Students are introduced to kinetic energy, work, and the work-energy theorem. These concepts are needed to understand collisions and to design safety features. Relate these concepts to the *Investigate* and students' observations. Consider asking students how they would describe their observations in physics terms. Record students' ideas and revisit them during and after the presentation of physics concepts.

Teaching Tip

When having the student throw the egg at the bed sheet, adhere to the following precautions:

- A fitted sheet may prevent excess mess. When a student throws the egg, the egg will hit the sheet, and then slide down the sheet, getting caught by the edge of the fitted sheet.
- Mark a location on the sheet where the thrower should aim. In case of an accident, place the egg in a sealed bag and consider having some paper on the floor, under the location where the egg should hit.
- Have students hold the sheet tilted at a slight angle away from the thrower to make it easier to catch the egg at the bottom of the sheet.
- Show students holding the sheet how to hold it. It should be held with one hand at the top and one hand at the bottom, with one student on each side. All the students who are observing the demonstration should be behind the thrower.
- Warn the students who are holding the sheet to hold it firmly! A loosely held sheet will be pulled out of their hands by the egg's impact.
- Most importantly, the student who throws the egg should be no more than 3 ft away from the sheet. Do not be swayed by a student who claims to be a star pitcher on the baseball team, and can easily hit the sheet from 30 ft away. They have been known to miss with disastrous consequences.

CHAPTER 3

Initiate a discussion on kinetic energy. Remind students that this is the energy an object has because of its motion. Discuss the relationship between kinetic energy, mass, and speed. Ask students to describe how the kinetic energy of the egg changed when it collided with the hard and soft surfaces. Emphasize that the kinetic energies of the eggs were the same, but the kinetic energy changed much more quickly during the collision with the hard surface than the soft surface.

Remind students that work is done whenever a net force acts on an object to displace it. Emphasize that work is done only if the net force acting on the object is in the same or opposite direction to the motion of the object. Ask students if a net force was acting on the egg before it crashed or/and when it crashed and have them explain their answer. They should realize that while the egg's motion was changing, a net force acted on it. Describe how the net force exerted on the egg during the collision did work on the egg to change its motion and bring it to rest. Let students know that the total work done on an object is equal to the change in its kinetic energy.

Discuss how important it is to stop an occupant's motion in a vehicle that is in an accident, how to do it safely using the work-energy theorem from the examples provided in the student text, and how this relates to their observations with the egg.

Highlight the information presented in the student text concerning the relationship between speed and kinetic energy, and how this affects the stopping distance. Emphasize that for a given force, the stopping distance will be directly proportional to the speed squared. Students will construct graphs of the relationships between work and kinetic energy, work and speed, and work and mass later in this section.

Remind students of SI units and the importance of dimensional analysis. If needed, discuss how dimensional analysis is a way of making sure the equation is correct by checking that each term of the equation has the same dimensions. Review the examples provided, emphasizing that these examples should assist them in designing a safety device for the challenge.

Discuss the units and dimensional analysis of force, work, and energy. Consider pointing out that these units are all based on just a few fundamental units (length, time, and mass). New units, such as "newtons" and "joules" were given because force and energy are important and often-used concepts, and to honor the scientists they are named after (Sir Isaac Newton and James Prescott Joule).

NOTES

NOTES

CHAPTER 3

Chapter 3 Safety

To stop the egg, a surface had to apply a force over some distance. This distance can be seen as the indentation of the surface. For a hard surface, you cannot see the indentation. For the soft surface, you were able to measure the indentation.

Work and Change in Kinetic Energy

In order to stop an automobile safely, the braking system must decrease the speed of the vehicle and effectively eliminate the kinetic energy by applying a great deal of force over a large distance. When force is applied over a distance, *work* is being done. **Work** is calculated using the following equation:

$$\text{Work} = \text{force} \times \text{distance}$$

$$W = F \cdot d$$

Physics Words

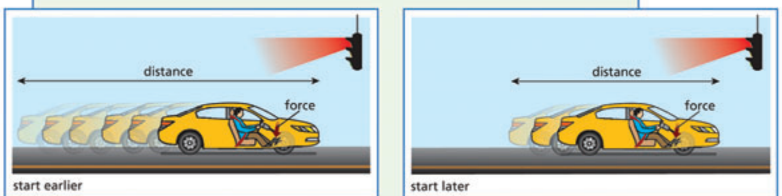
work: the amount of force applied on an object over a certain distance; $W = F \cdot d$

Work is equal to the change in kinetic energy. Work can either increase the kinetic energy or decrease the kinetic energy depending on the direction of the applied force and the distance (displacement) that the object moves.

You can write this as a new equation using the symbol Δ to represent "change in."

$$W = \Delta KE$$

Getting rid of the kinetic energy that an automobile and its occupants have before a collision can be done in different ways. It can be done either safely, or dangerously (causing injury to the passengers). This is what automotive safety engineers call energy management. They need to create a system that transfers the energy of the automobile safely. The work that is needed to stop the automobile traveling at a given speed is a fixed quantity, so it could be done with a small force and a large distance, or a large force and a small distance.



Work = force • **distance** (safely)   Work = **force** • distance (dangerously)

If the change in kinetic energy (*KE*) equals 5000 J (joules), different forces and distances can all provide this change.

Kinetic energy	Force	Distance	Work = *F* • *d*
5000 J	50,000 N	0.10 m	5000 J
5000 J	10,000 N	0.50 m	5000 J
5000 J	5000 N	1.00 m	5000 J

You should see that the smaller the stopping distance, the larger the force. You noticed this in the *Investigate* in which egg # 1 hitting the hard surface had more damage than egg # 2 hitting the soft surface which has a larger indentation or distance. This is what happens in a collision, where the automobile and its passengers come to a stop in a very small distance. If a passenger strikes the interior of the automobile, such as an unpadded steering wheel or windshield, the stopping distance will be very small. That would require an extremely large force. Such a force would certainly cause serious injury. That is why air bags are used. An air bag increases the distance over which the stopping force is applied. The force is reduced considerably.

Chapter 3 Safety

Speed and Kinetic Energy

You noticed that the work, *W*, equals the change in kinetic energy, *KE*. The fact that $W = \Delta KE$, also helps to explain why slowing down is always a good safety move.

