SECTION 1

Velocity and Acceleration: The Big Thrill

Section Overview

Students begin investigating roller coasters by drawing a roller coaster of their own design and then consider the Terminator Express roller coaster, which they will modify for the *Chapter Challenge*. To understand what makes roller coasters such fun, students start by blindfolding a person in a chair with wheels and pushing the chair around by varying the direction and speed. The rider rates each type of move according to the level of "thrill" that he or she experiences on a 1-to-5 scale. Students then decide whether it is displacement, velocity, or acceleration during the ride that provides the excitement, and investigate which part of a blindfolded chair ride caused the rider's greatest reactions. Students also measure and analyze relationships between speed and acceleration for a ball on a track. Their observations support the concepts of displacement, speed, velocity, and acceleration. Finally, students apply what they know to solve problems on the concepts they have investigated.

Background Information

Velocity is defined as the change of position (displacement) divided by the time elapsed. This definition can be written as an equation:

$$v = \Delta d / \Delta t$$

where Δd is the displacement and Δt is the time elapsed. The units for displacement are meters and the units for time are seconds; hence the units for velocity are m/s (meters per second). Velocity is a vector quantity. It has both a magnitude and a direction. The direction of the displacement is the direction of the velocity.

Although you recognize speed and velocity as you move about in cars, trains, planes or walking, there are misconceptions that you are well aware of and you must listen intently to your students to catch these misconceptions and help them confront them. For example, students may confuse position with velocity. When one car passes another, students may think that at the instant one car passes another, their speeds are identical.

Acceleration is defined as a change in velocity divided by the time elapsed. This definition can be written as an equation:

$$a = \Delta v / \Delta t$$

The units for velocity are m/s and the units for time are seconds; the units for acceleration are (m/s)/s (meters per second every second). It is often abbreviated as the equivalent m/s^2 (meters per second squared) but student understanding will be increased if the units are stated as m/s every second. This will continue to reinforce the definition of acceleration as a change in velocity divided by the time elapsed. Acceleration is a vector quantity. It has both a magnitude and a direction. The direction of the change in velocity is the direction of the acceleration. Acceleration is a change of velocity with respect to time, while velocity is, in itself, a change of position (displacement) with respect to time. It's very difficult for students to grasp a change of a change. In calculus, you recognize a change of a change as the second derivative of the function.

Strictly speaking, the velocity and acceleration as defined above are quantities averaged over the time elapsed. More sophisticated treatments would let the elapsed time become very short, so we could talk about the velocity or acceleration at a particular instant of time. Although the distinction between average velocity and instantaneous velocity is important in some circumstances, the difference is not crucial for the sections discussed in this chapter.

Crucial Physics

- A vector quantity has magnitude (how much) and direction (which way). A scalar quantity has only magnitude (how much). There is no direction associated with it. Both quantities require units for a complete description.
- Speed is calculated by dividing the distance (the path length) traveled by the elapsed time. Both speed and distance are scalar quantities, having no direction. Speed is measured in meters/second.
- The average velocity is given by the displacement (change in position) over the time elapsed. Both displacement and velocity are vector quantities. The average velocity is in the same direction as the displacement. Velocity is measured in meters/second.
- The acceleration of an object is defined as the change in velocity divided by the time elapsed. Whenever an object's velocity changes (either its magnitude, direction, or both) the object accelerates. Acceleration is measured in meters/second/second.
- You can "feel" your acceleration because of the forces on you that must be exerted to accelerate you and your internal organs.

Learning Outcomes	Location in the Section	Evidence of Understanding
Sketch and interpret a top view and a side view of a roller-coaster ride.	***Investigate*** Steps 1 and 2	Students sketch diagrams and interpret the advantages and disadvantages of having two sketches.
Identify whether thrills in roller-coaster rides come from speeds, accelerations, or changes in each.	***Investigate*** Steps 3-7	A student pushes a blindfolded student around in a chair at different speeds and directions, and from the reaction of the blindfolded person determines the extent of the blindfolded person's reaction.
Define accelerations as a change in velocity with respect to time and recognize the units of acceleration.	***Investigate*** Steps 4-8 ***Physics Talk***	Students note the change in velocity while pushing a blindfolded rider, and arrive at the definition of acceleration.
Calculate and measure velocity and acceleration.	***Investigate*** Part C: Steps 1-7	Students correctly calculate the velocity and acceleration of the ball on the track.

NOTES

Section 1 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Beespi	1 per group	
Ball, steel sphere, 3/4 in.	1 per group	
Track (plastic piece for roller coaster)	1 per group	
Track, wood, base pack (to include hardware)	1 per group	
Holder, right angle, cast iron	1 per group	
Rod, aluminum, 3/8 in. x 12 in. (to act as crossarm)	1 per group	
Ring stand, large	1 per group	
Meter stick	1 per group	
Stopwatch	1 per group	
C-clamp, 3 in.	1 per group	
Ruler, metric, in./cm	1 per group	
Battery, alkaline, AAA	2 per group	
Blindfold*		1 per class
Chair (w/ wheels)*		1 per class
Access to a flat surface*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow one and a half 45-minute class periods or 65 minutes for this investigation.

Teacher Preparation

- If you are not familiar with making orthographic (top and side view) drawings, ask an art or mechanical-drawing teacher for assistance.
- If a chair with casters is not normally available, arrange to have one in the classroom for this day, as well as material to blindfold the students who will ride in the chair and the appropriate safety equipment.
- If you are using the velocimeters, familiarize yourself and the students with how to convert the readings to meters/second. If you are using photogates, show the students how to place the photogate so the center of the ball passes through the gate and how to calculate the ball's speed.
- If tracks are not available for the ball, inclined planes with meter sticks taped on may be used to provide a path.

Safety

NOTE: Unless stated otherwise, safety goggles should always be worn during lab investigations.

- Students who will be riding in the chair in *Part B* should wear appropriate safety equipment, including a helmet, and elbow and kneepads. To ensure safe chair behavior, it is best if the teacher pushes the chair for *Part B*.
- The students should keep careful control over the steel balls used in *Part C*. The steel balls should not land on the floor where someone may slip on them.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Beespi		1 per class
Ball, steel sphere, 3/4 in.		1 per class
Track (plastic piece for roller coaster)		1 per class
Track, wood, base pack (to include hardware)		1 per class
Holder, right angle, cast iron		1 per class
Rod, aluminum, 3/8 in. x 12 in. (to act as crossarm)		1 per class
Ring stand, large		1 per class
Meter stick		1 per class
Stopwatch	1 per group	
C-clamp, 3 in.		1 per class
Ruler, metric, in./cm		1 per class
Battery, alkaline, AAA		2 per class
Blindfold*		1 per class
Chair (w/ wheels)*		1 per class
Access to a flat surface*		1 per class

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes to do the *Investigate* and *Physics Talk* discussion.

Teacher Preparation

- Most of the planning for *Plan A* still applies, but only one material setup is required. Prepare one track and velocimeter or photogate setup for the front of the classroom. Several students should be recruited to assist you in taking the measurements and recording them on the board for the rest of the class to record in their journals. If a camera and projection system is available it should be used so the students can see more clearly what is occurring.
- Practice several trials with the track and ball prior to the class to be certain consistent results are obtained. Mark the positions for the ball on the track that you will be using, and make the conversions from the km/h recorded by the velocimeter to the m/s needed for calculation prior to the start of class.
- Make a Blackline Master of the diagrams in *Part A*, *Step 4* and a transparency of *Part C*, *Step 7* of the *Investigate* in the *Student Edition*.
- Summarize the *Investigate* to familiarize the students with what they will be observing.
- *Part B* of the *Investigate* should be done with the teacher pushing the chair and a student riding.

Safety

NOTE: Unless stated otherwise, safety goggles should always be worn during lab investigations.

- Students who will be riding in the chair in *Part B* should wear appropriate safety equipment including a helmet, and elbow and kneepads. To ensure safe chair behavior, it is best if the teacher pushes the chair for *Part B*.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Learning and using content vocabulary	***Chapter Challenge*** Physics Corner	**Augmentation** • A strategy that is very effective to teach new vocabulary to students who struggle to decode words or who have difficulty with memory is to pre-teach vocabulary. Introduce all of the words in this list before the class begins the chapter. It is not necessary to teach all of the word meanings at this point, but allow students to read the list aloud and activate prior knowledge by trying to define the vocabulary in their own words. As the class progresses through the chapter, ask students to check their definitions and decide if they need to add to or delete parts of their predicted definitions. **Accommodation** • For students who struggle with basic reading and writing tasks, provide a typed word list that students can easily access. This list can be used to practice reading the words with a parent, special education teacher, speech and language therapist, etc. Also, students can reference the list when they are answering questions or working on the *Chapter Challenge*.
Lacking a common experience	***What Do You Think?***	**Augmentation** • Assume that at least one student in the class has never seen or ridden a roller coaster. Show video footage of people riding roller coasters and ask students to record their observations. Explicitly tell students to record the reactions of the riders at each part of the roller coaster. Students may need to watch the footage more than once to record meaningful observations. • Students in the class who have been on a roller coaster could also describe how they felt when they rode a roller coaster.
Sketching a roller coaster	***Investigate*** Part A, Steps 1-4 ***Investigate*** Part D, Step 1 ***Physics to Go*** Questions 1, 10.b)	**Augmentation** • Students who do not see drawing as a personal strength or who have difficulty with fine motor tasks, may take an excessive amount of time to complete these tasks. Provide students with a reasonable time limit for each step. Also, explain that a sketch is a quick drawing with little detail that may be turned into a more detailed drawing at a later time. • Teach students the meaning of roller-coaster vocabulary including "descend," "horizontal," and "vertical," by asking students to explain the definitions in their own words. • Create a class list of the characteristics of the preferred sketches to be used as a reference throughout *Chapter 4*. **Accommodation** • Provide a photocopy of *Part D*, *Step 1*, for students who have significant difficulties with fine motor skills or vision. This will allow students to focus on labeling the diagram to understand the concept of "pulling *g*'s" instead of focusing on drawing skills.
Maintaining control of one's impulses, especially when caught up in the moment	***Investigate*** Part B, Step 3	**Augmentation** • Students who have difficulty with impulse control may know and understand the safety precautions put forth by the teacher, however, when they get caught up in the excitement of the activity, these students may not remember the rules of the activity. Before students begin pushing their classmates in the chairs, establish an alert sign or phrase such as flashing the lights, clapping, or saying the word "stop." This alert signal will allow the teacher to immediately get the attention of all of the students in the room if things are getting out of control or if someone is being unsafe. • Assign groups with a student leader who does not struggle with impulse control.

