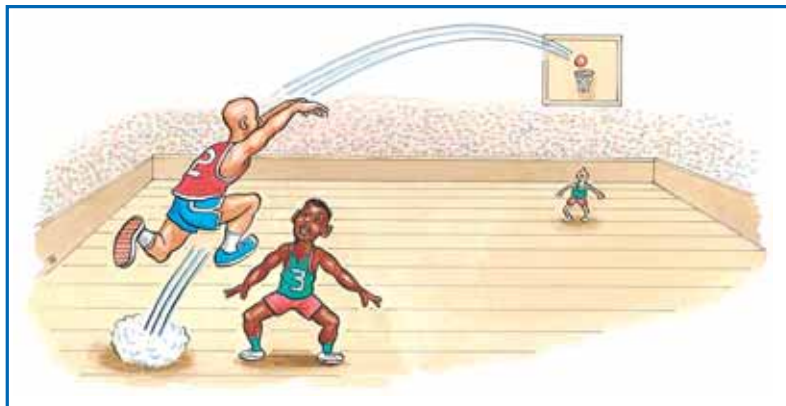




# Activity 1

## A Running Start and Frames of Reference



### GOALS

In this activity you will:

- Understand and apply Galileo's Principle of Inertia.
- Understand and apply Newton's First Law of Motion.
- Recognize inertial mass as a physical property of matter.



### What Do You Think?

Many things that happen in athletics are affected by the amount of “running start” speed an athlete can produce.

- **What determines the amount of horizontal distance a basketball player travels while “hanging” to do a “slam dunk” during a fast break?**
- **How do figure skaters keep moving across the ice at high speeds for long times while seldom “pumping” their skates?**

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



### For You To Do

1. Use a salad bowl and a ball to explore the question, “When a ball is released to roll down the inside surface of a salad bowl, is the motion of the ball up the far side of the bowl the ‘mirror image’ of the ball’s downward motion?” Use a nonpermanent pen to mark a starting position for the ball near the top edge of the bowl. Use a

flexible ruler to measure, in centimeters, the distance along the bowl's curved surface from the bottom-center of the bowl to the mark.

a) Make a table similar to the one below in your log.

| Start  | Trial | Starting Distance (cm) | Recovered Distance (cm) | $\frac{\text{Recovered Distance}}{\text{Starting Distance}}$ |
|--------|-------|------------------------|-------------------------|--|
| High   | 1     |                        |                         |  |
|        | 2     |                        |                         |  |
|        | 3     |                        |                         |  |
| Medium | 1     |                        |                         |  |
|        | 2     |                        |                         |  |
|        | 3     |                        |                         |  |
| Low    | 1     |                        |                         |  |
|        | 2     |                        |                         |  |
|        | 3     |                        |                         |  |

b) Record the measured distance in your table as the High Starting Distance.

2. Prepare to observe and mark the position on the far side of the bowl where the ball stops when it is released from the starting position. Release the ball from the starting position and mark the position where it stops. Measure the distance from the bottom-center to the stop mark.

a) Record the distance in your table as the High Recovered Distance.

3. Repeat **Step 2** above two more times to see if the results are consistent.

a) Record the data for all three trials.

4. Mark two more starting positions on the surface of the bowl, one for Medium Starting Distance and another for Low Starting Distance.

a) Measure and record each of the new distances.



Do not use a glass bowl, if possible.



- b) Observe, mark, measure and record the recovered distances for three trials at each of the medium and low starting positions.
- c) Complete the table by calculating and recording the value of the ratio of the Recovered Distance to the Starting Distance for each trial. (The ratio is the Recovered Distance divided by the Starting Distance.)

Example:

If the Recovered Distance is 6.0 cm for a Starting Distance of 10.0 cm, the value of the ratio is  $\frac{6.0 \text{ cm}}{10.0 \text{ cm}} = 0.6$ .

- d) For each of the three starting distances, to what extent is the motion of the ball up the far side of the bowl the “mirror image” of the downward motion? Use data as evidence for your answer.
  - e) Does the fraction of the starting distance “recovered” when going up the far side of the bowl depend on the amount of starting distance? Describe any pattern of data that supports your answer.
5. Repeat the activity but roll the ball along varying slopes during its upward motion. Make a track that has the same slope on both sides, as shown below. Your teacher will suggest how high the ends of the track sections should be elevated. This time, concentrate on comparing the vertical height of the ball’s release position to the vertical height of the position where the ball stops.



- a) Measure and record the vertical height (not the distance along the track) from which the ball will be released at the top end of the left-hand section of track.
- b) Prepare to observe and mark the position on the right-hand section of track where the ball stops when it is released from the starting position. Release the ball from the top end of the left-hand section of track and mark the position where it stops. Measure and record the vertical height of the position where the ball stops.