To stop an automobile moving at 9 m/s (20 mi/h) requires the force of the brakes to be applied over a fairly large distance. An automobile traveling at 9 m/s requires about 6 m to stop safely. Imagine that an automobile going three times as fast would require three times the distance to stop, but this is not the case. If you carefully examine the formula for kinetic energy ($KE = \frac{1}{2}mv^2$), you will notice that the energy is proportional to the square of the velocity. That is, if you triple the speed, the *KE* is not three times greater, but it is nine times greater (3^2 or 3×3). It would take an automobile traveling at 27 m/s nine times the distance to stop than at 9 m/s, assuming that the brakes apply the same force. That means that it would require 54 m (9×6 m) to stop safely. The fact that kinetic energy is proportional to the square of the velocity also explains why high speed greatly increases the damage done during a collision. The automobile at three times the speed has nine times as much kinetic energy requiring nine times the distance to stop safely.

If you assume that the mass of a car is 1000 kg, you can see the effect of speed on kinetic energy and stopping distance for a given braking force. In the table below, you should notice the following:

- The speed has tripled from 9 m/s in the first row to 27 m/s in the second row.
- The kinetic energy has increased nine times as the speed tripled.
- The work required to stop the car is equal to the kinetic energy at all speeds.
- The braking force of the car is constant irrespective of the speed.
- The stopping distance increased by a factor of nine when the speed tripled.

Speed (meters per second)	$KE = \frac{1}{2}mv^2$ (joules)	Work to stop car $W = \Delta KE$ (joules)	Braking force (newtons)	Stopping distance (meters)
9	40,500	40,500	6740	6
27	364,500	364,500	6740	54

Section 3 Energy and Work: Why Air Bags?

On dry roads, you can safely stop a car traveling at 9 m/s in 6 m. Drivers are used to this speed-to-distance relationship after many years of driving. When the road is wet or icy, there is less force between the tires and the road. With less force you need a larger distance to stop, since the work is still the same for a given amount of kinetic energy. Alternatively, you can decrease the speed of your car so that the kinetic energy decreases and the required work and stopping distance will be smaller. The key to safety when road conditions change is to slow down. Slowing down will permit a safer stop and will also significantly decrease the kinetic energy (and damage) if there is an accident.

For example, imagine a 70.0-kg passenger traveling at a speed of 13 m/s. That person's kinetic energy is

$$KE = \frac{1}{2}mv^2$$
$$= \frac{(70.0\text{ kg}) \times (13\text{ m/s})^2}{2}$$
$$= 5915\text{ J or } 5900\text{ J (rounded off to two significant figures)}$$

Dimensional Analysis

Notice how the numbers and units were handled in the solution. The numbers were multiplied together to get the numerical answer:

$$\frac{1}{2} \times 70 \times 13^2 = \frac{70 \times 13 \times 13}{2}$$
$$= 5915$$

CHAPTER 3

Chapter 3 Safety

The units were also multiplied together in the same way:

$$kg \times \left(\frac{m}{s}\right)^2 = kg \times \left(\frac{m}{s}\right) \times \left(\frac{m}{s}\right)$$

$$= kg \cdot \frac{m^2}{s^2}$$

This derived SI unit is given a special name. The unit for energy is called a joule (J).

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

Paying attention to units is an important problem-solving skill and tool. It is called dimensional analysis.

To stop the person, something has to do the 5900 J of work to get rid of that energy. In an accident, it could be the windshield. What would happen if the person strikes the windshield? Since the windshield is fairly rigid, it might only give 3.0 cm (0.030 m) in stopping the person. So the work done by the windshield is

$$\text{Work} = \text{force} \times \text{distance}$$

$$5900\ J = \text{force} \times 0.3\ m$$

$$\text{Force} = \frac{5900\ J}{0.030\ m}$$

$$= 196{,}667\ N \text{ or } 197{,}000\ N \text{ when rounded off}$$

That is a lot of force exerted on the skull. What happens if the passenger strikes a fully inflated air bag instead of the windshield? Suppose that the air bag creates a stopping distance of 30.0 cm (10x greater stopping distance). The amount of work to be done is still the same, 5900 J. But this time, it is applied over a greater distance than the 3 cm of the windshield.

$$\text{Work} = \text{force} \times \text{distance}$$

$$5900\ J = \text{force} \times 0.3\ m$$

$$\text{Force} = \frac{5900\ J}{0.3\ m}$$

$$= 19{,}667\ N \text{ or } 19{,}700\ N$$

284
Active Physics

Section 3 Energy and Work: Why Air Bags?

This is still a lot of force, but it is much less than before (10x smaller force). Air bags are not the only system in the automobile that is designed to absorb energy. Seat belts and crumple zones in the frame of the automobile also help a lot. You will learn more about crumple zones in a later section.

The work done by the air bag decreases the kinetic energy of the person. However, energy in the entire system must remain the same. In this case, the kinetic energy of the person decreases while the energy of the air bag increases. An air bag with increased energy may become a bit hotter as all the molecules in the air bag gain some kinetic energy. Some of the energy during the collision may have produced some sound energy as well.

SI Units of Force, Work, and Energy

Notice that dimensional analysis was used, once again, in calculating the force and the work.

Newton's second law states that force is equal to mass multiplied by acceleration.

$$F = ma$$

The units of mass (kg) multiplied by the units of acceleration (m/s²) provide the units for force ($\frac{\text{kg} \cdot \text{m}}{\text{s}^2}$ or $\text{kg} \cdot \text{m/s}^2$).

Since force is such an important concept in physics, this unit is given a special name, the newton (N).

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

Work is equal to force multiplied by distance. $W = F \cdot d$

Referring only to the units

$$\begin{aligned} W &= \text{N} \cdot \text{m} \\ &= \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \cdot \text{m} \\ &= \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} \text{ or } \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \\ &= \text{J} \end{aligned}$$

285

Active Physics

Chapter 3 Safety

Work and kinetic energy are equivalent, and therefore both are expressed in joules.

Also, notice the unit in the following calculation:

$$\begin{aligned} F &= \frac{W}{d} \\ &= \frac{J}{m} \\ &= \frac{kg \cdot m^2 \cdot s^{-2}}{m} \\ &= \frac{kg \cdot m}{s^2} \text{ or } kg \cdot m/s^2 \\ &= N \end{aligned}$$

Sample Problem

A total of 12,000 J of work is required to stop a 45-kg cart.

a) What speed would the cart be traveling before it was brought to a stop?

Strategy: This problem involves work required to stop a moving object. Work and kinetic energy are equivalent. That is, 12,000 J of work are necessary to change 12,000 J of *KE* of the cart to 0 J. You are given the mass of the cart. You can use the equation that relates kinetic energy and mass to calculate the speed of the cart.