Learning Issue	Reference	Augmentation and Accommodations
Understanding the concept of a vector Drawing vectors	***Investigate*** Part B, Steps 6-7	**Augmentation** • Understanding that acceleration can change because of a change in direction, even though the magnitude remains constant, is a difficult concept for students who are concrete learners because vectors are more abstract concepts. • Explain what a vector represents and the reasons scientists draw vectors. • Review the basic rules for drawing vectors. 1) Vectors are represented with arrows. 2) The direction and length of the arrows are important. • Provide opportunities to practice drawing vectors and receive feedback from the teacher or peers. • This activity could be differentiated by using the *Active Physics Plus* section to challenge students with more advanced math skills, while the teacher is reviewing basic vector rules with the rest of the class.
Differentiating distance and displacement	***Physics Talk*** ***Checking Up*** Question 1	**Augmentation** • For many students, the difference between distance and displacement is too subtle to seem important and too abstract to be understood conceptually. Help the students create a few concrete diagrams to represent situations for which the distance and displacement are the same and situations for which they are different. • To begin, students could draw diagrams of the situations described in *Physics Talk*. Then students could draw new situations that compare distance and displacement and share the drawings with their peers. • Remember that conceptually understanding distance and displacement will make it much easier for students to understand the concepts of velocity and speed. **Accommodation** • Provide diagrams of scenarios and ask students to label the distance and displacement on the diagrams.
Using formulas to do calculations	***Physics to Go*** Questions 3, 4, 6, 7, and 8	**Augmentation** • Students often need many opportunities to practice and receive feedback when using new skills. • Model or ask volunteers to model the problem-solving method required in class using the speed, velocity, and acceleration formulas. Providing sample problems for students to refer back to when they are working through problems independently helps increase student accuracy and success. • Practicing a problem-solving method with these more simple formulas will also be helpful later in the chapter when more complicated formulas are introduced. **Accommodation** • Provide a sheet of blank problem-solving boxes (a graphic organizer) for students who struggle to organize their steps or have had difficulty with problem solving in the past.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate*** Part A: Step 5	You may need to explain "loading platform." You may also wish to review the term "radius" and explain that it applies not only to circles but also to smooth curves. The terms "vertical" and "horizontal" were reinforced in *Physics in Action, Projectile Motion*, and now would be a good time to practice fluency in the use of these terms.
Comprehension	***Investigate*** Part B: Step 2	Rating something on a scale of 1 to 5 may not be a familiar practice to some ELL students. They may benefit from an example or two.
Vocabulary comprehension	***Investigate*** Part B: Step 3	Help students understand the word "exhibits" in context. They may be familiar with the use of this term as a noun, for example in a museum exhibit. Work around to the verb form by asking what a museum exhibit does (shows the item on display). So, to exhibit a thing or an emotion is to show it.
Comprehension	***Investigate*** Part B: Step 7.b)	Before moving on, make sure students understand that accelerations elicited the strongest responses from the rider.
Understanding concepts	***Investigate*** Part C: Step 1.a)	Make sure students identify instruments for measuring distance, direction, and time as the tools necessary for measuring velocity.
Vocabulary comprehension	***Investigate*** Part C: Step 2.a)	All students may benefit from a discussion of the terms "distance," "position," and "displacement." Point out that because position can be described by two coordinates on a grid, with no reference to direction, position is a scalar. A change in position (displacement) always has a direction, so it is a vector. The term "distance" gives the magnitude of the change in position, but because it does not specify the direction, it is a scalar.
Understanding concepts	***Investigate*** Part C: Step 4	When you demonstrate the use of a photogate timer, make sure to tell students which kind you are using, double-beam or single-beam. Make sure students understand how it works. Even if you have a double-beam photogate timer, which computes the speed for you, you will need to make sure students understand how the single-beam type works, because they will need to make calculations for scenarios using that type of timer. Before you move on to *Step 5*, make sure students can answer the question at the end of *Step 4.b)* [the diameter of the steel ball].
Understanding concepts	***Investigate*** Part D: Step 1.a)	The phrase "pulling *g*'s" may be confusing for ELL students. The term "*g*" is used here as a noun, so it can be used in a plural form. Explain that one *g* would be an acceleration of 9.8 m/s^s, and two *g*'s would be double that, or 19.6 m/s^s. The phrase "pulling *g*'s" refers to a force that would produce accelerations greater than *g.* If this force is in the same direction as the force of gravity, the rider feels heavy. If this force is in the opposite direction to the force of gravity, the rider feels light.
Understanding concepts	***Physics Talk***	Provide opportunities for ELL students to use the terms "distance" and "displacement" in a class discussion. Have one student read aloud the paragraph that begins, "For a person walking one lap around a city block…" Then ask for a volunteer to explain why the displacement and velocity are zero. To encourage further development of language skills, encourage students to debate whether a person with a velocity of zero has moved.
Vocabulary comprehension	***Inquiring Further***	Make sure students understand "innovations" and "retained" in context.

CHAPTER 4

NOTES

SECTION 1

Teacher Suggestions and Sample Answers

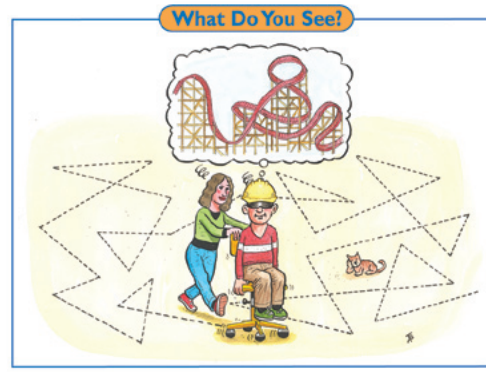
What Do You See?

The *What Do You See?* illustration is designed to stimulate students' curiosity. Consider using an overhead to highlight certain aspects and trace the zigzag paths that are shown, asking students what these patterns might suggest. Encourage students to ponder each visual and what the details might suggest. As a prompt, you could ask them why the person has been blindfolded or why is the person being pushed around in a chair with wheels. As students begin to warm up to the discussion with answers, ask them to recall these initial impressions as they move further along in the chapter.

Chapter 4 Thrills and Chills

Section 1 Velocity and Acceleration: The Big Thrill

What Do You See?



Learning Outcomes

In this section, you will

- **Sketch** and interpret a top view and a side view of a roller-coaster ride.
- **Identify** whether thrills in roller-coaster rides come from speeds, accelerations, or changes in each.
- **Define** acceleration as a change in velocity with respect to time and recognize the units of acceleration.
- **Calculate** and measure velocity and acceleration.

What Do You Think?

The tallest wooden roller coaster has a height of about 66 m (218 ft). The tallest steel roller coaster is 128 m (420 ft) high. This is as tall as a 40-story high-rise building.

- **Which part of the roller-coaster ride produces the loudest screams? Why?**

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

Investigate

Part A: Sketch of the Roller Coaster

1. Sketch a roller coaster with a first hill of 15 m that quickly descends to 6 m and then turns to the right in a big circle (radius of 10 m) and then descends back to the ground.
   a) Include a copy of the sketch in your *Active Physics* log.
2. Compare the sketch of your roller-coaster design with those of others on your design team.
   a) Which sketch do you like the best? Provide three reasons why you prefer that sketch.

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Students' Prior Conceptions

Prior to this study of the concepts developed in *Thrills and Chills*, teachers should brainstorm with students to assure that they do not confuse energy issues. Students shouldn't confuse or conflate the scientific law of conservation of energy with environmental conservation or with conservation of energy issues widely discussed in current events, the media, and/or in other study areas. This first section enables students to explore their prior conceptions on gravity, particularly the direction in which gravity acts.

1. **Students believe that objects are pushed down rather than pulled down by gravity.** Given the opportunity to measure and to calculate accelerations and to understand that the velocity changes as roller-coaster rides go up and down hills offer students opportunities to check their nascent ideas on how objects behave in a gravitational field. Calculating decreasing speeds at the top and increasing speeds at the bottom of hills should affirm the pull of gravity on objects in student thinking. Thrills accompany the greater velocity as riders are pulled down the hill of the coaster.

What Do You Think?

Ask students to use the illustration presented in the *What Do You See*? to help them answer this question. Students might want to talk of their own experiences on a roller coaster. Encourage them to write down their responses and point out that they will be returning to the question again, and will be given a chance to modify their answers based on their investigations. At this stage, students should be evaluated on the level of their engagement and not for the correctness of their responses. You should emphasize that this question is designed to elicit students' prior understanding.

What Do You Think?

A Physicist's Response

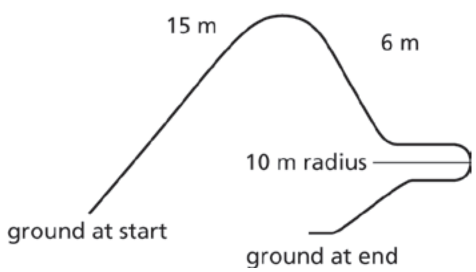
Although when screams will occur may seem to be a subjective question, in general, the loudest screams on a roller coaster take place when two criteria are met: The first one is that the rider undergoes a large change in velocity (acceleration). This occurs when the rider is changing speeds quickly, or possibly going around a loop. The change in velocity is also associated with a rapid change in the force that is holding the rider against the seat of the car, affecting their sense of security. The roller-coaster builders strive to achieve this in a manner that is as safe as possible for the riders. The second criterion is that the rider's visual stimulus suggests that something particularly dangerous is about to occur. This is often done by adjusting either the scenery, or putting the riders in a novel situation that also affects their sense of security. And when you are scared, you scream.

Investigate

Part A: Sketch of the Roller Coaster

1.a)

Before the students draw the roller-coaster ride, you might have the students draw a side view sketch and top view sketch of a simple straight incline. Have the students talk about the relationship between the sketches and the actual incline. This should help the students get started on the roller coaster sketches. One possible sketch might appear like the one below:



2.a)

Students who have experience with top and side views may prefer their sketches to those that tried a different approach. Students' reasons for preferring a specific sketch over others should express clarity.

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3.a)

Students should realize that the advantage of having both a top and a side-view sketch provides information in three dimensions rather than the two dimensions from a single sketch.

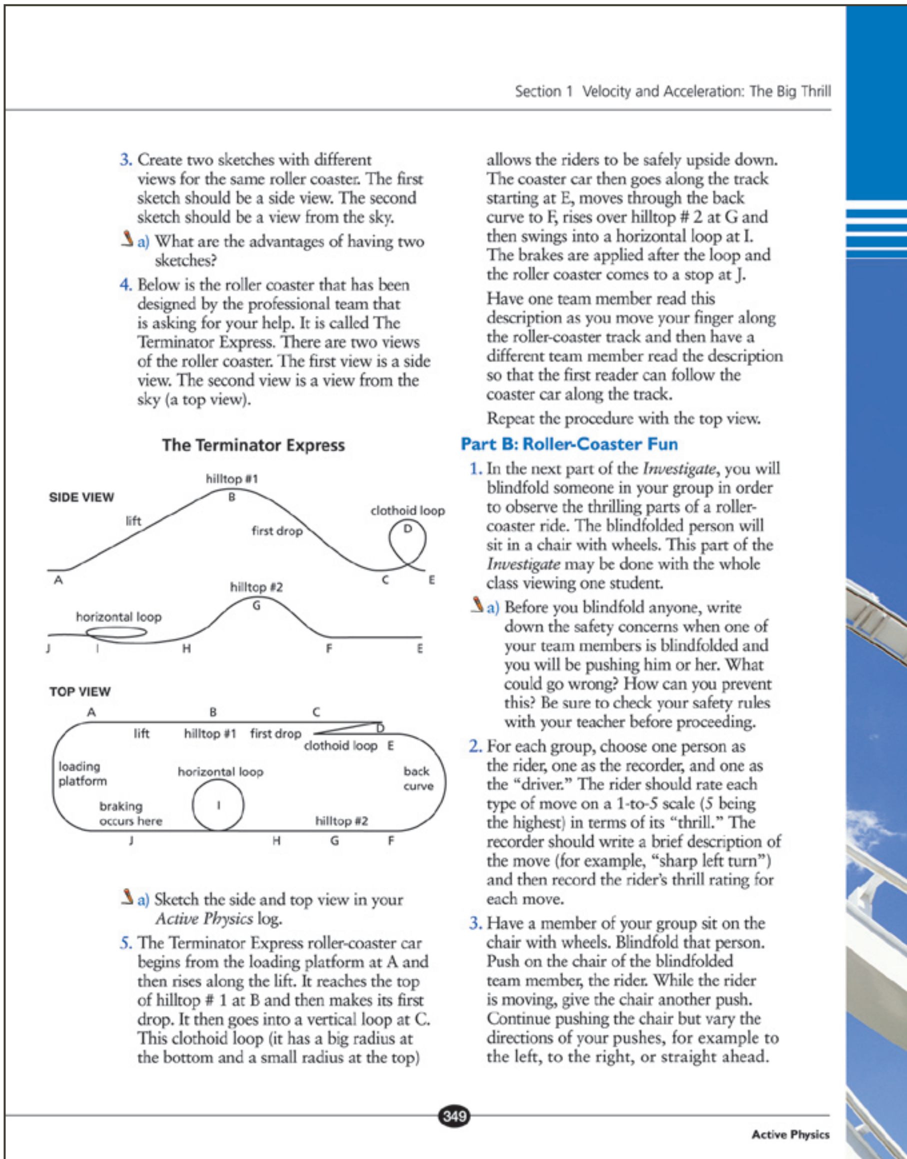
Teaching Tip

Try drawing a simple roller coaster on the board or overhead projector and ask the students to draw a side and top view for practice. Then show a side and top view.

