SECTION 5

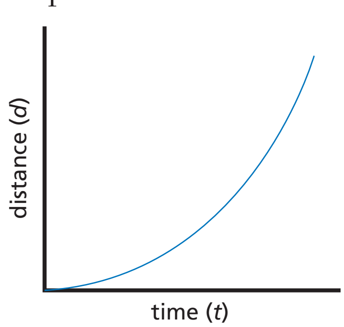
Negative Acceleration: Braking Your Automobile

Section Overview

This section addresses the distance traveled during negative acceleration as a function of the initial speed. Students continue the cart-stopping investigation by analyzing the problem of "slowing down" a cart. Students collect data by setting up an experiment in which a toy cart is rolled down a ramp. The initial speed of the cart versus its braking distance is plotted on a graph. The change in speed of the cart as it comes to a stop is explained by using the term negative acceleration. The effect of increasing the initial speed is recorded as data and then plotted on a speed versus time graph. Students study the similarities and differences in their data to find the relationship of initial speed to the braking distance. Braking distance is finally defined and determined to be proportional to the initial velocity squared.

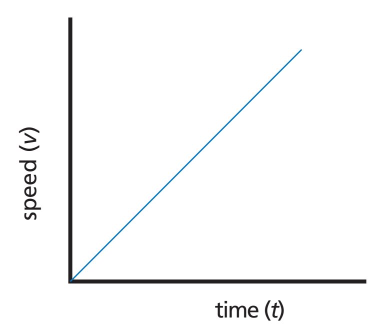
Background Information

The physics of stopping a cart involves reaction time while moving with constant or uniform motion, and braking time while braking with changing speed or nonuniform motion. If students plot the data for distance versus time, for nonuniform motion, they get a parabola.



Unfortunately, reading and making predictions from a parabola is very difficult. Students would require calculus to make sense of such a graph. Changing speed or acceleration is the change in the speed of an object in a given time period. Acceleration, $a = \Delta v / \Delta t$ (Δv represents the change in velocity that is measured by recording velocity at two different periods). The initial velocity is often indicated as v_1 and final velocity as v_2. In this section, the students will be solving for the distance required to stop, while traveling at different velocities.

Plotting speed vs. time, results in a straight line, with the slope of that line indicating acceleration.



$a = \Delta v / \Delta t$

The unit for v is m/s and for t is s.

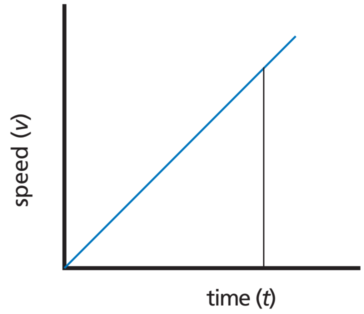
Therefore,

$$a = \frac{\Delta v}{\Delta t}$$

and with units,

$$a = \frac{\text{m/s}}{\text{s}} = \text{m/s}^2$$

However, when looking at braking distances, distance traveled is the primary concern. For example, knowing the distance a plane requires to land is important when building a runway. It is also important to know how far an automobile will travel while braking. Therefore, the distance that is required when an automobile is slowing down is considered. From a speed-time graph, finding the area under the graph will give the total distance covered.



The area under the graph above is expressed as Area $= \frac{1}{2} b \times h$. Using the units from the graph, $d = vt/2$. Going back to the original equation of acceleration, $a = v/t$, and rearranging to solve for t gives $t = v/a$. Combining $d = vt/2$, and gives $d = v^2/2a$, which is the distance an object travels proportional to the square of its speed. Therefore, when the speed the object is traveling is doubled, the distance traveled is quadrupled.

EXAMPLE

An object is traveling at 3 m/s with a negative acceleration of 2 m/s^2, what is the distance traveled?

Negative acceleration means that the car is slowing down. Therefore,

$$d = \frac{v^2}{2a}$$

or ,

$$d = \frac{(3 \text{ m/s})^2}{2(2 \text{ m/s}^2)} = 2.25 \text{ m}.$$

Now suppose the speed is doubled to 6 m/s,

$$d = \frac{(6 \text{ m/s})^2}{2(2 \text{ m/s}^2)} = 9 \text{ m}.$$

The kinematics of the relationship which relates braking distance and speed is $v^2 = 2ad$.

In this section, expect students to recognize that v^2 is proportional to distance. This can be best understood by looking at changes in the braking distance as it relates to changes in the initial velocity. If the velocity doubles, the braking distance quadruples. If the velocity triples, the braking distance is nine times as great. If the velocity quadruples, the braking distance is sixteen times longer. Similarly, if the velocity is halved, the braking distance is quartered.

This equation can be derived from the definition of velocity and acceleration.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t}$$
$$v_f = at + v_i$$

Since

$$v_f = 0 \text{ and } v_i = -at$$
$$v_i^2 = a^2t^2 = \left(\tfrac{1}{2}at^2\right)2a = 2ad.$$

In addition, this section pays particular attention to the concept of negative acceleration, both as an indication of decreasing speed, and also in the context of the vector nature of acceleration. Rather than use the term "deceleration," the term negative acceleration is used.

To clarify the physicist's use of the term negative acceleration, it is necessary to deal with the vector nature of acceleration. Acceleration may occur in any direction. If one direction, for example, east, is arbitrarily chosen to be positive, an increasing speed in the easterly direction would be a positive acceleration, while a decreasing speed in that direction would be considered negative. An increase in speed toward the west (the negative direction) would then be a negative acceleration. If the speed increases, it becomes more negative. If the speed decreases in the negative direction, it gradually becomes less negative and ultimately changes to a positive velocity, indicating a positive acceleration.

As an enrichment activity, the students can run the same investigation on different surfaces. They could then draw analogies to stopping on different road surfaces and how they would drive under those circumstances. An example might be running the cart on sandpaper, wet floor, dirt surface, etc.

Crucial Physics

- Braking distance is dependent on the negative acceleration of the car (brakes, road surface) and reaction time.
  - $d = v^2/2a$.
  - Tripling the speed requires nine times the braking distance.
- Positive acceleration and negative acceleration are not associated uniquely with speeding up or slowing down.
  - One determines if an object speeds up or slows down by considering both the direction of the initial velocity and the direction of the acceleration.

Learning Outcomes	Location in the Section	Evidence of Understanding
Plan and carry out an experiment to relate braking distance to initial speed.	***Investigate*** Steps 2, 3, and 4	Students plan and carry out an experiment to see how the initial speed of a cart affects its braking distance by varying the speed of a cart traveling down a ramp.
Determine braking distance.	***Investigate*** Step 5	Students use data to determine the braking distance of a cart.
Examine accelerated motion.	***Investigate*** Steps 5–8	Students study graphs to see how varying the initial speed changes the braking distance.

NOTES

Section 5 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Meter stick, wood	1 per group	
Ring stand, large	1 per group	
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as crossarm)	1 per group	
Holder, right angle (to act as crossarm)	1 per group	
Inclined plane ramp for lab cart	1 per group	
Dynamics cart	1 per group	
Scissors	1 per group	
Extension clamp	2 per group	
Velocimeter	1 per group	
Index cards, pkg 100		1 per class
Folder, file		10 per class
Paper, graph, pkg of 50		1 per class

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Meter stick, wood		1 per class
Ring stand, large		1 per class
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as crossarm)		1 per class
Holder, right angle (to act as crossarm)		1 per class
Inclined plane ramp for lab cart		1 per class
Dynamics cart		1 per class
Scissors		1 per class
Extension clamp		2 per class
Velocimeter		1 per class
Index cards, pkg 100		1 per class
Folder, file		10 per class
Paper, graph, pkg of 50		1 per class

*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

In order for students to run 10 good trials, after proper instruction, they would need at least 45 min. (If there is only one set of equipment for the entire class, then adjust the appropriate amount of time accordingly.) Allow for one more class period to plot the data and analyze the graph.

Teacher Preparation

- Determine the speed-measuring equipment to be used. If a velocimeter or a motion detector is not available, you may use a camcorder, monitor, and a VCR with stop, forward, and advance to show a clear picture of each frozen frame. Practice using the camcorder if you are not familiar with it. Be ready to advise students on how to use the freeze frame advance capability of the tape player or camcorder. Secure a suitable scale behind the path of the cart so that its position is easily observed on the screen.
- If no method is available to measure the speed at the bottom of the ramp, measure the time of descent from rest to the bottom of the ramp. Calculate the average speed on the ramp and double it to get the speed at the bottom. While this method avoids much apparatus, it requires them to trust and understand the mathematics. They are more likely to trust the technology that gives a direct measurement. Be sure that the transition from the ramp to the floor is smooth. A file folder taped to the inclined plane and the surface will suffice.
- If the *Investigate* is to be performed on the floor, inform students the day prior so they may wear appropriate clothing.

Safety Requirements

- If the *Investigate* is done on the floor, students should be aware of the equipment so they do not walk into it. The carts rolling along the floor may present a tripping hazard, and should be collected and returned to the inclined plane as soon as the braking distance has been measured.
- If the *Investigate* is done in a hallway, notify other local teachers that it will be occurring. All the equipment must be picked up and safely stored prior to a change of class.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

<table>
<tr><th>Learning Issue</th><th>Reference</th><th>Augmentation and Accommodations</th></tr>
<tr><td>Planning an experiment to collect data</td><td>Investigate
Step 2</td><td>Augmentation
• If students are unable to come up with a plan, consider allowing students to ask yes/no questions for feedback.
• Students with reading and processing issues may struggle to organize the information to answer the list of eight planning questions. Provide a worksheet with the experiment's planning questions to give students a place to record their answers.
Accommodation
• Model an experiment setup that could work. Then, as a group, go through the list of planning questions. Students will still have ownership for planning the experiment, but modeling the setup gives students a visual to guide their thinking.</td></tr>
<tr><td>Recording data in a table</td><td>Investigate
Step 4.a)</td><td>Augmentation
• Students are asked to draw a table, to record times and braking distance, and to calculate initial speeds. Students with visual-spatial and graphomotor issues struggle to create tables, especially without a model. Model how to create a four-column table as shown below with a row for each trial. Pair auditory, step-by-step directions with visual cues, and check to see that student tables are adequate for recording data.
<table>
<tr><th>Trial
(n)</th><th>Time
(s)</th><th>Braking Distance
(m)</th><th>Initial Speed
(v_i)</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>
Accommodation
• Give students a blank table to complete.</td></tr>
<tr><td>Drawing a graph using data from a table</td><td>Investigate
Step 5

Physics to Go
Questions 1 and 6</td><td>Augmentation
• Students struggle to label the correct axes on a graph and to set up reasonable scales on each axis. Check in with students to make sure that initial speed is labeled on the x-axis and braking distance is labeled on the y-axis. Help students recognize the pattern of scales for initial speed and braking distance.
• Review how to plot points on a graph. Provide students with a ruler or index card to aid in the tracking required to plot points on a graph.
• Provide a model graph for students to reference.
Accommodation
• Provide students with a graph that already has labels and scales. Ask them to sketch the lines and check for understanding.</td></tr>
<tr><td>Flipping pages to locate information on a table</td><td>Investigate
Step 8

Physics to Go
Questions 5–7</td><td>Augmentation
• Students with visual-spatial and memory issues have trouble flipping between pages to locate and record information from a table. Provide students with a ruler or index card to mark the page with the table. The ruler or index card can also be used to help students visually scan columns and rows to find information on a table.
Accommodation
• Students will be more successful if they can look at a table or graph and the corresponding questions side-by-side. Provide a copy of any table(s) not located on the same page as the questions. When writing exams, make sure tables and graphs are located on the same page as the corresponding questions.</td></tr>
</table>