Given:

$KE = 12{,}000 \text{ J}$

$m = 45 \text{ kg}$

Solution:

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

$$v^2 = \frac{2KE}{m}$$

$$v^2 = \frac{2(12{,}000)\text{J}}{45 \text{ kg}}$$

$$v^2 = 533.3 \frac{\text{J}}{\text{kg}}$$

$$v = \sqrt{533.3 \frac{\cancel{kg} \cdot m^2 \cdot s^{-2}}{\cancel{kg}}}$$

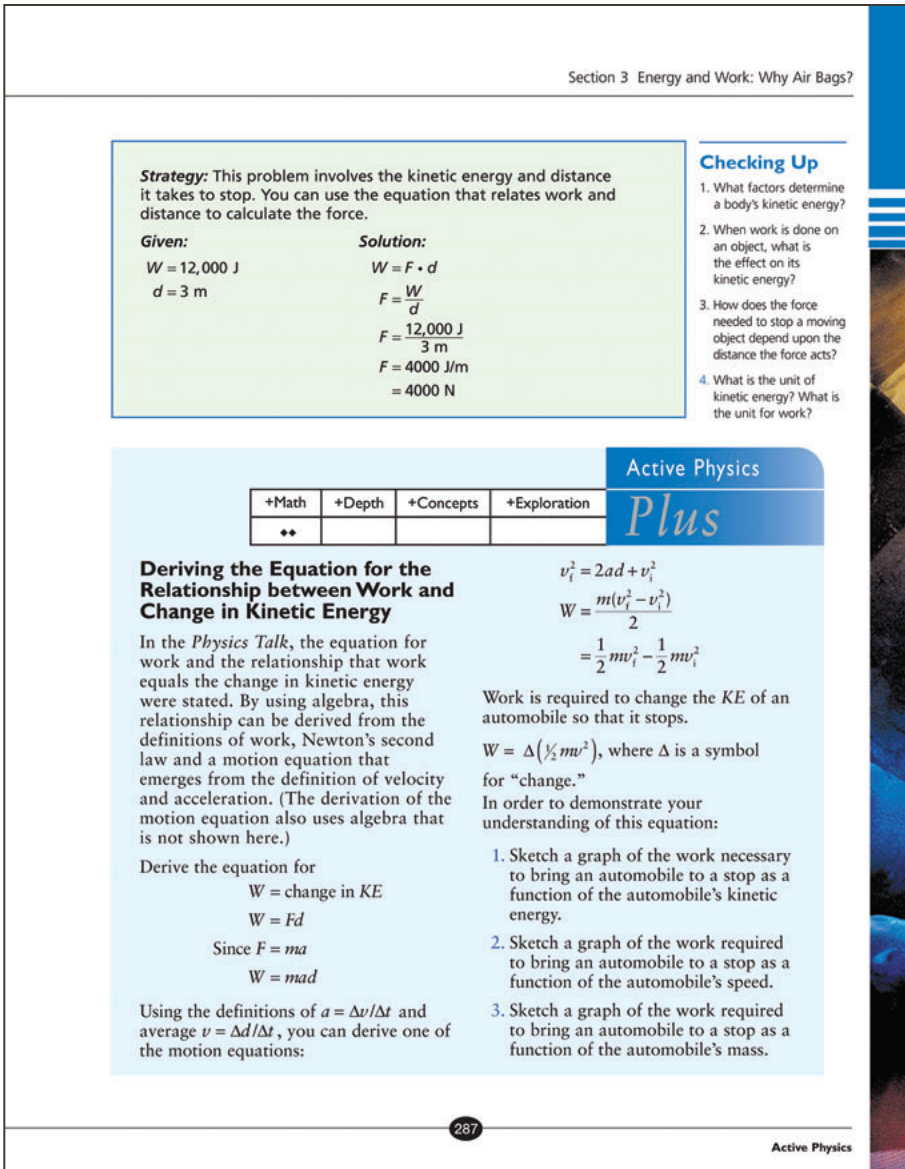
$$= 23 \text{ m/s}$$

The speed of the cart was 23 m/s.

b) If the cart stopped in a distance of 3 m, what force was needed to stop the cart?

286

Active Physics


Section 3 Energy and Work: Why Air Bags?

Strategy: This problem involves the kinetic energy and distance it takes to stop. You can use the equation that relates work and distance to calculate the force.

Given:

$W = 12{,}000\ \text{J}$

$d = 3\ \text{m}$

Solution:

$$W = F \cdot d$$
$$F = \frac{W}{d}$$
$$F = \frac{12{,}000\ \text{J}}{3\ \text{m}}$$
$$F = 4000\ \text{J/m}$$
$$= 4000\ \text{N}$$

Checking Up

1. What factors determine a body's kinetic energy?
2. When work is done on an object, what is the effect on its kinetic energy?
3. How does the force needed to stop a moving object depend upon the distance the force acts?
4. What is the unit of kinetic energy? What is the unit for work?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆◆			

Deriving the Equation for the Relationship between Work and Change in Kinetic Energy

In the *Physics Talk*, the equation for work and the relationship that work equals the change in kinetic energy were stated. By using algebra, this relationship can be derived from the definitions of work, Newton's second law and a motion equation that emerges from the definition of velocity and acceleration. (The derivation of the motion equation also uses algebra that is not shown here.)

Derive the equation for

$$W = \text{change in } KE$$
$$W = Fd$$
$$\text{Since } F = ma$$
$$W = mad$$

Using the definitions of $a = \Delta v / \Delta t$ and average $v = \Delta d / \Delta t$, you can derive one of the motion equations:

$$v_f^2 = 2ad + v_i^2$$
$$W = \frac{m(v_f^2 - v_i^2)}{2}$$
$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Work is required to change the KE of an automobile so that it stops.

$W = \Delta\left(\frac{1}{2}mv^2\right)$, where Δ is a symbol for "change."

In order to demonstrate your understanding of this equation:

1. Sketch a graph of the work necessary to bring an automobile to a stop as a function of the automobile's kinetic energy.
2. Sketch a graph of the work required to bring an automobile to a stop as a function of the automobile's speed.
3. Sketch a graph of the work required to bring an automobile to a stop as a function of the automobile's mass.

287

Active Physics

Checking Up

1.

The factors that determine a body's kinetic energy are mass and speed.

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

2.

An object's kinetic energy changes when work is done on an object. The total work done on the object is equal to the change in its kinetic energy. For constant mass this is written as

$$W_{\text{net}} = \Delta KE = \tfrac{1}{2}mv_{\text{final}}^2 - \tfrac{1}{2}mv_{\text{initial}}^2$$

3.

The force needed to bring a moving object to rest can be found using the work-energy theorem. This shows that as the distance the net force acts on the object increases, the amount of force needed decreases. This only applies to the net force in or opposite to the direction of motion.

$$W_{\text{net}} = F_{\text{net} \parallel \text{d}}\, d = \Delta KE = \tfrac{1}{2}mv_{\text{final}}^2 - \tfrac{1}{2}mv_{\text{initial}}^2$$

$$F_{\text{net} \parallel \text{d}} = \frac{\Delta KE}{d}$$

4.

