SECTION 1

Newton's First Law: A Running Start

Section Overview

Students investigate the presence of inertia and friction in relation to Newton's first law of motion by letting a ball roll up a tracked slope. They change the height of the slope to see how the change affects the rolling motion of the ball, the height the ball recovers before it comes to a stop, why it stops, and the force that causes the ball to stop. Students explore these questions along with the concept of Frames of Reference.

Background Information

Two major ideas introduced in this section are Galileo's law of inertia (Newton's first law of motion) and frames of reference (relative velocities). Before attempting to identify causes and effects for generating, sustaining, and arresting motion, a pivotal question first must be answered: What kinds of motion require explanation?

Two distinct kinds of motion along a straight line are often encountered in nature. These are motion with constant speed and motion with uniform, or constant, acceleration. Since the contributions of Galileo, physics has operated from the perspective that the first of these kinds of motion, constant speed, has no cause. Galileo devised a number of arguments and demonstrations, some of which are replicated in this section, to support this notion. The cause of all accelerated motion is force; some agent(s) must be pushing or pulling—exerting a force—on any object observed to be accelerating. Sources or kinds of forces abound.

Every situation that involves acceleration has an associated net force. If an orange is dropped, it accelerates because of the downward force due to gravity. When the orange hits the floor, it stops due to another force. The force that stops the orange is provided by the floor, upward. A magnet brought near another magnet will cause the magnets to accelerate; therefore, there must be a magnetic force. Sometimes, forces hiding in constant-speed linear motion can also be discovered. Drop a coffee filter. The filter accelerates downward for a bit, but the amount of acceleration drops to zero, so that the coffee filter falls most of the way at constant speed. Did the force of gravity decrease or disappear? No, a coffee filter seems to weigh (a measure of the force of gravity) the same at every point in the descent path. Therefore, there must be another force, the force of air resistance, acting in the opposite direction to gravity. The force of air resistance eventually balances out the gravitational force.

It is possible for a combination of forces to have a net effect of zero. So, it is the net force on an object that imparts the acceleration. Newton's first law of motion states that an object at rest tends to remain at rest, and an object in motion (in a straight line) tends to remain in motion, unless acted upon by an outside (net, nonzero) force. This statement is more complete than the one provided to the students in *Section 1* of *Active Physics*. Whenever speed, direction, or both speed and direction are observed to change, a net force is the cause. The first law of Newton does not attempt to quantify the relationship between accelerations and the forces that cause them. Establishing the quantitative relationship requires experimental evidence, which is the purpose of the next section.

Crucial Physics

- An object at rest remains at rest.
- An object in motion remains in motion at a constant speed unless acted upon by a force.
- Two people, one on a moving train and one on a platform, can measure different speeds for the same object. Both are correct for their frame of reference.
- Rest is a special case of motion in a straight line with a constant speed (namely, speed equals zero).
- Motion in a straight line with a constant speed is included in Newton's first law of motion and therefore requires no additional explanation.
- The magnitude of an object's velocity depends on the frame of reference in which it is measured.
- Velocities as measured in different frames of reference differ by an amount equal to the relative velocity between the two reference frames.

Learning Outcomes	Location in the Section	Evidence of Understanding
Describe Galileo's law of inertia.	***Investigate*** Steps 1-4 ***Physics Talk***	Students release a ball from a certain height and observe its motion on a tracked slope. This motion is described by Galileo's law of inertia.
Apply Newton's first law of motion.	***Investigate*** Step 5	Students apply their knowledge of Newton's first law to determine what would keep the ball rolling on a horizontal track.
Recognize inertial mass as a physical property of matter.	***Physics Talk***	Students read about Galileo's law of inertia and learn why the mass of an object is the measure of its inertia.
Use examples to demonstrate that speed is always relative to some other object.	***Physics Talk***	Students use different examples to show how the speed of one object is relative to another object's position.
Explain that the speed of an object depends on the reference frame from which it is being observed.	***Physics Talk*** ***Frames of Reference***	Students explain how the speed of an object is relative to the frame of reference from which the motion of the object is being observed.

Section 1 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Ball, steel, 1 in. (diameter)	1 per group	
Track, plastic (for roller coaster)	1 per group	
Ruler, metric, 30 cm	1 per group	
C-clamp, steel, 3 in.	1 per group	
Pen, marking, felt tip	1 per group	
Tape, masking, 3/4 in. x 60 yds		6 per class

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Ball, steel, 1 in. (diameter)		1 per class
Track, plastic (for roller coaster)		1 per class
Ruler, metric, 30 cm		1 per class
C-clamp, steel, 3 in.		1 per class
Pen, marking, felt tip		1 per class
Tape, masking, 3/4 in. x 60 yds		6 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

This *Investigate* requires 30 minutes.

Teacher Preparation

- If you are using the tracks provided in the kits, you may wish to screw the center of the track onto a board to make it easier for the students to manipulate the ends. Having stacks of books or other material available to prop up the ends of the track would be helpful.

Safety Requirement

- Make sure the students immediately pick up any balls that may have rolled onto the floor, to prevent anyone from slipping on them. One-inch steel balls should be handled carefully and not tossed around the classroom.

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Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Making accurate measurements	***Investigate*** Steps 1, 3, and 4	**Augmentation** Students with fine-motor, visual-motor, and/or attention issues often struggle to make accurate measurements. Teach students how to make accurate measurements by modeling proper use of measuring devices. • Draw a larger version of a portion of a meter stick on the board and teach students how to read the scale. • Model how to mark the recovered height for measurement. • Assign group responsibilities for completing this task (recorder, marker, measurer, and roller). **Accommodation** • Use close proximity or hand-over-hand (physically guided) techniques to help students practice measuring. Decrease assistance as accuracy and independence is gained.
Recording organized data	***Investigate***	**Augmentation** • Students with sequential-learning and executive-function issues may struggle to organize collected data in a way that allows comparison. • Ask students to silently read the directions in the *Investigate* and write down the kind of information that needs to be recorded. Then model how to create a table with all of the required information. (See model on the next page.) **Accommodation** • Provide students with a blank copy of the table to complete.
Vocabulary review	***Physics Talk***	**Augmentation** • Students sometimes struggle to commit new vocabulary to their long-term memory. To improve their retention, review the terms vector and scalar in relation to velocity and speed. Continue to add vector and scalar quantities to the class poster created during *Chapter 1.*
Reading comprehension	***Physics Talk*** Frames of Reference	**Augmentation** • The concept of a frame of reference may be difficult for many students to understand. Students with reading issues may not comprehend the examples provided in this section. • Divide the class into groups of four. Assign a frame-of-reference scenario to each of the four groups. Ask them to make a poster and give a 3- to 5-minute presentation to explain their scenario. Students can also create their own scenarios to teach the class.
Using academic vocabulary	***Physics Words*** ***Checking Up*** ***Physics Essential Questions***	**Augmentation** • Students are reluctant to use science vocabulary and often resort to common language that they are comfortable using. Require students to use their *Physics Words* when answering questions orally in class, or when writing answers to *Checking Up* or *Physics Essential Questions.*
Synthesizing information to use in a new way	***Physics to Go*** Question 10	**Augmentation** • Students may not have prior experience of a sports commentary. Without this prior knowledge, they may decide not to complete this task rather than risk an incorrect answer. Provide audio examples of entertaining sportscasts and then generate a class list of traits that would make the commentary, entertaining as well as educational.

Model of a table for the *Investigate*

Scenario	Starting Height (cm)	Predicted Recovered Height (cm)	Measured Recovered Height (cm)
Same slope			
Smaller slope of recovered height			
Smallest slope of recovered height			

