SECTION 4

Projectile Motion: Launching Things into the Air

Section Overview

By observing the results of horizontally projected objects, students see how vertical motion of an object in free fall remains unaffected by the horizontal motion of the object and vice versa. In the *Investigate*, students project a coin from across a table to hit another coin placed near the table's edge to observe the rate of fall of each coin. They then compare the motion of the dropped coin and the projected coin to see how they fall relative to each other from a raised surface. Students also observe the combined vertical and horizontal motions of a ball as it is thrown upward at an angle and then allowed to fall as they try to duplicate the trajectory. The upward path of an object and its vertical descent are explained in terms of the rate of change of velocity to demonstrate that all objects fall with the same acceleration.

Background Information

Free Fall: All objects in a state of free fall, regardless of mass, shape, or other characteristics, experience a uniform (constant) acceleration of approximately 10 m/s^2 in the downward direction. (Notice that free fall does not include objects that experience a significant force due to air resistance.)

Projectile Motion: Inertia (an object in motion remains in motion unless a force acts to cause a change in motion) causes a projectile to retain any horizontal motion that it has at the instant it is launched, and it retains that motion in the form of constant horizontal speed.

Gravity causes a projectile to exhibit vertical acceleration that matches free fall, whether or not the projectile has simultaneous horizontal motion. This section does not approach projectile motion quantitatively, but it clearly demonstrates that a coin which simply falls strikes the floor after the same amount of time as a coin launched horizontally from the same height at the same instant. The only way this can happen is if both objects fall downward with identical motions. The fact that one coin simultaneously moves horizontally (at constant speed) as it falls affects where it lands, not when. This section further demonstrates that a ball thrown upward does not have its upward and downward motion affected by any horizontal motion which it may have at the time of launch. The horizontal motion remains one of constant speed and is independent of the vertically accelerated motion. If a student sitting in a stationary chair throws a ball upward, it lands in her hand; if the chair is moving at constant speed throughout the vertical toss, inertia demands that the ball also land in the student's hand. Quantitative treatment of projectile motion, with additional background for the teacher, is presented in the next activity.

Crucial Physics

- Objects in free fall have only the force due to gravity acting on them and move vertically upward or downward with a downward acceleration equal to $g = 9.81\ m/s^2$.
- The horizontal motion and the vertical motion of a trajectory are independent of one another.
- Free fall is a special case in which the horizontal velocity is zero. When the horizontal velocity is not zero, the object's horizontal motion has no acceleration (its velocity is constant) and the object's vertical motion is "free fall" (acceleration equals *g*). The horizontal and vertical motions operate independently of each other.
- The range of a projectile depends on its initial velocity, the angle its initial velocity makes with the horizontal, and the difference in height of its starting and ending locations.

Learning Outcomes	Location in the Section	Evidence of Understanding
Apply the terms free fall, projectile, trajectory, and range.	***Investigate*** Part B: Step 2.a) ***Physics Talk***	Students write in their logs what they observed for trials in which they varied the speed of the chair and the launching speed of the ball to see how the range and trajectory are affected. The *Physics Talk* applies the term *projectile motion* to help students understand how objects move as observed in the *Investigate*.
Provide evidence concerning projectiles launched horizontally from the same height at different launch speeds (including zero launch speed).	***Investigate*** Part A: Steps 1 and 2.	Students first drop coins from a certain height, then flick a coin across a desk to hit another coin hanging over the edge of a table to observe whether both coins hit the floor at the same time.
Explain the relationship between the vertical and horizontal components of a projectile's motion.	***Investigate*** Part B: Steps 1 and 2. ***Physics Talk***	Students observe a ball's trajectory and range as they throw the ball up from a moving chair and try to catch it. The horizontal and vertical movement of a hit or thrown ball is explained in the *Physics Talk*.
Recognize the factors that affect the range of a projectile.	***Physics Talk***	Students recognize that a change in velocity of $9.8\ m/s^2$ acts vertically downwards on the coin while the horizontal velocity of the coin does not change.
Infer the shape of a projectile's trajectory.	***Physics Talk***	Students study the shape of a projectile's trajectory in a graph that represents the motion of an object through different time intervals.

Section 4 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Launcher, projectile	1 per group	
Ball, tennis		1 per class
Coins (pennies, nickels)*		1 per class
Chalkboard*		1 per class
Chalk*		1 per class
Chair (with wheels)*		1 per class
Safety helmet*		1 per class
Pads, knee*		1 per class
Pads, elbow*		1 per class
Stack of books*		1 per class

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Launcher, projectile		1 per class
Ball, tennis		1 per class
Coins (pennies, nickels)*		1 per class
Chalkboard*		1 per class
Chalk*		1 per class
Chair (with wheels)*		1 per class
Safety helmet*		1 per class
Pads, knee*		1 per class
Pads, elbow*		1 per class
Stack of books*		1 per class

*Additional items needed not supplied

Note: Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

Time Requirements

Time required is approximately one period or 40 minutes.

Teacher Preparation

Part A

- Obtain the coins necessary for the *Investigate*. Have extra coins on hand in case some are lost. If you do not have them, coin launchers may be easily built from a piece of scrap metal and a wooden block. This will facilitate the student launching the coins at the same time. If you choose to do the activity with the students "flicking" the coins, the students should do so from a distance of only a few centimeters to increase the chance of a hit.

Part B

- Obtain a sturdy office chair on rollers. It should preferably have five legs, and arms for the student to hold onto while pushed. This *Investigate* should be done as a class demonstration, rather than in individual groups. Before the chair is pushed, have the student who will be sitting in the chair practice throwing the ball straight up and down so that it lands in the same spot from which it was thrown. When the chair is being pushed it is very important that the student be traveling with constant velocity when the ball is thrown upward, and continues with constant velocity while the ball is in the air.

Safety Requirements

- If you use the coin launchers, tell the students not to launch at very high speeds, unless under your direct supervision. Make certain that the students do not leave the coins on the floor, to prevent a slipping hazard.