Learning Issue	Reference	Augmentation and Accommodations
Understanding positive and negative relative to direction (vectors)	***Physics Talk***	**Augmentation** • Students struggle to understand positive and negative numbers as a general math concept. Adding directions that can be positive and negative is even more confusing. Use the sketch provided in *Physics Talk* to provide direct instruction about this topic.
Vocabulary	***Physics Talk*** Calculating Braking Distance	**Augmentation** • Many students do not understand what "derive" means. Explain the meaning of "derive" and then complete the derivation described in this section as a group. Students may not understand every step of this process, but they will have a much better understanding of what it means to derive an equation.
Choosing correct equation to solve a problem	***Physics to Go*** Question 4	**Augmentation** • Students have learned many motion equations in this chapter, and students with problem-solving or memory issues struggle to figure out which equation to use. Model a problem-solving method or graphic organizer such as the problem-solving box described in the Accommodation for *Section 3*. Make sure the directions are sequential and pair a visual model with auditory cues. Instruct students to identify what question the problem is asking and what information is given. Then model a think-aloud to show students how to choose the correct equation. **Accommodation** • Limit choice to two equations for students who are unable to master this skill with more equations. Increase number of equations from which to choose as the skill is mastered. • Provide a step-by-step checklist with the directions for the problem-solving method. • Provide student with blank problem-solving boxes.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate*** Step 2	Students need to have a working definition of "friction": a contact force that opposes the motion of an object. In an automobile, brakes use friction to reduce speed; there is rolling friction between the tires and the road, and there is friction acting on the spinning axle. Check for understanding by asking students where the friction forces act on the cart.
Vocabulary comprehension	***Investigate*** Step 2	Help ELL students with the contextual usage of "trials," meaning "repetitions" or "attempts." In other words, how many times will you do the experiment at each initial speed? Discuss reasons why a single trial at a given initial speed might not give reliable data.
Comprehension	***Investigate*** Step 3	To encourage practice in writing, ask an ELL student from each group to create the flowchart or outline. Check the work for understanding.
Vocabulary comprehension	***Investigate*** Step 6	Have students attempt to determine the meaning of "corresponds to" from context: "goes with" or "matches."
Vocabulary comprehension Answering higher order questions	***Investigate*** Steps 6.a), 7.a)	Be sure students understand the terms "doubling" and "tripling," and that it is clear to them that they should choose actual data. Because students were not directed to double the initial speed in the procedure, they may not have data for initial speeds that are in a 2-to-1 ratio. It may help to teach students how to decode a question with a complex sentence structure. When they read "what is the effect of doubling the initial speed on the distance traveled during braking?" they can simplify by cutting out words: "What is the effect on the distance traveled during braking?"
Understanding complex concepts	***Physics Talk, Negative Acceleration and Positive Acceleration***	Negative acceleration is a difficult concept. Sentences such as "An object could have a negative acceleration by decreasing its speed in the positive direction or increasing its speed in the negative direction" are difficult for all students to unravel. A language barrier can make the task daunting. Spend time reviewing the illustrations of positive and negative acceleration, along with their corresponding descriptions. You may wish to photocopy the page and cut apart the three diagrams illustrations and the three written descriptions, and then have students try to match each illustration with its description. Before moving on, be sure all students understand the conditions of both positive acceleration and negative acceleration. When you think students are comfortable with describing positive and negative acceleration, discuss the equations that represents each condition. Allow students sufficient time to become comfortable with integrating the information in the table.
Understanding graphs	***Physics Talk*** ***Checking Up***	There are three graphs for negative acceleration at the end of *Physics Talk.* Choose one ELL student to interpret each graph orally. You can check their understanding of the graphs and give them speaking practice as well.
Understanding equations	***Active Physics Plus*** Step 3	Check students' understanding of the five motion equations by having them state each equation in words.

CHAPTER 1

NOTES

SECTION 5

Teaching Suggestions and Sample Answers

What Do You See?

The *What Do You See?* illustration will evoke a variety of responses. Students might comment on the tilted vehicle or the unfazed moose. This will be a good opportunity for you to guide them to the topic of this section. You could ask them why the author chose to show a "near miss" collision. A review of the illustration after completing the *Investigate* and the *Physics Talk* would help students in examining how speed affects breaking distance.

What Do You Think?

After posing the *What Do You Think?* question, create a master list and allow the students to give their arguments as they try to justify some factors and dismiss others in order to avoid hitting the animal. The few students who have taken a course in driving may know that the most important factor is speed, and that distance is proportional to the square of the speed. The experiment in the *Investigate* will provide a basis for this relationship.

What Do You Think?

A Physicist's Response

The most important factors in determining if you will stop in time is speed and reaction time. The distance required to stop is proportional to the square of the speed. Other factors include: road conditions, driver's physical health, and environmental conditions.

Students' Prior Conceptions

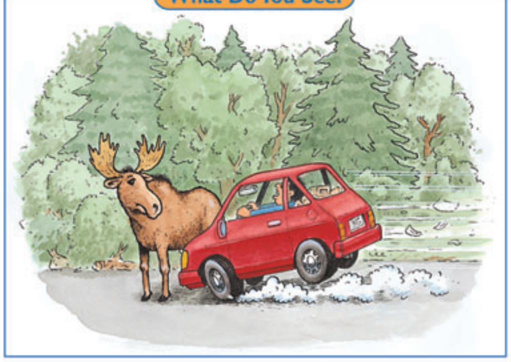
1. **Force is a property of an object.** An object has force and when it runs out of force it stops moving. This is the traditional view of impetus; an object possesses a force that causes it to move and when that force is used up, the object stops moving. The best way to confront this prior conception is to take a bowling ball or another heavy ball and a billiard or a lacrosse ball and apply the same force to them, or even to try to push them with a finger or a nose. It takes a larger force to propel the larger mass with the same velocity, and each object will continuously roll with a constant velocity on a continuous smooth surface until something impedes the motion.

2. **Friction always hinders motion. Thus, you always want to eliminate friction.** Students will use friction, as applied by the brakes of vehicles, to hinder motion along the road. They also speak about air resistance as a retarding frictional force; however, it will be later in their study of pairs of action-reaction forces that students need to understand that these equal and opposite pairs of objects always act on different objects. It is the friction between the shoe and the surface that enables a walker to move forward.

Section 5 Negative Acceleration: Braking Your Automobile

Section 5 Negative Acceleration: Braking Your Automobile

What Do You See?



Learning Outcomes

In this section, you will

- **Plan** and carry out an experiment to relate braking distance to initial speed.
- **Determine** braking distance.
- **Examine** accelerated motion.

What Do You Think?

In recent years, more than 80 percent of speed-related traffic deaths happened on secondary highways (such as two-lane, rural roads). Imagine you are driving at the speed limit on a secondary highway, and you suddenly see an animal crossing the road ahead of you. Suppose you cannot swerve to miss the animal because of trees on each side of the road.

- **What factors must you consider to determine if you will be able to stop in the distance between you and the animal to avoid hitting it?**

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

Investigate

In this *Investigate*, you will plan and carry out an experiment to determine the relationship between the initial speed and the braking distance of an automobile.

1. Knowing how far your automobile will travel after you have stepped on the brake pedal is important. One factor that may have an impact on braking distance is the initial speed of the automobile.

3. **The motion of an object is always in the direction of the net force applied to the object.** This alternative view of how things work in the physical world hinders student appreciation of how the combination of forces results in a net force that opposes the forward motion but that the forward motion continues until the velocity decreases to zero in that direction. This prior conception also appears in student explanations when they encounter moving along curves in *Section 7*, where the net force is perpendicular to the path of the vehicle.

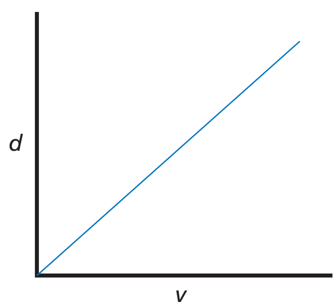
4. **Frictional forces are due to irregularities in surfaces moving past each other.** It puzzles students that larger areas of the same materials do not exhibit larger amounts of friction. Intuitively, students know that rougher surfaces have more static friction and even that you can tilt a surface gently and not have an object immediately move down along the surface. Yet, it is only the mathematical analysis of situations and the analysis of graphs of forces applied over time that help to provide students with the realization that there is an adhesion between the surface molecules, even very smooth ones, that retards motion, just until the applied force equals the force of static friction.

Investigate

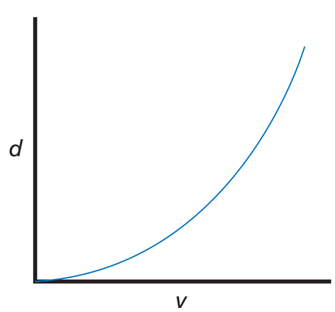
1.a)

The students may initially think the graph of braking distance vs. speed will look like graph A. After completion of the *Investigate*, they should have a graph that looks like graph B.

A



B



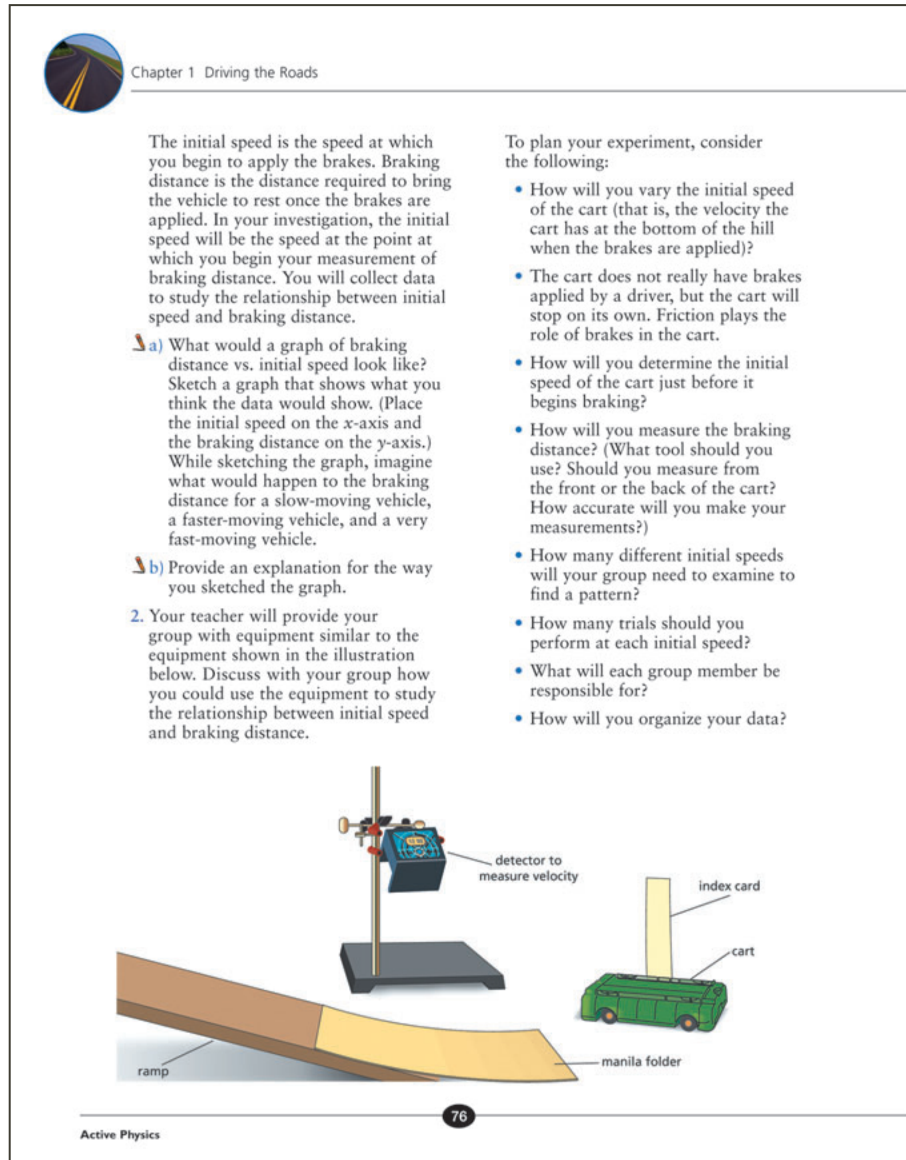
1.b)

The students will probably say that increasing speed implies increasing braking distance.