Strategies for Students with Limited English-Language Proficiency

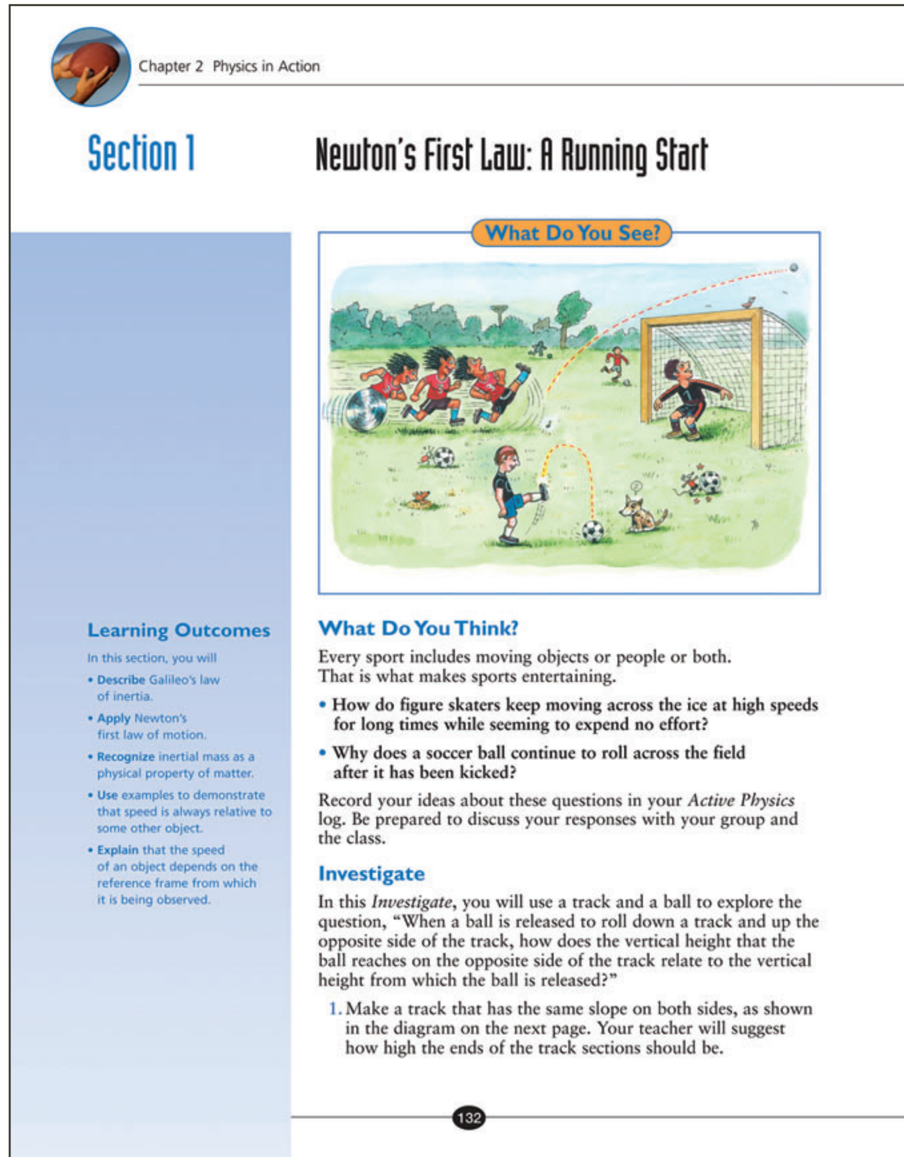
Learning Issue	Reference	Augmentation
Accessing prior knowledge	***Investigate*** Step 1	Accessing prior knowledge, which is common in the science classroom, can be particularly helpful with ELL students. It shows that students have some experience with a concept and gives you a way to connect the concept back to what students already know, independent of their grasp of the vocabulary. After students have set up the apparatus for Step 1, before they perform Step 1.a), ask if any students have had experience with sloped tracks (skateboarding, for example). Have these students predict whether the recovered height of the ball will be as high as the starting height, and have them explain their reasoning to the class. Students may have experience with recovered height in other real-world contexts as well. For example, a student who plays basketball could talk about how the ball bounces when you stop dribbling. (The ball's height decreases with each bounce.)
Active learning	***Investigate*** Step 2.a)	When students write and explain their predictions in their *Active Physics* logs, they may benefit from drawing and labeling diagrams to accompany their predictions. This extra step gives students additional experience with the terminology "release point," "starting height," and "recovered height" in context, and helps to demonstrate their understanding of those words. It also allows them to draw arrows from their written predictions to specific points on the drawings to help express their thoughts.
Vocabulary comprehension	***Physics Talk***	The term "frictional force" appears in the *Physics Talk*. Point out that "friction" has been turned into the adjective "frictional" and is modifying "force." Help students understand that "frictional force" is just another way of saying "force of friction."
Vocabulary comprehension Using tools and manipulatives	***Active Physics Plus*** ***Physics to Go*** Question 7.c)	When students learn about velocity, they need to understand cardinal directions. Use a map or a globe to point out north, south, east, and west. Show students the word that goes with each direction.
Comprehension	***Active Physics Plus***	Collaborate with the students' math teachers to determine what level of comprehension students have obtained for working with angles.
Vocabulary comprehension Using tools and manipulatives	***Physics to Go*** Question 7.c)	Use two pencils to show the meaning of "perpendicular" and contrast this to the term "parallel." It may help to review other frame-of-reference terms such as "horizontal" and "vertical."

SECTION 1

Teaching Suggestions and Sample Answers

What Do You See?

The *What Do You See?* section gives you an opportunity to catch students' interest. There are vignettes in the illustration that you may want to highlight in relation to Newton's first law. You could query your students on the look of bewilderment/surprise on the players' faces as they see the soccer ball flying over the net. A color overhead would provide a more powerful visual and make it easier for you to steer a probing discussion.



Chapter 2 Physics in Action

Section 1 Newton's First Law: A Running Start

What Do You See?

Learning Outcomes

In this section, you will

- **Describe** Galileo's law of inertia.
- **Apply** Newton's first law of motion.
- **Recognize** inertial mass as a physical property of matter.
- **Use** examples to demonstrate that speed is always relative to some other object.
- **Explain** that the speed of an object depends on the reference frame from which it is being observed.

What Do You Think?

Every sport includes moving objects or people or both. That is what makes sports entertaining.

- **How do figure skaters keep moving across the ice at high speeds for long times while seeming to expend no effort?**
- **Why does a soccer ball continue to roll across the field after it has been kicked?**

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

Investigate

In this *Investigate*, you will use a track and a ball to explore the question, "When a ball is released to roll down a track and up the opposite side of the track, how does the vertical height that the ball reaches on the opposite side of the track relate to the vertical height from which the ball is released?"

1. Make a track that has the same slope on both sides, as shown in the diagram on the next page. Your teacher will suggest how high the ends of the track sections should be.

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Students' Prior Conceptions

This section establishes the foundation for students to seek consistent explanations for describing an object at rest. Students are led to appreciate both "active" and "passive" forces acting on objects. They read that balanced or unbalanced forces act on an object, and inertial mass and motion are intrinsic to each other. Some preconceptions that may occur are listed below:

1. **The only "natural" motion is for an object to be at rest.** Recognizing that Earth and all objects on Earth are in motion and only seem at rest relative to each other is fundamental to understanding that what is considered to be "natural motion," an object at rest, is at relative motion. The teacher needs to help students to recognize and to apply appropriate frames of reference for motion.
2. **Students tend to consider "true" motion as the motion of an object relative to Earth.** This preconception is directly associated with the previous idea about "natural" motion.
3. **Constant speed needs a cause to sustain it.** Modeling Galileo's historical experiment will enable students to measure distance and time to see that an object in motion can continue to maintain that constant motion without an active force to propel it.

What Do You Think?

Students are not expected to know a "right" answer. These questions are supposed to elicit students' beliefs regarding a very specific prediction or outcome, and students should write a specific answer in their logs. At the same time, they should not shy away from any answer they think is valid. *What Do You Think?* allows the freedom of thinking broadly. Students should not be held back by the notion of being wrong.

What Do You Think?

A Physicist's Response

Skaters maintain speed on ice due to very low friction between the blades and the ice. The skaters' inertia explains the continued motion but in reality no explanation is needed. Uniform motion in a straight line is the starting point for the theory of dynamics. This theory concerns itself with explaining deviations from uniform motion in a straight line. The soccer ball also continues to roll because of the natural tendency of all objects to remain at rest or in motion until a net external force acts on the object.

Investigate

Teaching Tip

As you move about the room during the investigations, you can ask students questions to ascertain their learning and to check on their progress and understanding.

1.a)

Students record the vertical height from which the ball is released.

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4. **Friction always hinders motion; you always want to eliminate friction.** The concept of friction is ingrained in students' minds as something that always retards motion. Only with more experience and study will students come to understand that friction is also a vital component to being able to move, for example to walk across very smooth surfaces or even to sit on a chair. *Section 1* is more important in enabling students to recognize relatively steady motion under low friction conditions than in measuring how friction retards motion or causes an object to come to rest.
5. **Objects resist acceleration from the state of rest because of friction.** Students confound the concept of friction with that of inertial mass. The teacher needs to lead students to understand that inertial mass is a property of matter and that objects resist acceleration due to their amount of matter rather than to the friction between the surfaces in contact.
6. **Alternative ideas on measurement.** Through observations and careful data collection, students find that measurement is not only linear. They discover any quantity can be measured as accurately as the tools available and that they can only measure to the smallest unit shown on the measuring device.

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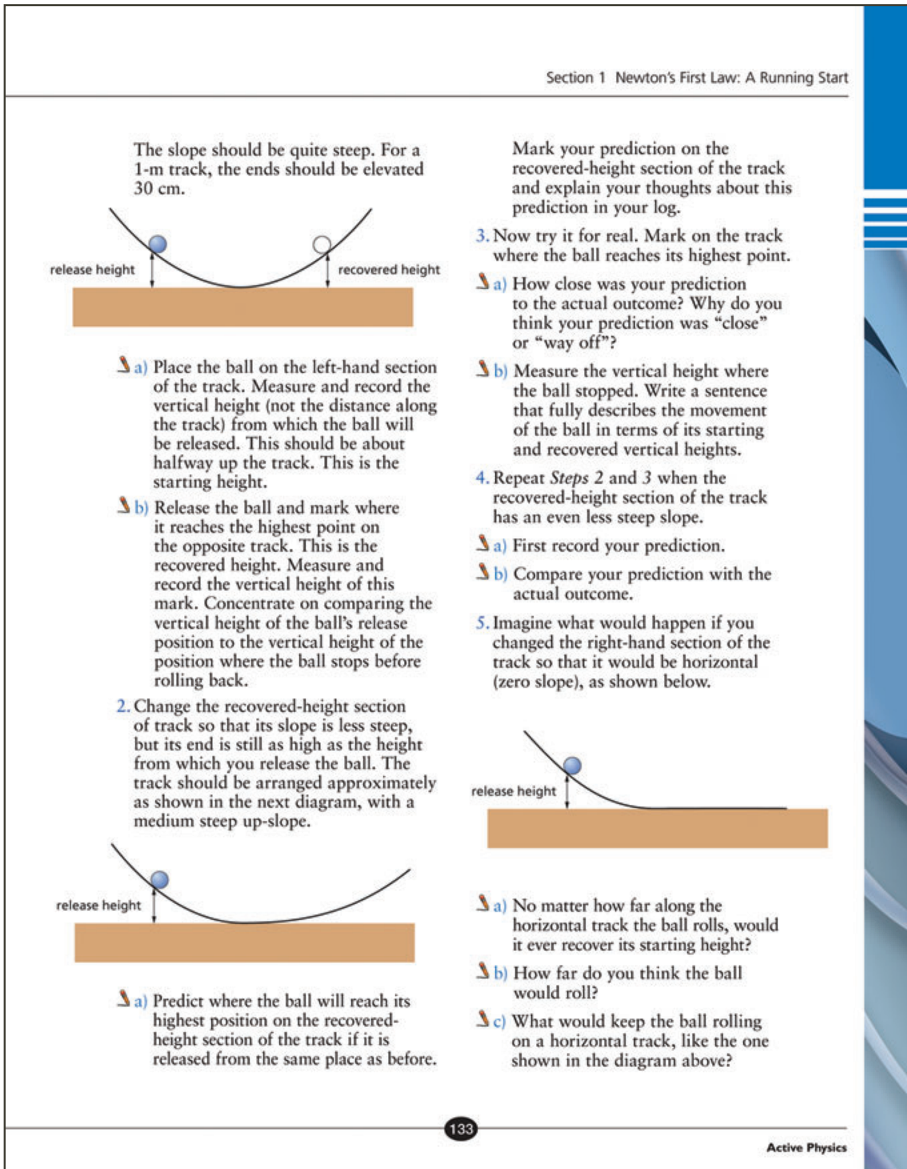


The slope should be quite steep. For a 1-m track, the ends should be elevated 30 cm.

a) Place the ball on the left-hand section of the track. Measure and record the vertical height (not the distance along the track) from which the ball will be released. This should be about halfway up the track. This is the starting height.

b) Release the ball and mark where it reaches the highest point on the opposite track. This is the recovered height. Measure and record the vertical height of this mark. Concentrate on comparing the vertical height of the ball's release position to the vertical height of the position where the ball stops before rolling back.