- For *Part B*, instruct the student pushing the chair on how to push with a uniform velocity that will not endanger the rider. High speed is not necessary to demonstrate the principle. As an extra precaution you may choose to have the rider wear a safety helmet and elbow and knee pads. Do not allow the students to play with the chair, or try to push it at very high velocities, as it may pose a danger to the rider.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Hearing the coins hit the floor	***Investigate*** Part A Steps 1-4	**Augmentation** • Students with hearing, auditory-processing, attention issues may struggle to discriminate the sound of their own coins dropping. Spread groups out as much as possible to do this *Investigate*. • Ask students to set up and practice the procedure for flicking or launching the coins. Then ask one group at a time to flick or launch their coins while the other groups quietly watch and listen. This repetition may help convince more students that both coins hit at the same time and will decrease background noise. **Accommodation** • Perform the procedure as a demonstration with the entire class watching and listening quietly. • Use two of the same objects that are larger and will make a louder sound when hitting the ground.
Understanding vocabulary	***Investigate*** Part B ***Physics Essential Questions***	**Augmentation** • Students may not know the meaning of vertical and horizontal. Ask a student in the class to explain the meaning of both words and show examples.
Maintaining focus during a large group task	***Investigate*** Part B	**Augmentation** • Students with attention issues struggle to focus and follow directions during large-group tasks. Make sure the whole group knows the purpose of the activity and each student knows the task she or he is supposed to complete to assist the large group. • Ask students to repeat directions back to the teacher or a partner to ensure that they have heard and understand their role. **Accommodation** • Ask the students with the most severe attention issues to be the ones sitting in the chair or pushing the chair.
Understanding vocabulary	***Physics Words***	**Augmentation** • Ask students to draw pictures to represent each of the four vocabulary words in this section. This section will aid the students in committing these words to their long-term memories and help the teacher check for understanding.
Understanding vocabulary	***Physics Talk,*** ***Physics to Go*** Question 4	**Augmentation** • Students may not know the meaning of air resistance. Ask a volunteer to explain the meaning of air resistance. • Drop a feather and a coin at the same time to show an example of air resistance.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Making inferences Vocabulary comprehension	***Active Physics Plus*** Step 2.d)	To answer the question, students will need to understand the meaning of the word "magnitude." Students may remember that they encountered this word in *Chapter 1* when learning about vectors. Guide students in remembering or inferring the meaning here, which is "size." Be sure students do not think of magnitude in the current context as a synonym for speed.
Making inferences Vocabulary comprehension	***Physics Essential Questions***	To answer the question, "What does it mean to say that the horizontal motion of a projectile is independent of the vertical motion of the same projectile?" students will need to infer the meaning of "independent" in this context. Allow ELL students time to think through and write an answer. Then look at the answers and offer additional guidance if necessary. You may wish to suggest that students think in terms of "separate" or "apart."

Point out new vocabulary words in context and practice using the words as much as possible throughout the section.

air resistance	range
free fall	resultant velocity
horizontal	shot put
javelin	trajectory
launch	variable
projectile	vertical

ELL students benefit from writing in English. Have students write a summary of what they did in this section, using the words in the list above and any other vocabulary words they choose. You may wish to have students work in pairs. Review and correct student work.

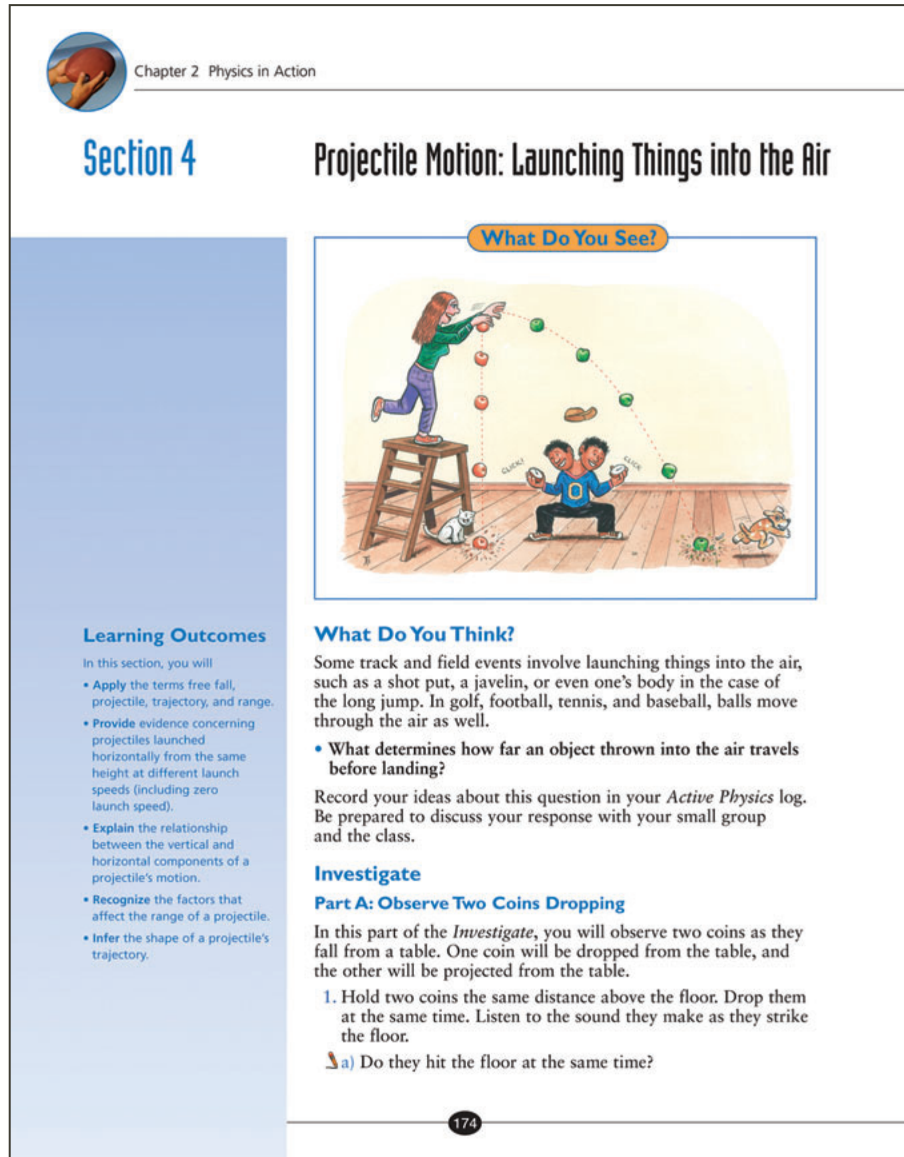
Rapid feedback about students' sentences is essential, because the sentences and errors will be fresh in students' minds. A quick and powerful method for providing this feedback is to prepare a list of examples of sentences containing errors from the students' work. Divide examples into the following categories: incorrect science, incorrect usage of vocabulary, incorrect sentence structure, and incorrect grammar. Choose several examples from the collected work to use in each category and edit the sentences until they contain only one or two obvious errors. At the beginning of class the next day, provide each student with a page containing a double-spaced, typed list of the incorrect sentences, with headings for the four categories. Allow students ten minutes to silently make corrections to the sentences. Then place a copy of the list on the overhead projector and ask students to suggest ideas for how to correct the sentences. During the exercise, guide students toward correct science and correct English usage.