2.

The students need to measure stopping distance and initial velocity. Things students should consider include:

- Varying the starting height of the cart on the ramp will control speed and allow for repeated accurate trials.
- Because the friction on the rolling wheels is low, long distances may be necessary to stop the cart.
- The velocimeter will be used to measure speed (or another method as described above, in the advanced preparation and setup section.)
- Because braking distances may be large, a tape measure or meter stick will be needed to measure these distances. Measuring from the flag position as it leaves the velocimeter to the flag's final stopped position would give the distance the cart has traveled.
- About six to eight different initial speeds will give a good range, and allow students to find speeds that are triple the beginning speed.
- About four different trials to ensure uniformity would be good.
- One student will be needed for releasing the cart on the ramp, another to measure the velocity, and a third to measure the braking distance.
- The data should be organized in a table.



Chapter 1 Driving the Roads

The initial speed is the speed at which you begin to apply the brakes. Braking distance is the distance required to bring the vehicle to rest once the brakes are applied. In your investigation, the initial speed will be the speed at the point at which you begin your measurement of braking distance. You will collect data to study the relationship between initial speed and braking distance.

a) What would a graph of braking distance vs. initial speed look like? Sketch a graph that shows what you think the data would show. (Place the initial speed on the *x*-axis and the braking distance on the *y*-axis.) While sketching the graph, imagine what would happen to the braking distance for a slow-moving vehicle, a faster-moving vehicle, and a very fast-moving vehicle.

b) Provide an explanation for the way you sketched the graph.

2. Your teacher will provide your group with equipment similar to the equipment shown in the illustration below. Discuss with your group how you could use the equipment to study the relationship between initial speed and braking distance.

To plan your experiment, consider the following:

- How will you vary the initial speed of the cart (that is, the velocity the cart has at the bottom of the hill when the brakes are applied)?
- The cart does not really have brakes applied by a driver, but the cart will stop on its own. Friction plays the role of brakes in the cart.
- How will you determine the initial speed of the cart just before it begins braking?
- How will you measure the braking distance? (What tool should you use? Should you measure from the front or the back of the cart? How accurate will you make your measurements?)
- How many different initial speeds will your group need to examine to find a pattern?
- How many trials should you perform at each initial speed?
- What will each group member be responsible for?
- How will you organize your data?

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Active Physics

3. After discussing these questions in your group, develop a plan for what your group will do. Your teacher may ask you to either draw a flowchart or an outline showing the steps you will take.

4. Set up your equipment and perform your experiment.

a) Record both numerical data and observations in your *Active Physics* log.

Place the ramp on the floor in a way that does not obstruct people's ability to walk around the classroom. Do not block the emergency exit.

If you are setting up the ramp on the table, provide some means to contain the cart and prevent it from falling off the table.

5. Use the data you collected to complete the following:

a) Draw a graph showing how the braking distance depends on the initial speed. Place the initial speed on the horizontal axis and the braking distance on the vertical axis.

b) How does the braking distance change with initial speed?

c) How does your graph compare to the graph you sketched in *Step 1.a)*?

d) Compare your graph with those of other groups. What are some similarities and some differences?

e) Does looking at the other groups' graphs make you feel more confident or less confident about your data? Explain your answer.

6. Select two values of initial speed from your graph, with one value approximately twice the value of the other. Note the braking distance which corresponds to each initial speed.

a) What is the effect of doubling the initial speed on the distance traveled during braking?

7. Select two values of initial speed from your graph, with one value approximately three times as fast as the other. Note the braking distance which corresponds to each initial speed.

a) What is the effect of tripling the initial speed on the distance traveled during braking?

b) Predict how going four times faster will affect the braking distance.

8. Use the data on the sports car provided at the end of this chapter on pages 116-117 to answer the following:

a) Where is the braking data located?

b) The braking distance is shown for two speeds. The ratio of the two speeds is 80 mi/hr : 60 mi/hr. This ratio is $80/60 = 1.33$. This is an increase of 133 percent. Do you expect the ratio of the braking distances to also be in the ratio of $80/60 = 1.33$? What is the ratio of the braking distances? How does it compare with the ratio of the two speeds?

c) How does this data correspond to what you found in your experiment?

Teaching Tip

There may be some confusion about when the speed is to be measured and why. Make sure your students understand that their problem is to find out how far the cart travels on the level surface. The speed you need is its maximum value, which is just as the cart begins to travel horizontally. The purpose of the adjustable ramp is simply to provide a variable series of initial speeds.

3.

Students write out their plan.

4.a)

Students record data and observations.

5.a)

Students graph data in their logs.

5.b)

As you increase the initial speed, the braking distance increases at a much faster pace.

5.c)

The graph will be a parabola, concave side facing upward, which will probably be different from the students' initial graph.

5.d)

All graphs should be roughly parabolic, facing upward. The graphs should differ in values for the velocities and how closely they mimic a parabola.

Note: Unless the students choose a range of values for speed, when the speed doubles and triples, the graph may appear almost linear. If a group does this, have them choose additional values to meet this condition.

5.e)

Looking at the other groups' graphs should improve student confidence.

6.a)

The distance should quadruple.

7.a)

Increasing the speed three times gives a stopping distance about nine times as great.

7.b)

Because this is a quadratic relationship, the braking distance will be 16 times greater.

8.a)

The braking data is located below the data for Fuel Economy.

8.b)

The ratio of the braking distances is approximately 1.69. Students should predict a ratio of $(80)^2$ to $(60)^2$, which would be a 178% increase. The braking ratio listed is 209 ft/118 ft, or a 177% increase.

8.c)

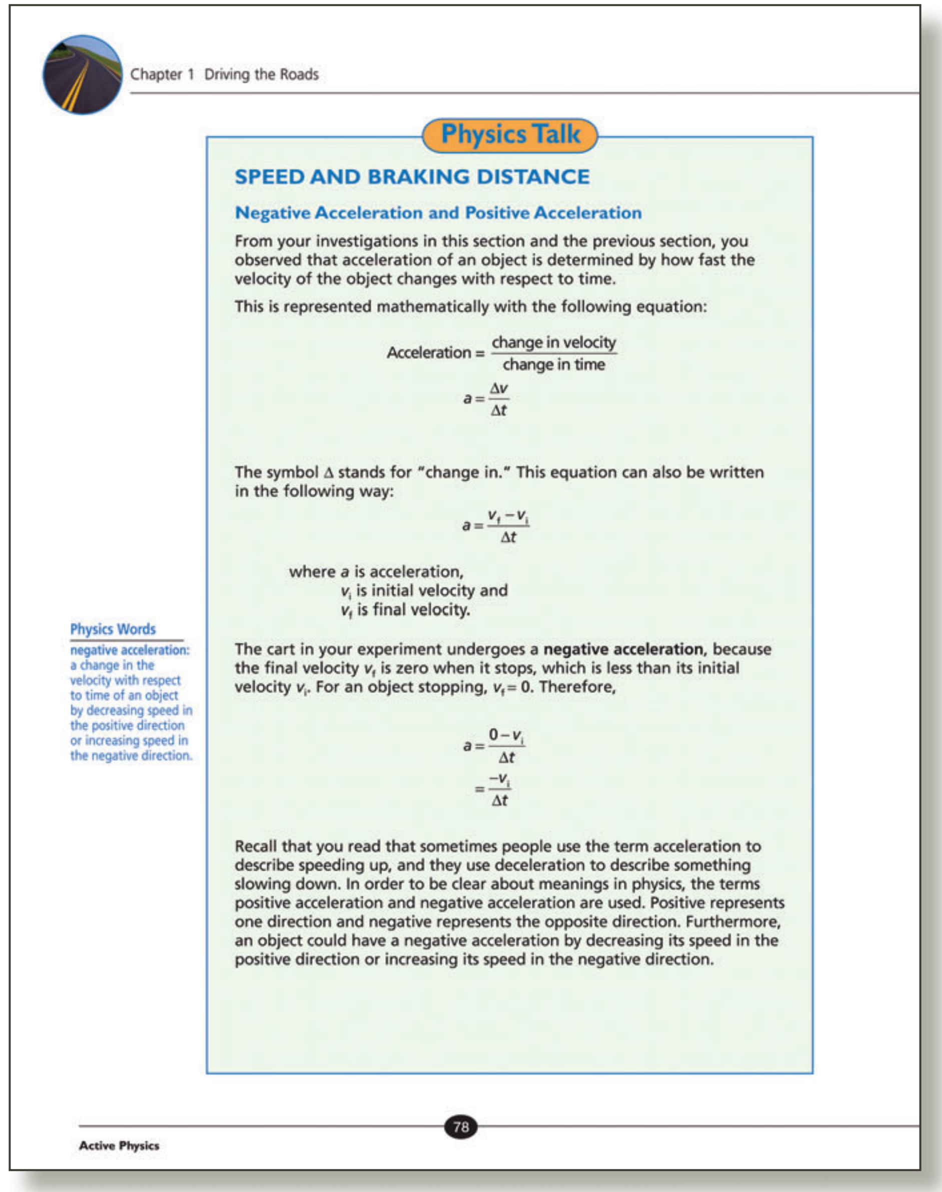
Because the braking distance is proportional to the square of the initial velocity, the ratio of the speeds should be proportional to the square root of 1.69 = 1.3. The ratio 80/60 = 1.33.

Physics Talk

The *Physics Talk* discusses the concept of acceleration as well as the relationship between velocity and braking distance. The change in velocity of an automobile gradually coming to a stop is defined as negative acceleration, if the direction is assumed to be positive. Discuss the concept of negative acceleration in terms of changing speeds in the positive and negative directions. Students should be able to contrast negative acceleration with positive acceleration to highlight the difference between speeding up and slowing down in a particular direction. To further clarify the meaning of positive and negative acceleration, have students define both the terms in their *Active Physics* logs. You might want to emphasize why the use of the term (negative acceleration) is preferred instead of deceleration.

Students should also be reminded that according to the *Investigate,* braking distance is related to the initial velocity of an automobile through the equation $v_i^2 = -2ad$. The negative sign in the equation is the result of the automobile undergoing a negative acceleration while traveling in the positive direction. Students should fully grasp how the knowledge of $v_i^2 = -2ad$ can save lives.