2. Change the recovered-height section of track so that its slope is less steep, but its end is still as high as the height from which you release the ball. The track should be arranged approximately as shown in the next diagram, with a medium steep up-slope.

a) Predict where the ball will reach its highest position on the recovered-height section of the track if it is released from the same place as before.

Mark your prediction on the recovered-height section of the track and explain your thoughts about this prediction in your log.

3. Now try it for real. Mark on the track where the ball reaches its highest point.

a) How close was your prediction to the actual outcome? Why do you think your prediction was "close" or "way off"?

b) Measure the vertical height where the ball stopped. Write a sentence that fully describes the movement of the ball in terms of its starting and recovered vertical heights.

4. Repeat *Steps 2* and *3* when the recovered-height section of the track has an even less steep slope.

a) First record your prediction.

b) Compare your prediction with the actual outcome.

5. Imagine what would happen if you changed the right-hand section of the track so that it would be horizontal (zero slope), as shown below.

a) No matter how far along the horizontal track the ball rolls, would it ever recover its starting height?

b) How far do you think the ball would roll?

c) What would keep the ball rolling on a horizontal track, like the one shown in the diagram above?

1.b)

Students record the vertical height of the ball where it reaches the highest point on the opposite track.

2.a)

Students may predict that they expect the ball to travel the same distance along the track as the ball going down the incline, or to reach the same height as the ball started from.

3.a)

Students record data. Their answers may vary.

3.b)

When rolling the ball within the track, students should find the recovered height to be very nearly equal to the starting height.

4.a)

Students record data.

4.b)

The ratio of recovered distance to starting distance should be only slightly less than 1.00 and typically 0.90 or more. The actual value will, of course, depend on the coefficient of friction for the particular kind of ball and track used. The error of measurement will be nearly as much as the observable difference in distances, indicating nearly complete "conservation" of distance. The ratio should remain essentially constant, regardless of the starting height. Ask the students if there is a pattern that does not depend on the starting distance.

5.a)

The ball can never recover its starting height on a horizontal track.

5.b)

The ball should roll forever in an attempt to recover its starting height.

5.c)

The students may say that the ball's stored motion (inertia) keeps it rolling. More correctly, there is no reason for the ball to stop because there is no force acting on it. The actual reason the ball stops is due to deformation of the track and the ball.

2-1a **Blackline Master**

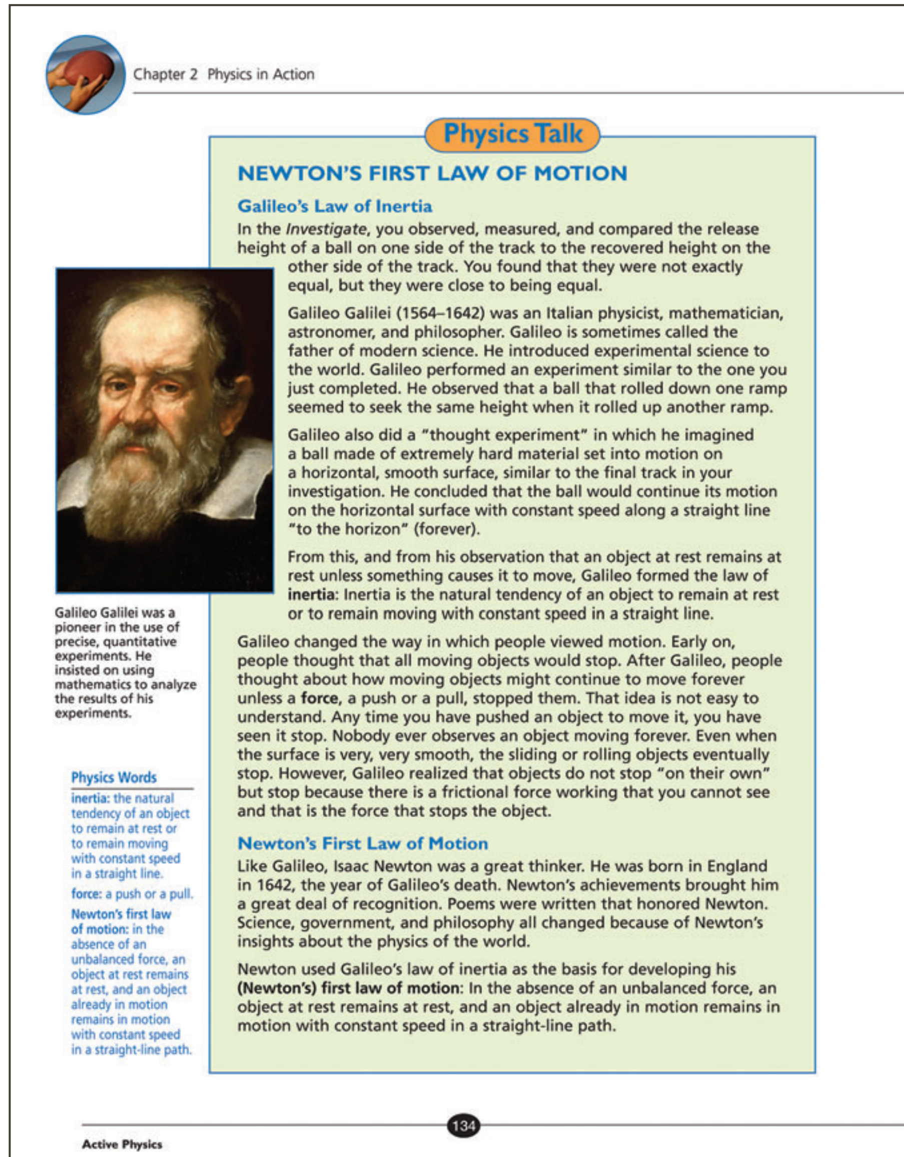
CHAPTER 2

Physics Talk

After students have read the *Physics Talk*, draw their attention to the similarity between Galileo's analysis of rolling balls down a ramp and the *Investigate*. Students should be able to relate their investigations to the property of inertia. Ask them to write definitions of important physics terms in their logs, so that they can refer to these terms when solving problems later on in the section. Consider giving an assignment that requires them to paraphrase how Galileo arrived at the law of inertia. Students could pull a heavy mass and then a light one to see which mass has greater inertia. Discuss the force of friction and how it relates to Newton's first law.

You might want to use examples of other sports, in addition to lacrosse, to reinforce how "running starts" impact speed. Have students demonstrate their understanding of relative speed by choosing an example of a sport they play. Discuss how their knowledge of velocity would improve their chances of winning a game. Ask them to explain the difference between speed and velocity. Make sure that they also understand the distinction between velocity and acceleration. Assure them that they will revisit these concepts several times in *Active Physics*.

As students become familiar with the term *frames of reference*, introduce various examples of moving objects to point out how a frame of reference would impact the measurement of velocity.



Chapter 2 Physics in Action

Physics Talk

NEWTON'S FIRST LAW OF MOTION

Galileo's Law of Inertia

In the *Investigate*, you observed, measured, and compared the release height of a ball on one side of the track to the recovered height on the other side of the track. You found that they were not exactly equal, but they were close to being equal.

Galileo Galilei (1564–1642) was an Italian physicist, mathematician, astronomer, and philosopher. Galileo is sometimes called the father of modern science. He introduced experimental science to the world. Galileo performed an experiment similar to the one you just completed. He observed that a ball that rolled down one ramp seemed to seek the same height when it rolled up another ramp.

Galileo also did a "thought experiment" in which he imagined a ball made of extremely hard material set into motion on a horizontal, smooth surface, similar to the final track in your investigation. He concluded that the ball would continue its motion on the horizontal surface with constant speed along a straight line "to the horizon" (forever).

From this, and from his observation that an object at rest remains at rest unless something causes it to move, Galileo formed the law of **inertia**: Inertia is the natural tendency of an object to remain at rest or to remain moving with constant speed in a straight line.

Galileo Galilei was a pioneer in the use of precise, quantitative experiments. He insisted on using mathematics to analyze the results of his experiments.

Galileo changed the way in which people viewed motion. Early on, people thought that all moving objects would stop. After Galileo, people thought about how moving objects might continue to move forever unless a **force**, a push or a pull, stopped them. That idea is not easy to understand. Any time you have pushed an object to move it, you have seen it stop. Nobody ever observes an object moving forever. Even when the surface is very, very smooth, the sliding or rolling objects eventually stop. However, Galileo realized that objects do not stop "on their own" but stop because there is a frictional force working that you cannot see and that is the force that stops the object.

Newton's First Law of Motion

Like Galileo, Isaac Newton was a great thinker. He was born in England in 1642, the year of Galileo's death. Newton's achievements brought him a great deal of recognition. Poems were written that honored Newton. Science, government, and philosophy all changed because of Newton's insights about the physics of the world.

Newton used Galileo's law of inertia as the basis for developing his **(Newton's) first law of motion**: In the absence of an unbalanced force, an object at rest remains at rest, and an object already in motion remains in motion with constant speed in a straight-line path.