4.a)

Having students actually sketch the diagrams from the text in their logs is preferable to giving them a copy of the diagram at this time.

4-1a Blackline Master



Section 1 Velocity and Acceleration: The Big Thrill

3. Create two sketches with different views for the same roller coaster. The first sketch should be a side view. The second sketch should be a view from the sky.

   a) What are the advantages of having two sketches?

4. Below is the roller coaster that has been designed by the professional team that is asking for your help. It is called The Terminator Express. There are two views of the roller coaster. The first view is a side view. The second view is a view from the sky (a top view).

The Terminator Express

   a) Sketch the side and top view in your *Active Physics* log.

5. The Terminator Express roller-coaster car begins from the loading platform at A and then rises along the lift. It reaches the top of hilltop # 1 at B and then makes its first drop. It then goes into a vertical loop at C. This clothoid loop (it has a big radius at the bottom and a small radius at the top) allows the riders to be safely upside down. The coaster car then goes along the track starting at E, moves through the back curve to F, rises over hilltop # 2 at G and then swings into a horizontal loop at I. The brakes are applied after the loop and the roller coaster comes to a stop at J.

   Have one team member read this description as you move your finger along the roller-coaster track and then have a different team member read the description so that the first reader can follow the coaster car along the track.

   Repeat the procedure with the top view.

Part B: Roller-Coaster Fun

1. In the next part of the *Investigate*, you will blindfold someone in your group in order to observe the thrilling parts of a roller-coaster ride. The blindfolded person will sit in a chair with wheels. This part of the *Investigate* may be done with the whole class viewing one student.

   a) Before you blindfold anyone, write down the safety concerns when one of your team members is blindfolded and you will be pushing him or her. What could go wrong? How can you prevent this? Be sure to check your safety rules with your teacher before proceeding.

2. For each group, choose one person as the rider, one as the recorder, and one as the "driver." The rider should rate each type of move on a 1-to-5 scale (5 being the highest) in terms of its "thrill." The recorder should write a brief description of the move (for example, "sharp left turn") and then record the rider's thrill rating for each move.

3. Have a member of your group sit on the chair with wheels. Blindfold that person. Push on the chair of the blindfolded team member, the rider. While the rider is moving, give the chair another push. Continue pushing the chair but vary the directions of your pushes, for example to the left, to the right, or straight ahead.

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5.

Ensure that lab partners reverse roles when shifting from the top view to the side view so that each has a chance to move a finger around the roller coaster. Encourage all of the students to participate.

Part B: Roller-Coaster Fun

1.a)

Students should list safety precautions before blindfolding someone in their group, and write them on the board. Have the student wear a bicycle helmet and hold onto the arms of the chair. Choose a large open area for this *Investigate* so there is no danger of running into any obstacles. High velocities are not necessary and violent forces leading to extremely rapid changes in direction should not be attempted. If the rider starts to feel ill or nauseous the investigation should be terminated immediately. The safety rule should include all those previously mentioned. Include any additional suggestions the students have that seem reasonable for safety.

After completing the safety precautions listed above move the chair at a constant speed and then quickly change directions. Play with sudden stops, quick turns, and large increases in speed. Have the other students record the rider's reactions. Maintain the safety of the rider at all times. Your students will find that the rider will smile, laugh, or make sounds during the accelerations.

2.

These are instructions for the student rider. You may ask the rider to shout out a number on the 1–5 scale as the chair is being pushed.

3.

Any change in direction or speed will probably produce a reaction, regardless of the direction of the push. Keep the safety of the student rider and watchers paramount at all times during this investigation.

CHAPTER 4

3.a)

Have the students record both the thrill factor and what the motion was that caused that factor's number in their logs.

4.a)

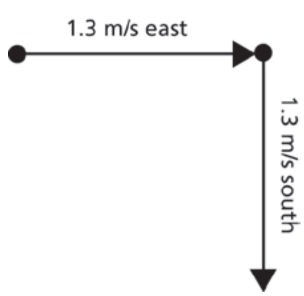
The velocity by itself does not produce a large reaction by the rider. It is the changes in the velocity that the rider feels most strongly. These changes could be increases or decreases in the speed or a change in direction of the speed or a combination of the two simultaneously. The highest ratings will probably be for sudden changes in direction and speed simultaneously.

5.a)

Using change in velocity as the difference between the beginning and the ending velocities, students calculate the change in velocity to be 1.5 m/s – 1.1 m/s = 0.4 m/s.

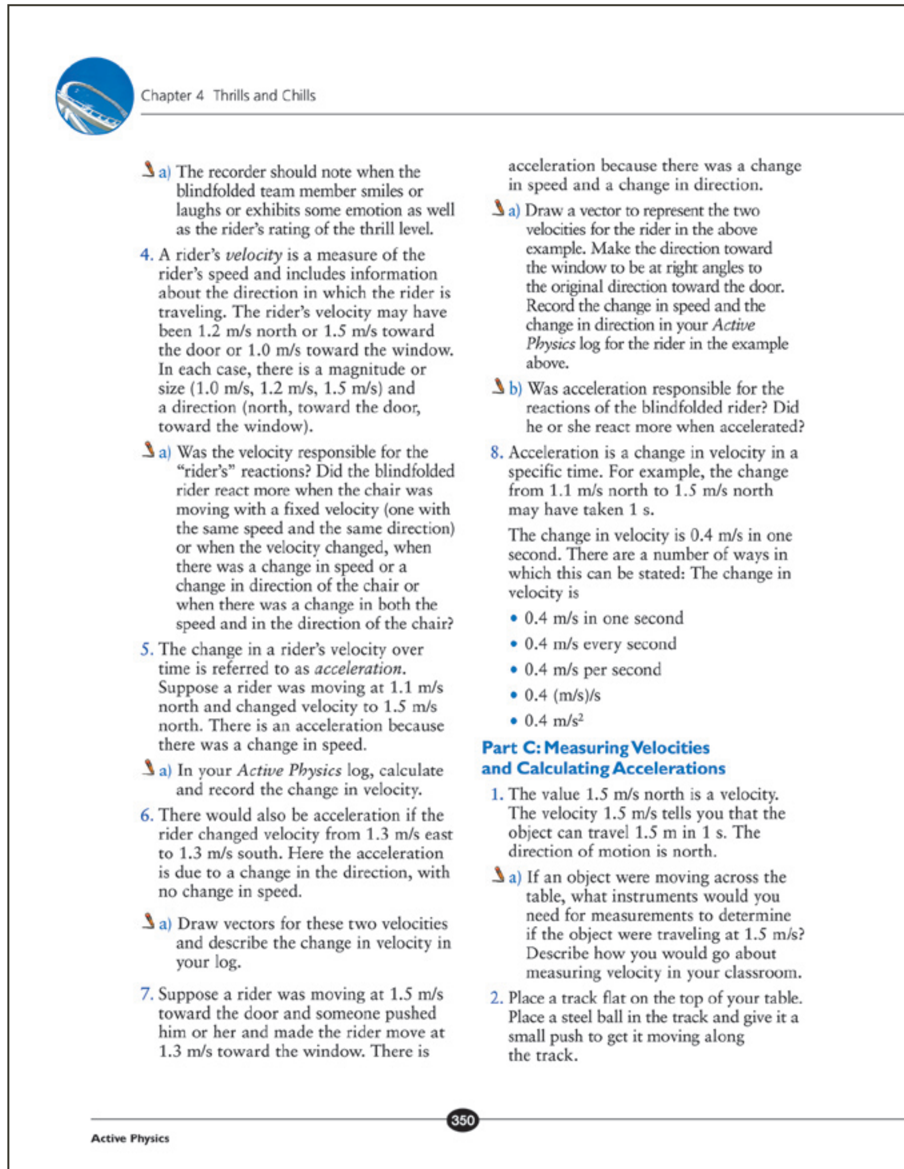
6.a)

Students' drawings should look like the one below:



7.a)

Students' diagrams should be similar to the one shown to the right. Direction of the vectors is not important, but they should be at right angles. Students should record a change in speed of 0.2 m/s and a direction change of 90 degrees.



Chapter 4 Thrills and Chills

a) The recorder should note when the blindfolded team member smiles or laughs or exhibits some emotion as well as the rider's rating of the thrill level.

4. A rider's *velocity* is a measure of the rider's speed and includes information about the direction in which the rider is traveling. The rider's velocity may have been 1.2 m/s north or 1.5 m/s toward the door or 1.0 m/s toward the window. In each case, there is a magnitude or size (1.0 m/s, 1.2 m/s, 1.5 m/s) and a direction (north, toward the door, toward the window).

a) Was the velocity responsible for the "rider's" reactions? Did the blindfolded rider react more when the chair was moving with a fixed velocity (one with the same speed and the same direction) or when the velocity changed, when there was a change in speed or a change in direction of the chair or when there was a change in both the speed and in the direction of the chair?

5. The change in a rider's velocity over time is referred to as *acceleration*. Suppose a rider was moving at 1.1 m/s north and changed velocity to 1.5 m/s north. There is an acceleration because there was a change in speed.

a) In your *Active Physics* log, calculate and record the change in velocity.

6. There would also be acceleration if the rider changed velocity from 1.3 m/s east to 1.3 m/s south. Here the acceleration is due to a change in the direction, with no change in speed.

a) Draw vectors for these two velocities and describe the change in velocity in your log.

7. Suppose a rider was moving at 1.5 m/s toward the door and someone pushed him or her and made the rider move at 1.3 m/s toward the window. There is acceleration because there was a change in speed and a change in direction.

a) Draw a vector to represent the two velocities for the rider in the above example. Make the direction toward the window to be at right angles to the original direction toward the door. Record the change in speed and the change in direction in your *Active Physics* log for the rider in the example above.

b) Was acceleration responsible for the reactions of the blindfolded rider? Did he or she react more when accelerated?

8. Acceleration is a change in velocity in a specific time. For example, the change from 1.1 m/s north to 1.5 m/s north may have taken 1 s.

The change in velocity is 0.4 m/s in one second. There are a number of ways in which this can be stated: The change in velocity is

- 0.4 m/s in one second
- 0.4 m/s every second
- 0.4 m/s per second
- 0.4 (m/s)/s
- 0.4 m/s^2

Part C: Measuring Velocities and Calculating Accelerations

1. The value 1.5 m/s north is a velocity. The velocity 1.5 m/s tells you that the object can travel 1.5 m in 1 s. The direction of motion is north.

a) If an object were moving across the table, what instruments would you need for measurements to determine if the object were traveling at 1.5 m/s? Describe how you would go about measuring velocity in your classroom.

2. Place a track flat on the top of your table. Place a steel ball in the track and give it a small push to get it moving along the track.

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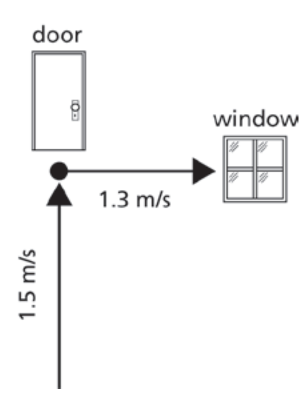
Active Physics



7.b)

Students should now be able to point out that the rider reacted to a greater degree when there was an acceleration, either as a change in speed, a change in direction, or both.

8.

The various possible units for acceleration are listed for the students. The unit meters per second every second should be used primarily in the beginning until the students become more comfortable with the concept of acceleration. The unit m/s^2 should not be used until later.