- c) Calculate the ratio of the recovered height to the starting height. How is this case, and the result, similar to what you did when using the salad bowl? How is it different?
6. Leave the left-hand starting section of track unchanged, but change the right-hand section of track so that it has less slope and is at least long enough to allow the ball to recover the starting height. The track should be arranged approximately as shown below.



- a) Predict the position where the ball will stop on the right-hand track if it is released from the same height as before on the left-hand track. Mark the position of your guess on the right-hand track and explain the basis for your prediction in your log.
7. Release the ball from the same height on the left-hand section of track as before and mark the position where the ball stops on the right-hand section of track.
- a) How well did you guess the position? Why do you think your guess was “on” or “off”?
- b) Measure the vertical height of the position where the ball stopped and again calculate the ratio of the recovered height to the starting height. Did the ratio change? Why, do you think, did the ratio change or not change?
8. Imagine what would happen if you again did not change the left-hand starting section of track, but changed the right-hand section of track so that it would be horizontal, as shown below.



- a) How far along the horizontal track would the ball need to roll to recover its starting height (or most of it)? How far do you think the ball would roll?
- b) When rolling on the horizontal track, what would “keep the ball going”?



## FOR YOU TO READ

### Inertia

Italian philosopher Galileo Galilei (1564–1642), who can be said to have introduced science to the world, noticed that a ball rolled down one ramp seems to seek the same height when it rolls up another ramp. He 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 **For You To Do**. 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 Principle 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.**

Isaac Newton, born in England on Christmas day in 1642 (within a year of Galileo’s death), used Galileo’s Principle of Inertia as the basis for developing his First Law of Motion, presented in **Physics Talk**. Crediting Galileo and others for their contributions to his thinking, Newton said, “If I have seen farther than others, it is because I have stood on the shoulders of giants.”

### Running Starts

Running starts take place in many sporting activities. Since there seems to be this prior motion in many sports, there must be some advantage to it.

In sports where the objective is to maximize the speed of an object or the distance traveled in air, the prior motion may be essential. When a javelin is thrown, at the instant of release it has the same speed as the hand that is propelling it.

- 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 moving forward.
- The javelin speed then is the sum of each of the above speeds. If the thrower is not running forward, that speed does not add into the equation.

You can write a **velocity** equation to show the speeds involved.

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

Motion captures everyone’s attention in sports. Starting, stopping, and changing direction (**accelerations**) are part of the motion story, and they are exciting components of many sports. Ordinary, straight-line motion is just as important but is easily overlooked.



**PHYSICS TALK****Newton's First Law of Motion**

Isaac Newton included Galileo's Principle of Inertia as part of his **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.

Here is an example of how Newton's First Law of Motion works:

Inertia is expressed in kilograms of mass. If an empty grocery cart has a mass of 10 kg and a cart full of groceries has a mass of 100 kg, which cart would be more difficult to move (have a greater tendency to remain at rest)? If both carts already were moving at equal speeds, which cart would be more difficult to stop (would have a greater tendency to keep moving)? Obviously in both cases, the answer is the cart with more mass.

**Physics Words**

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

**acceleration:** the change in velocity per unit time.

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

**FOR YOU TO READ**  
**Frames of Reference**

In this activity, 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 probably now be sure to

ask if you could have a running start. If you run with the 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, 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.







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 at rest. When the skateboard is given an initial push, the skateboard is able to travel at 3 m/s. If the cannon releases the ball while the skateboard is moving, 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.  $7 \text{ m/s} + 3 \text{ m/s} = 10 \text{ m/s}$ .

You may be wondering if the ball is 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 Earth.

Imagine that you are on a train that is stopped at the platform. You begin to walk toward the front of the train at 3 m/s. Everybody in the train will agree that you are moving at 3 m/s toward the front of the train. This is your speed *relative to* the train. Everybody looking into the train from the platform will also agree that you are moving at 3 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 9 m/s. You begin to walk toward the front of the train at 3 m/s. Everybody in the train will agree that you are moving at 3 m/s toward the



front of the train. This is your speed *relative to* the train. Everybody looking into the train from the platform will say that you are moving at 12 m/s ( $3 \text{ m/s} + 9 \text{ m/s}$ ) toward the front of the train. 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 Earth, this is assumed in

the problem. If your frame of reference is the Earth, then it all seems quite obvious. If your frame of reference is the moving train, then different speeds are observed.

In sports where you want to provide the greatest speed to a baseball, a javelin, a 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 and inappropriate for many reasons, 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.