Physics Words

inertia: the natural tendency of an object to remain at rest or to remain moving with constant speed in a straight line.

force: a push or a pull.

Newton's first law of motion: in the absence of an unbalanced force, an object at rest remains at rest, and an object already in motion remains in motion with constant speed in a straight-line path.

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Active Physics

Students should be able to explain the examples given in the *Physics Talk* by drawing diagrams that illustrate movement in relative terms.

Section 1 Newton's First Law: A Running Start

Newton also explained that an object's **mass** is a measure of its inertia, or tendency to resist a change in motion. Given different masses moving at the same speed, the one with the greatest mass has the greatest inertia. The tendency of an object at rest to remain at rest appears to be common sense and few people think otherwise. The tendency of an object that is moving to continue moving (forever) unless acted upon by an unbalanced force is very different from what common sense would tell you. The evidence from the investigation you conducted should help to convince you that objects in motion stay in motion unless a force acts upon them. You will have to remind yourself of this many, many times since most people's intuition is that moving objects do not remain in motion, but tend to stop.

Physics Words

mass: the amount of matter in an object.

Isaac Newton credited Galileo and others for their contributions to his thinking. He is quoted as saying, "If I have seen farther than others, it is because I have stood on the shoulders of giants."

Here is an example of how Newton's first law of motion works: An empty grocery cart has a mass of 10 kg and a cart full of groceries has a mass of 30 kg. The cart with the greater mass has greater inertia.

To test your understanding of Newton's first law of motion, decide which of the following carts has the greatest inertia:

a) 1 kg moving at 5 m/s
b) 2 kg moving at 3 m/s
c) 3 kg moving at 1 m/s
d) 4 kg moving at 1 m/s

The correct response is d) because the 4-kg cart has the most inertia. The speed is not important in determining inertia.

SI System: The Kilogram

In this section, you read that inertia is related to mass. The kilogram is the base unit of mass. This particular base unit is a bit unusual. It is the only base unit that has a prefix. The prefix, kilo (k) placed in front of gram (g) stands for one thousand (10^3). The kilogram is equal to one thousand grams (1 kg = 1000 g).

It might be useful for you to relate the SI units that you will be using in *Active Physics* to the units that you use every day. A two-pound brick has a mass of about one kilogram.

In one of the most important science books of all time, *Principia*, Isaac Newton wrote his first law of motion. It is interesting both historically and in terms of understanding physics to read Newton's first law in his own words:

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Chapter 2 Physics in Action

"Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."

In Newton's time, "right line" meant "straight line."

Running Starts

You saw how Newton's first law of motion applies to a ball rolling down one track and up another track. Think about how Newton's first law of motion applies to sporting events.

"Running starts" take place in many sporting activities. In sports, where the objective is to maximize the speed of an object or the distance traveled in air, the prior motion of a running start is very important.

For example, in the javelin throw, an athlete is running holding a javelin. At the instance of release, the speed of the javelin is the same as the speed of the hand that is throwing the javelin. Newton's first law of motion tells you that when the athlete releases the javelin, the javelin will continue at the same speed. If the athlete then applies additional force to move the elbow and the shoulder of the arm carrying the javelin forward, the speed of the javelin will be the sum of these speeds.

The hand has a forward speed relative to the elbow, the elbow has a forward speed relative to the shoulder (because the arm is rotating around the elbow and shoulder joints), and the shoulder has a forward speed relative to the ground because the body is rotating and the body is also running forward.

Physics Words

speed: the change in distance per unit of time.

velocity: speed in a given direction.

acceleration: the change in velocity per unit of time.

The **speed** of the javelin is the sum of each of the above speeds. If the thrower is not running forward very fast, then the running speed does not add very much to the javelin's speed relative to the ground.

You can write a velocity equation to show the speeds involved. The letter *v* stands for velocity.

$$v_{javelin} = v_{hand} + v_{elbow} + v_{shoulder} + v_{body}$$

The term velocity is used in physics more than the term speed. **Velocity** is speed in a given direction. The two terms, speed and velocity, have slightly different meanings, but at this point, you can use them interchangeably.

Motion captures everyone's attention in sports. Sometimes speeds are constant. These motions are examples of Newton's first law: Objects in motion (at constant speed) stay in motion (at constant speed) unless a force acts on them. When a force acts, the speeds change. This change in speed during a specific time is referred to as **acceleration**. Acceleration occurs during starting, stopping, and changing direction.

Section 1 Newton's First Law: A Running Start

Acceleration is definitely an exciting component of many sports. You will be learning about acceleration in other sections of this chapter. However, ordinary, straight-line motion is just as important in sports, but it is easily overlooked.

Speed and Velocity

In *Active Physics*, you will often explore the same topic several times. Being exposed to the same topic at different times and in different situations helps you learn and understand the topic better. The difference between speed and velocity will be explored frequently in this book.

Frames of Reference

In this section, you investigated Newton's first law. In the absence of external forces, an object at rest remains at rest and an object in motion remains in motion. If you were challenged to throw a ball as far as possible, you would now be sure to ask if you could have a running start. If you run with a ball prior to throwing it, the ball gets your speed before you even try to release it.

If you can run at 5 m/s (meters per second), then the ball will get the additional speed of 5 m/s when you throw it. When you do throw the ball, the ball's speed is the sum of your speed before releasing the ball, 5 m/s, and the speed of the release relative to your body.

It may be easier to understand this if you think of a toy cannon that could be placed on a skateboard. The toy cannon always shoots a small ball forward at 7 m/s. This can be checked with multiple trials. The toy cannon is then attached to the skateboard. A release mechanism is set up so that the cannon continues to shoot the ball forward at 7 m/s when the skateboard is held at rest. Now imagine that the skateboard is moved along at a constant speed of 3 m/s. If the cannon releases the ball while the skateboard is being moved at 3 m/s, the ball's speed is now measured to be 10 m/s. From where did the additional speed come? The ball's speed is the sum of the ball's speed from the cannon plus the speed of the skateboard (7 m/s + 3 m/s = 10 m/s).

You may be wondering if the ball is really moving at 7 m/s or 10 m/s. Both values are correct — it depends on your **frame of reference**. The ball is moving at 7 m/s relative to the skateboard. The ball is moving at 10 m/s relative to the ground.

Physics Words

frame of reference: a vantage point with respect to which position and motion may be described.

CHAPTER 2

Checking Up

1.

Inertia is the property of an object to remain at rest or in motion unless something causes it to move. Inertia resists a change in an object's state of motion.

2.

Newton's first law of motion states that in the absence of an external force, an object at rest remains at rest, and an object already in motion remains in motion with constant speed in a straight-line path.

3.

A force needs to act on an object to stop it from moving at a constant speed.

4.

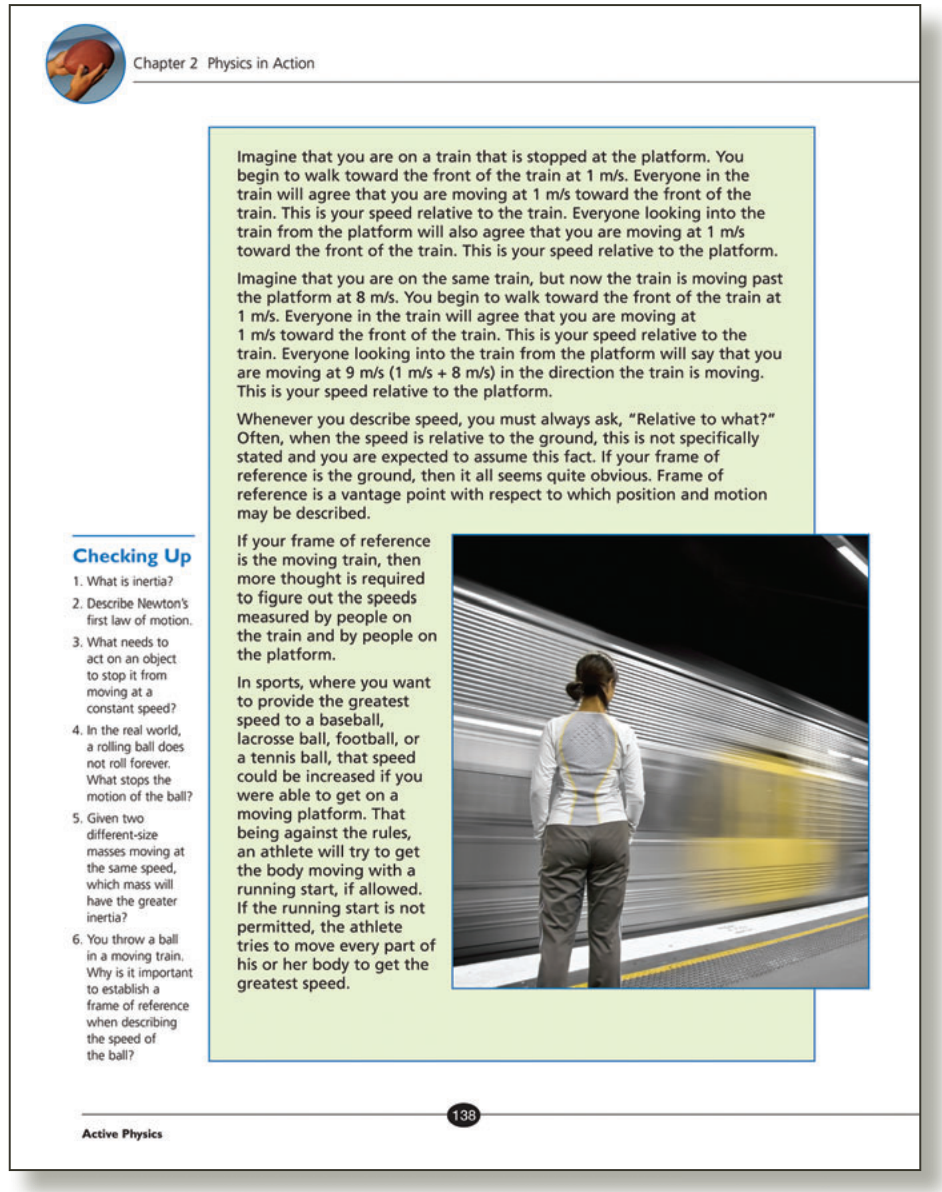
An unbalanced external force stops the ball from moving. This force might be provided by friction or some other force.