SECTION 4

Teaching Suggestions and Sample Answers

What Do You See?

Most students will offer quick responses when they see a visual set in a classroom. Remind students that they will be returning to this illustration further along in this section. Stimulate their interest by asking probing questions that connect to the *Learning Outcomes*. Emphasize that all answers will be considered as a step toward understanding future concepts. You might also want to point out this section provides a backdrop for the concepts they are about to learn. Once they have read this section, they should be able to explain the artist's purpose behind the illustration.



Chapter 2 Physics in Action

Section 4 Projectile Motion: Launching Things into the Air

What Do You See?

Learning Outcomes

In this section, you will

- **Apply** the terms free fall, projectile, trajectory, and range.
- **Provide** evidence concerning projectiles launched horizontally from the same height at different launch speeds (including zero launch speed).
- **Explain** the relationship between the vertical and horizontal components of a projectile's motion.
- **Recognize** the factors that affect the range of a projectile.
- **Infer** the shape of a projectile's trajectory.

What Do You Think?

Some track and field events involve launching things into the air, such as a shot put, a javelin, or even one's body in the case of the long jump. In golf, football, tennis, and baseball, balls move through the air as well.

- **What determines how far an object thrown into the air travels before landing?**

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

Investigate

Part A: Observe Two Coins Dropping

In this part of the *Investigate*, you will observe two coins as they fall from a table. One coin will be dropped from the table, and the other will be projected from the table.

1. Hold two coins the same distance above the floor. Drop them at the same time. Listen to the sound they make as they strike the floor.

a) Do they hit the floor at the same time?

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Students' Prior Conceptions

Students should understand that constant acceleration is the result of a constant force acting on a projectile; forces that act perpendicular to one another act independently on an object; and a projectile can exhibit constant motion in one direction and constant acceleration in another direction, simultaneously. Students should identify what happens to the velocity, both its magnitude and its direction, of an object that is thrown vertically upward in one case and that is projected horizontally in another situation.

1. **The motion of an object is always in the direction of the net force applied to the object.** Measuring and analyzing the velocity of a ball thrown directly upward as a result of the constant downward pull of gravity enables the student to recognize that the ball moves upward until the instantaneous velocity at the top of the trajectory is zero then moves downward with increasing speed; both motions are influenced by the same force of gravity and the same acceleration.
2. **Students may not understand that gravity is a force, believing that the motion of a falling body is natural, therefore needing no further explanation.** Through examining the vertical motions of objects, students learn to recognize that falling is not due to the internal effort of the falling object.
3. **Objects fall with a constant velocity.** Measuring the speed of falling objects at different points in a trajectory is vital for students to align their thinking with the laws governing freely falling objects; the speed of a falling object is directly proportional to the time of fall in the absence of air resistance.

What Do You Think?

You might want to ask your students what happens when they play sports in which they launch things into the air. Invite them to share their answers in class, so that a discussion is started where everybody is encouraged to participate. Your task is to skillfully guide them toward the main question. Make sure they record their answers for another discussion after they have studied this section in more detail.

What Do You Think?

A Physicist's Response

The trajectory of an object is determined by its initial vertical speed and initial horizontal speed, its position at the beginning of the trajectory, and any extra factors (such as friction or fluid speed) that may be important to the specific situation. The initial velocity (speed and direction) determines the range of a projectile; a difference in the elevations of the launch and landing points would also affect the range. A ball with a 100-mph pitch thrown horizontally by a major league player will hit the ground in the same amount of time as a ball with a 10-mph pitch thrown horizontally from the same height by a child. It is a near certainty that many students will not believe this type of fact without some personal experience. The work with coins should present a discrepancy for them which, hopefully, will cause them to confront their misconceptions about projectiles.

Investigate

Part A

1.a)

Both coins will hit the ground at the same time if released at the same time.

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4. **Gravity only operates when an object falls.** Measuring the velocity at various points along the trajectory of the path of a ball that is thrown straight up and allowed to return to its origin enables students to see that the acceleration due to gravity slows down the ball in a regular way as the ball travels to the top of its path and speeds up the ball in a similar manner as it falls down again.
5. **An object traveling fast enough in the horizontal direction can defy gravity.** Students may exhibit confusion on this concept as they explore ideas associated with rockets and space travel; they may not recognize that the force of gravity decreases according to the inverse square law as an object moves further away from Earth. They liken breaking away from Earth's pull in the vertical direction with avoiding Earth's pull in the horizontal direction by moving fast enough.
6. **The faster something travels horizontally, the slower it falls.** Propelling two coins or two tennis balls from the same height simultaneously, one vertically and the other horizontally, encourages students to hear and to recognize that the two objects hit the floor simultaneously, regardless of the horizontal speed. Instructional material provides evidence that all projectiles launched horizontally from the same height strike a level surface in equal times, regardless of the launch speed, including a zero launch speed.

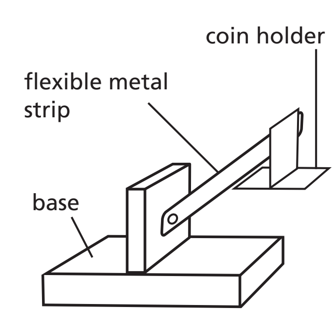
NOTES

2.a)

The coins hit the floor at the same time.