### Sample Problem I

A sailboat has a constant velocity of 22 m/s east. Someone on the boat prepares to toss a rock into the water.

- Before being tossed, what is the speed of the rock with respect to the boat?
- Before being tossed, what is the speed of the rock with respect to the shore?



- If the rock is tossed with a velocity of 16 m/s east, what is the rock's velocity with respect to shore?
- If the rock is tossed with a velocity of 16 m/s west, what is the rock's velocity with respect to 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 of the rock also impacts the final answer.

**Given:**

$$v_b = 22 \text{ m/s east}$$

$$v_r = 16 \text{ m/s (direction varies)}$$

**Solution:**

- 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 wouldn't notice this velocity if you were in the boat's frame of reference.
- With respect to shore, the rock's velocity is 22 m/s east.  
The rock is on the boat, which is traveling at 22 m/s east. Relative to the shore, the boat and everything on it act as a system traveling at the same velocity.
- With respect to the shore, the rock's velocity is now 38 m/s east.  
It is the sum of the velocity values. Since each is directed east, the relative velocity is the sum of the two.

$$\begin{aligned} v &= v_b + v_r \\ &= 22 \text{ m/s east} + 16 \text{ m/s east} \\ &= 38 \text{ m/s east} \end{aligned}$$







d) With respect to shore, the rock's velocity is now 6 m/s east.

Since the directions are opposite, the relative velocity is the difference between the two.

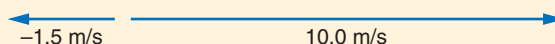
$$\begin{aligned}v &= v_b - v_r \\ &= 22 \text{ m/s east} - 16 \text{ m/s west} \\ &= 6 \text{ m/s east}\end{aligned}$$

### 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, 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.

**Givens:**



**Solution:**

Add the velocities.

$$10.0 \text{ m/s} + (-1.5 \text{ m/s}) = 8.5 \text{ m/s}$$

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



### Reflecting on the Activity and the Challenge

Running starts can 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. “Immovable objects,” such as football linemen, illustrate the tendency of highly massive objects to remain at rest and can be observed in many sports. You should have no problem finding a great variety of video segments that illustrate Newton’s First Law.

## Physics To Go



1. Provide three illustrations 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. Describe these same three illustrations in the manner of an entertaining sportscaster.
2. Find out about a sport called curling (it is an Olympic competition that involves some of the oldest Olympians) and how this sport could be used to illustrate Newton's First Law of Motion.
3. When a skater glides across the ice on only one skate, what kind of motion does the skater have? Use principles of physics as evidence for your answer.
4. Use what you have learned in **Activity 1** 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. Why do baseball players often slide into second base and third base, but almost never slide into first base after hitting the ball? (The answer depends on both the rules of baseball and the laws of physics.)
6. 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.





7. You are pulling your little brother in his red wagon. He has a ball, and he throws it straight up into the air while you are pulling him forward at a constant speed.
  - a) What will the path of the ball look like to your little brother in the wagon?
  - b) What will the path of the ball look like to a little girl who is standing on the sidewalk watching you?
  - c) If your brother throws the ball forward at a velocity of  $2.5 \text{ m/s}$  while you are pulling the wagon at a velocity of  $4.5 \text{ m/s}$ , at what speed does the girl see the ball go by?
8. A track and field athlete is running forward with a javelin at a velocity of  $4.2 \text{ m/s}$ . If he throws the javelin at a velocity relative to him of  $10.3 \text{ m/s}$ , what is the velocity of the javelin relative to the ground?
9. You are riding the train to school. Since the train car is almost empty, you and your friend are throwing a ball back and forth. The train is moving at a velocity of  $5.6 \text{ m/s}$ . Suppose you throw the ball to each other at the same speed,  $2.4 \text{ m/s}$ .
  - a) What is the velocity of the ball relative to the tracks when the ball is moving toward the front of the car?
  - b) What is the velocity of the ball relative to the tracks when it is moving toward the back of the car?
  - c) What if you and your friend throw the ball perpendicular to the aisle of the train? What is the ball's velocity then?
10. Two athletes are running toward the pole vault. One is running at  $3.8 \text{ m/s}$  and the other is running at  $4.3 \text{ m/s}$ .
  - a) What is their velocity relative to each other?
  - b) If they leave the ground at their respective velocities, which one has the energy to go higher in the vault? Explain.
11. While riding a horse, a competitor shoots an arrow toward a target. The speed of the arrow as it reaches the target is  $85 \text{ m/s}$ . If the horse was traveling at  $18 \text{ m/s}$ , at what speed did the arrow leave the bow? (Assume the horse and arrow are traveling in the same direction.)