Invite students to discuss how knowledge of the v^2 relationship can save lives when confronted with a situation requiring an emergency stop. Draw their attention to the three graphs that represent negative acceleration in terms of distance vs. time, velocity vs. time, and acceleration vs. time. Ask them why each graph is different and how the slope of each graph shows that the automobile is coming to a rest. Emphasize that the graphs give no information on direction, so the decrease in speed is assumed to be a negative acceleration.


Chapter 1 Driving the Roads

Physics Talk

SPEED AND BRAKING DISTANCE

Negative Acceleration and Positive Acceleration

From your investigations in this section and the previous section, you observed that acceleration of an object is determined by how fast the velocity of the object changes with respect to time.

This is represented mathematically with the following equation:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$a = \frac{\Delta v}{\Delta t}$$

The symbol Δ stands for "change in." This equation can also be written in the following way:

$$a = \frac{v_f - v_i}{\Delta t}$$

where a is acceleration,
v_i is initial velocity and
v_f is final velocity.

Physics Words
negative acceleration: a change in the velocity with respect to time of an object by decreasing speed in the positive direction or increasing speed in the negative direction.

The cart in your experiment undergoes a **negative acceleration**, because the final velocity v_f is zero when it stops, which is less than its initial velocity v_i. For an object stopping, $v_f = 0$. Therefore,

$$a = \frac{0 - v_i}{\Delta t} = \frac{-v_i}{\Delta t}$$

Recall that you read that sometimes people use the term acceleration to describe speeding up, and they use deceleration to describe something slowing down. In order to be clear about meanings in physics, the terms positive acceleration and negative acceleration are used. Positive represents one direction and negative represents the opposite direction. Furthermore, an object could have a negative acceleration by decreasing its speed in the positive direction or increasing its speed in the negative direction.

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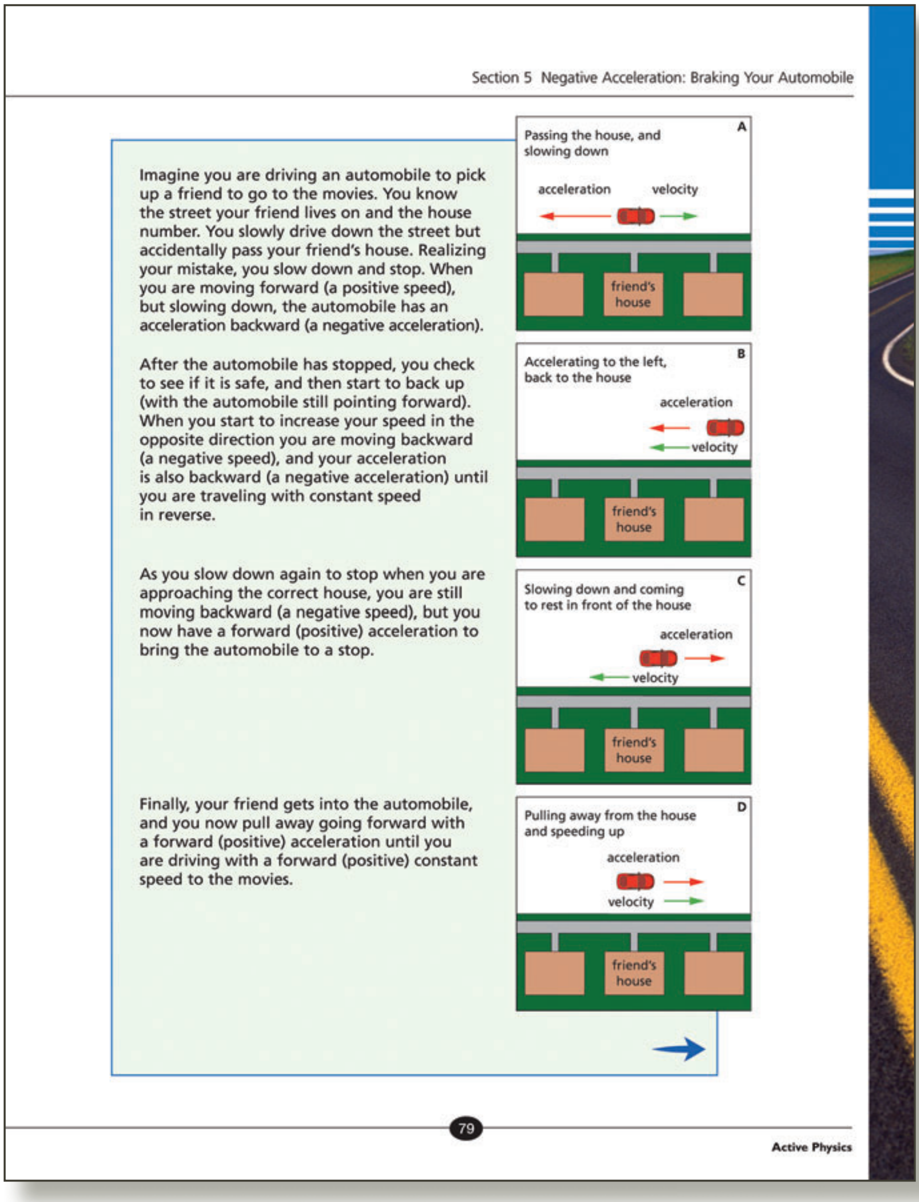
Active Physics

1-5a **Blackline Master**

CHAPTER 1



Imagine you are driving an automobile to pick up a friend to go to the movies. You know the street your friend lives on and the house number. You slowly drive down the street but accidentally pass your friend's house. Realizing your mistake, you slow down and stop. When you are moving forward (a positive speed), but slowing down, the automobile has an acceleration backward (a negative acceleration).

After the automobile has stopped, you check to see if it is safe, and then start to back up (with the automobile still pointing forward). When you start to increase your speed in the opposite direction you are moving backward (a negative speed), and your acceleration is also backward (a negative acceleration) until you are traveling with constant speed in reverse.

As you slow down again to stop when you are approaching the correct house, you are still moving backward (a negative speed), but you now have a forward (positive) acceleration to bring the automobile to a stop.

Finally, your friend gets into the automobile, and you now pull away going forward with a forward (positive) acceleration until you are driving with a forward (positive) constant speed to the movies.

1-5b Blackline Master

Motion of Car	Time (s)	Velocity of car (ft/s)	Acceleration of car (ft/s²)	Positive or Negative
Car moving forward and slowing down (Diagram A)	0	+6	$\frac{v_f - v_i}{\Delta t} = \frac{(+4)-(+6)}{1} = -2$	negative acceleration
	1	+4		
Car moving forward, slowing down and car stops	2	+2	$\frac{v_f - v_i}{\Delta t} = \frac{(0)-(+2)}{1} = -2$	negative acceleration
	3	0		
Car moving backward and speeding up (Diagram B)	4	-2	$\frac{v_f - v_i}{\Delta t} = \frac{(-4)-(-2)}{1} = -2$	negative acceleration
	5	-4		
Car moving backward and slowing down (Diagram C)	6	-6	$\frac{v_f - v_i}{\Delta t} = \frac{(-4)-(-6)}{1} = +2$	positive acceleration
	7	-4		
Car moving backward and stopping	8	-2	$\frac{v_f - v_i}{\Delta t} = \frac{(0)-(-2)}{1} = +2$	positive acceleration
	9	0		
Car moving forward and speeding up (Diagram D)	9	0	$\frac{v_f - v_i}{\Delta t} = \frac{(+2)-(0)}{1} = +2$	positive acceleration
	10	2		

In this example, you can see that a negative acceleration can sometimes decrease the speed of an automobile $(t = 0 \text{ to } t = 3)$ or increase the speed of an automobile $(t = 4 \text{ to } t = 5)$, but it always decreases the velocity of the automobile by exactly 2 ft/s every second $(\text{from} +6 \text{ to} +4 \text{ to} +2 \text{ to } 0 \text{ to} -2 \text{ to} -4)$.

CHAPTER 1

Calculating Braking Distance

Using the definition of velocity and acceleration, you can derive an equation for the braking distance when a vehicle comes to rest. The equation is shown below:

$$v_f^2 = 2ad + v_i^2$$

v_f is the final velocity of the car.

v_i is the initial velocity of the vehicle. Notice that it must be squared. This is the same as multiplying it by itself, $v_i^2 = v_i \times v_i$.

a is the acceleration. It is a negative acceleration.

d is the braking distance.

Because the final velocity of a vehicle is zero after the car comes to a stop, you may put a zero in for the final velocity, and of course zero times zero is still zero.

$$0 = 2ad + v_i^2$$

or

$$v_i^2 = -2ad$$

You can use the helpful circle to solve for any of the variables in this equation as well.

Of all the equations in your first year of physics, this one may have the greatest impact on your safety. Understanding this equation may one day even help to save your life! From this equation, you can see that if you double the initial velocity, then the braking distance d will have to quadruple. If you triple the initial velocity, then the braking distance d will be nine times as great.

You probably found in the *Investigate* that doubling the speed increased the distance traveled while the vehicle was braking by about a factor of four and that tripling the speed increased the braking distance by about a factor of nine. Look at the data for the sports car. The speed increased by 1.33 while the braking distance increased by approximately 1.33 × 1.33 = 1.77. Experiments completed with a great deal of care, ensuring that the braking acceleration is constant between trials, find that this relationship is true.

Checking Up

1.

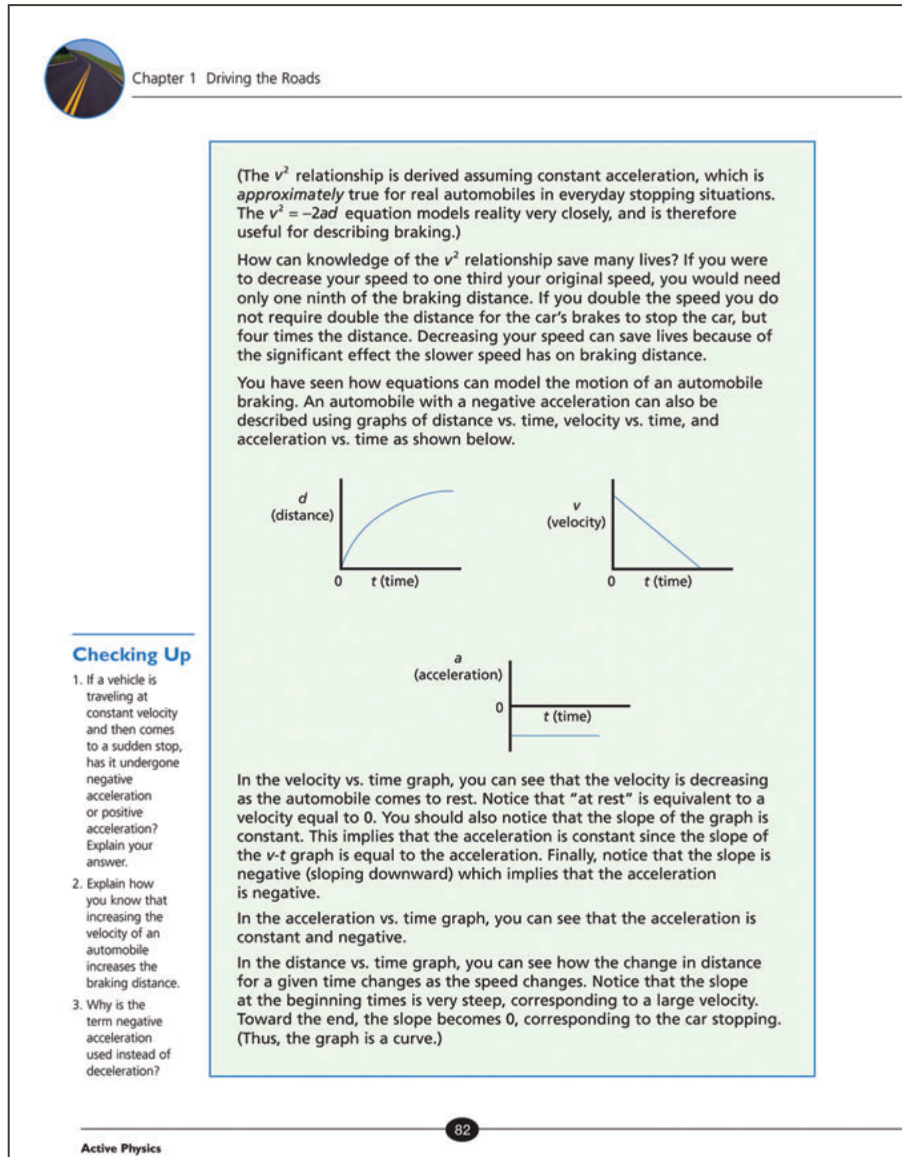
The braking automobile has undergone negative acceleration because the automobile's velocity decreases to zero as it comes to a sudden stop.

