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?**

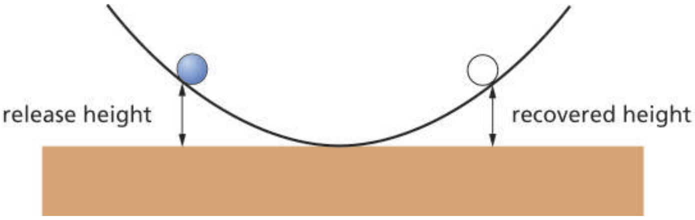
Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your group and the class.

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.

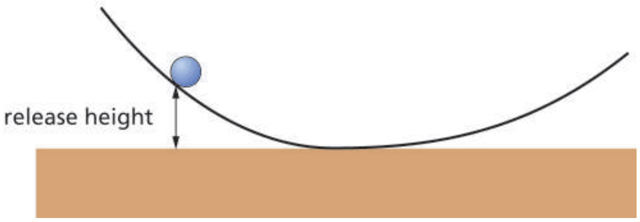
The slope should be quite steep. For a 1-m track, the ends should be elevated 30 cm.



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"?

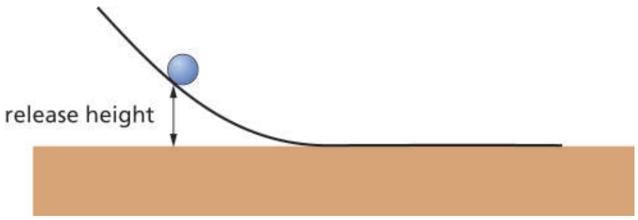
b) Measure the vertical height where the ball stopped. Write a sentence that fully describes the movement of the ball in terms of its starting and recovered vertical heights.

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?

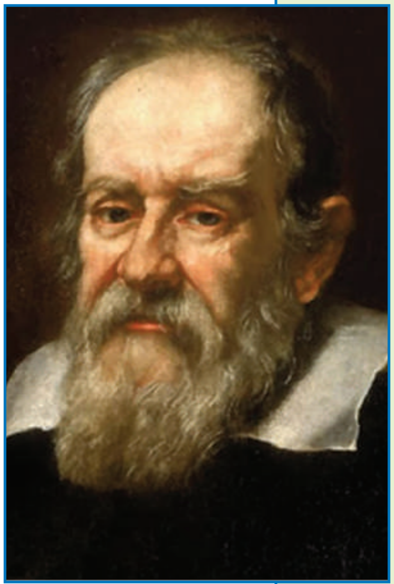
c) What would keep the ball rolling on a horizontal track, like the one shown in the diagram above?

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

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 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.

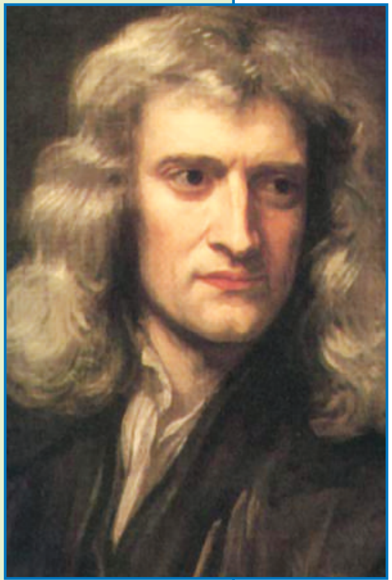
force: a push or a pull.

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.

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:

"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.

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

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.

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.