5.

The heavier mass will have the greater inertia.

6.

The velocity of the ball measured from the frame of reference of a moving train would differ from the velocity of a ball from the frame of reference of a person standing outside on the ground.


Chapter 2 Physics in Action

Imagine that you are on a train that is stopped at the platform. You begin to walk toward the front of the train at 1 m/s. Everyone in the train will agree that you are moving at 1 m/s toward the front of the train. This is your speed relative to the train. Everyone looking into the train from the platform will also agree that you are moving at 1 m/s toward the front of the train. This is your speed relative to the platform.

Imagine that you are on the same train, but now the train is moving past the platform at 8 m/s. You begin to walk toward the front of the train at 1 m/s. Everyone in the train will agree that you are moving at 1 m/s toward the front of the train. This is your speed relative to the train. Everyone looking into the train from the platform will say that you are moving at 9 m/s (1 m/s + 8 m/s) in the direction the train is moving. This is your speed relative to the platform.

Whenever you describe speed, you must always ask, "Relative to what?" Often, when the speed is relative to the ground, this is not specifically stated and you are expected to assume this fact. If your frame of reference is the ground, then it all seems quite obvious. Frame of reference is a vantage point with respect to which position and motion may be described.

If your frame of reference is the moving train, then more thought is required to figure out the speeds measured by people on the train and by people on the platform.

In sports, where you want to provide the greatest speed to a baseball, lacrosse ball, football, or a tennis ball, that speed could be increased if you were able to get on a moving platform. That being against the rules, an athlete will try to get the body moving with a running start, if allowed. If the running start is not permitted, the athlete tries to move every part of his or her body to get the greatest speed.

Checking Up

1. What is inertia?
2. Describe Newton's first law of motion.
3. What needs to act on an object to stop it from moving at a constant speed?
4. In the real world, a rolling ball does not roll forever. What stops the motion of the ball?
5. Given two different-size masses moving at the same speed, which mass will have the greater inertia?
6. You throw a ball in a moving train. Why is it important to establish a frame of reference when describing the speed of the ball?

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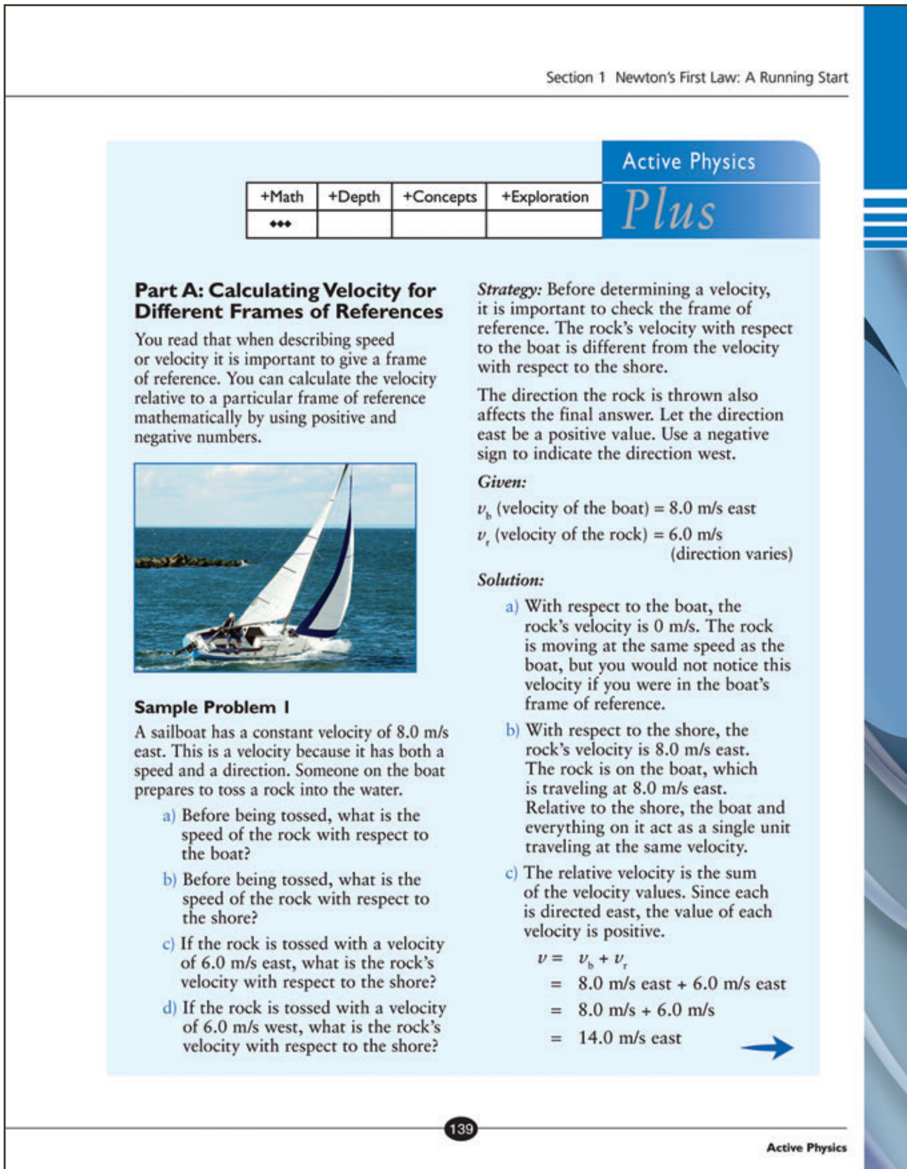
Active Physics



Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
●●●			

Part A: Calculating Velocity for Different Frames of References

You read that when describing speed or velocity it is important to give a frame of reference. You can calculate the velocity relative to a particular frame of reference mathematically by using positive and negative numbers.

Sample Problem I

A sailboat has a constant velocity of 8.0 m/s east. This is a velocity because it has both a speed and a direction. Someone on the boat prepares to toss a rock into the water.

a) Before being tossed, what is the speed of the rock with respect to the boat?

b) Before being tossed, what is the speed of the rock with respect to the shore?

c) If the rock is tossed with a velocity of 6.0 m/s east, what is the rock's velocity with respect to the shore?

d) If the rock is tossed with a velocity of 6.0 m/s west, what is the rock's velocity with respect to the shore?

Strategy: Before determining a velocity, it is important to check the frame of reference. The rock's velocity with respect to the boat is different from the velocity with respect to the shore.

The direction the rock is thrown also affects the final answer. Let the direction east be a positive value. Use a negative sign to indicate the direction west.

Given:

v_b (velocity of the boat) = 8.0 m/s east

v_r (velocity of the rock) = 6.0 m/s (direction varies)

Solution:

a) With respect to the boat, the rock's velocity is 0 m/s. The rock is moving at the same speed as the boat, but you would not notice this velocity if you were in the boat's frame of reference.

b) With respect to the shore, the rock's velocity is 8.0 m/s east. The rock is on the boat, which is traveling at 8.0 m/s east. Relative to the shore, the boat and everything on it act as a single unit traveling at the same velocity.

c) The relative velocity is the sum of the velocity values. Since each is directed east, the value of each velocity is positive.

$$\begin{aligned} v &= v_b + v_r \\ &= 8.0 \text{ m/s east} + 6.0 \text{ m/s east} \\ &= 8.0 \text{ m/s} + 6.0 \text{ m/s} \\ &= 14.0 \text{ m/s east} \end{aligned}$$

Active Physics Plus

Students doing this section will get the opportunity to extend their understanding of inertia in relation to an object's mass. They will also be able to relate frames of reference to velocity by calculating the velocity of an object thrown from a moving body.

CHAPTER 2

1.

The important physical principle is that the ball will roll up the right-hand ramp to a height equal to its starting height. Therefore, $4.2\ \text{m/s} + 10.3\ \text{m/s} = 14.5\ \text{m/s}$ and $h = 10$ cm for all the triangles, regardless of the angle of the ramp. If θ is the angle of the ramp, then $\sin\theta = h/d$, so $d = h/\sin\theta$. The distance, d, along the ramp would be for the angles listed.

1.a)