2.

The braking distance is determined by the v^2 equation, which shows that braking distance is raised to the power of two as velocity increases. Thus, if velocity is doubled, braking distance is quadrupled, and if velocity is tripled, braking distance increases by a factor of nine.

3.

Deceleration means slowing down, but does not indicate the direction of velocity as an object slows down. A more precise term, negative acceleration, implies that the body in motion is slowing down in the direction opposite to its velocity, or increasing its velocity in the negative direction.



Chapter 1 Driving the Roads

(The v^2 relationship is derived assuming constant acceleration, which is *approximately* true for real automobiles in everyday stopping situations. The $v^2 = -2ad$ equation models reality very closely, and is therefore useful for describing braking.)

How can knowledge of the v^2 relationship save many lives? If you were to decrease your speed to one third your original speed, you would need only one ninth of the braking distance. If you double the speed you do not require double the distance for the car's brakes to stop the car, but four times the distance. Decreasing your speed can save lives because of the significant effect the slower speed has on braking distance.

You have seen how equations can model the motion of an automobile braking. An automobile with a negative acceleration can also be described using graphs of distance vs. time, velocity vs. time, and acceleration vs. time as shown below.

In the velocity vs. time graph, you can see that the velocity is decreasing as the automobile comes to rest. Notice that "at rest" is equivalent to a velocity equal to 0. You should also notice that the slope of the graph is constant. This implies that the acceleration is constant since the slope of the v-t graph is equal to the acceleration. Finally, notice that the slope is negative (sloping downward) which implies that the acceleration is negative.

In the acceleration vs. time graph, you can see that the acceleration is constant and negative.

In the distance vs. time graph, you can see how the change in distance for a given time changes as the speed changes. Notice that the slope at the beginning times is very steep, corresponding to a large velocity. Toward the end, the slope becomes 0, corresponding to the car stopping. (Thus, the graph is a curve.)

Checking Up

1. If a vehicle is traveling at constant velocity and then comes to a sudden stop, has it undergone negative acceleration or positive acceleration? Explain your answer.
2. Explain how you know that increasing the velocity of an automobile increases the braking distance.
3. Why is the term negative acceleration used instead of deceleration?

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Active Physics

Section 5 Negative Acceleration: Braking Your Automobile

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•••	••	••	

Motion Equations

Five motion equations can describe all the relations among position, velocity, and constant acceleration. The equations are all derived from the definitions of velocity and acceleration.

$$d = \bar{v}t$$
$$v_f = at + v_i$$
$$\bar{v} = \frac{v_f + v_i}{2}$$
$$d = \frac{1}{2}at^2 + v_i t$$
$$v_f^2 = 2ad + v_i^2$$

The first equation is a restatement of the definition of average velocity. (The v with a bar over the top is a shorthand way of writing $v_{average}$.) The second equation is a restatement of the definition of acceleration. The third equation is for average velocity when there is constant acceleration. The fourth equation helps to determine distance traveled if you know the acceleration and time without the need for first finding the final velocity. The fifth equation relates the stopping distance to the acceleration and velocities without the need for calculating the time.

The fifth equation can be derived from the other four equations using algebra. Assume that the initial velocity equals zero to ease the mathematics.

You may want to try to derive the equation with acceleration not being zero, using the same approach.

These are the variables in the motion equations: d, t, a, v_f, v_i and $v_{average}$.

$$v_f = at + v_i$$

Assuming $v_i = 0$,

$$v_f = at$$

Square each side

$$v_f^2 = a^2t^2$$
$$v_f^2 = 2a\left(\frac{1}{2}at^2\right)$$
$$v_f^2 = 2ad$$

If the acceleration is constant and you are able to find or are given any three of these variables, you can use the motion equations to solve for the other two variables and completely describe the motion of the object. The object can be an automobile, an animal, a galaxy, or a cell. The motion equations describe them all.

Sample Problem I

A softball pitcher accelerates a ball from rest to a speed of 25 m/s over a distance of 1.8 m. What is the ball's acceleration?

Strategy:

Using the fifth equation of motion, derived from the other four equations using algebra, and knowing v_i, v_f, and d, you can solve for acceleration.

Given:

$$v_i = 0$$
$$v_f = 25 \text{ m/s}$$
$$d = 1.8 \text{ m}$$

Solution:

Knowing that $v_f^2 = 2ad + v_i^2$, and that $v_i = 0$, the equation becomes $v_f^2 = 2ad$.

Active Physics Plus

By solving problems and analyzing graphs, students further explore how acceleration affects braking distance. Have the students write the five motion equations in their logs. A discussion of the variables in these equations and how they are derived will help clarify their meaning and how they relate to each other. You might want to ask those students who are able to grasp how the equations are derived to explain the derivations to other students in the class.

CHAPTER 1

1.a)

Negative, since the acceleration is in the opposite direction of the positive motion.

1.b)

$$a = \frac{v}{t} = \frac{-90\ \text{m/s}}{1.5\ \text{s}} = -60\ \text{m/s}^2$$

1.c)

$$v_{\text{average}} = \frac{v_{\text{i}} + v_{\text{f}}}{2} =$$

$$\frac{90\ \text{m/s} + 0\ \text{m/s}}{2} = 45\ \text{m/s}$$

1.d)

$$d = v_{\text{i}}t + \tfrac{1}{2}at^2 = (90\ \text{m/s})(1.5\ \text{s}) + \tfrac{1}{2}(-60\ \text{m/s}^2)(1.5\ \text{s})^2 = 67.5\ \text{m}$$

2.a)

$$v_{\text{f}} = v_{\text{i}} + at = 0 + (5\ \text{m/s}^2)(5\ \text{s}) = 25\ \text{m/s}$$

2.b)

$$d = v_{\text{i}}t + \tfrac{1}{2}at^2 = 0 + \tfrac{1}{2}(8\ \text{m/s})^2 \times (6\ \text{s})^2 = 144\ \text{m}$$

2.c)

$$d_{\text{car}} = v_{\text{i car}}t_{\text{car}} + \tfrac{1}{2}a_{\text{car}}t_{\text{car}}^2$$

$$150\ \text{m} = 0 + \tfrac{1}{2}(5\ \text{m/s}^2)t_{\text{car}}^2$$

$$t_{\text{car}} = \sqrt{\frac{150\ \text{m}}{2.5\ \text{m/s}^2}} = 7.7\ \text{s}.$$

$$d_{\text{cycle}} = v_{\text{i cycle}}t_{\text{cycle}} + \tfrac{1}{2}a_{\text{cycle}}t_{\text{cycle}}^2$$

$$200\ \text{m} = 0 + \tfrac{1}{2}(8\ \text{m/s}^2)t_{\text{cycle}}^2$$

$$t_{\text{cycle}} = \sqrt{\frac{200\ \text{m}}{4\ \text{m/s}^2}} = 7.1\ \text{s}.$$

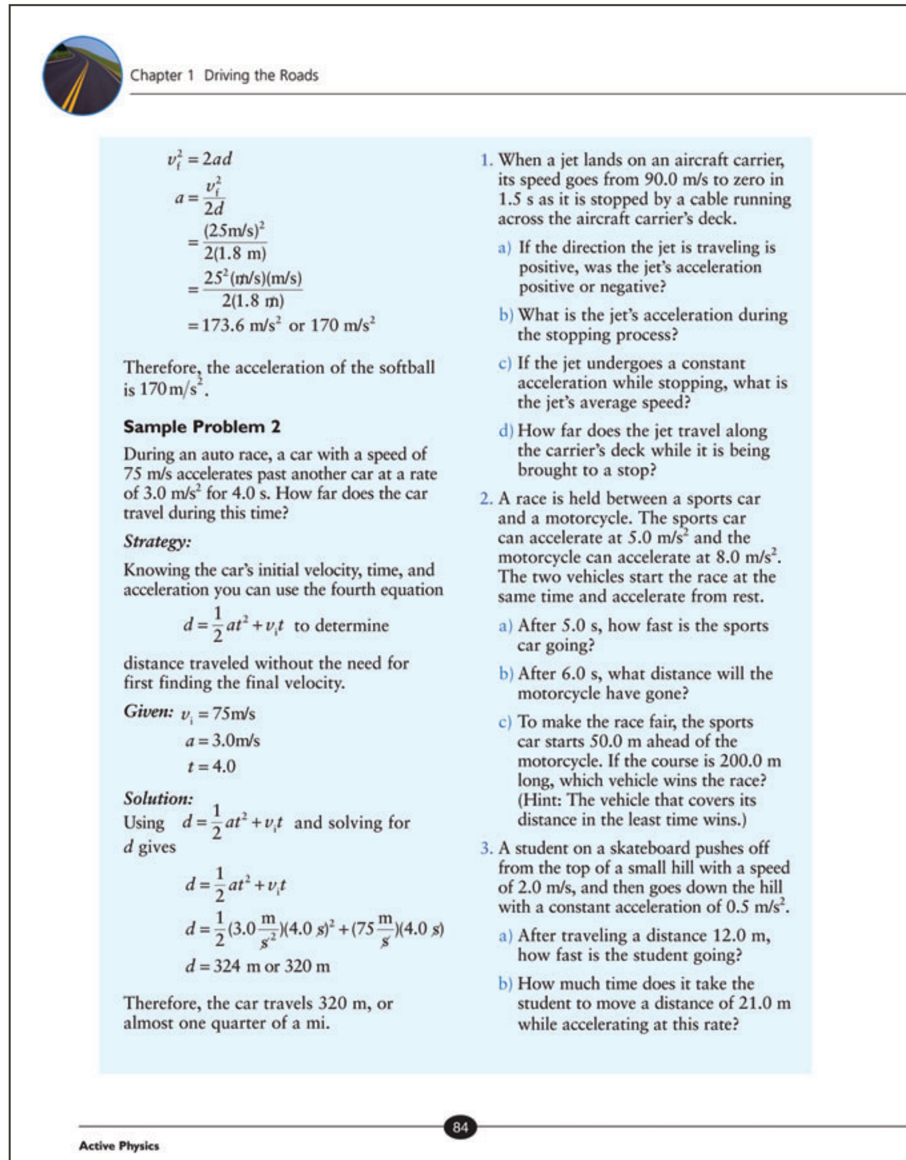
The motorcycle wins!