Part C: Measuring Velocities and Calculating Accelerations

1.a)

You would need an instrument to measure distance and an instrument to measure time. Distance measurement instruments could be rulers, meter sticks, or tape measures.

A shoe (roughly one foot long) could also be a measurement instrument. Time could be measured with a clock, a stopwatch, or your heartbeat.

NOTES

NOTES

2.a)

Students should make the measurement and use the format for calculations that include the equation first written in words, then in symbols, substituting values into the equation with units, and finally calculating the result with units. For instance, if the ball has moved 25 cm in 4.0 s, a student would write the calculation as follows:

velocity = displacement/time elapsed

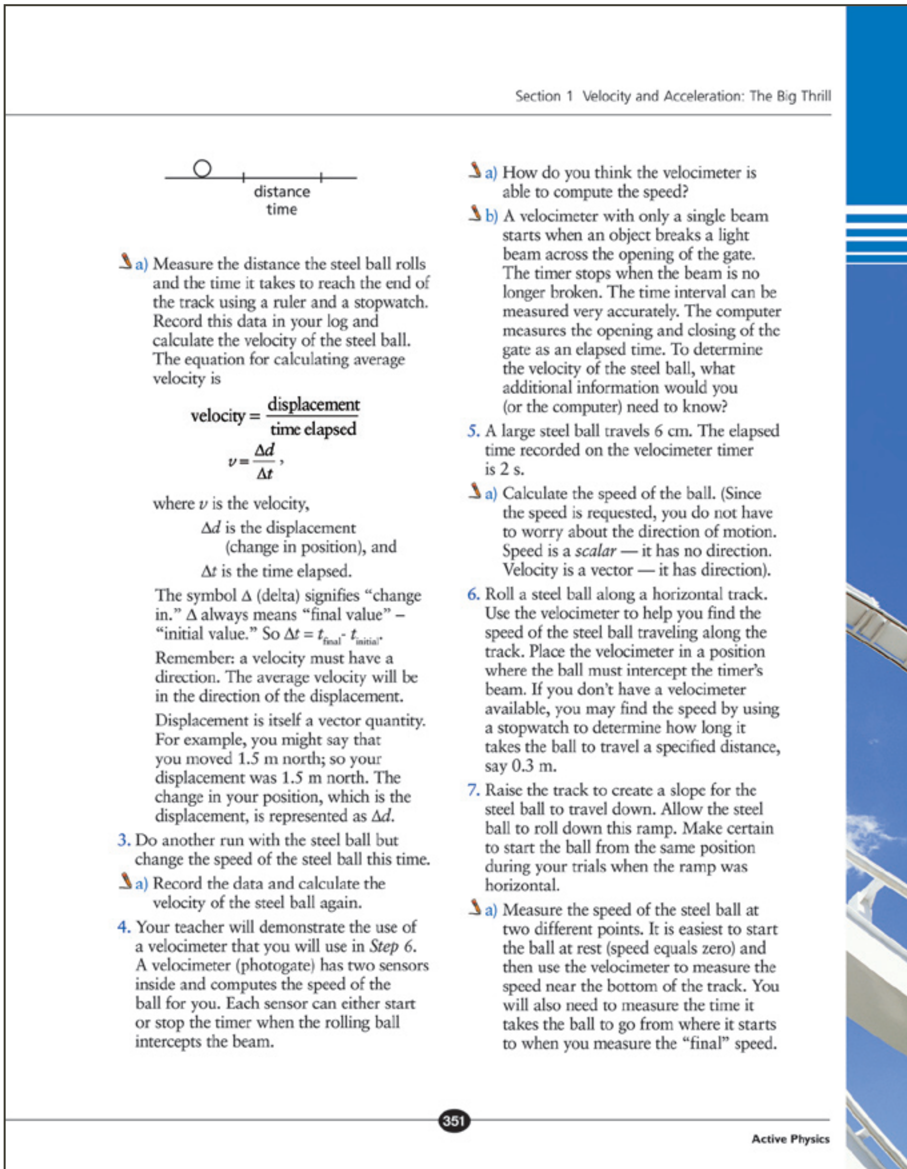
$v = \Delta d/\Delta t$

$v = 25 \text{ cm}/4 \text{ s} = 6.3 \text{ cm/s}$

The students should be prompted to say something about the direction of the velocity. Something simple like "north" or "east" or "toward the door" would be fine.

3.a)

Students should repeat the calculation with the ball, moving either more slowly or faster. Insist that students write the equation and show the calculation with the units. The students should again be prompted to say something about the direction of the velocity.



Section 1 Velocity and Acceleration: The Big Thrill

distance
time

a) Measure the distance the steel ball rolls and the time it takes to reach the end of the track using a ruler and a stopwatch. Record this data in your log and calculate the velocity of the steel ball. The equation for calculating average velocity is

$$\text{velocity} = \frac{\text{displacement}}{\text{time elapsed}}$$

$$v = \frac{\Delta d}{\Delta t},$$

where v is the velocity,
Δd is the displacement (change in position), and
Δt is the time elapsed.

The symbol Δ (delta) signifies "change in." Δ always means "final value" – "initial value." So $\Delta t = t_{final} - t_{initial}$.

Remember: a velocity must have a direction. The average velocity will be in the direction of the displacement.

Displacement is itself a vector quantity. For example, you might say that you moved 1.5 m north; so your displacement was 1.5 m north. The change in your position, which is the displacement, is represented as Δd.

3. Do another run with the steel ball but change the speed of the steel ball this time.
   a) Record the data and calculate the velocity of the steel ball again.
4. Your teacher will demonstrate the use of a velocimeter that you will use in *Step 6*. A velocimeter (photogate) has two sensors inside and computes the speed of the ball for you. Each sensor can either start or stop the timer when the rolling ball intercepts the beam.
   a) How do you think the velocimeter is able to compute the speed?
   b) A velocimeter with only a single beam starts when an object breaks a light beam across the opening of the gate. The timer stops when the beam is no longer broken. The time interval can be measured very accurately. The computer measures the opening and closing of the gate as an elapsed time. To determine the velocity of the steel ball, what additional information would you (or the computer) need to know?
5. A large steel ball travels 6 cm. The elapsed time recorded on the velocimeter timer is 2 s.
   a) Calculate the speed of the ball. (Since the speed is requested, you do not have to worry about the direction of motion. Speed is a *scalar* — it has no direction. Velocity is a vector — it has direction).
6. Roll a steel ball along a horizontal track. Use the velocimeter to help you find the speed of the steel ball traveling along the track. Place the velocimeter in a position where the ball must intercept the timer's beam. If you don't have a velocimeter available, you may find the speed by using a stopwatch to determine how long it takes the ball to travel a specified distance, say 0.3 m.
7. Raise the track to create a slope for the steel ball to travel down. Allow the steel ball to roll down this ramp. Make certain to start the ball from the same position during your trials when the ramp was horizontal.
   a) Measure the speed of the steel ball at two different points. It is easiest to start the ball at rest (speed equals zero) and then use the velocimeter to measure the speed near the bottom of the track. You will also need to measure the time it takes the ball to go from where it starts to when you measure the "final" speed.

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4.a)

The velocimeter is an accurate clock. It consists of two light beams (often invisible, infrared beams) a fixed distance apart that are interrupted by an object as it passes through. The time it takes the object to first intercept one beam and then the other is recorded. Since the distance between the beams is known, the velocity is just the distance between the beams divided by the time taken to travel between the beams. Alternatively, a photogate with just one beam may be used. This device records the time during which the beam is interrupted.

4.b)

The length of the object traveling through the beam must be known to calculate the velocity using the length divided by the time.

You should have the students experiment with the velocimeter by interrupting the light beam when passing a small card through the beam and seeing how the reading is related to the motion of the card.

5.a)

The speed of the large steel ball is 6 cm/2 s = 3 cm/s.

6.

Be sure that the steel ball size is compatible with the size of the velocimeter's opening. The velocimeter will calculate the speed. Students could also calculate the speed by writing the equation, substituting the measured values of distance and time into the equation, and then displaying their answer with units.

7.a)

The speed can be measured near the top of the ramp and near the bottom of the ramp.

The increase in speed will be visible to the students. If only one velocimeter is available, the velocity at the top when first released can be used as zero, and the velocity at another point measured. Using a stopwatch to determine the time it takes the ball to go from start to the velocimeter or between velocimeters is sufficiently accurate for these purposes.

CHAPTER 4

7.b)

The calculation of acceleration requires the students to know the speed at each location and the time between the measurements (i.e., the time for the ball to move down the incline). The students will use the reading on the velocimeter divided by the time of travel from the beginning or the difference between the readings on the velocimeters and the time to travel between velocimeters to determine the acceleration. For example, if the ball starts from rest (zero velocity) and the reading on the velocimeter is 2 m/s, the change in velocity is 2.0 m/s. If a stopwatch measures the time of travel from the beginning to the velocimeter to be 0.74 s, the acceleration is

acceleration = change in velocity/change in time

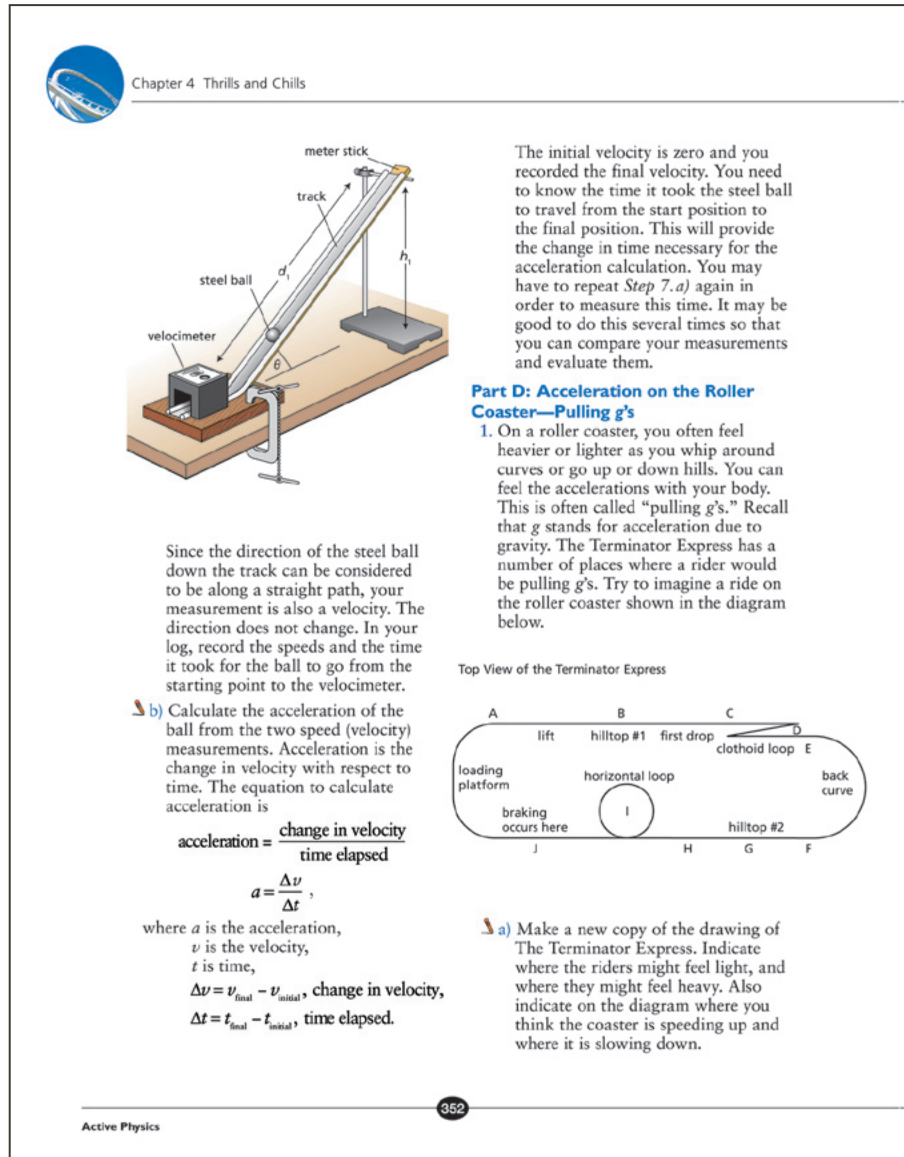
$a = \Delta v / \Delta t$

$a = 2 \text{ m/s} \div (0.74 \text{ s}) = 2.7 \text{ m/s}^2$

Part D: Acceleration on the Roller Coaster—Pulling *g*'s

1.a)

Students will probably know from experience that they will feel light as they go over the top of a hill, heavy at the bottom of a hill, and lighter at the top of a loop than at the bottom. They will feel lighter at B and G, and at the top of the loop between C and D. The will feel heavier at C and H. For a clothoid loop, the students should feel the same, heavier force all around the loop between C and D. They may also realize that they will be heavier going around the back loop and the horizontal loop as the direction changes.