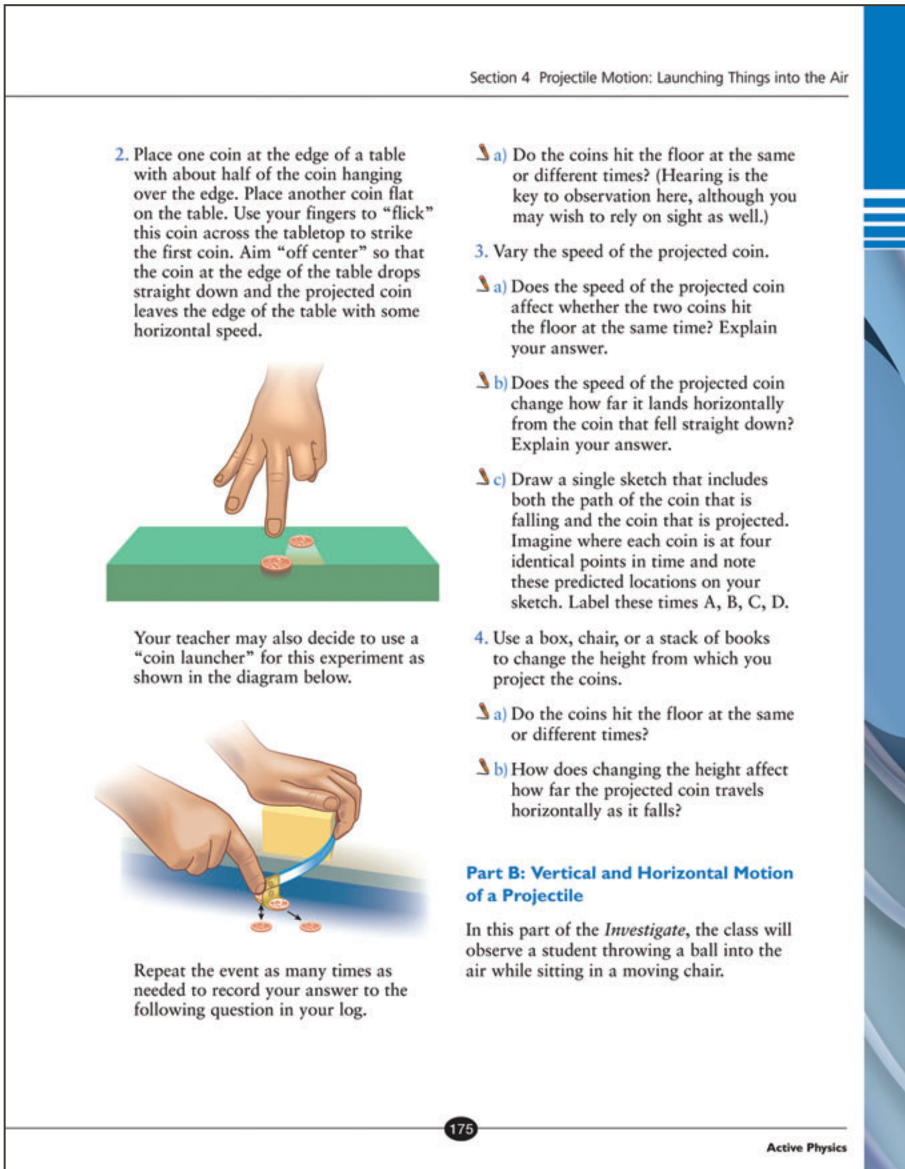
Teaching Tip

Having the students make a glancing collision between the two coins at the edge of the table in the first part of the activity may prove frustrating for some students. A device to launch a coin horizontally while simultaneously dropping a second coin may be made from a wood stand, a metal strip like a hacksaw blade, and a folded piece of file folder to hold the coins before they are "launched" as shown in the diagram to the right.



coin launcher

The two coins are placed on opposite sides of the folded file folder at the end of the metal strip. When the strip is then



Section 4 Projectile Motion: Launching Things into the Air

2. Place one coin at the edge of a table with about half of the coin hanging over the edge. Place another coin flat on the table. Use your fingers to "flick" this coin across the tabletop to strike the first coin. Aim "off center" so that the coin at the edge of the table drops straight down and the projected coin leaves the edge of the table with some horizontal speed.

Your teacher may also decide to use a "coin launcher" for this experiment as shown in the diagram below.

Repeat the event as many times as needed to record your answer to the following question in your log.

a) Do the coins hit the floor at the same or different times? (Hearing is the key to observation here, although you may wish to rely on sight as well.)

3. Vary the speed of the projected coin.

a) Does the speed of the projected coin affect whether the two coins hit the floor at the same time? Explain your answer.

b) Does the speed of the projected coin change how far it lands horizontally from the coin that fell straight down? Explain your answer.

c) Draw a single sketch that includes both the path of the coin that is falling and the coin that is projected. Imagine where each coin is at four identical points in time and note these predicted locations on your sketch. Label these times A, B, C, D.

4. Use a box, chair, or a stack of books to change the height from which you project the coins.

a) Do the coins hit the floor at the same or different times?

b) How does changing the height affect how far the projected coin travels horizontally as it falls?

Part B: Vertical and Horizontal Motion of a Projectile

In this part of the *Investigate*, the class will observe a student throwing a ball into the air while sitting in a moving chair.

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pulled back horizontally and released, one coin is propelled horizontally, and the second coin slides off the folder and falls almost vertically to the floor.

3.a)

The initial speed of the coin being "flicked" or launched has no effect on the amount of time it takes for either coin to fall to the floor. Ask the students to go through their reasoning when answering the question. The only way to compare trials with different speeds is to always impart very little velocity to the stationary coin. In other words, a coin falling straight down is the common element in all trials and the basis for comparison.

3.b)

The coin with the greater initial velocity will have a greater range; it will travel further across the floor. Ask the students if this makes sense in light of their answer to *Step 3.a)*. The coin that had the highest initial horizontal speed will maintain that speed as it falls, allowing it to travel farther. The faster the coin is moving, the further it will move.

3.c)

The student's sketch should look similar to the diagram in *Step 2* in the text. Coins labeled with the same time should be the same height from the floor.

4.a)

When the two coins start from a lower elevation, they still hit at the same time. Ask the students what *does* change as the height decreases.

4.b)

With the decreased starting height, the projected coin travels a shorter distance horizontally than it did from a higher starting position. Ask the students if this makes sense, given their observations from the previous parts.

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Teaching Tip

This activity may be done by either increasing the time of fall from that of the initial position or decreasing the time of fall. If you are using the coin launcher, increasing the time of fall to the floor is probably easier than trying to have the coins land on a specified target. To do this, just place the coin launcher on a stack of books on the table. The students should make certain they pull the coin launcher back an equal distance for both trials at the different heights to ensure that the difference in range is due to different time of flight, and not a different horizontal velocity.

1. To illustrate an object that has both vertical and horizontal motion at the same time, your teacher will supervise a class activity in which one student sits on a chair that is moving at constant speed. While the chair is moving, the student on the chair will throw a ball straight up into the air and try to catch it when it comes down. The class will stand in a line beside the path of the chair to observe the event, prepared to mark the vertical position of the ball as it passes them.

   a) In your log, write your prediction of what you think will happen.