3.a)

$$v_{\text{f}}^2 = v_{\text{i}}^2 + 2ad$$

$$v_{\text{f}}^2 = (2\ \text{m/s})^2 + 2(0.5\ \text{m/s}^2) \times (12\ \text{m}) = 16\ \text{m}^2/\text{s}^2$$

and $v_{\text{f}} = 4$ m/s.


Chapter 1 Driving the Roads

$$v_i^2 = 2ad$$

$$a = \frac{v_i^2}{2d} = \frac{(25\text{m/s})^2}{2(1.8\ \text{m})} = \frac{25^2(\text{m/s})(\text{m/s})}{2(1.8\ \text{m})} = 173.6\ \text{m/s}^2 \text{ or } 170\ \text{m/s}^2$$

Therefore, the acceleration of the softball is 170 m/s^2.

Sample Problem 2

During an auto race, a car with a speed of 75 m/s accelerates past another car at a rate of 3.0 m/s^2 for 4.0 s. How far does the car travel during this time?

Strategy:

Knowing the car's initial velocity, time, and acceleration you can use the fourth equation $d = \frac{1}{2}at^2 + v_it$ to determine distance traveled without the need for first finding the final velocity.

Given: $v_i = 75$m/s
$a = 3.0$m/s
$t = 4.0$

Solution:
Using $d = \frac{1}{2}at^2 + v_it$ and solving for d gives

$$d = \frac{1}{2}at^2 + v_it$$

$$d = \frac{1}{2}(3.0\frac{\text{m}}{\text{s}^2})(4.0\ \text{s})^2 + (75\frac{\text{m}}{\text{s}})(4.0\ \text{s})$$

$$d = 324\ \text{m or } 320\ \text{m}$$

Therefore, the car travels 320 m, or almost one quarter of a mi.

1. When a jet lands on an aircraft carrier, its speed goes from 90.0 m/s to zero in 1.5 s as it is stopped by a cable running across the aircraft carrier's deck.
   a) If the direction the jet is traveling is positive, was the jet's acceleration positive or negative?
   b) What is the jet's acceleration during the stopping process?
   c) If the jet undergoes a constant acceleration while stopping, what is the jet's average speed?
   d) How far does the jet travel along the carrier's deck while it is being brought to a stop?
2. A race is held between a sports car and a motorcycle. The sports car can accelerate at 5.0 m/s^2 and the motorcycle can accelerate at 8.0 m/s^2. The two vehicles start the race at the same time and accelerate from rest.
   a) After 5.0 s, how fast is the sports car going?
   b) After 6.0 s, what distance will the motorcycle have gone?
   c) To make the race fair, the sports car starts 50.0 m ahead of the motorcycle. If the course is 200.0 m long, which vehicle wins the race? (Hint: The vehicle that covers its distance in the least time wins.)
3. A student on a skateboard pushes off from the top of a small hill with a speed of 2.0 m/s, and then goes down the hill with a constant acceleration of 0.5 m/s^2.
   a) After traveling a distance 12.0 m, how fast is the student going?
   b) How much time does it take the student to move a distance of 21.0 m while accelerating at this rate?

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Active Physics

3.b)

$$d = v_{\text{i}}t + \tfrac{1}{2}at^2$$

$$21\ \text{m} = (2\ \text{m/s})t + \tfrac{1}{2}(0.5\ \text{m/s}^2)t^2$$

$$(0.25\ \text{m/s}^2)t^2 + (2\ \text{m/s})t - 21\ \text{m} = 0$$

Using the quadratic equation,

$$t = \frac{-(2\ \text{m/s}) \pm \sqrt{(2\ \text{m/s})^2 - 4(0.25\ \text{m/s}^2)(-21\ \text{m})}}{2(0.25\ \text{m/s}^2)}$$

$= 6$ s.

Section 5 Negative Acceleration: Braking Your Automobile

Graphing Models

You have been using graphs to better understand motion. You have seen that there is a relationship among corresponding *d-t*, *v-t* and *a-t* graphs.

The slope of a *d-t* graph of an automobile is equal to the velocity of the automobile.

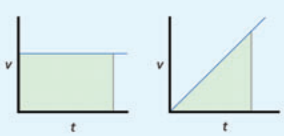
The slope of a *v-t* graph of an automobile is equal to the acceleration of the automobile.

Given a *d-t* graph, you can use this information to determine the *v-t* graph and the *a-t* graph as you have seen earlier.

The velocity vs. time graph can also tell you about the distance traveled.

In the following two velocity vs. time graphs, the shaded areas under the velocity vs. time graphs are equal to the distance traveled. This can be proven in the following way.

In the first velocity vs. time graph, the average velocity is constant, because the velocity does not change. With no change in velocity, the acceleration must be zero. The shaded area under the graph is equal to the distance traveled. The shaded area under the graph is the area of a rectangle (A = height × base). This area is (average velocity) × (time), which is the definition of distance traveled.



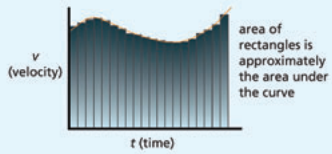
Velocity vs. Time

The second graph shows a constant acceleration. The area under the second graph is identical to the area of a triangle. The area of a triangle is ½ height × base. The base is the time. The height is the final velocity. One half the height is the average of the final velocity and the initial velocity of 0.

$$\frac{1}{2}\ \text{height} \times \text{base} = \frac{1}{2}\ (\text{final velocity}) \times (\text{time})$$
$$= (\text{average velocity}) \times (\text{time})$$

$$\frac{1}{2} h \times b = \frac{1}{2}(v_f) \times (t)$$
$$= (v_{\text{average}}) \times (t)$$

Once again, from the definition of average velocity (average velocity = distance/time), there is a way to calculate the distance traveled.



The area under a velocity vs. time graph is always equal to the distance traveled. For non-constant accelerations, the velocity vs. time graph is a curve. You can see in the diagram above how you can break a curve into a series of tiny rectangles that approximates the curve. The total area under the curve is approximately equal to the total area of all the rectangles. This is the beginning of your introduction to calculus—an advanced mathematics invented by Sir Isaac Newton, an English physicist and mathematician, to better understand physics.

1.

The object accelerates forward from rest to a speed of 5 m/s from 0 to 2 s, continues at a constant speed of 5 m/s from 2 to 4 s, accelerates from 5 m/s to 10 m/s from 4 to 6 s, and then slows down from 10 m/s to rest (negative acceleration) from 6 to 8 s.

2.

For 0 to 2 s, $a = \dfrac{(5 \text{ m/s} - 0)}{2 \text{ s}} = 2.5 \text{ m/s}^2$

For 2 to 4 s, $a = \dfrac{(5 \text{ m/s} - 5 \text{ m/s})}{2 \text{ s}} = 0$

For 4 to 6 s, $a = \dfrac{(10 \text{ m/s} - 5 \text{ m/s})}{2 \text{ s}} = 2.5 \text{ m/s}^2$

For 6 to 8 s, $a = \dfrac{(0 - 10 \text{ m/s})}{2 \text{ s}} = -5 \text{ m/s}^2$

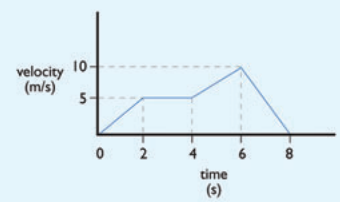
3.

The distance traveled for each interval is equal to the area under the graph for that interval.

For 0 to 2 s, the area of the triangle is $\text{Area}_t = \frac{1}{2}(\text{base})_t \times (\text{height})_t = \frac{1}{2}(2 \text{ s})(5 \text{ m/s}) = 5 \text{ m}$.

For 2 to 4 s, the area of the rectangle is $\text{Area}_r = (\text{base})_r(\text{height})_r = (2 \text{ s})(5 \text{ m/s}) = 10 \text{ m}$.

For 4 to 6 s, the area of the rectangle plus the triangle is $\text{Area}_r + \text{Area}_t = (\text{base})_r(\text{height})_r + \frac{1}{2}(\text{base})_t(\text{height})_t = (2 \text{ s})(5 \text{ m/s}) + \frac{1}{2}(2 \text{ s})(5 \text{ m/s}) = 10 \text{ m} + 5 \text{ m} = 15 \text{ m}$.



For the velocity vs. time graph shown:

1. Describe the motion from $t = 0$ to $t = 8$ s.
2. Calculate the acceleration of the object for each 2 s.
3. Calculate the distance traveled for each 2 s. (Hint: For $t = 4$ to $t = 6$, the area under the curve is a trapezoid made up of both a rectangle and a triangle.)
4. Calculate the total distance traveled.

What Do You Think Now?

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

- **What factors must you consider to determine if you will be able to stop in the distance between you and the animal to avoid hitting it?**

How would you answer this question now? After studying the equations of motion, how do you think velocity affects the time it takes to suddenly stop an automobile? According to the equation for braking distance, if you double an automobile's speed, what happens to the distance needed for a vehicle's brakes to bring the vehicle to a stop?

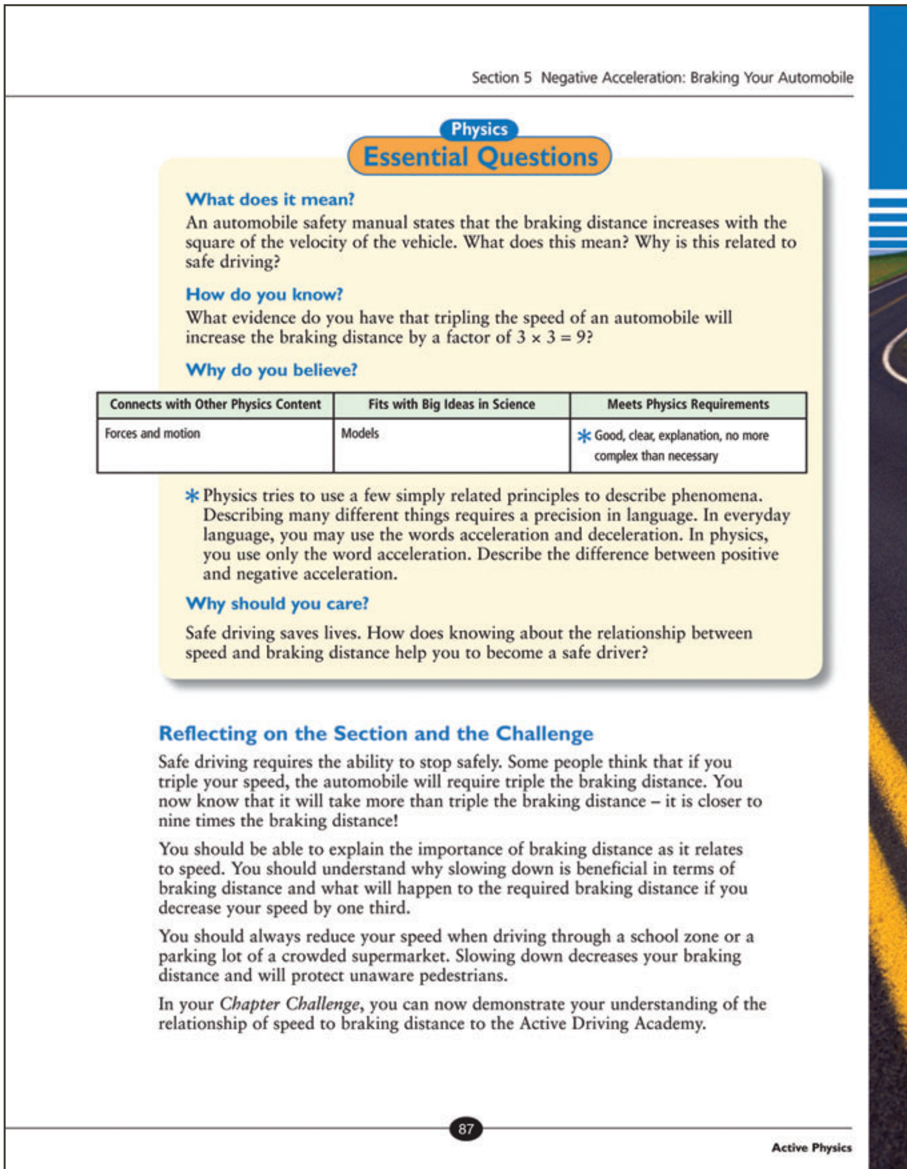
For 6 to 8 s, the area of the triangle is $\text{Area}_t = \frac{1}{2}(\text{base})_t(\text{height})_t = \frac{1}{2}(2 \text{ s})(10 \text{ m/s}) = 10 \text{ m}$.