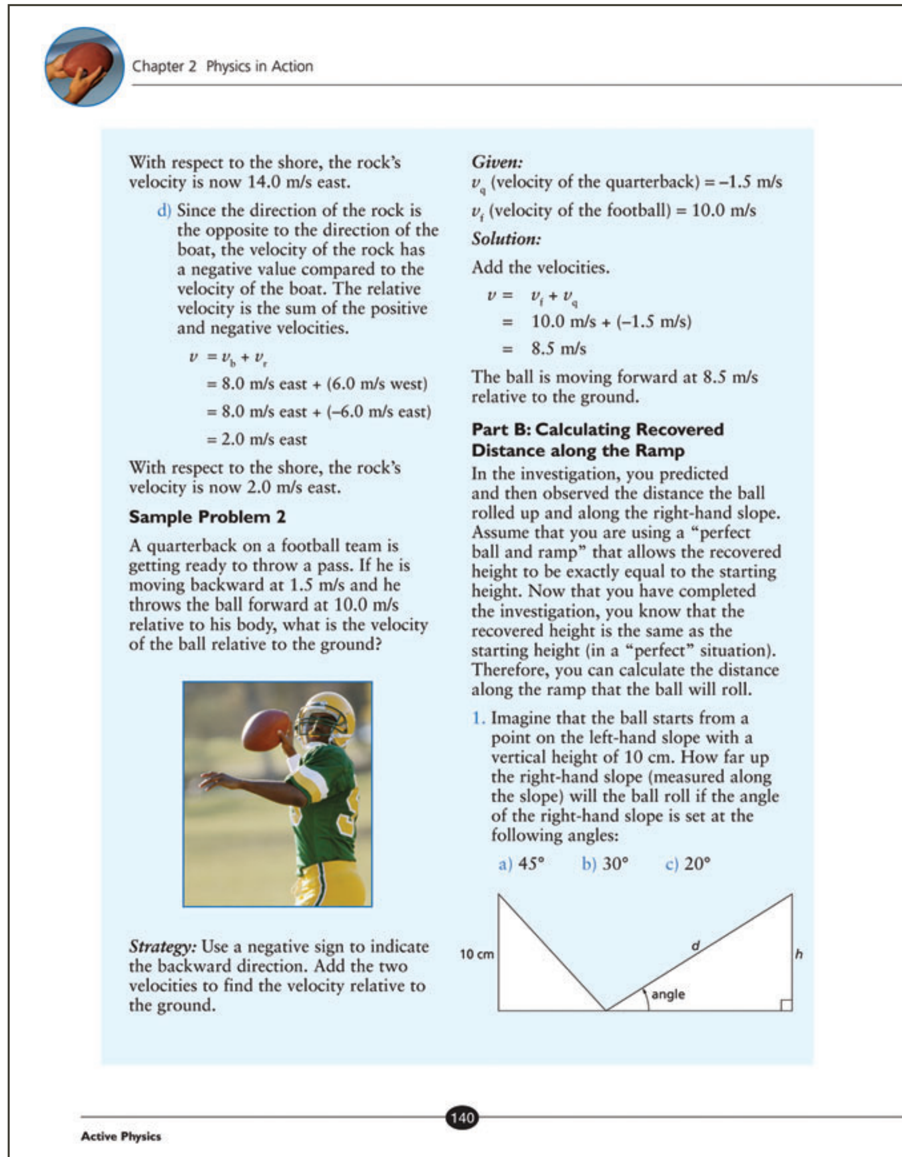
14 cm

1.b)

20 cm

1.c)

29 cm



Chapter 2 Physics in Action

With respect to the shore, the rock's velocity is now 14.0 m/s east.

d) Since the direction of the rock is the opposite to the direction of the boat, the velocity of the rock has a negative value compared to the velocity of the boat. The relative velocity is the sum of the positive and negative velocities.

$v = v_b + v_r$

$= 8.0$ m/s east + (6.0 m/s west)

$= 8.0$ m/s east + (−6.0 m/s east)

$= 2.0$ m/s east

With respect to the shore, the rock's velocity is now 2.0 m/s east.

Sample Problem 2

A quarterback on a football team is getting ready to throw a pass. If he is moving backward at 1.5 m/s and he throws the ball forward at 10.0 m/s relative to his body, what is the velocity of the ball relative to the ground?

Strategy: Use a negative sign to indicate the backward direction. Add the two velocities to find the velocity relative to the ground.

Given:

v_q (velocity of the quarterback) = −1.5 m/s

v_f (velocity of the football) = 10.0 m/s

Solution:

Add the velocities.

$v = v_f + v_q$

$= 10.0$ m/s + (−1.5 m/s)

$= 8.5$ m/s

The ball is moving forward at 8.5 m/s relative to the ground.

Part B: Calculating Recovered Distance along the Ramp

In the investigation, you predicted and then observed the distance the ball rolled up and along the right-hand slope. Assume that you are using a "perfect ball and ramp" that allows the recovered height to be exactly equal to the starting height. Now that you have completed the investigation, you know that the recovered height is the same as the starting height (in a "perfect" situation). Therefore, you can calculate the distance along the ramp that the ball will roll.

1. Imagine that the ball starts from a point on the left-hand slope with a vertical height of 10 cm. How far up the right-hand slope (measured along the slope) will the ball roll if the angle of the right-hand slope is set at the following angles:

a) 45° b) 30° c) 20°

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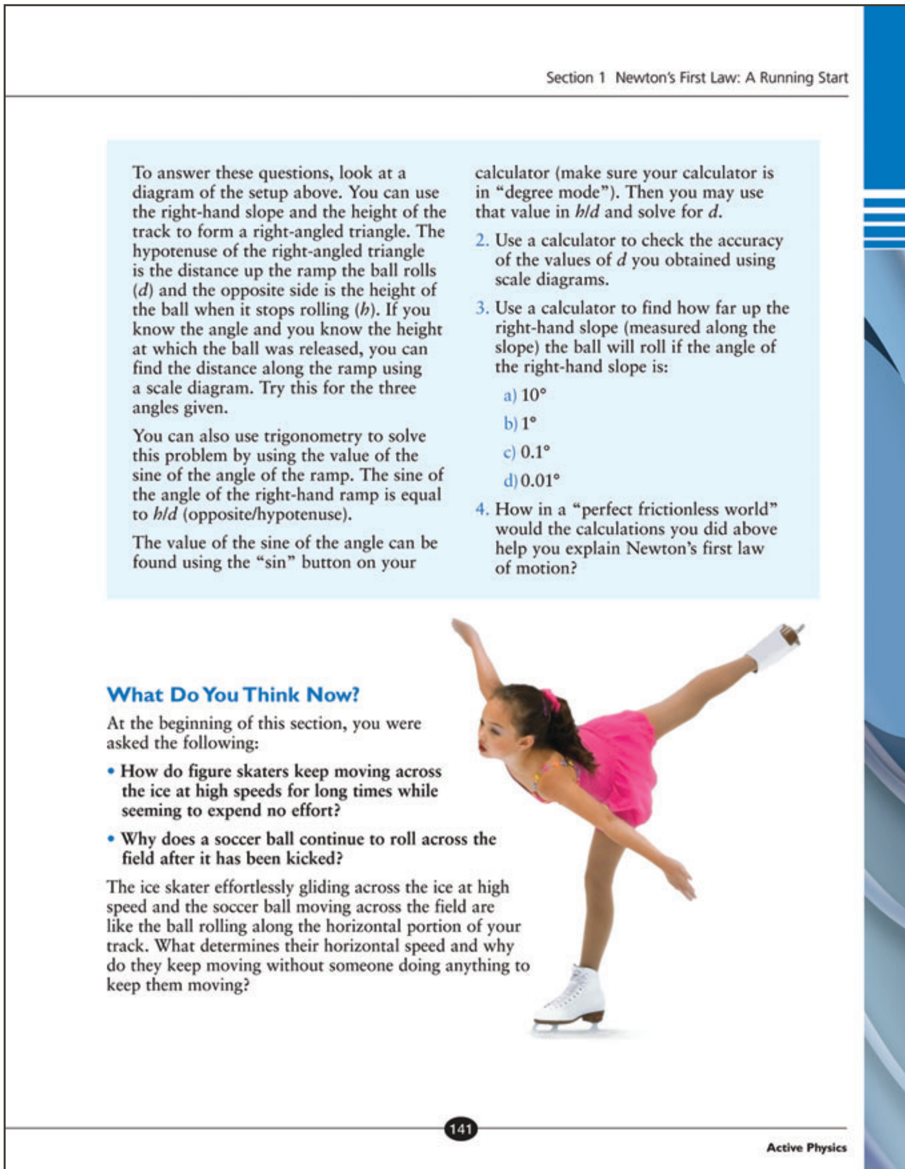
Active Physics



To answer these questions, look at a diagram of the setup above. You can use the right-hand slope and the height of the track to form a right-angled triangle. The hypotenuse of the right-angled triangle is the distance up the ramp the ball rolls (*d*) and the opposite side is the height of the ball when it stops rolling (*h*). If you know the angle and you know the height at which the ball was released, you can find the distance along the ramp using a scale diagram. Try this for the three angles given.

You can also use trigonometry to solve this problem by using the value of the sine of the angle of the ramp. The sine of the angle of the right-hand ramp is equal to *h*/*d* (opposite/hypotenuse).

The value of the sine of the angle can be found using the "sin" button on your calculator (make sure your calculator is in "degree mode"). Then you may use that value in *h*/*d* and solve for *d*.

2. Use a calculator to check the accuracy of the values of *d* you obtained using scale diagrams.
3. Use a calculator to find how far up the right-hand slope (measured along the slope) the ball will roll if the angle of the right-hand slope is:
   a) 10°
   b) 1°
   c) 0.1°
   d) 0.01°
4. How in a "perfect frictionless world" would the calculations you did above help you explain Newton's first law of motion?

What Do You Think Now?

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

- **How do figure skaters keep moving across the ice at high speeds for long times while seeming to expend no effort?**
- **Why does a soccer ball continue to roll across the field after it has been kicked?**

The ice skater effortlessly gliding across the ice at high speed and the soccer ball moving across the field are like the ball rolling along the horizontal portion of your track. What determines their horizontal speed and why do they keep moving without someone doing anything to keep them moving?

2.

The calculator values should closely match the scale diagram values.

3.a)

58 cm

3.b)

570 cm

3.c)

5700 cm

3.d)

57,000 cm

4.