Kinetic energy is measured in joules, as is work.

Active Physics Plus

This *Active Physics Plus* derives the equation for the relationship between work and energy based on the equation for force and the kinematic equations. This provides students with more mathematical depth. They are also asked to graph and analyze the net work done on an automobile as a function of its kinetic energy, mass, and initial speed to show their understanding of the factors in the work-energy theorem.

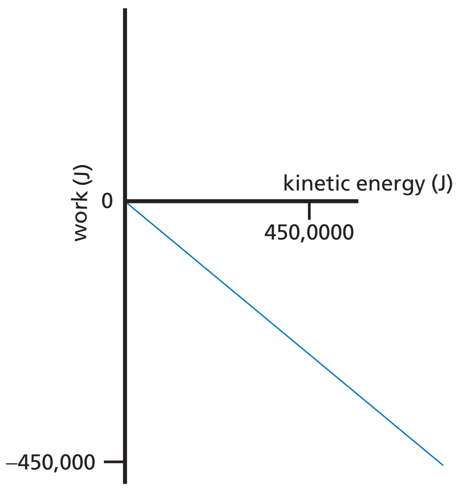
Discuss how the work-energy theorem can be derived from the definition of work, following the information in the student text. Have students demonstrate their understanding of the work-energy theorem by graphing relationships involving work.

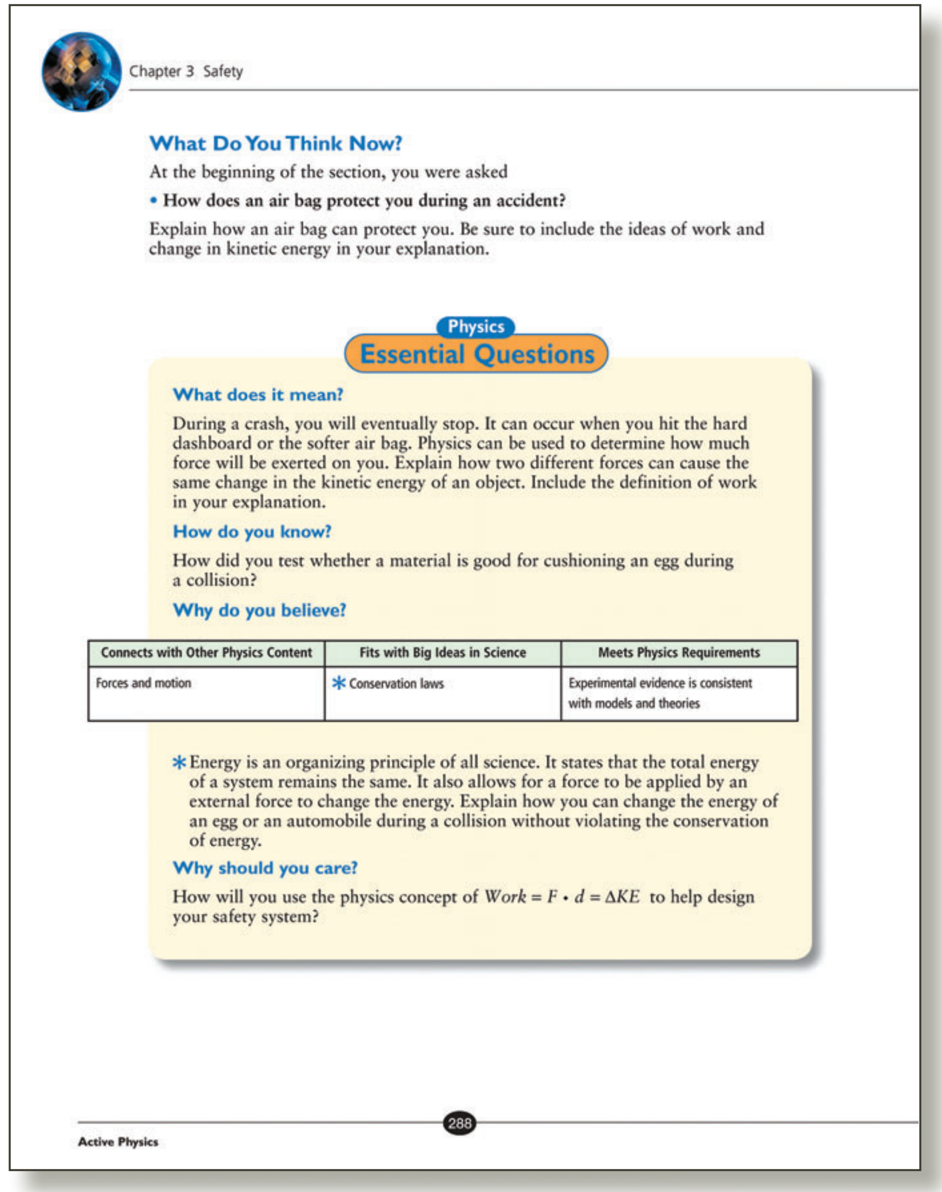
1.

Students' graphs should include axes labels and units, and should look similar to the following linear graph, indicating a linear relationship between work and change in kinetic energy to bring a vehicle to rest. The change in

CHAPTER 3

kinetic energy is negative because the vehicle comes to rest, and hence, the work done is negative. This is because the force doing the work opposes the direction of motion.





Chapter 3 Safety

What Do You Think Now?

At the beginning of the section, you were asked

- **How does an air bag protect you during an accident?**

Explain how an air bag can protect you. Be sure to include the ideas of work and change in kinetic energy in your explanation.

Physics

Essential Questions

What does it mean?

During a crash, you will eventually stop. It can occur when you hit the hard dashboard or the softer air bag. Physics can be used to determine how much force will be exerted on you. Explain how two different forces can cause the same change in the kinetic energy of an object. Include the definition of work in your explanation.

How do you know?

How did you test whether a material is good for cushioning an egg during a collision?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	* Conservation laws	Experimental evidence is consistent with models and theories

* Energy is an organizing principle of all science. It states that the total energy of a system remains the same. It also allows for a force to be applied by an external force to change the energy. Explain how you can change the energy of an egg or an automobile during a collision without violating the conservation of energy.

Why should you care?

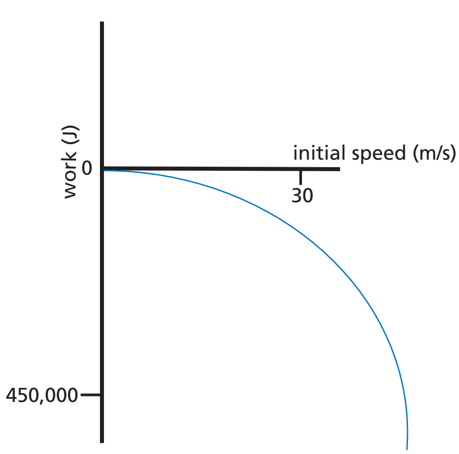
How will you use the physics concept of $Work = F \cdot d = \Delta KE$ to help design your safety system?