4.

The total distance traveled is equal to the sum of all the areas under the graph, or 44 m.

What Do You Think Now?

You were given a *Physicist's Response* to the *What Do You Think?* question for your reference. Provide students with that answer and encourage discussion. Students should be able to articulate the concepts they learned in relation to their responses. Have students respond by pointing out the use of the v^2 equation in determining the braking distance. Write a few responses on the board to draw a connection to concepts they have learned, as these concepts emerge in class discussion.



Physics

Essential Questions

What does it mean?

An automobile safety manual states that the braking distance increases with the square of the velocity of the vehicle. What does this mean? Why is this related to safe driving?

How do you know?

What evidence do you have that tripling the speed of an automobile will increase the braking distance by a factor of $3 \times 3 = 9$?

Why do you believe?

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

* Physics tries to use a few simply related principles to describe phenomena. Describing many different things requires a precision in language. In everyday language, you may use the words acceleration and deceleration. In physics, you use only the word acceleration. Describe the difference between positive and negative acceleration.

Why should you care?

Safe driving saves lives. How does knowing about the relationship between speed and braking distance help you to become a safe driver?

Reflecting on the Section and the Challenge

Safe driving requires the ability to stop safely. Some people think that if you triple your speed, the automobile will require triple the braking distance. You now know that it will take more than triple the braking distance – it is closer to nine times the braking distance!

You should be able to explain the importance of braking distance as it relates to speed. You should understand why slowing down is beneficial in terms of braking distance and what will happen to the required braking distance if you decrease your speed by one third.

You should always reduce your speed when driving through a school zone or a parking lot of a crowded supermarket. Slowing down decreases your braking distance and will protect unaware pedestrians.

In your *Chapter Challenge*, you can now demonstrate your understanding of the relationship of speed to braking distance to the Active Driving Academy.

Reflecting on the Section and the Challenge

You might wish to read this section aloud and have a class discussion, or have groups of students spend a few minutes in discussion.

Encourage students to reflect on how their knowledge of initial speed versus braking distance contributes to their understanding of driving safely. They should be able to reflect on how speed affects safety and how this can be woven into their *Chapter Challenge*. It is an important opportunity to consolidate the concepts they have learned and relate them to the importance of v^2 in determining braking distances.

Physics Essential Questions

What does it mean?

If you triple your speed, the braking distance will increase by a factor of nine. That's because $3^2 = 9$. Safe drivers realize that dropping their speed can produce a drastic change in braking distance.

How do you know?

When the automobile's speed tripled, the distance along the floor was actually almost nine times as long.

Why do you believe?

If a vehicle is moving to the right (a positive velocity), a positive acceleration will also be to the right and will increase the speed of the vehicle. If the vehicle is moving to the right, a negative acceleration will be to the left and will decrease the speed of the vehicle.

If a vehicle is moving to the left (a negative velocity), a positive acceleration will be to the right and will decrease the speed of the vehicle. If the vehicle is moving to the left, a negative acceleration will also be to the left and will increase the speed of the vehicle.

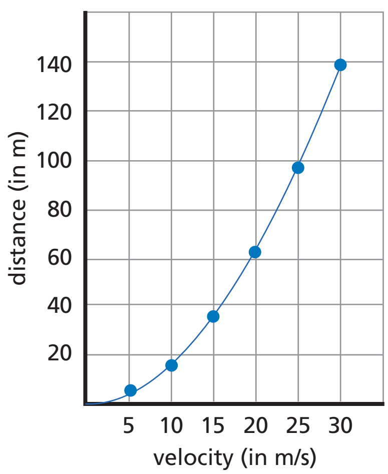
Why should you care?

It provides guidance about the value and importance of slowing down. If you cut your speed by 1/3, then you will only need 1/9 the distance to stop. Having such a small stopping distance can assist you in places where children may surprise you by running into the road.

Physics to Go

1.

The graph should be a parabola as shown below. Emphasize to students the need for a curved line of best fit. As the speeds increase, the braking distances increase at a much greater rate.



2.

Automobile B has the greater braking distance at slower speeds than automobile A. Using braking distances to determine safety, automobile B is safer.

3.a)

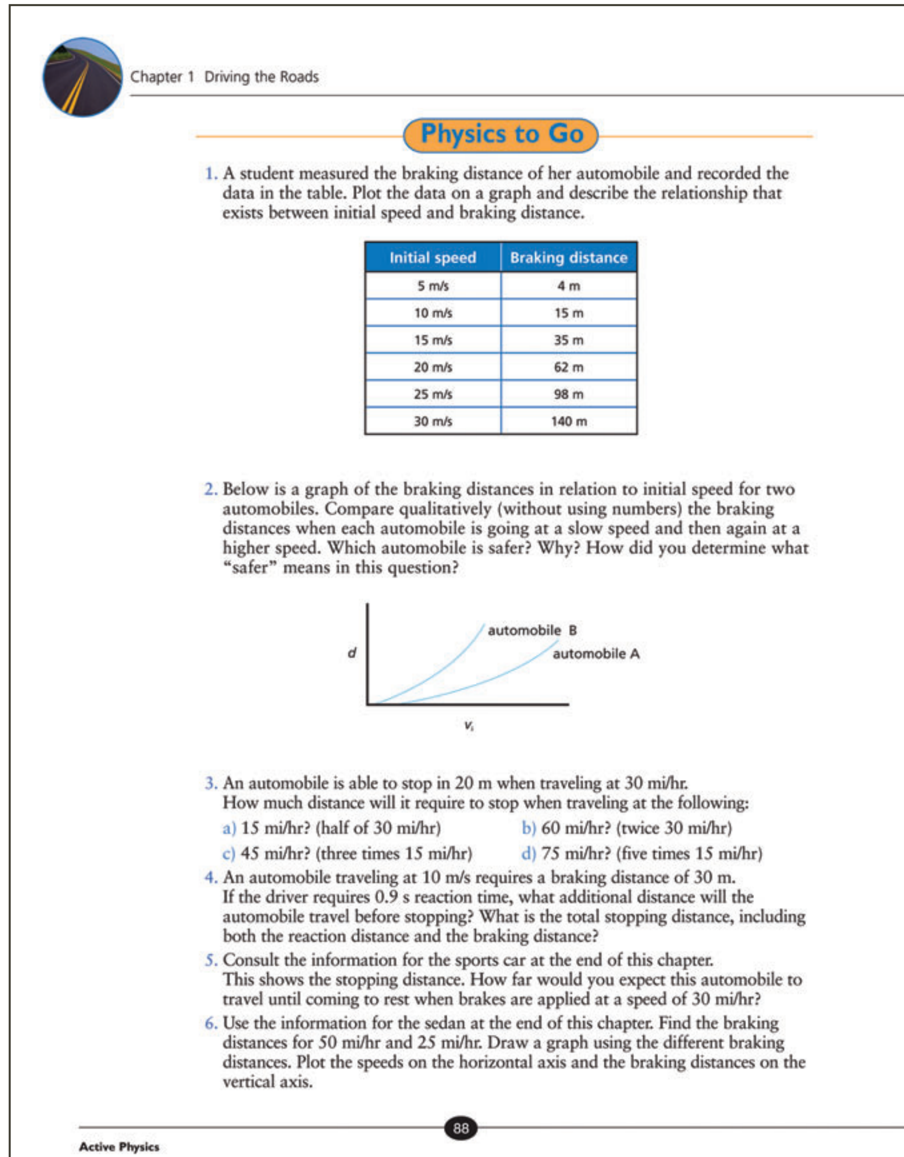
Students should recognize that the braking distance for half the speed will be ¼ of the distance. Therefore, the distance required to stop at 15 mi/h will be 5 m.

3.b)

60 mi/h is twice 30 mi/h; therefore, the distance required to stop will be four times the braking distance, or 100 m.

3.c)

45 mi/h is three times the speed of 15 mi/h; therefore, the distance required to stop will be nine times the braking distance at 15 mi/h or 45 m.



Chapter 1 Driving the Roads

Physics to Go

1. A student measured the braking distance of her automobile and recorded the data in the table. Plot the data on a graph and describe the relationship that exists between initial speed and braking distance.

Initial speed	Braking distance
5 m/s	4 m
10 m/s	15 m
15 m/s	35 m
20 m/s	62 m
25 m/s	98 m
30 m/s	140 m

2. Below is a graph of the braking distances in relation to initial speed for two automobiles. Compare qualitatively (without using numbers) the braking distances when each automobile is going at a slow speed and then again at a higher speed. Which automobile is safer? Why? How did you determine what "safer" means in this question?

3. An automobile is able to stop in 20 m when traveling at 30 mi/hr. How much distance will it require to stop when traveling at the following:
   a) 15 mi/hr? (half of 30 mi/hr)
   b) 60 mi/hr? (twice 30 mi/hr)
   c) 45 mi/hr? (three times 15 mi/hr)
   d) 75 mi/hr? (five times 15 mi/hr)
4. An automobile traveling at 10 m/s requires a braking distance of 30 m. If the driver requires 0.9 s reaction time, what additional distance will the automobile travel before stopping? What is the total stopping distance, including both the reaction distance and the braking distance?
5. Consult the information for the sports car at the end of this chapter. This shows the stopping distance. How far would you expect this automobile to travel until coming to rest when brakes are applied at a speed of 30 mi/hr?
6. Use the information for the sedan at the end of this chapter. Find the braking distances for 50 mi/hr and 25 mi/hr. Draw a graph using the different braking distances. Plot the speeds on the horizontal axis and the braking distances on the vertical axis.