2. This activity can be done in several ways. It is ideal if the chair's path can be parallel to the chalkboard. Another option is to take a large roll of paper and tape the paper to a wall parallel to the path of the chair on the opposite side from the observing students. The bottom horizontal side of the board or paper should be at the height the student in the chair launches and catches the ball. Each student observing the event draws a vertical line on the board or paper marking their position beside the path. As the event takes place, each observing student keeps track of the height of the ball as it passes the line representing their position. After the event, each student puts a mark on the board or paper corresponding to the point where the ball passed the line.

   a) Write in your log what you observed about the ball's trajectory (shape of the ball's path) and the ball's approximate range (horizontal distance) for trials in which you varied the speed of the chair and the launching speed of the ball. Remember, to see the effect of both the ball's trajectory and approximate range, be sure to only change one variable at a time during your trials.

   b) According to your observations, what factors affect the range of the ball?

Part B

1.a)

It is important that students record their predictions before the activity is completed. This permits them to confront their misconceptions, if there are any. If students are not encouraged to commit to a prediction, they will often predict the "right answer" after the fact. Although students may learn to respond with the correct answer, they may still not have confronted their misconceptions.

2.

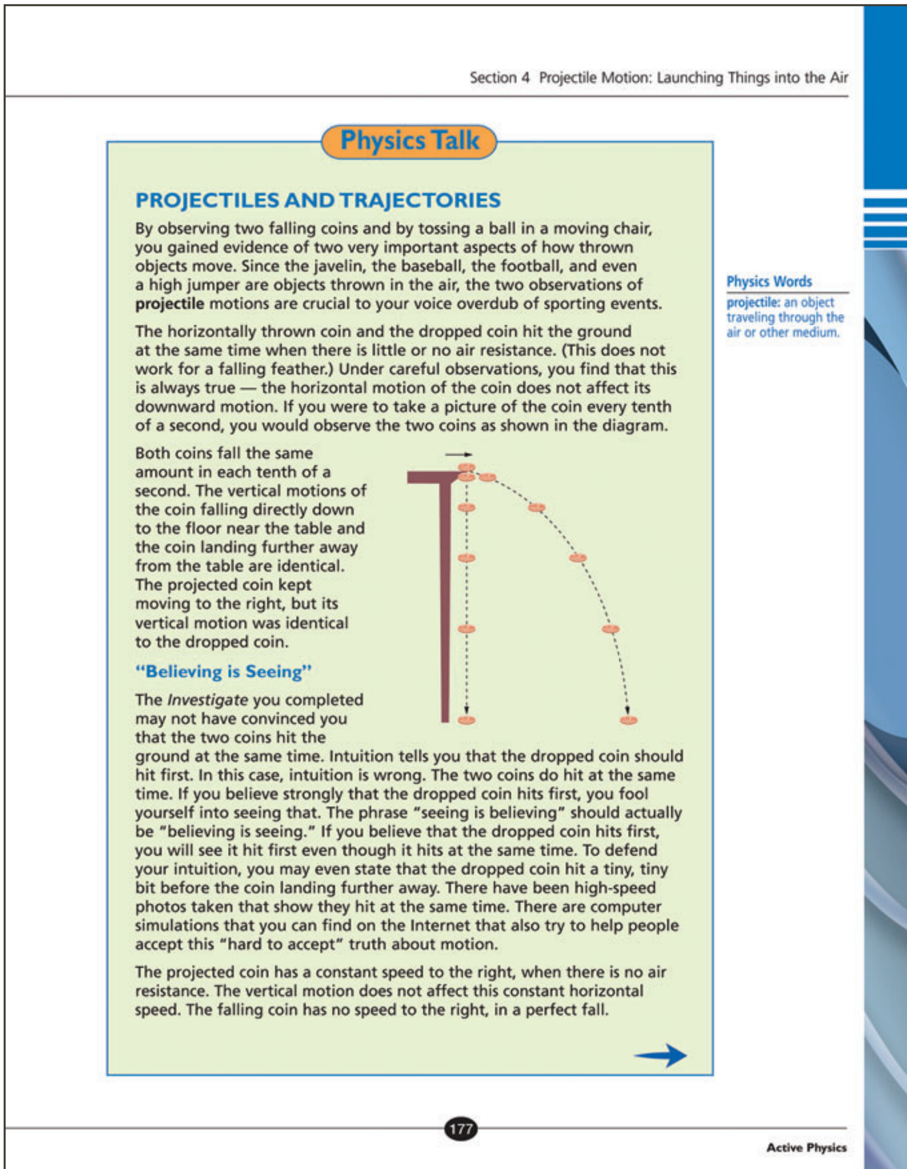
The ball should land in the student's hands as if the chair were not moving when thrown straight upward because, due to inertia, the ball retains its horizontal speed as it independently flies up and down with accelerated vertical motion due to gravity.

2.a)

Students may see that the ball follows a curved path. Hopefully they will measure and record that increased horizontal speed increases range. Increased vertical speed also increases range.

2.b)

Two factors that affect the range of the ball are the vertical speed at which the ball is launched, and the horizontal speed of the chair (and ball) when the ball is launched.



Section 4 Projectile Motion: Launching Things into the Air

Physics Talk

PROJECTILES AND TRAJECTORIES

By observing two falling coins and by tossing a ball in a moving chair, you gained evidence of two very important aspects of how thrown objects move. Since the javelin, the baseball, the football, and even a high jumper are objects thrown in the air, the two observations of **projectile** motions are crucial to your voice overdub of sporting events.

The horizontally thrown coin and the dropped coin hit the ground at the same time when there is little or no air resistance. (This does not work for a falling feather.) Under careful observations, you find that this is always true — the horizontal motion of the coin does not affect its downward motion. If you were to take a picture of the coin every tenth of a second, you would observe the two coins as shown in the diagram.

Both coins fall the same amount in each tenth of a second. The vertical motions of the coin falling directly down to the floor near the table and the coin landing further away from the table are identical. The projected coin kept moving to the right, but its vertical motion was identical to the dropped coin.

"Believing is Seeing"

The *Investigate* you completed may not have convinced you that the two coins hit the ground at the same time. Intuition tells you that the dropped coin should hit first. In this case, intuition is wrong. The two coins do hit at the same time. If you believe strongly that the dropped coin hits first, you fool yourself into seeing that. The phrase "seeing is believing" should actually be "believing is seeing." If you believe that the dropped coin hits first, you will see it hit first even though it hits at the same time. To defend your intuition, you may even state that the dropped coin hit a tiny, tiny bit before the coin landing further away. There have been high-speed photos taken that show they hit at the same time. There are computer simulations that you can find on the Internet that also try to help people accept this "hard to accept" truth about motion.