288

Active Physics

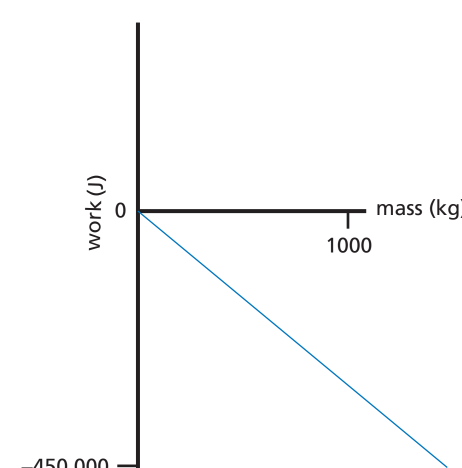
2.

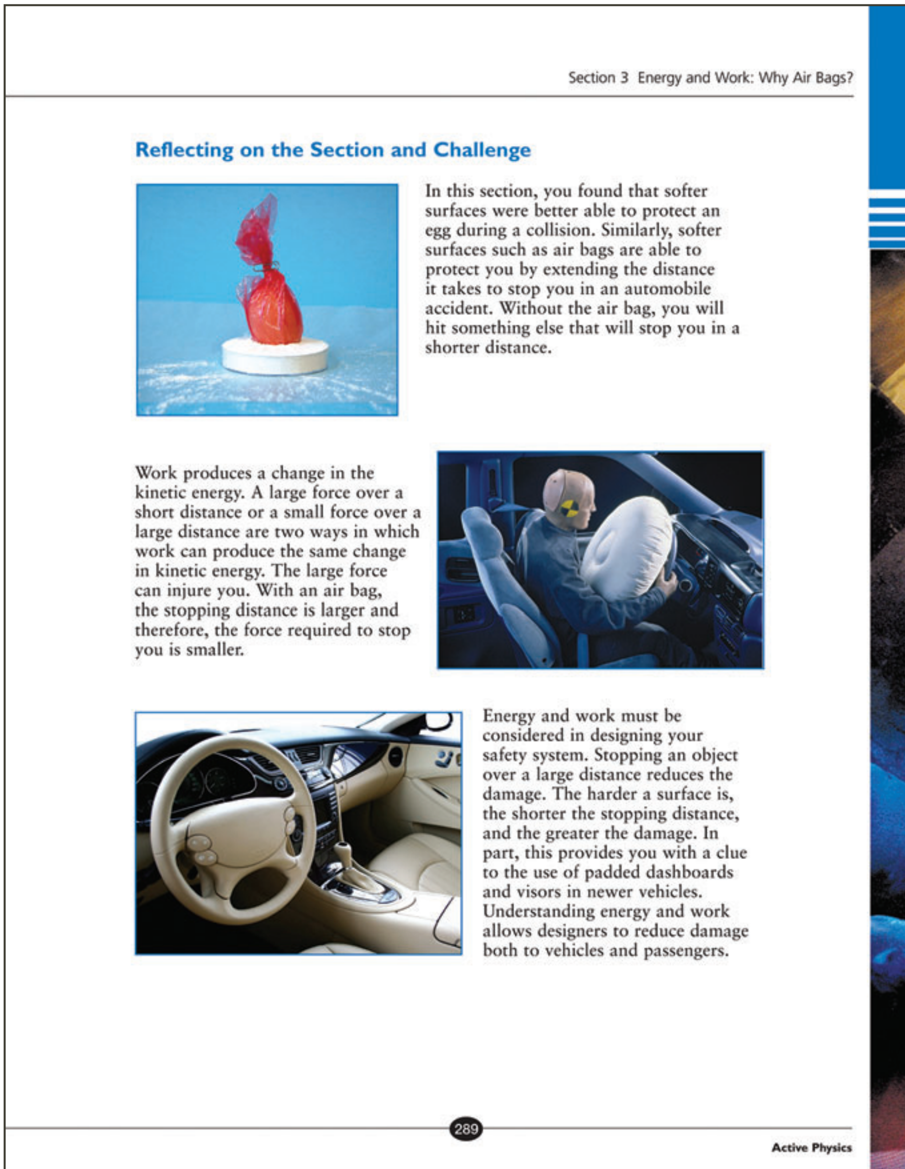
Students' graphs should look similar to the graph shown below, indicating that the amount of negative work (work done by a force opposing the direction of motion) increases as the square of the initial speed. The work done is negative because the force doing the work is opposite to the direction of motion.



3.

Students' graphs should look similar to the graph shown to the right.





Reflecting on the Section and Challenge

In this section, you found that softer surfaces were better able to protect an egg during a collision. Similarly, softer surfaces such as air bags are able to protect you by extending the distance it takes to stop you in an automobile accident. Without the air bag, you will hit something else that will stop you in a shorter distance.

Work produces a change in the kinetic energy. A large force over a short distance or a small force over a large distance are two ways in which work can produce the same change in kinetic energy. The large force can injure you. With an air bag, the stopping distance is larger and therefore, the force required to stop you is smaller.

Energy and work must be considered in designing your safety system. Stopping an object over a large distance reduces the damage. The harder a surface is, the shorter the stopping distance, and the greater the damage. In part, this provides you with a clue to the use of padded dashboards and visors in newer vehicles. Understanding energy and work allows designers to reduce damage both to vehicles and passengers.

What Do You Think Now?

Students should reflect on their earlier answers to the *What Do You Think?* question and revise them based on their current understanding of the work-energy theorem. You might want to provide students with *A Physicist's Response* to give them a better understanding of how air bags work and the physics behind how they can reduce the severity of injury during a collision.

Reflecting on the Section and the Challenge

Emphasize to students that the main physics concept in this section is the work-energy theorem, which can explain why a smaller force can be used to stop a moving object (or person) in a collision if it can be applied over a greater distance. Remind students that they should use this information when they are designing and building a prototype and preparing an explanation for the *Chapter Challenge*.

Physics Essential Questions

What does it mean?

The change in kinetic energy is due to a force applied over a distance (defined as work). A large force over a short distance can do the same work as a small force over a large distance.

How do you know?

The egg was dropped on different surfaces. The damage to the egg was less for certain "soft" materials.

Why do you believe?