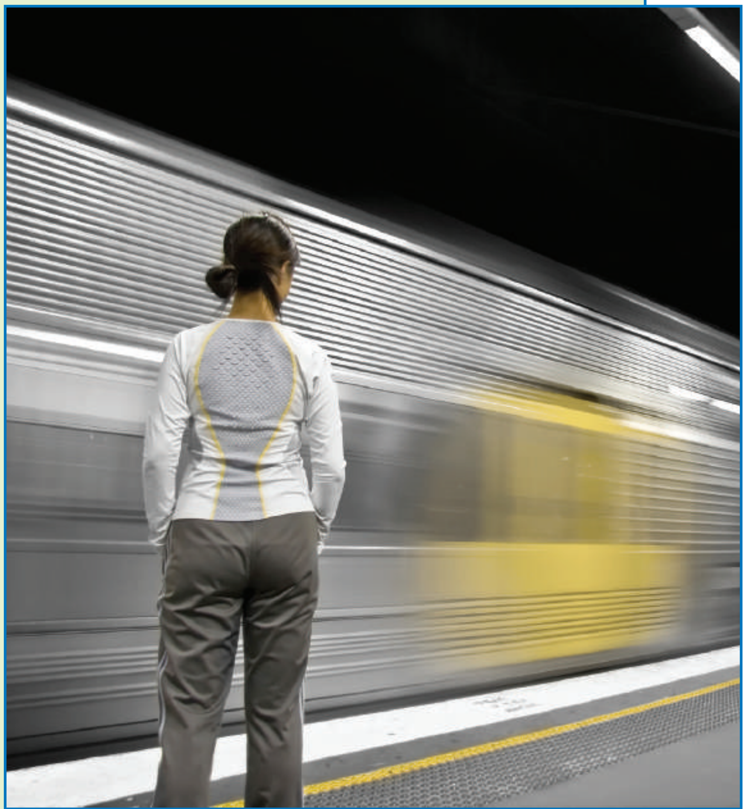
Imagine that you are on a train that is stopped at the platform. You begin to walk toward the front of the train at 1 m/s. Everyone in the train will agree that you are moving at 1 m/s toward the front of the train. This is your speed relative to the train. Everyone looking into the train from the platform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

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.

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

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.

$$\begin{aligned} v &= v_b + v_r \\ &= 8.0 \text{ m/s east} + (6.0 \text{ m/s west}) \\ &= 8.0 \text{ m/s east} + (-6.0 \text{ m/s east}) \\ &= 2.0 \text{ m/s east} \end{aligned}$$

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.

$$\begin{aligned} v &= v_f + v_q \\ &= 10.0 \text{ m/s} + (-1.5 \text{ m/s}) \\ &= 8.5 \text{ m/s} \end{aligned}$$

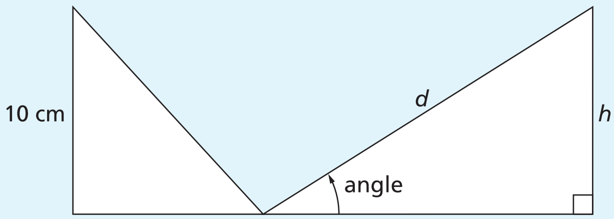
The ball is moving forward at 8.5 m/s relative to the ground.

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°



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?

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.

- 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?

8. Active Physics Plus While riding a horse, a competitor shoots an arrow horizontally toward a target. The speed of the arrow relative to the ground as it reaches the target is 85 m/s. If the horse was traveling at 18 m/s, at what speed did the arrow leave the bow? (Assume the horse and arrow are traveling in the same direction.)

9. Active Physics Plus A ball is released on a ramp at a vertical height of 15 cm. Calculate how far up a second ramp (measured along the slope) the ball will roll if the angle of the second ramp is:

a) 45° b) 20° c) 15° d) 5°

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

a) Provide three examples of Newton's first law in sporting events. Describe the sporting event and which object when at rest stays at rest, or when in motion stays in motion.

b) Describe these same three examples in the manner of a sportscaster.

Inquiring Further

1. **Curling and Newton's first law**

Find out about a sport called curling. It is an Olympic competition that involves some of the oldest Olympians. How can this sport be used to illustrate Newton's first law of motion?

2. **Sliding into base**

Why do baseball players often slide into second base and third base, but they almost never slide into first base after hitting the ball? (Hint: The answer depends on both the rules of baseball and the laws of physics.)