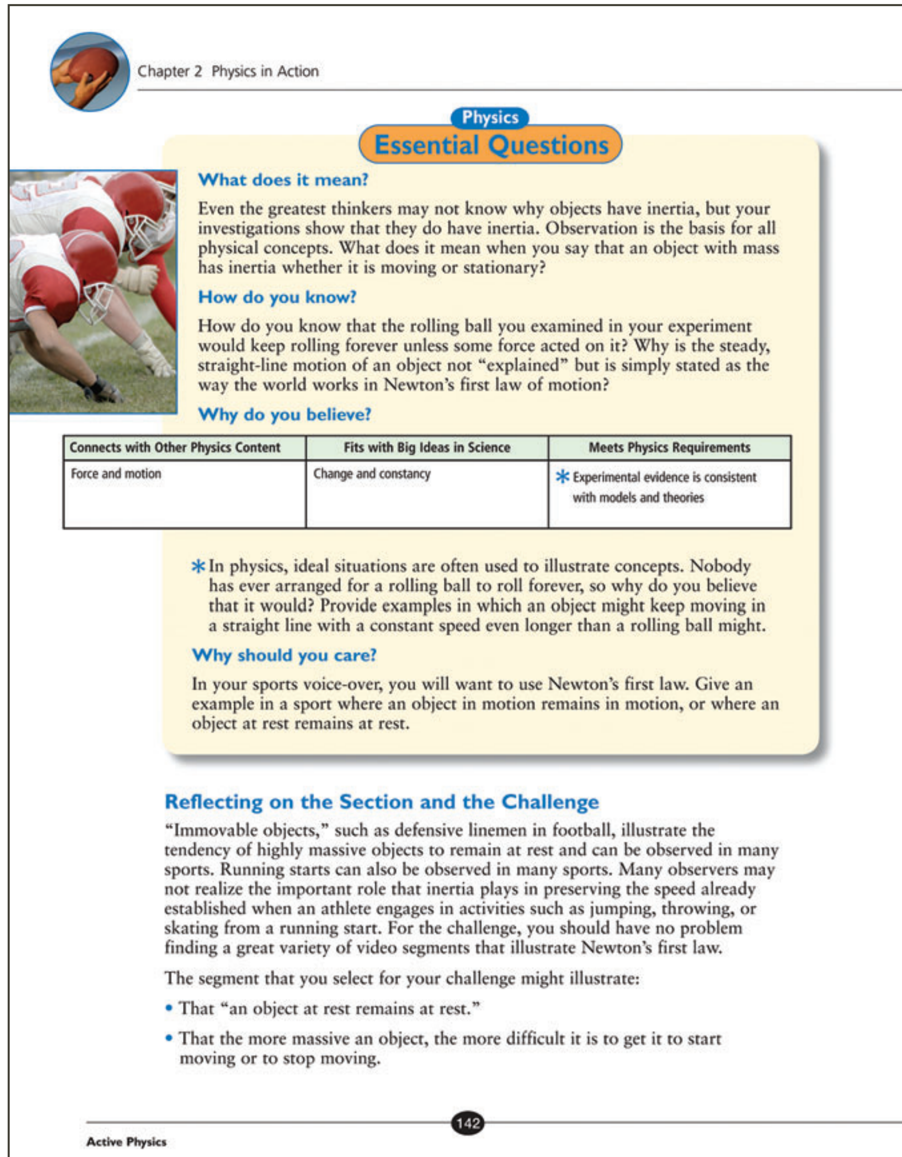
The lower the slope, the further the ball will travel. When the slope goes to zero, the ball should roll "forever," which is a statement of Newton's first law.

What Do You Think Now?

Students should by now have a fair understanding of the main concepts discussed in this section. You might want to share *A Physicist's Response* with them, provided at the beginning of this section. Stress the importance of Newton's first law in determining the answers to the *What Do You Think?* questions. Have students revise the answers they originally wrote in their logs. Ask them if their answers have remained the same. Encourage them to discuss any doubts they might have.

Reflecting on the Section and the Challenge

Encourage students to think of the many ways they can incorporate Newton's first law and the properties of matter into their *Chapter Challenge*. Ask them to ponder how they would use the knowledge they now have to improve their "science commentary." Have them read the *Reflecting on the Section and the Challenge* carefully and emphasize that they should watch a variety of sports video segments that illustrate Newton's first law. Tell them to draw links between running starts and inertia and to consider illustrating those links in their voice-over narration.



Chapter 2 Physics in Action

Physics Essential Questions

What does it mean?

Even the greatest thinkers may not know why objects have inertia, but your investigations show that they do have inertia. Observation is the basis for all physical concepts. What does it mean when you say that an object with mass has inertia whether it is moving or stationary?

How do you know?

How do you know that the rolling ball you examined in your experiment would keep rolling forever unless some force acted on it? Why is the steady, straight-line motion of an object not "explained" but is simply stated as the way the world works in Newton's first law of motion?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Force and motion	Change and constancy	* Experimental evidence is consistent with models and theories

* In physics, ideal situations are often used to illustrate concepts. Nobody has ever arranged for a rolling ball to roll forever, so why do you believe that it would? Provide examples in which an object might keep moving in a straight line with a constant speed even longer than a rolling ball might.

Why should you care?

In your sports voice-over, you will want to use Newton's first law. Give an example in a sport where an object in motion remains in motion, or where an object at rest remains at rest.

Reflecting on the Section and the Challenge

"Immovable objects," such as defensive linemen in football, illustrate the tendency of highly massive objects to remain at rest and can be observed in many sports. Running starts can also be observed in many sports. Many observers may not realize the important role that inertia plays in preserving the speed already established when an athlete engages in activities such as jumping, throwing, or skating from a running start. For the challenge, you should have no problem finding a great variety of video segments that illustrate Newton's first law.

The segment that you select for your challenge might illustrate:

- That "an object at rest remains at rest."
- That the more massive an object, the more difficult it is to get it to start moving or to stop moving.

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Physics Essential Questions

What does it mean?

A massive object has a tendency to keep moving if it is moving and a tendency to stay at rest if it is at rest. This is called inertia.

How do you know?

Newton's first law of motion tells us what happens if there is no external force acting on something. This is an ideal situation—there is always some force acting on an object. The object will keep moving because of the thought experiment that logically shows this as a result.

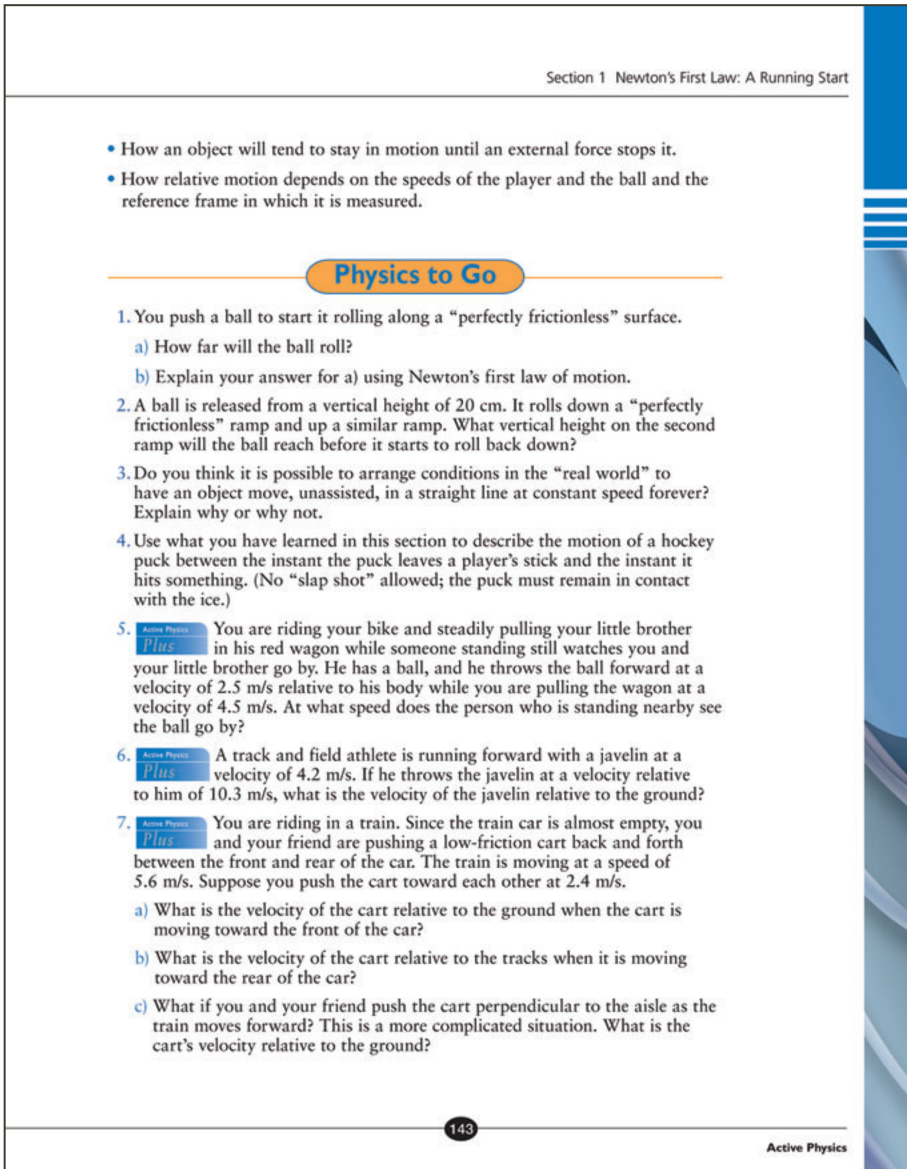
Why do you believe?

As friction and air resistance are gradually decreased on an object, the object will keep moving further and further. If these forces were completely removed, the ball would keep rolling forever. A wheel with good ball bearings will roll further than a ball.

Why should you care?

A football is thrown and will keep moving until someone catches it or it hits the ground.

A sumo wrestler has enormous inertia and if he is at rest, he will stay at rest unless someone applies a force to move him.



Section 1 Newton's First Law: A Running Start

- How an object will tend to stay in motion until an external force stops it.
- How relative motion depends on the speeds of the player and the ball and the reference frame in which it is measured.

Physics to Go

1. You push a ball to start it rolling along a "perfectly frictionless" surface.
   a) How far will the ball roll?
   b) Explain your answer for a) using Newton's first law of motion.
2. A ball is released from a vertical height of 20 cm. It rolls down a "perfectly frictionless" ramp and up a similar ramp. What vertical height on the second ramp will the ball reach before it starts to roll back down?
3. Do you think it is possible to arrange conditions in the "real world" to have an object move, unassisted, in a straight line at constant speed forever? Explain why or why not.
4. Use what you have learned in this section to describe the motion of a hockey puck between the instant the puck leaves a player's stick and the instant it hits something. (No "slap shot" allowed; the puck must remain in contact with the ice.)
5. Active Physics Plus You are riding your bike and steadily pulling your little brother in his red wagon while someone standing still watches you and your little brother go by. He has a ball, and he throws the ball forward at a velocity of 2.5 m/s relative to his body while you are pulling the wagon at a velocity of 4.5 m/s. At what speed does the person who is standing nearby see the ball go by?
6. Active Physics Plus A track and field athlete is running forward with a javelin at a velocity of 4.2 m/s. If he throws the javelin at a velocity relative to him of 10.3 m/s, what is the velocity of the javelin relative to the ground?
7. Active Physics Plus You are riding in a train. Since the train car is almost empty, you and your friend are pushing a low-friction cart back and forth between the front and rear of the car. The train is moving at a speed of 5.6 m/s. Suppose you push the cart toward each other at 2.4 m/s.
   a) What is the velocity of the cart relative to the ground when the cart is moving toward the front of the car?
   b) What is the velocity of the cart relative to the tracks when it is moving toward the rear of the car?
   c) What if you and your friend push the cart perpendicular to the aisle as the train moves forward? This is a more complicated situation. What is the cart's velocity relative to the ground?