An egg or an automobile can do work on an object by applying a force over a distance and changing the kinetic energy of the object. The object receives energy that was transferred to it from the egg or the automobile. The amount of energy the object receives is equal to the reduction in energy of the egg or automobile. The energy was transferred by the egg or automobile applying a force over a distance on the object. The total energy of the system (egg or automobile and the object) stays the same.

Physics to Go

1.a)

The padding of the mitt increases the stopping distance of the ball, as does the catcher's hand when it recoils backward as the ball strikes the glove. Because the stopping distance is increased, less force is required to bring the ball to rest.

1.b)

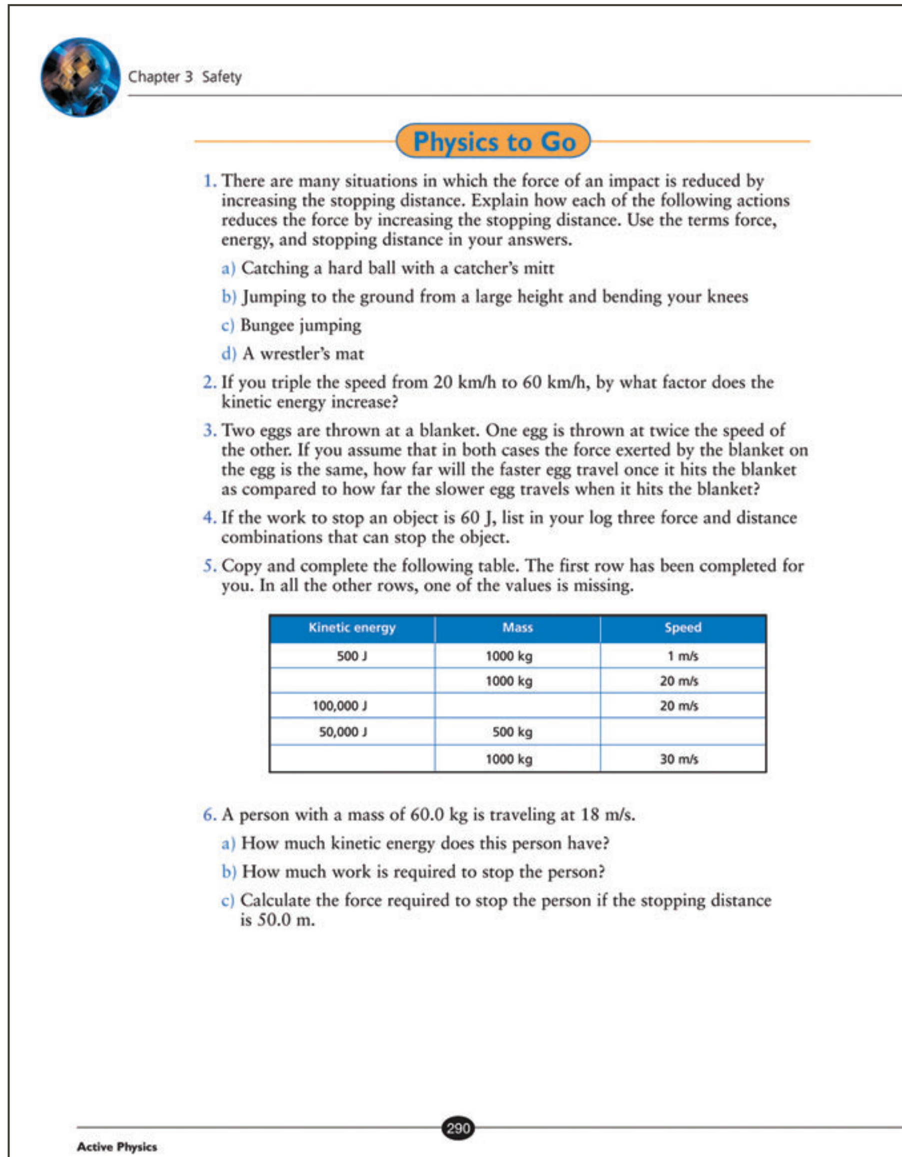
When a person jumps onto the ground from a large height, he or she bends his or her knees, which flex as the person's feet strike the ground. This increases the stopping distance and thus, less force is needed by the legs to stop the person.

1.c)

When a person bungee jumps, kinetic energy is gained as he or she falls. To stop the person, the bungee rope provides a small force over a very long distance as the rope stretches. This small force reduces the jumper's speed (and his or her kinetic energy) to zero, allowing the jumper to be safely stopped without injury.

1.d)

The mat used in professional wrestling is generally soft and has a certain amount of spring to it that allows the wrestlers to fall onto the mat without being hurt. The mat's padding and spring allow the wrestlers to be stopped over a longer distance, requiring less force to bring them to rest. The mat is also constructed to make a pronounced sound when a wrestler falls on it, adding to the drama.


Chapter 3 Safety

Physics to Go

1. There are many situations in which the force of an impact is reduced by increasing the stopping distance. Explain how each of the following actions reduces the force by increasing the stopping distance. Use the terms force, energy, and stopping distance in your answers.
   a) Catching a hard ball with a catcher's mitt
   b) Jumping to the ground from a large height and bending your knees
   c) Bungee jumping
   d) A wrestler's mat
2. If you triple the speed from 20 km/h to 60 km/h, by what factor does the kinetic energy increase?
3. Two eggs are thrown at a blanket. One egg is thrown at twice the speed of the other. If you assume that in both cases the force exerted by the blanket on the egg is the same, how far will the faster egg travel once it hits the blanket as compared to how far the slower egg travels when it hits the blanket?
4. If the work to stop an object is 60 J, list in your log three force and distance combinations that can stop the object.
5. Copy and complete the following table. The first row has been completed for you. In all the other rows, one of the values is missing.

Kinetic energy	Mass	Speed
500 J	1000 kg	1 m/s
	1000 kg	20 m/s
100,000 J		20 m/s
50,000 J	500 kg	
	1000 kg	30 m/s

6. A person with a mass of 60.0 kg is traveling at 18 m/s.
   a) How much kinetic energy does this person have?
   b) How much work is required to stop the person?
   c) Calculate the force required to stop the person if the stopping distance is 50.0 m.