Chapter 4 Thrills and Chills

Since the direction of the steel ball down the track can be considered to be along a straight path, your measurement is also a velocity. The direction does not change. In your log, record the speeds and the time it took for the ball to go from the starting point to the velocimeter.

b) Calculate the acceleration of the ball from the two speed (velocity) measurements. Acceleration is the change in velocity with respect to time. The equation to calculate acceleration is

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time elapsed}}$$

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

where a is the acceleration,
v is the velocity,
t is time,
$\Delta v = v_{\text{final}} - v_{\text{initial}}$, change in velocity,
$\Delta t = t_{\text{final}} - t_{\text{initial}}$, time elapsed.

The initial velocity is zero and you recorded the final velocity. You need to know the time it took the steel ball to travel from the start position to the final position. This will provide the change in time necessary for the acceleration calculation. You may have to repeat *Step 7.a)* again in order to measure this time. It may be good to do this several times so that you can compare your measurements and evaluate them.

Part D: Acceleration on the Roller Coaster—Pulling g's

1. On a roller coaster, you often feel heavier or lighter as you whip around curves or go up or down hills. You can feel the accelerations with your body. This is often called "pulling *g*'s." Recall that *g* stands for acceleration due to gravity. The Terminator Express has a number of places where a rider would be pulling *g*'s. Try to imagine a ride on the roller coaster shown in the diagram below.

Top View of the Terminator Express

a) Make a new copy of the drawing of The Terminator Express. Indicate where the riders might feel light, and where they might feel heavy. Also indicate on the diagram where you think the coaster is speeding up and where it is slowing down.

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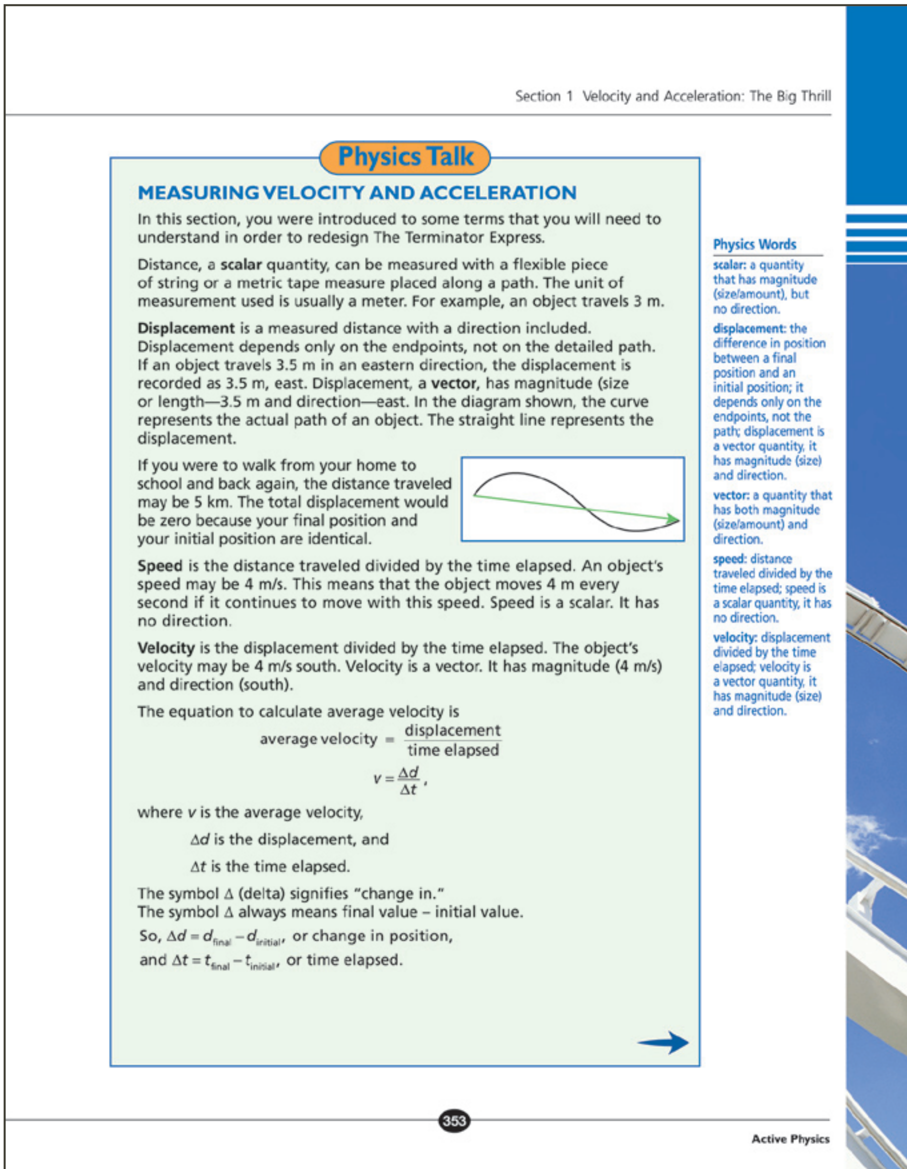
Active Physics

The heavier and lighter feelings are related to their accelerations. The students should be able to recognize where accelerations (changes in speed or changes of direction) are taking place in the depicted roller coaster.

There are changes in speed from A to B, B to C, C to D to E, G to H, and during braking.

There are changes in direction from C to D to E, E to F, and during I. The roller coaster has accelerations due to speeding up from B to C and G to H, slowing down from F to G and at J. Between C and D, the students may think they will slow down on the way up the loop and speed up on the way down the loop. This would be true if it were not a clothoid loop. Do not discuss this point yet.

CHAPTER 4


Section 1 Velocity and Acceleration: The Big Thrill

Physics Talk

MEASURING VELOCITY AND ACCELERATION

In this section, you were introduced to some terms that you will need to understand in order to redesign The Terminator Express.

Distance, a **scalar** quantity, can be measured with a flexible piece of string or a metric tape measure placed along a path. The unit of measurement used is usually a meter. For example, an object travels 3 m.

Displacement is a measured distance with a direction included. Displacement depends only on the endpoints, not on the detailed path. If an object travels 3.5 m in an eastern direction, the displacement is recorded as 3.5 m, east. Displacement, a **vector**, has magnitude (size or length—3.5 m and direction—east. In the diagram shown, the curve represents the actual path of an object. The straight line represents the displacement.

If you were to walk from your home to school and back again, the distance traveled may be 5 km. The total displacement would be zero because your final position and your initial position are identical.

Speed is the distance traveled divided by the time elapsed. An object's speed may be 4 m/s. This means that the object moves 4 m every second if it continues to move with this speed. Speed is a scalar. It has no direction.

Velocity is the displacement divided by the time elapsed. The object's velocity may be 4 m/s south. Velocity is a vector. It has magnitude (4 m/s) and direction (south).

The equation to calculate average velocity is

$$\text{average velocity} = \frac{\text{displacement}}{\text{time elapsed}}$$

$$v = \frac{\Delta d}{\Delta t},$$

where v is the average velocity,

Δd is the displacement, and

Δt is the time elapsed.

The symbol Δ (delta) signifies "change in."
The symbol Δ always means final value – initial value.

So, $\Delta d = d_{final} - d_{initial}$, or change in position,

and $\Delta t = t_{final} - t_{initial}$, or time elapsed.

Physics Words

scalar: a quantity that has magnitude (size/amount), but no direction.

displacement: the difference in position between a final position and an initial position; it depends only on the endpoints, not the path; displacement is a vector quantity, it has magnitude (size) and direction.

vector: a quantity that has both magnitude (size/amount) and direction.

speed: distance traveled divided by the time elapsed; speed is a scalar quantity, it has no direction.

velocity: displacement divided by the time elapsed; velocity is a vector quantity, it has magnitude (size) and direction.

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Active Physics

Physics Talk

This *Physics Talk* defines important terms needed to understand velocity and acceleration. Students read the difference between distance and displacement, and speed and velocity, before arriving at a definition of acceleration. The distinction between distance and displacement, between speed and velocity and between velocity and acceleration becomes particularly important when students have to make calculations to understand various aspects of the roller-coaster ride. To help students understand the fine distinction between distance and displacement, discuss the definition of each term and ask them to explain the two terms in their logs by giving examples. Students should be able to describe why distance is a scalar quantity and displacement is a vector. Similarly, students should be able to describe the difference between speed and velocity and point out that speed is a scalar quantity while velocity is a vector.

The concept of acceleration also has nuances that might confuse students. For the purpose of clarification, provide practice by having groups of students come up with examples of acceleration. Have each group listen to the example and respond with the correct terminology. Write students' examples of acceleration on the board and emphasize the steps of the *Investigate*, where students varied the speed and direction of the blindfolded rider and the ball on an inclined track to calculate acceleration.

Checking Up

1.

Distance is a scalar quantity and only represents a certain length that can be measured with a piece of string or a metric tape measure. Displacement is the total distance covered with the direction included. Displacement depends only on the endpoints and not on the detailed path. Displacement is a vector quantity.

2.

Your displacement is zero.

3.

Speed is the distance covered by the time elapsed. Speed is a scalar quantity. Velocity is the total displacement divided by the time elapsed. Velocity is a vector.

4.

You can find the acceleration of an object by measuring its velocity at two different times, then divide this difference by the time interval between the two velocity measurements.

This is the method you used to measure the speed of the ball in the *Investigate*. If you also recorded the direction in which the ball was moving, then you have the information needed to describe the ball's velocity.

For a person walking one lap around a city block, the distance is equal to the perimeter of the city block. The speed is equal to this distance divided by the time to complete the walk. The displacement for the entire trip equals zero (since the person ended up where she started) and the velocity equals zero as a result.

You will find that in some cases it is distance that is important and in other cases displacement is important. It will be important to keep the difference between the two ideas in mind. It may seem that defining both distance and displacement as well as speed and velocity complicates things. However, scientists occasionally introduce terms and distinctions that seem to make simple things more complicated because they are then able to make very difficult things much easier to explain and understand.

Physics Words

acceleration: the change in velocity divided by the time elapsed; acceleration is a vector quantity, it has magnitude (size) and direction.

Acceleration is the change in velocity divided by the time elapsed. An object's acceleration may be 5 m/s per second. If the direction stays the same, this means that the object changes its speed by 5 m/s every second if it continues with the same acceleration. The speed will increase from 0 m/s to 5 m/s to 10 m/s to 15 m/s with each change requiring one second. The acceleration of 5 m/s every second is also written as 5 m/s² (five meters per second squared).