The projected coin has a constant speed to the right, when there is no air resistance. The vertical motion does not affect this constant horizontal speed. The falling coin has no speed to the right, in a perfect fall.

Physics Words

projectile: an object traveling through the air or other medium.

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2-4a Blackline Master

Physics Talk

Few students have thought much about trajectories. Emphasize that a projectile aimed horizontally will always hit the ground below the point of aim by some amount. In order to hit a target at the same elevation, but at a distance, a projectile must rise first, and then fall. Students who have tried archery might know that they have to aim upward to get an arrow to hit a distant target. Good field and woods archers may even check for obstructions above their line of sight to be sure that the arrow can get to the target without hitting a branch on the way.

Students may take a while to believe that the horizontal motion of an object does not affect its vertical motion, and that the horizontal velocity remains constant throughout the fall. Point out that the value of acceleration of an object thrown upward will be the same as the value of acceleration of that object falling down. However, the object's velocity on its way down will carry a negative sign. Quizzing students on the investigations they made earlier would help them to understand this phenomenon. At the same time, reading the *Physics Talk* should provide focus and explain the *Investigate*.

CHAPTER 2

Checking Up

1.

They will reach the ground at the same time because all objects fall to the ground with the same acceleration, at the rate of 9.8 m/s^2.

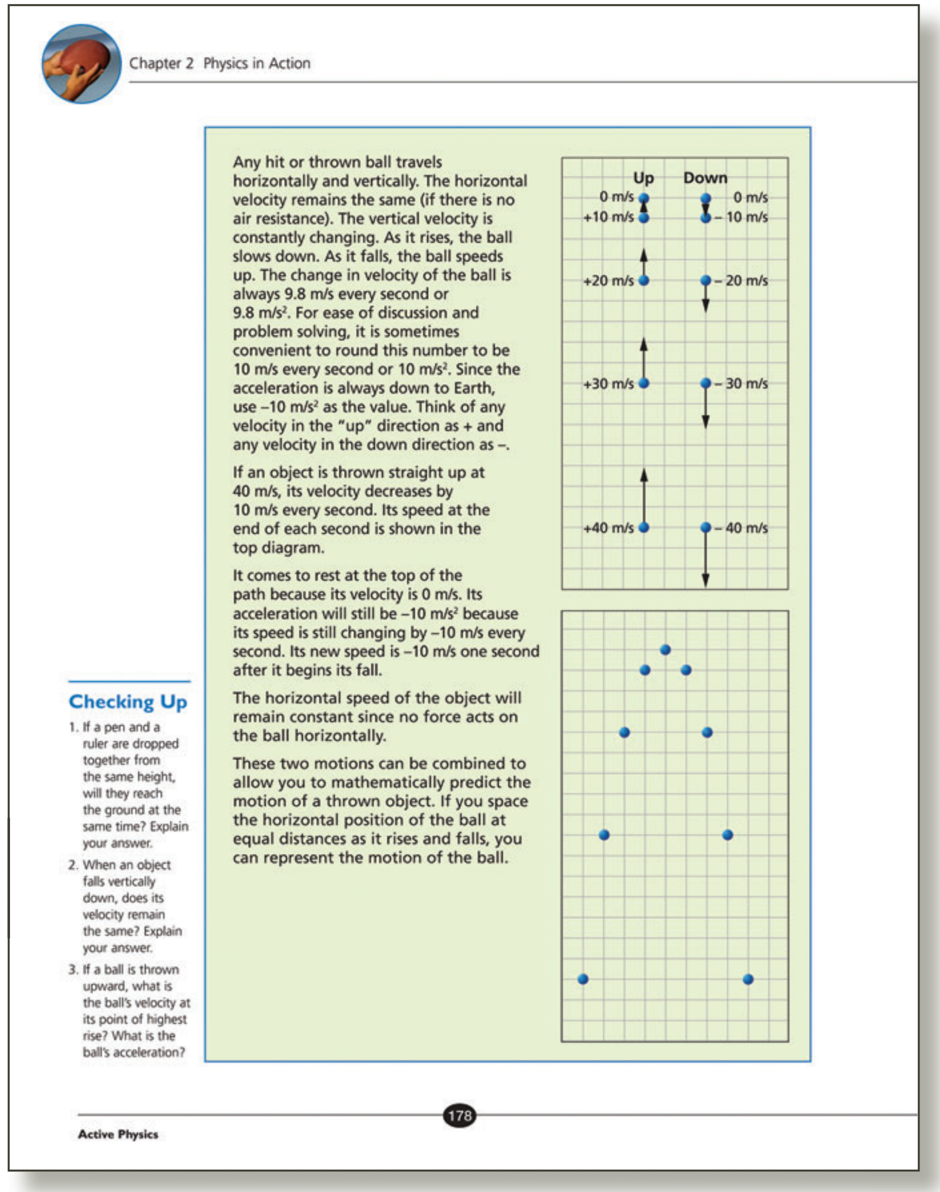
2.

As an object falls, its vertical velocity is constantly increasing because it is accelerating due to the unbalanced force of gravity.

3.

At the ball's point of highest rise, the velocity momentarily goes to zero as the ball is changing directions from up to down, and the acceleration is the acceleration of gravity, or 9.8 m/s^2 downward.

2-4b **Blackline Master**



Chapter 2 Physics in Action

Any hit or thrown ball travels horizontally and vertically. The horizontal velocity remains the same (if there is no air resistance). The vertical velocity is constantly changing. As it rises, the ball slows down. As it falls, the ball speeds up. The change in velocity of the ball is always 9.8 m/s every second or 9.8 m/s^2. For ease of discussion and problem solving, it is sometimes convenient to round this number to be 10 m/s every second or 10 m/s^2. Since the acceleration is always down to Earth, use –10 m/s^2 as the value. Think of any velocity in the "up" direction as + and any velocity in the down direction as –.

If an object is thrown straight up at 40 m/s, its velocity decreases by 10 m/s every second. Its speed at the end of each second is shown in the top diagram.

It comes to rest at the top of the path because its velocity is 0 m/s. Its acceleration will still be –10 m/s^2 because its speed is still changing by –10 m/s every second. Its new speed is –10 m/s one second after it begins its fall.

The horizontal speed of the object will remain constant since no force acts on the ball horizontally.

These two motions can be combined to allow you to mathematically predict the motion of a thrown object. If you space the horizontal position of the ball at equal distances as it rises and falls, you can represent the motion of the ball.