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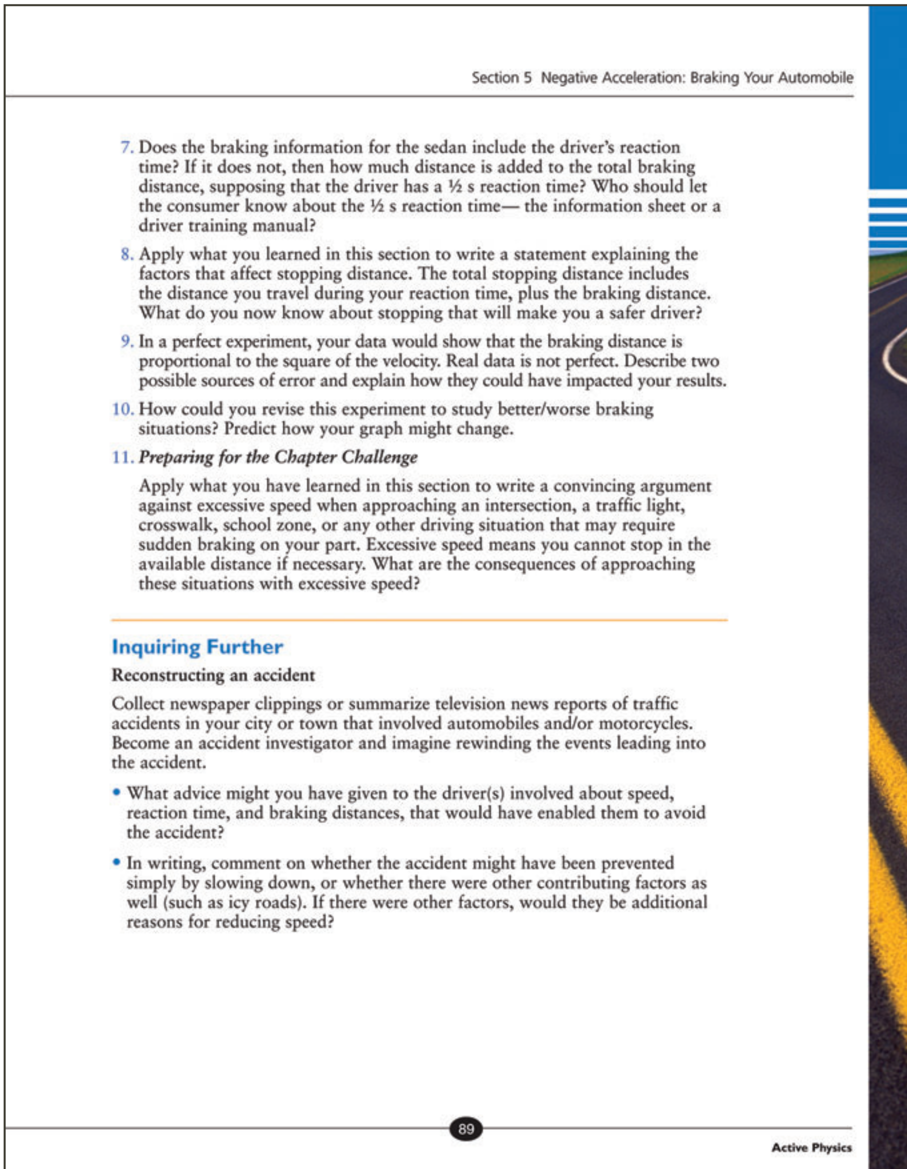
Active Physics

3.d)

75 mi/h is five times the speed of 15 mi/h; therefore, the distance required to stop will be 52 m, or 25 times the braking distance, or 125 m.

4.

The additional distance traveled can be found using $v = d/t$ and solving for d. $d = vt$ gives $d = (10\text{ m/s})(0.9\text{ s}) = 9\text{ m}$ for the distance covered during the driver's reaction time. The total stopping distance covered during the driver's reaction time (9 m) plus the braking distance (30 m) for a total stopping distance of 39 m. The driver's manual will not include this information, since reaction time for each driver varies; therefore, only the braking distance is listed.



7. Does the braking information for the sedan include the driver's reaction time? If it does not, then how much distance is added to the total braking distance, supposing that the driver has a ½ s reaction time? Who should let the consumer know about the ½ s reaction time— the information sheet or a driver training manual?
8. Apply what you learned in this section to write a statement explaining the factors that affect stopping distance. The total stopping distance includes the distance you travel during your reaction time, plus the braking distance. What do you now know about stopping that will make you a safer driver?
9. In a perfect experiment, your data would show that the braking distance is proportional to the square of the velocity. Real data is not perfect. Describe two possible sources of error and explain how they could have impacted your results.
10. How could you revise this experiment to study better/worse braking situations? Predict how your graph might change.
11. ***Preparing for the Chapter Challenge***

    Apply what you have learned in this section to write a convincing argument against excessive speed when approaching an intersection, a traffic light, crosswalk, school zone, or any other driving situation that may require sudden braking on your part. Excessive speed means you cannot stop in the available distance if necessary. What are the consequences of approaching these situations with excessive speed?

Inquiring Further

Reconstructing an accident

Collect newspaper clippings or summarize television news reports of traffic accidents in your city or town that involved automobiles and/or motorcycles. Become an accident investigator and imagine rewinding the events leading into the accident.

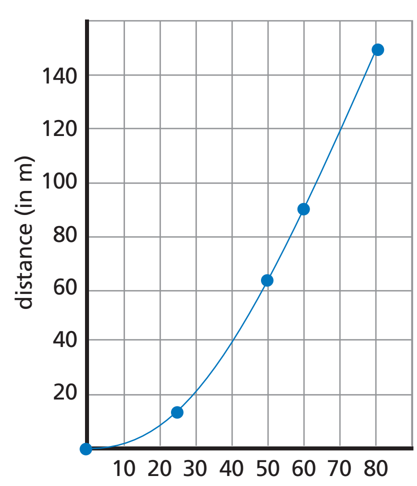
- What advice might you have given to the driver(s) involved about speed, reaction time, and braking distances, that would have enabled them to avoid the accident?
- In writing, comment on whether the accident might have been prevented simply by slowing down, or whether there were other contributing factors as well (such as icy roads). If there were other factors, would they be additional reasons for reducing speed?

5.

At 30 mi/h, half of 60 mi/h, the stopping distance will be ¼ of 118 ft, or about 30 ft.

6.

The braking distance for 50 mi/h is about 94 ft. The braking distance for 25 mi/h is about 23 ft. The shape of the graph should be a parabola.



7.

The driver's reaction time is not included on the data sheet. The driver's reaction time would add an additional 44 ft at 60 mi/h. As to who should supply this information, students' answers will vary. Look for sound arguments that can be shared with the class.

8.

Answers will vary. Expect some of the following:

- speed of travel
- road conditions
- brake condition
- reaction times
- tire condition
- weather conditions

9.

Sources of differences between the idealized mathematical model and the real data might include the following:

- Acceleration is not precisely constant.
- Time and distance have measurement errors.

10.

Worse braking situations could use surfaces with less friction (ice, gravel); surfaces with variable friction (blacktop road with some gravel on it); different tires, etc. All the graphs would still remain parabolas, but the curves would be different — steeper for better brakes and less curved for poor brakes.

CHAPTER 1

11.

Preparing for the Chapter Challenge

Students' paragraphs should include information on how the braking distance increases with the square of the automobile's velocity. In areas where the situation may change rapidly and the driver would be required to stop at a short distance, slow speeds and short braking distances are needed.

Inquiring Further

The students should make suggestions detailing their knowledge of how braking distance depends upon the automobile's velocity and how the total braking distance depends upon the reaction distance (and thus reaction time) and the braking distance. If a rear-end collision occurred, they may make suggestions regarding a safe following distance and how this relates to reaction time and braking distances. The students should indicate whether a slower speed would have prevented the collision or if there were other conditions that should have been taken into consideration, such as a sharp bend in the road that might have obscured frontal vision.

The students should also discuss how road conditions might have affected the braking distances involved, and how the drivers might have responded to these conditions to prevent the accident. Conditions such as snow, or rain, will increase braking distances, and fog will increase both reaction time and reaction distance.

If students live in an area with very few automobile accidents, you may wish to provide stored clippings for them from local papers, or download descriptions from the Internet. Many papers have archived online editions that might provide descriptions of multiple vehicle accidents due to conditions such as fog, rain, and snowstorm "white-outs."

NOTES

SECTION 5 QUIZ

1-5c Blackline Master

1. For this question, the direction east is positive, and the direction west is negative. A vehicle is traveling east at 10 m/s when it starts to undergo a negative acceleration of -1 m/s^2 as it comes to rest. Which of the following quantities will be also be negative as the vehicle starts to undergo the negative acceleration coming to rest?

   a) The vehicle's velocity.

   b) The vehicle's change in position.

   c) Both the vehicle's velocity and its change in position.

   d) Neither the vehicle's velocity nor its change in position.

2. A skater uniformly decreases her speed from 6 m/s to zero over a distance of 12 m. Her acceleration would be

   a) 1.5 m/s^2. b) -1.5 m/s^2.

   c) 3 m/s^2. d) -3 m/s^2.

3. An automobile is going 20 m/s when it applies the brakes and stops after traveling a distance of 20 m. If the automobile was going at 10 m/s, it would be able to stop in a distance of

   a) 10 m. b) 20 m.

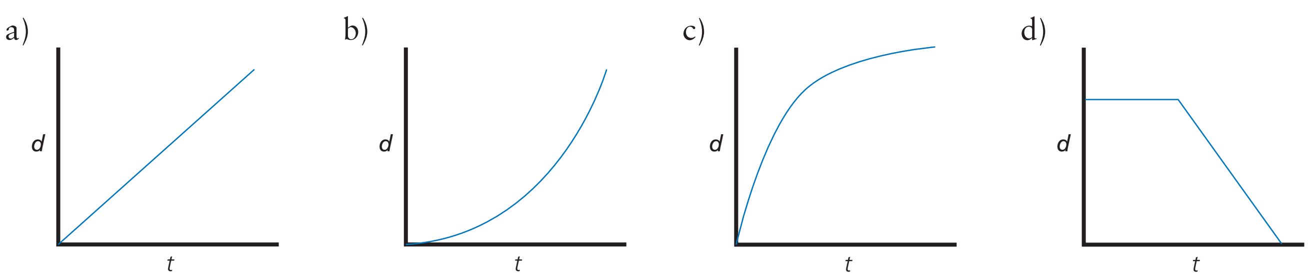
   c) 80 m. d) 5 m.

4. A driver of an automobile with poor brakes finds that if he triples his speed, his stopping distance is 9 times longer. The driver of another car with very good brakes tries the same test. If he triples his speed, he will find that his braking distance has increased by a factor of

   a) 3 times. b) between 6 and 9 times.

   c) between 3 and 6 times. d) 9 times.

5. Which distance vs. time graph to the right would best represent the velocity of a girl on a bike from the moment she sees the branch fall until the bike comes to rest?



SECTION 5 QUIZ ANSWERS

1. d) Although the vehicle has a negative acceleration, the vehicle will continue traveling east with a reduced velocity and move to the east until it comes to a stop, so both the velocity and change in position are positive even though the acceleration is negative.

2. b) Using the equation $v_i^2 = 2ad$ and solving for a, we have
$$a = \frac{v_i^2}{2d} = \frac{(6 \text{ m/s})^2}{2(12 \text{ m})} = 1.5 \text{ m/s}^2.$$
Because the skater is slowing down while moving forward, she should undergo a negative acceleration. Students who got the answer 3 m/s^2 did not divide by 2.

3. d) When the speed is cut in half, the braking distance becomes one fourth, or 5 m.

4. d) The driver of the automobile with good brakes would still take nine times the distance to stop when he triples his speed, but the distances would be smaller than those of the automobile with poor brakes.

5. c) The distance vs. time graph shows an object traveling with constant speed (the straight line section), and later with changing speed (the curved section) where the distance does not increase with time and the vehicle gradually comes to a stop.

NOTES