The equation to calculate acceleration is

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time elapsed}}$$

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

where a is the acceleration,

Δv is the change in velocity, and

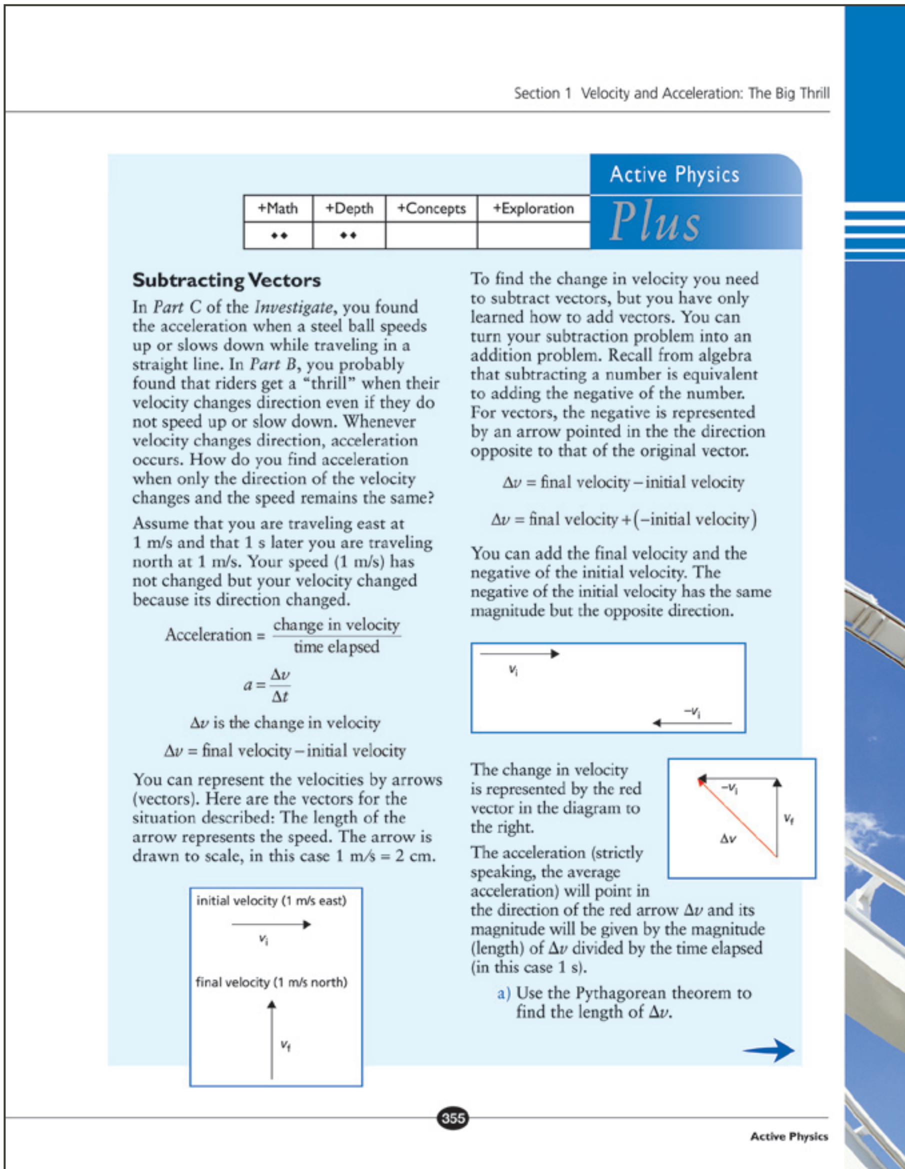
Δt is the time elapsed.

Note that the acceleration (a vector quantity) will be in the direction of the change in velocity.

When you measured the acceleration of the ball rolling down the incline in the *Investigate*, you measured the velocity of the ball at two different times. The acceleration is then given by the change in velocity divided by the time interval between the two velocity measurements. In *Active Physics Plus*, you will explore acceleration when the direction of the velocity changes.

Checking Up

1. Explain the difference between distance and displacement.
2. You went to school and back home, a total distance of 2 km. What is your displacement?
3. What is the difference between speed and velocity?
4. How can you find the acceleration of an object?



Active Physics Plus

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

Subtracting Vectors

In *Part C* of the *Investigate*, you found the acceleration when a steel ball speeds up or slows down while traveling in a straight line. In *Part B*, you probably found that riders get a "thrill" when their velocity changes direction even if they do not speed up or slow down. Whenever velocity changes direction, acceleration occurs. How do you find acceleration when only the direction of the velocity changes and the speed remains the same?

Assume that you are traveling east at 1 m/s and that 1 s later you are traveling north at 1 m/s. Your speed (1 m/s) has not changed but your velocity changed because its direction changed.

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

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

Δv is the change in velocity

Δv = final velocity − initial velocity

You can represent the velocities by arrows (vectors). Here are the vectors for the situation described: The length of the arrow represents the speed. The arrow is drawn to scale, in this case 1 m/s = 2 cm.

initial velocity (1 m/s east)

v_i

final velocity (1 m/s north)

v_f

To find the change in velocity you need to subtract vectors, but you have only learned how to add vectors. You can turn your subtraction problem into an addition problem. Recall from algebra that subtracting a number is equivalent to adding the negative of the number. For vectors, the negative is represented by an arrow pointed in the the direction opposite to that of the original vector.

Δv = final velocity − initial velocity

Δv = final velocity + (−initial velocity)

You can add the final velocity and the negative of the initial velocity. The negative of the initial velocity has the same magnitude but the opposite direction.

v_i

$-v_i$

The change in velocity is represented by the red vector in the diagram to the right.

$-v_i$

v_f

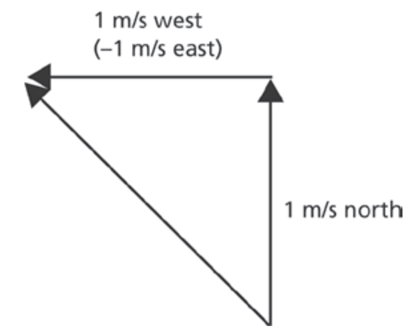
Δv

The acceleration (strictly speaking, the average acceleration) will point in the direction of the red arrow Δv and its magnitude will be given by the magnitude (length) of Δv divided by the time elapsed (in this case 1 s).

a) Use the Pythagorean theorem to find the length of Δv.

Active Physics Plus

Students learn to subtract vectors and calculate average acceleration. Students also draw a diagram, similar to the one below, showing the change in velocity. When students have solved the problems have them share their solutions with other students in the class.



a)

Given:

$v_i = 1$ m/s; $v_f = 1$ m/s; $\Delta t = 1$ s

Using the Pythagorean theorem to calculate the length of Δv gives

$$\Delta v = \sqrt{(-v_i)^2 + v_f^2} = \sqrt{(-1\text{ m/s})^2 + (1\text{ m/s})^2} = 1.4\text{ m/s}$$

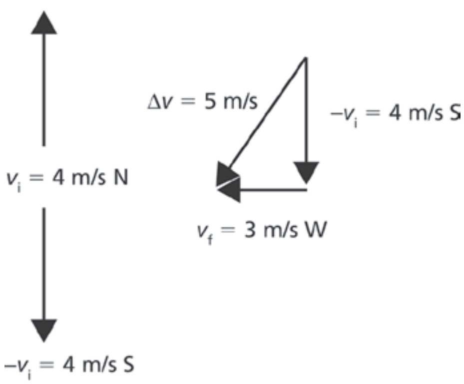
b)

The value of the acceleration is found by using $a_{\text{average}} = \Delta v / \Delta t = 1.4 \text{ m/s}^2$.

c)

To find the angle between Δv and east use either a protractor or one of the trigonometric functions of sine, cosine or tangent. The angle will be 37° west of south.

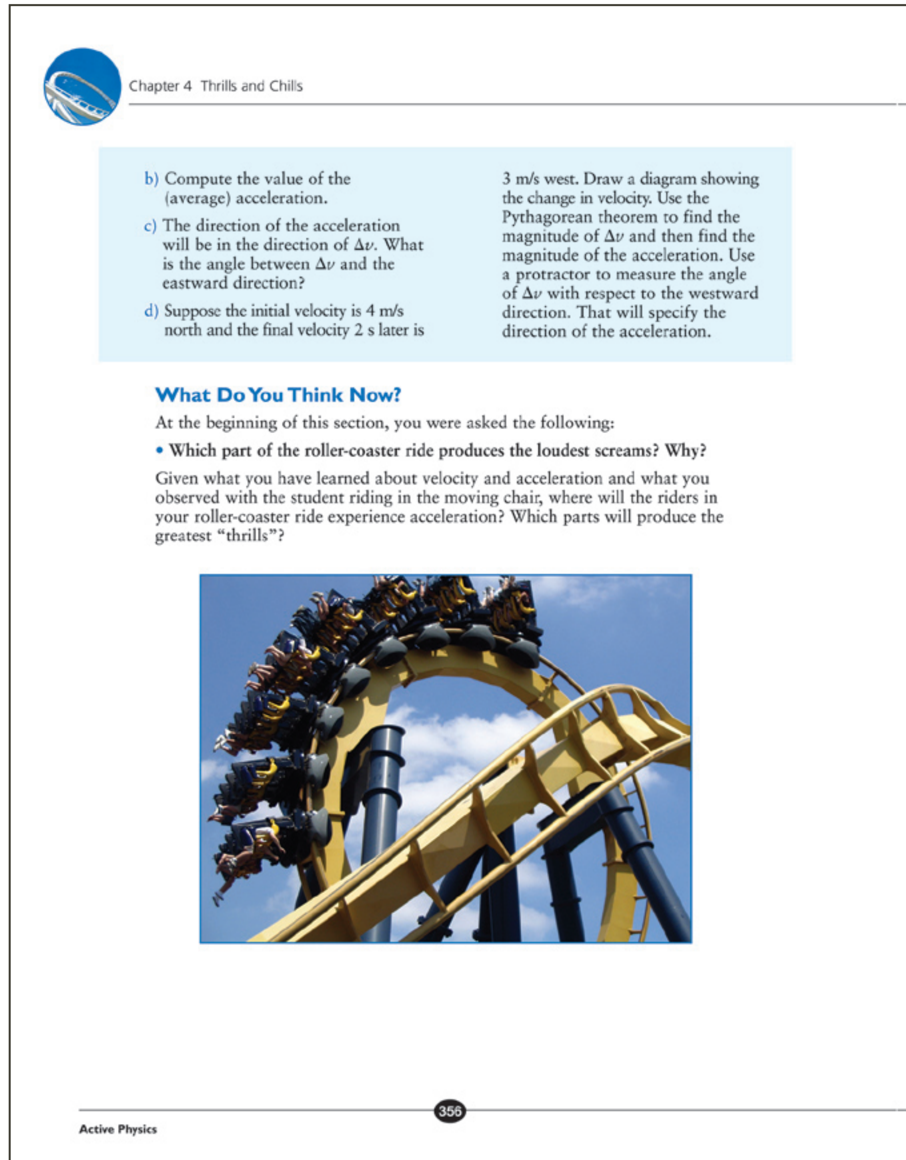
d)



Given:
$v_i = 4$ m/s; $v_f = -3$ m/s; $\Delta t = 2$ s

$$\Delta v = \sqrt{(-v_i)^2 + (v_f)^2} =$$
$$\sqrt{(-4 \text{ m/s})^2 + (-3 \text{ m/s})^2} = 5 \text{ m/s}$$
$$a = \Delta v / \Delta t = (5 \text{ m/s})/2 \text{ s} = 2.5 \text{ m/s}^2$$

Using a protractor, the angle will be 53° to the south of west.



Chapter 4 Thrills and Chills

b) Compute the value of the (average) acceleration.

c) The direction of the acceleration will be in the direction of Δv. What is the angle between Δv and the eastward direction?

d) Suppose the initial velocity is 4 m/s north and the final velocity 2 s later is 3 m/s west. Draw a diagram showing the change in velocity. Use the Pythagorean theorem to find the magnitude of Δv and then find the magnitude of the acceleration. Use a protractor to measure the angle of Δv with respect to the westward direction. That will specify the direction of the acceleration.

What Do You Think Now?