Checking Up

1. If a pen and a ruler are dropped together from the same height, will they reach the ground at the same time? Explain your answer.
2. When an object falls vertically down, does its velocity remain the same? Explain your answer.
3. If a ball is thrown upward, what is the ball's velocity at its point of highest rise? What is the ball's acceleration?

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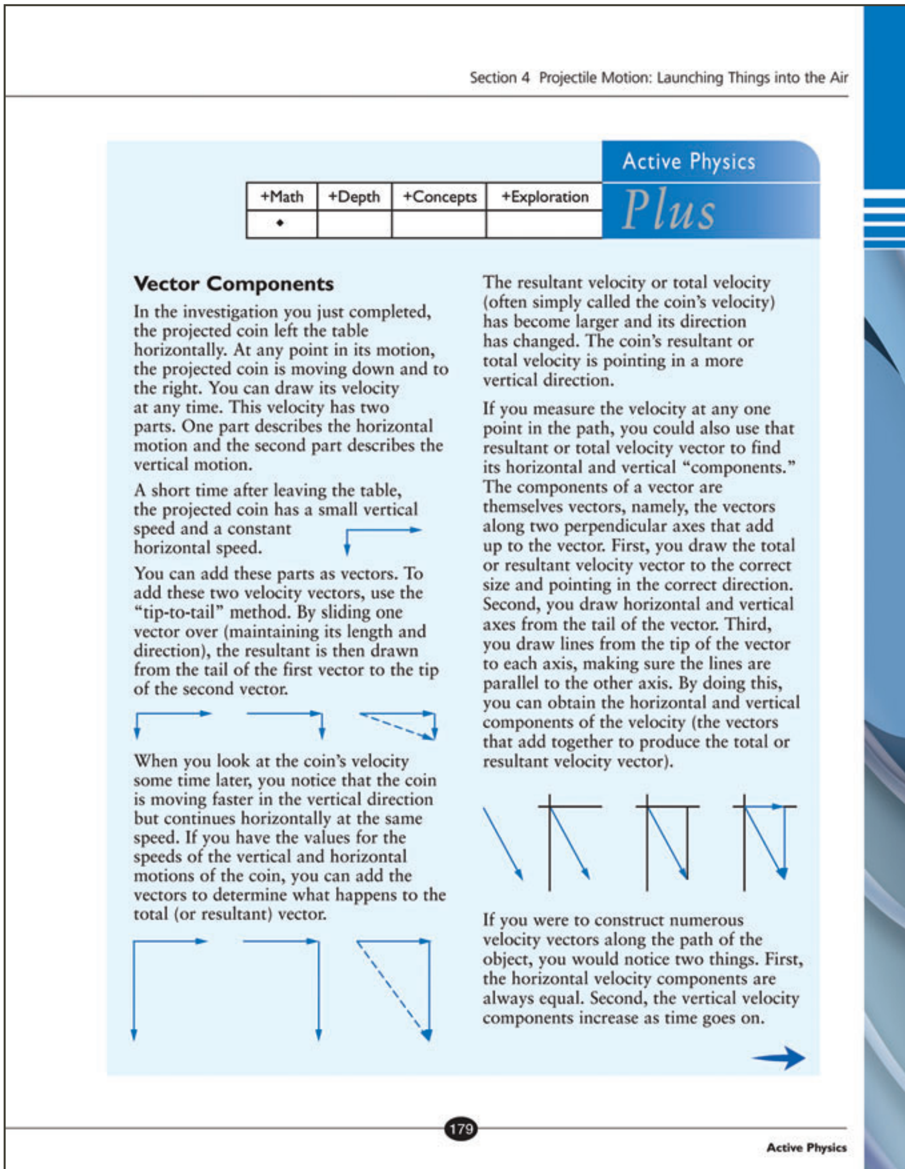

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+Math	+Depth	+Concepts	+Exploration
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Vector Components

In the investigation you just completed, the projected coin left the table horizontally. At any point in its motion, the projected coin is moving down and to the right. You can draw its velocity at any time. This velocity has two parts. One part describes the horizontal motion and the second part describes the vertical motion.

A short time after leaving the table, the projected coin has a small vertical speed and a constant horizontal speed.

You can add these parts as vectors. To add these two velocity vectors, use the "tip-to-tail" method. By sliding one vector over (maintaining its length and direction), the resultant is then drawn from the tail of the first vector to the tip of the second vector.

When you look at the coin's velocity some time later, you notice that the coin is moving faster in the vertical direction but continues horizontally at the same speed. If you have the values for the speeds of the vertical and horizontal motions of the coin, you can add the vectors to determine what happens to the total (or resultant) vector.

The resultant velocity or total velocity (often simply called the coin's velocity) has become larger and its direction has changed. The coin's resultant or total velocity is pointing in a more vertical direction.

If you measure the velocity at any one point in the path, you could also use that resultant or total velocity vector to find its horizontal and vertical "components." The components of a vector are themselves vectors, namely, the vectors along two perpendicular axes that add up to the vector. First, you draw the total or resultant velocity vector to the correct size and pointing in the correct direction. Second, you draw horizontal and vertical axes from the tail of the vector. Third, you draw lines from the tip of the vector to each axis, making sure the lines are parallel to the other axis. By doing this, you can obtain the horizontal and vertical components of the velocity (the vectors that add together to produce the total or resultant velocity vector).

If you were to construct numerous velocity vectors along the path of the object, you would notice two things. First, the horizontal velocity components are always equal. Second, the vertical velocity components increase as time goes on.

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As this *Active Physics Plus* focuses mainly on understanding velocity vectors through solving problems, encourage students to draw vectors representing speed and direction to understand the direction of the resultant vector. The students should be able to explain each step of the problem's solution, as vectors can sometimes be confusing. They should also be able to tell when velocity carries a negative sign.