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Active Physics

Physics to Go

1.a)

The ball keeps rolling if the surface is horizontal.

1.b)

Newton's first law states, in the absence of an external force, an object will continue in its state of rest or motion. When a ball rolls on a frictionless horizontal surface, it will continue to roll because there are no forces to stop it.

2.

The ball will reach a vertical height of 20 cm before it begins to roll down again.

3.

It does not seem possible to eliminate friction to arrive at perpetual motion in the real world, except perhaps in deep space far away from the influence of any source of gravity.

4.

Because the ice exerts almost no frictional force on the hockey puck, the puck will continue to slide with an almost constant speed in a straight line until a force is exerted upon it. If the object it hits exerts a force in the direction opposite its motion, the puck will slow down, stop, or even change direction depending upon the nature of the force. If the force is in another direction, the puck's direction and possibly its speed will change due to the force.

5.

The speed relative to the person watching will be $2.5\ \text{m/s} + 4.5\ \text{m/s} = 7.0\ \text{m/s}$.

6.

The relative velocity will be $4.2\ \text{m/s} + 10.3\ \text{m/s} = 14.5\ \text{m/s}$.

7.a)

The velocity relative to the ground is $5.6\ \text{m/s} + 2.4\ \text{m/s} = 8.0\ \text{m/s}$.

7.b)

The velocity relative to the tracks is $5.6\ \text{m/s} - 2.4\ \text{m/s} = 3.2\ \text{m/s}$.

7.c)

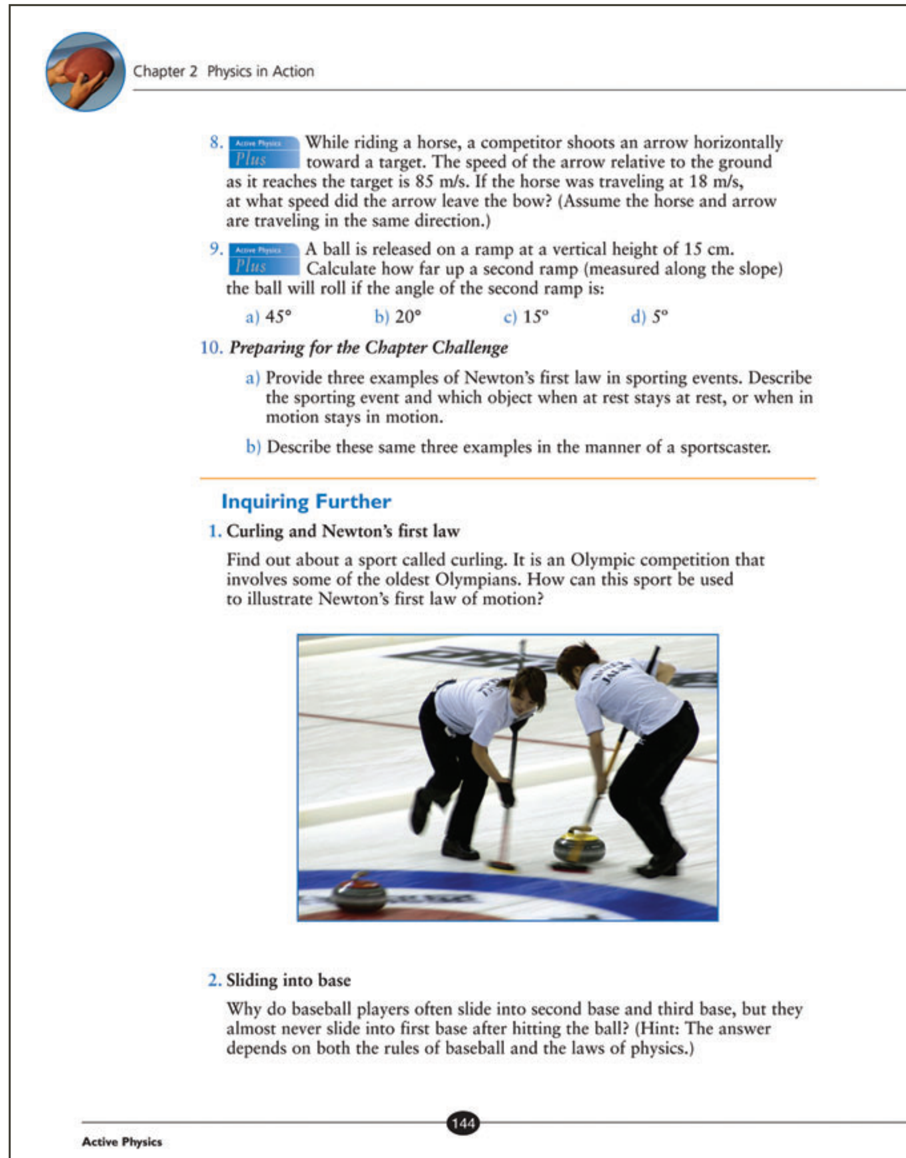
Since the two velocities are perpendicular, we must use the Pythagorean Theorem. So, $(5.6\ \text{m/s})^2 + (2.4\ \text{m/s})^2 = v^2$

$$v = \sqrt{37.12\ \text{m}^2/\text{s}^2}$$

$$v = 6.1\ \text{m/s}.$$

Using the tangent button on the calculator or a vector diagram, the angle is 67°. Students should be able to make the diagram. Some will use the Pythagorean theorem. (More emphasis on this will come in *Section 3*.)

CHAPTER 2



8.

The speed is
$85 \text{ m/s} - 18 \text{ m/s} = 67 \text{ m/s}$.

9.a)

21.2 cm

9.b)

43.9 cm

9.c)

58 cm

9.d)

172 cm

Preparing for the Chapter Challenge

10.a)

Examples of Newton's first law in sports might include objects in motion that continue in motion in a straight line—such as a hockey puck sliding across the ice, a kicked soccer ball rolling along the ground, a race-car driver traveling with constant speed in a straight line, and an ice skater gliding along the ice. Objects at rest that remain at rest would include a football at the line of scrimmage before it is hiked, race cars at the starting line, and a soccer ball waiting for a corner kick.

10.b)

The students will provide various answers, but the written material should show some of the excitement of the sport as well as the physics involved.

Inquiring Further

1.

Curling uses a heavy, polished, granite stone that is slid along ice toward a target. Once the person who starts the stone sliding releases it, the stone continues to slide with roughly constant speed, illustrating Newton's first law.

2.

Sliding in baseball is a way to both stop the runner and to allow forward velocity to reach a base quickly. Because baseball players can run past first base without penalty, most players will run over the base, relying on Newton's first law to allow them to continue in motion at a high rate of speed, once they are running, and get to the base as quickly as possible. Because a player who overruns second or third base may be tagged out, the players slide into the base to slow themselves down and stop at the base. This method allows them to continue running for a longer time and get to the base quicker.

SECTION 1 QUIZ

2-1b **Blackline Master**

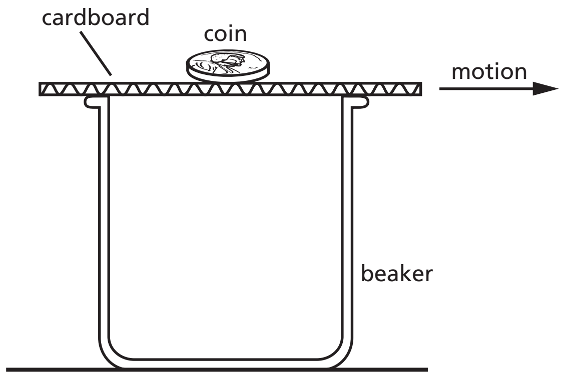
1. A rocket in space can travel without engine power at constant speed in the same direction. This condition is best explained by the concept of

   a) gravity.
   b) inertia.
   c) acceleration.
   d) frames of reference.

2. If the mass of a moving object is doubled, its inertia would be

   a) halved.
   b) the same.
   c) doubled.
   d) four times greater.

3. A coin is resting on a piece of cardboard on a beaker as shown in the diagram. When the cardboard is rapidly removed, the coin falls into the beaker. The two properties of the coin that best explain its fall are its weight and its



   a) temperature.
   b) inertia.
   c) volume.
   d) shape.

4. If there is no net force acting on an object, the object will

   a) slow down and stop.
   b) change its direction of motion.
   c) accelerate.
   d) continue with constant speed in a straight line.

5. Which person has the greatest inertia?

   a) A 110-kg wrestler resting on a mat
   b) A 90-kg man walking at 2 m/s
   c) A 70-kg long-distance runner traveling at 5 m/s
   d) A 50-kg girl sprinting at 9 m/s

SECTION 1 QUIZ ANSWERS

1. b) Inertia is a measure of mass. The more mass an object has the more inertia, without respect to what the object is composed of. Students may think that feathers would have less inertia than lead, but that is only true if they have less mass. Equal amounts of mass imply equal amounts of inertia.

2. d) The object with the greatest mass has the greatest inertia, irrespective of whether or not the object is in motion.

3. b) Because the object is at rest, it must have no net force acting on it.

4. d) According to the law of inertia, an object at rest or traveling with constant speed in a straight line has no net force acting upon it. A net force would be required to change the direction.

5. a) Inertia is a measure of the object's mass only. Size, shape, volume, and speed do not determine its inertia.

NOTES

NOTES