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

- **Which part of the roller-coaster ride produces the loudest screams? Why?**

Given what you have learned about velocity and acceleration and what you observed with the student riding in the moving chair, where will the riders in your roller-coaster ride experience acceleration? Which parts will produce the greatest "thrills"?

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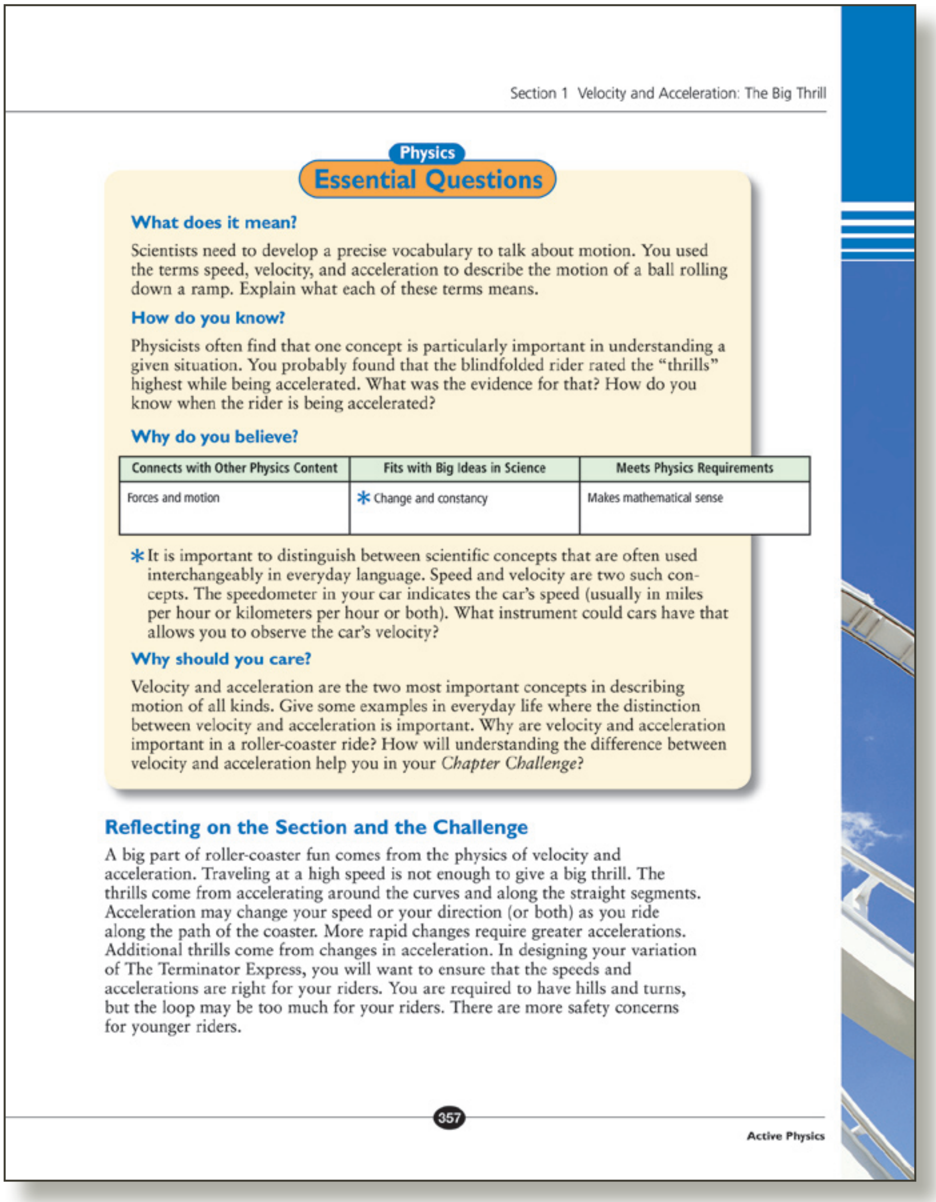
What Do You Think Now?

The *What Do You Think?* questions are revisited in this section and students have a chance to update their responses. Discuss how their investigations have helped them to develop their understanding of velocity and acceleration and why they should now be able to answer which part of the roller coaster-ride produces the loudest screams. You might want to provide them with an answer to *A Physicist's Response*. Ask students if the *What Do You See?* illustration now becomes more relevant. Students will continue to benefit from a review of previously recorded responses.

CHAPTER 4



Physics
Essential Questions

What does it mean?

Scientists need to develop a precise vocabulary to talk about motion. You used the terms speed, velocity, and acceleration to describe the motion of a ball rolling down a ramp. Explain what each of these terms means.

How do you know?

Physicists often find that one concept is particularly important in understanding a given situation. You probably found that the blindfolded rider rated the "thrills" highest while being accelerated. What was the evidence for that? How do you know when the rider is being accelerated?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	* Change and constancy	Makes mathematical sense

* It is important to distinguish between scientific concepts that are often used interchangeably in everyday language. Speed and velocity are two such concepts. The speedometer in your car indicates the car's speed (usually in miles per hour or kilometers per hour or both). What instrument could cars have that allows you to observe the car's velocity?

Why should you care?

Velocity and acceleration are the two most important concepts in describing motion of all kinds. Give some examples in everyday life where the distinction between velocity and acceleration is important. Why are velocity and acceleration important in a roller-coaster ride? How will understanding the difference between velocity and acceleration help you in your *Chapter Challenge*?

Reflecting on the Section and the Challenge

A big part of roller-coaster fun comes from the physics of velocity and acceleration. Traveling at a high speed is not enough to give a big thrill. The thrills come from accelerating around the curves and along the straight segments. Acceleration may change your speed or your direction (or both) as you ride along the path of the coaster. More rapid changes require greater accelerations. Additional thrills come from changes in acceleration. In designing your variation of The Terminator Express, you will want to ensure that the speeds and accelerations are right for your riders. You are required to have hills and turns, but the loop may be too much for your riders. There are more safety concerns for younger riders.

Reflecting on the Section and the Challenge

Students should now reflect on the Terminator Express roller coaster design that they have to modify for their *Chapter Challenge*. Ask them to revisit the main physics concepts presented in this section. Discuss the roller coaster experience that students simulated in the *Investigate*. Have a student read this section aloud in the student text. Remind students that they have to keep the safety factor in mind while making variations to the Terminator Express.

Physics Essential Questions

What does it mean?

Speed is the total distance traveled in a given time. Velocity is the total displacement traveled in a given time. The velocity includes the direction. If the ball were to travel up and down the ramp, the average speed for the entire trip would have a positive value, but the average velocity would be zero, since the net displacement is zero. Acceleration is the change in velocity with respect to time.

How do you know?

Students looked surprised when there was acceleration. This occurred with changes in speed and/or direction.

Why do you believe?

The speedometer could be connected to a GPS, which would take into account the direction of motion as well as the speed.

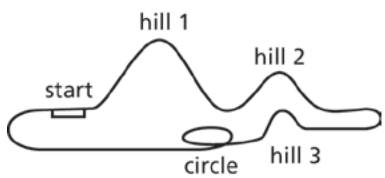
Why should you care?

When you enter a highway, your car must accelerate to reach the same velocity as the traffic. When purchasing a car, you want to know that it can travel at a speed of 60 mi/h, but you also want to know that it can accelerate to this speed quickly. It's great to travel fast on a roller coaster, but the thrills come from changes in velocity—the acceleration. The roller-coaster design should include places where there are large accelerations.

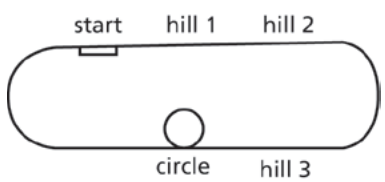
Physics to Go

1.

Student diagrams should resemble the ones below:



side view



top view

2.

The biggest thrill will probably be in the clothoid loop. This is where the riders are experiencing an acceleration due to a change in speed with respect to time and an acceleration due to a change in direction. They are also upside down for a few moments.

3.a)

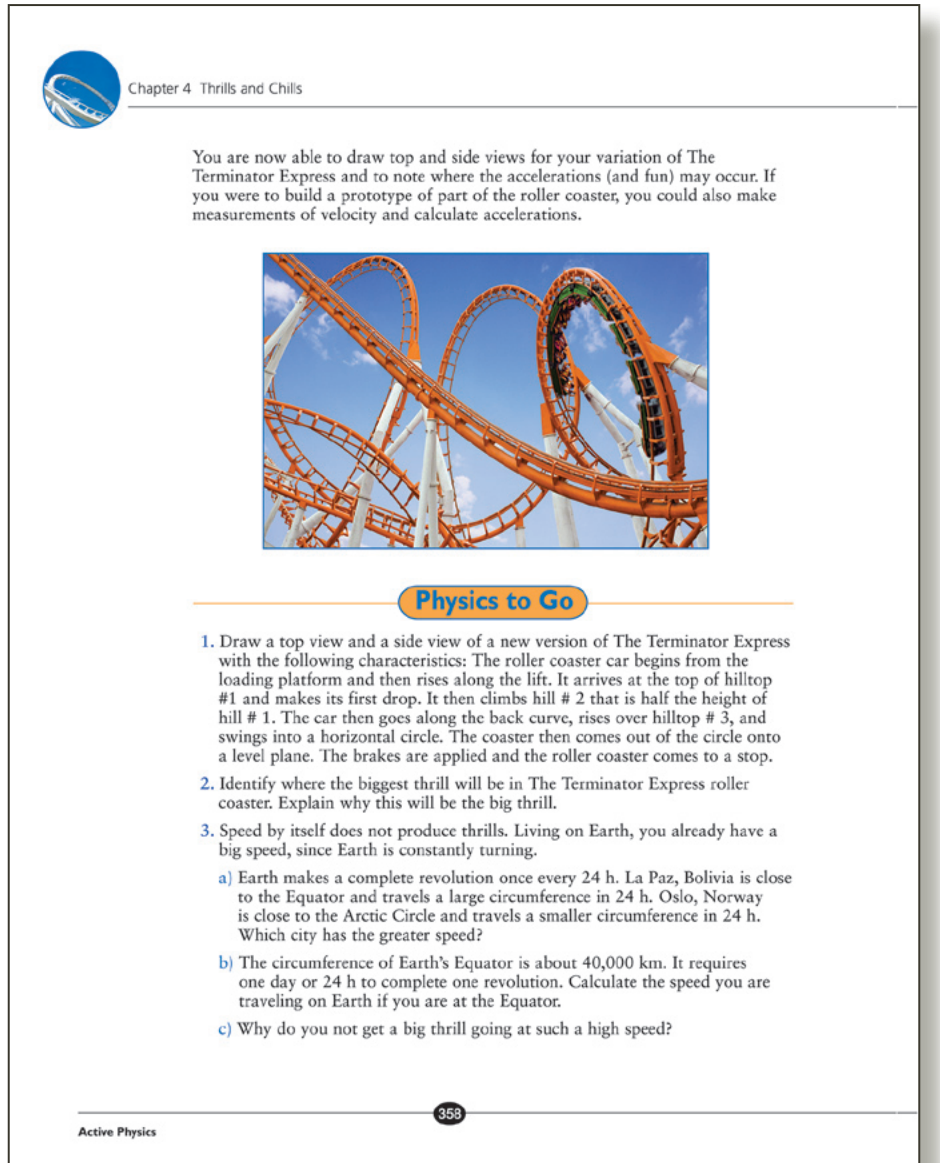
La Paz, Bolivia has the greater speed. Oslo, Norway has moved a much smaller distance in the 24 hours.

3.b)

Given:
$d = 40{,}000$ km; $t = 24$ h

The speed is approximately 1700 km/h (close to 1000 mi/h).

speed = distance traveled/time
speed = 40,000 km/24 h = 1667 km/h


Chapter 4 Thrills and Chills

You are now able to draw top and side views for your variation of The Terminator Express and to note where the accelerations (and fun) may occur. If you were to build a prototype of part of the roller coaster, you could also make measurements of velocity and calculate accelerations.