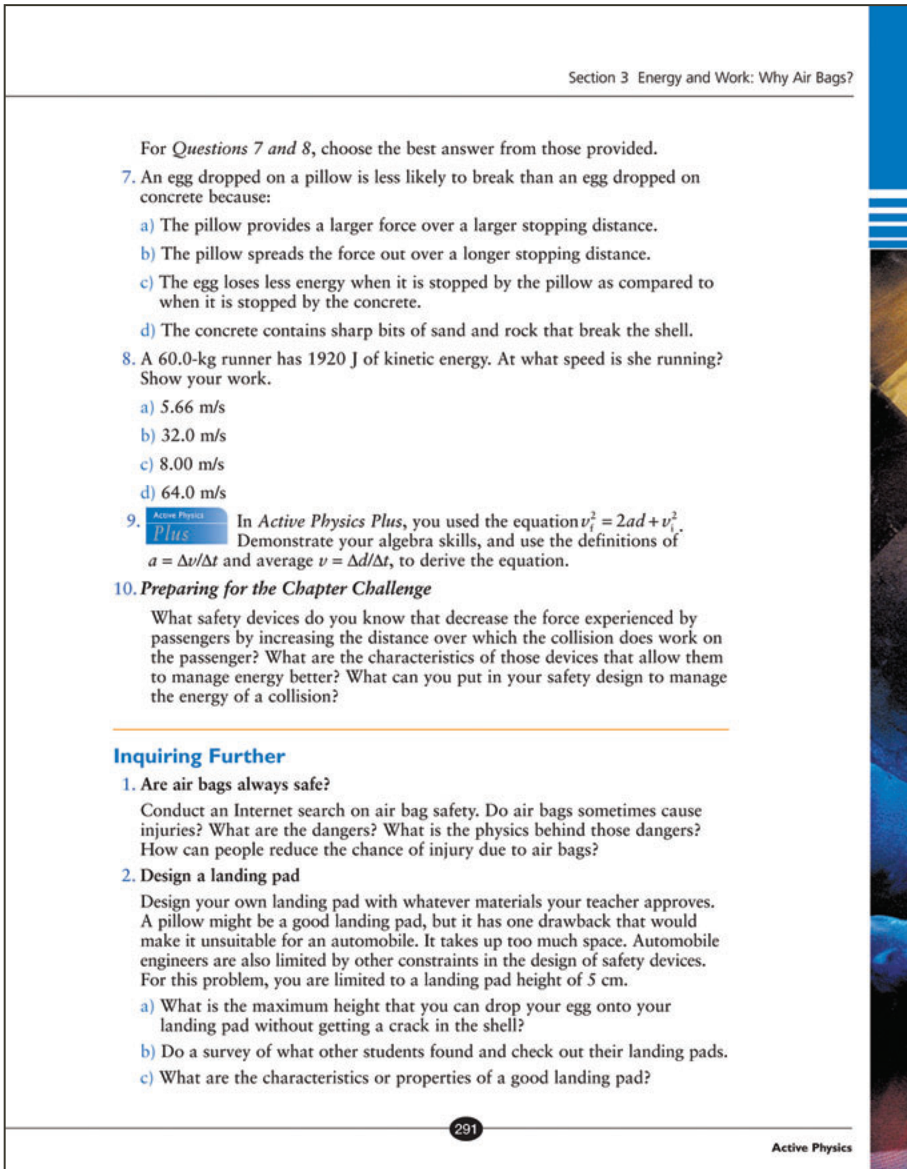
290

Active Physics

Physics Essential Questions

Why should you care?

The work-energy theorem is helpful in the design of a safety system because from it, you realize that the kinetic energy of the passenger must be reduced by applying a small force over a long distance. If the kinetic energy of the passenger is reduced over a short distance, the force on the passenger will be too great and will increase the chance of injury to the passenger.



For *Questions 7 and 8*, choose the best answer from those provided.

7. An egg dropped on a pillow is less likely to break than an egg dropped on concrete because:
   a) The pillow provides a larger force over a larger stopping distance.
   b) The pillow spreads the force out over a longer stopping distance.
   c) The egg loses less energy when it is stopped by the pillow as compared to when it is stopped by the concrete.
   d) The concrete contains sharp bits of sand and rock that break the shell.

8. A 60.0-kg runner has 1920 J of kinetic energy. At what speed is she running? Show your work.
   a) 5.66 m/s
   b) 32.0 m/s
   c) 8.00 m/s
   d) 64.0 m/s

9. Active Physics Plus In *Active Physics Plus*, you used the equation $v_f^2 = 2ad + v_i^2$. Demonstrate your algebra skills, and use the definitions of $a = \Delta v/\Delta t$ and average $v = \Delta d/\Delta t$, to derive the equation.

10. ***Preparing for the Chapter Challenge***

    What safety devices do you know that decrease the force experienced by passengers by increasing the distance over which the collision does work on the passenger? What are the characteristics of those devices that allow them to manage energy better? What can you put in your safety design to manage the energy of a collision?

Inquiring Further

1. **Are air bags always safe?**

   Conduct an Internet search on air bag safety. Do air bags sometimes cause injuries? What are the dangers? What is the physics behind those dangers? How can people reduce the chance of injury due to air bags?

2. **Design a landing pad**

   Design your own landing pad with whatever materials your teacher approves. A pillow might be a good landing pad, but it has one drawback that would make it unsuitable for an automobile. It takes up too much space. Automobile engineers are also limited by other constraints in the design of safety devices. For this problem, you are limited to a landing pad height of 5 cm.
   a) What is the maximum height that you can drop your egg onto your landing pad without getting a crack in the shell?
   b) Do a survey of what other students found and check out their landing pads.
   c) What are the characteristics or properties of a good landing pad?

2.

Kinetic energy is proportional to the square of the speed. If the speed increases by a factor of three, the kinetic energy increases by a factor of three squared, or nine times the energy.

3.

Students should use the work-energy theorem. When two eggs are thrown at a blanket, the egg thrown at twice the speed of the slower egg will have four times the kinetic energy. If the blanket applies the same amount of force to stop both eggs, the one thrown at twice the speed will need four times the distance to be stopped by the blanket. This is why speed is a determining factor in the seriousness of automobile accidents.

4.

Students' responses should include any force and distance combinations that when multiplied together equal 60 N · m. They should be aware that the force points opposite to the direction of motion. Some possible force and distance combinations to stop an object with a kinetic energy of 60 J are as follows:

Force	Distance
60 N	1 m
30 N	2 m
20 N	3 m
10 N	6 m

5.

Kinetic energy	Mass	Speed
500 J	1000 kg	1 m/s
200,000 J	1000 kg	20 m/s
100,000 J	500 kg	20 m/s
50,000 J	500 kg	14.1 m/s
450,000 J	1000 kg	30 m/s

6.a)

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

$\frac{1}{2}(60.0 \text{ kg})(18 \text{ m/s})^2 = 9720 \text{ J}.$

6.b)

Students should note that the work required to stop the person is equal to the change in kinetic energy, or –9720 J. The negative sign arises because the force doing the work must oppose the direction of motion.

6.c)

194 N. Students should use the relationship that the force times the distance is equal to the work done.

7.b)

The correct choice is *b)*. The pillow spreads out the force over a larger stopping distance.

CHAPTER 3

8.c)

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

$1920 \text{ J} = \frac{1}{2}(60 \text{ kg})v^2$

$v = \sqrt{\dfrac{2(1920 \text{ J})}{60 \text{ kg}}} = 8 \text{ m/s}$

9. Active Physics *Plus*

Students should note that for constant acceleration

$$a = \frac{\Delta v}{\Delta t} = \frac{\left(v_{\text{final}} - v_{\text{initial}}\right)}{t}$$

and that for constant acceleration the average velocity is given by

$$v_{\text{average}} = \frac{\Delta d}{\Delta t} = \frac{d}{t} \text{ and,}$$

$$v_{\text{average}} = \frac{\left(v_{\text{final}} + v_{\text{initial}}\right)}{2}.$$

Combining these two equations and solving for t you have

$$\frac{d}{t} = \frac{\left(v_{\text{final}} + v_{\text{initial}}\right)}{2}$$

$$t = \frac{2d}{\left(v_{\text{final}} + v_{\text{initial}}\right)}.$$

Substituting this value of t in the equation for the acceleration you have

$$at = \left(v_{\text{final}} - v_{\text{initial}}\right)$$

$$a\frac{2d}{\left(v_{\text{final}} + v_{\text{initial}}\right)} = \left(v_{\text{final}} - v_{\text{initial}}\right)$$

$$2ad = \left(v_{\text{final}} - v_{\text{initial}}\right)\left(v_{\text{final}} + v_{\text{initial}}\right) = v^2_{\text{final}} - v^2_{\text{initial}}.$$

Rearranging the terms, you have

$$2ad = v^2_{\text{final}} - v^2_{\text{initial}}$$

$$v^2_{\text{final}} = v^2_{\text{initial}} + 2ad.$$

10.

Preparing for the Chapter Challenge

Students should describe more than one safety device and how the devices increase the distance over which the collision does work on the passenger. Students should note that for each device, the increase in distance over which the collision does work reduces the amount of force needed to stop the vehicle, which reduces the amount of force needed to stop the passenger. In this case, the energy transferred to the passenger is reduced. The total energy is still conserved; however, some of that energy may go into deforming the vehicle, producing a sound, heating, or another form of energy. Some examples are provided below.

- The rear bumper might be mounted on a piston or a spring, which compresses when the bumper strikes an object. Even without a spring or piston, the bumper can dent before the rigid frame of the car strikes the object. This increases the distance of the collision, reducing the amount of force that acts, and decreases the amount of energy transferred to the passenger during the collision.
- The crush or crumple zones allow the vehicle to compress like an accordion. Previously, the sheet-metal parts of the vehicle were welded continuously along the seams, conveying the impact from object to occupants.

  After the front of the vehicle collides, the crumpling of the vehicle increases the distance over which the force of the collision acts, until the rest of the vehicle stops. This greatly reduces the force of the collision and decreases the amount of energy transferred to the passenger.
- The collapsible steering wheel crushes on impact. Rather than impaling the driver's body on the rigid shaft, the steering column telescopes inward, increasing the stopping distance. Increasing the stopping distance of the passenger decreases the force acting on the passenger.
- Soft padding on all surfaces increases the stopping distance and reduces force.

Inquiring Further

1. Are air bags always safe?

Students should research this question and their responses should contain the following information.

Air bags are not always safe, and can cause injury in certain situations. Air bags deploy at high speeds. If a driver or passenger is too close to the air bag, he or she could suffer injuries such as broken bones (rib cage) from air bag deployment. Small passengers, pregnant women, and small children (under the age of 12) can be severely injured or killed by air bags. For a child with little mass and a much shorter stature, air bags can be fatal. If an infant in a rear-facing child seat were to be placed in the front seat, his or her head would receive the greatest impact from the air bag.

Because the air bag must fill in a fraction of a second, the gas filling the air bag does so at extremely high speeds (around 200 mi/h) and pressure. The motion of this gas is toward the person and the person is moving toward the air bag. If the two collide while the air bag is filling, the force of impact is great over a short distance and time. In this case, the force acting on the moving passenger is enough to break bones. Once the air bag is filled, the gas inside quickly comes to equilibrium and starts to slowly evacuate the vents in the back of the air bag. As a person collides with a gas-filled air bag, the gas is pushed out of these vents slowly. The person's speed is decreased to zero over a distance, reducing the force exerted on the person to stop him or her.

To avoid the dangers associated with air bags, children less than 12 years of age should sit in the back seat of the vehicle. Passengers and drivers should have the air bag at least 10 in. from their breastbone, pointed toward their breastbone.

2. Design a landing pad.

Let students know what materials they are allowed to use or have them get your approval of the materials they wish to use. Emphasize that the landing pad can be no more than 5 cm high.

2.a)

Students should list the maximum height from which they dropped their egg without its shell cracking.

2.b)

Students should record what other students' maximum heights were and describe their landing pads. Consider asking students what physics concepts are shown, for example, landing pads that allowed for greater heights before cracking the egg must have dissipated the force over a larger area and/or allowed for the force to act over a greater distance.

2.c)

Students should note that a good landing pad is one that acts over a greater distance, requiring less force to stop the object, and dissipates the force over a greater area.

NOTES

SECTION 3 QUIZ

3-3a Blackline Master

1. In a demonstration, a student throws a raw egg at a bed sheet held by two other students, and the egg does not break. The best reason to explain why the egg does not break is that

   a) The sheet is made of soft cotton.

   b) The student threw the egg at an angle so it struck the sheet at a glancing blow.

   c) The sheet stops the egg over a large distance, leading to a small force.

   d) The egg landed on its end, which is harder to break.

2. A 50-kg girl is running along a track at 4 m/s. What is the girl's kinetic energy?

   a) 200 J b) 400 J

   c) 800 J d) 650 J

3. A 1.0-kg cart traveling at a constant 2.0 m/s across a level lab table 0.80 m above the floor is stopped in a distance of 0.20 m. The amount of work required to stop the cart is

   a) 1 J. b) 2 J.

   c) 2.5 J. d) 4 J.

4. In *Question 3*, if the cart stopped in half the distance, the force required to stop the cart would be

   a) half as great.

   b) the same.

   c) twice as great.

   d) four times as great.

5. In *Question 3*, if the cart stopped in half the distance, the amount of work required to stop it would be

   a) half as great.

   b) the same.

   c) twice as great.

   d) four times as great.

SECTION 3 QUIZ ANSWERS

1. c) The sheet stops the egg over a large distance, leading to a small force.
2. b) 400 J
3. b) 2 J.
4. c) twice as great.
5. b) the same.

NOTES