Physics to Go

1. Draw a top view and a side view of a new version of The Terminator Express with the following characteristics: The roller coaster car begins from the loading platform and then rises along the lift. It arrives at the top of hilltop #1 and makes its first drop. It then climbs hill # 2 that is half the height of hill # 1. The car then goes along the back curve, rises over hilltop # 3, and swings into a horizontal circle. The coaster then comes out of the circle onto a level plane. The brakes are applied and the roller coaster comes to a stop.
2. Identify where the biggest thrill will be in The Terminator Express roller coaster. Explain why this will be the big thrill.
3. Speed by itself does not produce thrills. Living on Earth, you already have a big speed, since Earth is constantly turning.
   a) Earth makes a complete revolution once every 24 h. La Paz, Bolivia is close to the Equator and travels a large circumference in 24 h. Oslo, Norway is close to the Arctic Circle and travels a smaller circumference in 24 h. Which city has the greater speed?
   b) The circumference of Earth's Equator is about 40,000 km. It requires one day or 24 h to complete one revolution. Calculate the speed you are traveling on Earth if you are at the Equator.
   c) Why do you not get a big thrill going at such a high speed?

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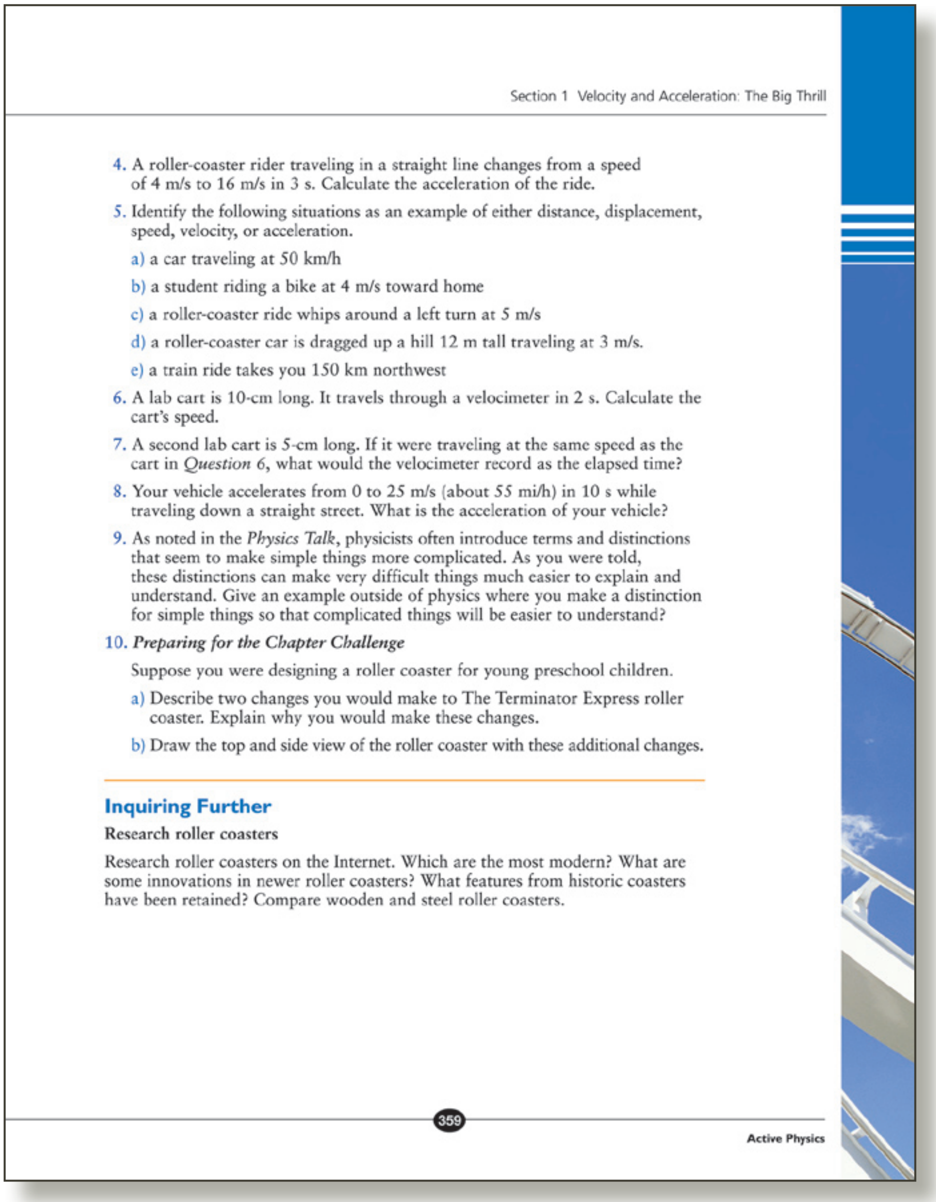
3.c)

Thrills are produced by changes in velocity. As Earth rotates, the speed of a place on the surface (relative to the center of Earth) does not change significantly.

The direction of the velocity does change (because the location is in circular motion) but the resulting acceleration is very small. This point need not be raised now.



Section 1 Velocity and Acceleration: The Big Thrill

4. A roller-coaster rider traveling in a straight line changes from a speed of 4 m/s to 16 m/s in 3 s. Calculate the acceleration of the ride.

5. Identify the following situations as an example of either distance, displacement, speed, velocity, or acceleration.
   a) a car traveling at 50 km/h
   b) a student riding a bike at 4 m/s toward home
   c) a roller-coaster ride whips around a left turn at 5 m/s
   d) a roller-coaster car is dragged up a hill 12 m tall traveling at 3 m/s.
   e) a train ride takes you 150 km northwest

6. A lab cart is 10-cm long. It travels through a velocimeter in 2 s. Calculate the cart's speed.

7. A second lab cart is 5-cm long. If it were traveling at the same speed as the cart in *Question* 6, what would the velocimeter record as the elapsed time?

8. Your vehicle accelerates from 0 to 25 m/s (about 55 mi/h) in 10 s while traveling down a straight street. What is the acceleration of your vehicle?

9. As noted in the *Physics Talk*, physicists often introduce terms and distinctions that seem to make simple things more complicated. As you were told, these distinctions can make very difficult things much easier to explain and understand. Give an example outside of physics where you make a distinction for simple things so that complicated things will be easier to understand?

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

    Suppose you were designing a roller coaster for young preschool children.
    a) Describe two changes you would make to The Terminator Express roller coaster. Explain why you would make these changes.
    b) Draw the top and side view of the roller coaster with these additional changes.

Inquiring Further

Research roller coasters

Research roller coasters on the Internet. Which are the most modern? What are some innovations in newer roller coasters? What features from historic coasters have been retained? Compare wooden and steel roller coasters.

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4.

Given:
$v_f = 16$ m/s; $v_i = 4$ m/s; $\Delta t = 3$ s

acceleration =
change in velocity/time elapsed
$a = \Delta v/\Delta t = (16 \text{ m/s} - 4 \text{ m/s})/3 \text{ s} = (12 \text{ m/s})/3 \text{ s} = 4 \text{ m/s}^2$

5.a)

Speed—a scalar (no direction)

5.b)

Velocity—a vector (speed with a direction)

5.c)

Acceleration—a vector (a change in velocity with respect to time)

5.d)

Displacement—a vector (has direction)

5.e)

Displacement—a vector (has direction)

6.

Given:
$d = 10$ cm; $t = 2$ s

speed =
distance traveled/time elapsed =
10 cm/2 s = 5 cm/s

7.

Going at the same speed, half the distance will take half the time or 1 s.

8.

Given:
$\Delta v = 25$ m/s; $t = 10$ s

acceleration =
change in velocity/time elapsed
$a = \Delta v/\Delta t =$
$(25 \text{ m/s} - 0 \text{ m/s})/10 \text{ s} = 2.5 \text{ m/s}^2$

9.

The history of science provides many examples of simple things being explained in a complicated way so that other things will be easier to explain. The Sun appears to move across the sky. To explain this simple observation as the complicated perceived motion of the stationary Sun from a rotating Earth allows us to then explain the solar system. In a student's everyday life, they may recognize that to learn certain moves in sports or dance, that they make a simple move more complex so that they will have good form and be able to be successful with complicated moves.

Preparing for the Chapter Challenge

10.a)

You may want to have smaller heights, gentler curves and smaller changes in acceleration. These changes should be made so that preschool children don't get terrified and enjoy the smaller variations in speed and direction.

10.b)

Students' drawings will vary. However, their drawings should show the changes suggested.

Inquiring Further

This *Inquiring Further* will be a moving target, since new roller coasters are constantly being built. The most modern (steel roller coasters) are constantly being improved, and new innovations are being tried. Roller coasters where the riders are suspended below the track are becoming more common rather than the more conventional roller-coaster car.

The typical twists, drops and turns of historic roller coasters have been retained, but loops have generally been added that were not available to the older wooden roller coasters.

Steel roller coasters are usually much higher, quieter, smoother and faster than the traditional wooden roller coasters of 50 years ago. The wooden coasters were often deliberately made to creak and shift slightly to add to the thrill, since the velocities were lower.

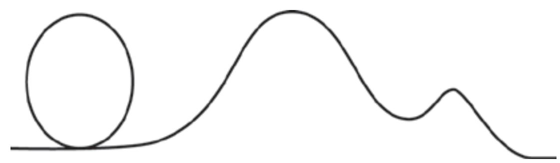
NOTES

NOTES

SECTION 1 QUIZ

4-1b **Blackline Master**

1. The diagram below shows a side view of a section of a roller coaster.



Which of the following views could be a top view of this section?

a) 

c) 

b) 

d)

2. To accelerate, an object must

a) change its speed.

b) change its direction.

c) either change its speed or its direction.

d) change both its speed and direction.

3. A steel ball rolls across a level track a distance of 1.35 meters in a time of 0.45 seconds. What is the velocity of the ball?

a) 0.33 m/s

b) 1.80 m/s

c) 3.0 m/s

d) 0.61 m/s

4. A student does an experiment rolling a cart down a ramp. The cart starts from rest a distance 0.80 m up the ramp, and 1.5 s later the cart has a velocity of 2.0 m/s. What is the cart's acceleration?

a) 1.2 m/s^2

b) 1.3 m/s^2

c) 3.0 m/s^2

d) 4.5 m/s^2

5. A cart that is 16 cm in length passes through a velocimeter. The reading on the velocimeter says the cart's velocity was 4.8 m/s during the time it took to pass through the meter. How long did it take the cart to pass through the meter?

a) 0.033 s

b) 0.25 s

c) 3.0 s

d) 0.77 s

SECTION 1 QUIZ ANSWERS

1. d) Since there is a loop in the track, the two halves of the loop cannot overlap, ruling out choice c). From a top view, only choices d) and c) would be possible for a straight-line run.

2. c) Acceleration is defined as the change in velocity with respect to time. Velocity has two components—speed and direction. Changing either one would change the velocity, thus causing an acceleration. It is not necessary to change both factors; changing either one is sufficient to have an acceleration.

3. c) Velocity is defined as the change in displacement with respect to time. If the displacement change (in this case the distance since it is in a straight line) is 1.35 m and the change in time is 0.45 s, then $v = \Delta d/t = 1.35\text{ m}/0.45\text{ s} = 3.0\text{ m/s}$.

4. b) Acceleration is the change in velocity with respect to time. Using the formula, $a = \Delta v/t$ gives $(2.0\text{ m/s})/(1.5\text{ s}) = 1.3\text{ m/s}^2$. As long as the cart starts up the ramp a distance sufficient for it to continue uniformly accelerating, the distance is not relevant in this case.

5. a) Using speed equals distance divided by time, if the cart has an average speed of 4.8 m/s, and is 0.16 m long yields $v = \Delta d/t$ or $4.8\text{ m/s} = (0.16\text{ m})/t$. Solving for t gives $(0.16\text{ m})/(4.8\text{ m/s}) = 0.033\text{ s}$.