CHAPTER 2

1.a)

The time an object spends in the air depends upon its initial vertical velocity. The force of gravity will provide a downward acceleration of $-9.81\ \text{m/s}^2$ (approximated as $-10\ \text{m/s}^2$) for each second the object is in the air. The acceleration is negative as it is downward compared to the positive upward initial velocity of the ball. When the football is kicked with a vertical velocity of 30 m/s, its vertical speed will change 10 m/s for each second of flight. For an object that is thrown upward and returns to the same elevation, the rise time is equal to the fall time. This can be shown by using the equation for accelerated motion developed in *Chapter 1, Section 5*.

$$s = v_i t + \tfrac{1}{2}at^2$$

Because the ball is coming back to the same height, the final position is zero. This gives

$$0 = 30\ \text{m/s}\,(t) + \tfrac{1}{2}\left(-10\ \text{m/s}^2\right)t^2.$$

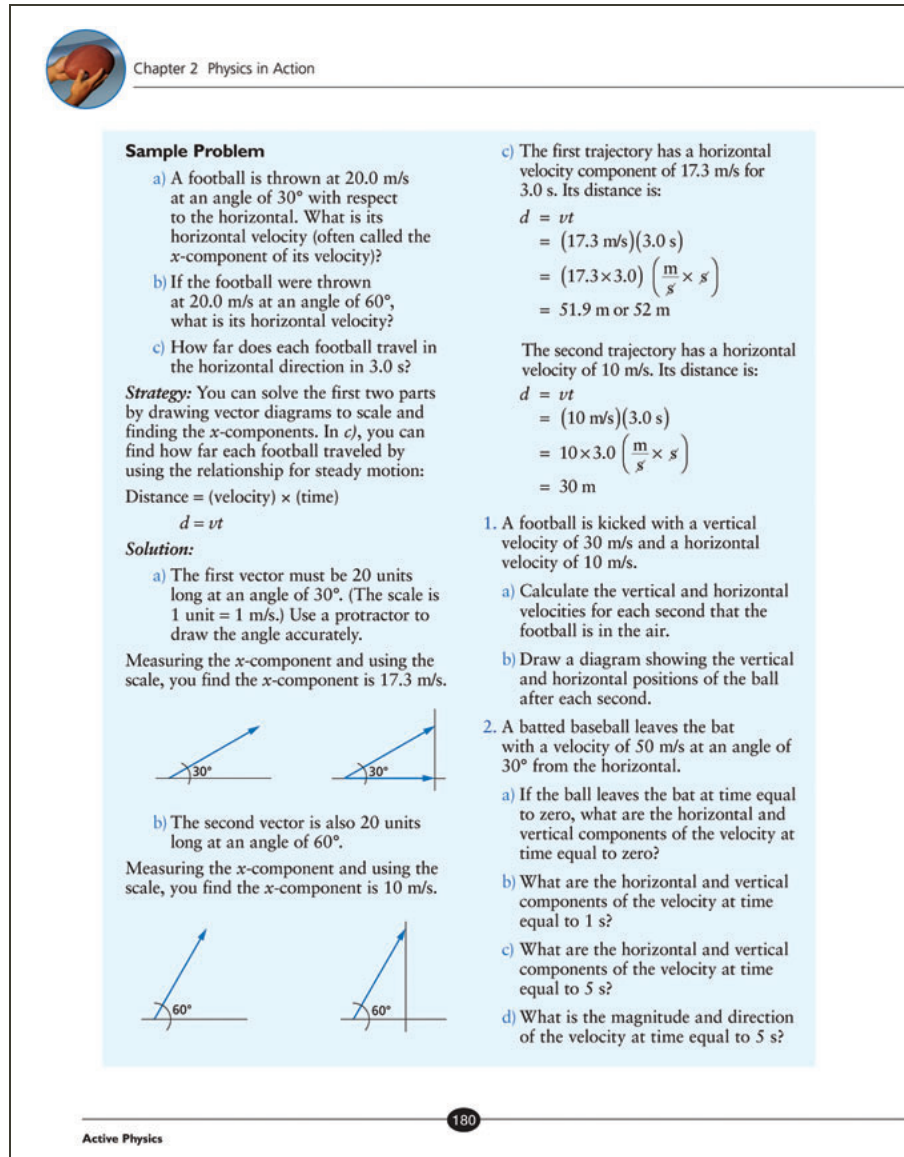
Solving for t we have

$$t = \frac{30\ \text{m/s}}{5\ \text{m/s}^2} = 6\ \text{s}$$ for the time to return to the ground.

The vertical speed of the ball then will be

$t = 0$	$v = 30$ m/s
$t = 1$	$v = 20$ m/s
$t = 2$	$v = 10$ m/s
$t = 3$	$v = 0$ m/s
$t = 4$	$v = -10$ m/s
$t = 5$	$v = -20$ m/s
$t = 6$	$v = -30$ m/s

The horizontal speed of the ball is always the same while in the air, 10 m/s, and does not change with the changing vertical velocity.


Chapter 2 Physics in Action

Sample Problem

a) A football is thrown at 20.0 m/s at an angle of 30° with respect to the horizontal. What is its horizontal velocity (often called the *x*-component of its velocity)?

b) If the football were thrown at 20.0 m/s at an angle of 60°, what is its horizontal velocity?

c) How far does each football travel in the horizontal direction in 3.0 s?

Strategy: You can solve the first two parts by drawing vector diagrams to scale and finding the *x*-components. In *c)*, you can find how far each football traveled by using the relationship for steady motion:

Distance = (velocity) × (time)

$d = vt$

Solution:

a) The first vector must be 20 units long at an angle of 30°. (The scale is 1 unit = 1 m/s.) Use a protractor to draw the angle accurately.

Measuring the *x*-component and using the scale, you find the *x*-component is 17.3 m/s.

b) The second vector is also 20 units long at an angle of 60°.

Measuring the *x*-component and using the scale, you find the *x*-component is 10 m/s.

c) The first trajectory has a horizontal velocity component of 17.3 m/s for 3.0 s. Its distance is:

$d = vt$
$= (17.3\ \text{m/s})(3.0\ \text{s})$
$= (17.3 \times 3.0)\left(\frac{\text{m}}{s} \times s\right)$
$= 51.9$ m or 52 m

The second trajectory has a horizontal velocity of 10 m/s. Its distance is:

$d = vt$
$= (10\ \text{m/s})(3.0\ \text{s})$
$= 10 \times 3.0\left(\frac{\text{m}}{s} \times s\right)$
$= 30$ m

1. A football is kicked with a vertical velocity of 30 m/s and a horizontal velocity of 10 m/s.
   a) Calculate the vertical and horizontal velocities for each second that the football is in the air.
   b) Draw a diagram showing the vertical and horizontal positions of the ball after each second.
2. A batted baseball leaves the bat with a velocity of 50 m/s at an angle of 30° from the horizontal.
   a) If the ball leaves the bat at time equal to zero, what are the horizontal and vertical components of the velocity at time equal to zero?
   b) What are the horizontal and vertical components of the velocity at time equal to 1 s?
   c) What are the horizontal and vertical components of the velocity at time equal to 5 s?
   d) What is the magnitude and direction of the velocity at time equal to 5 s?

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1.b)

The students would not be expected to go through the solution below, but only to provide the sketch shown. The solution below is for the teacher who may wish to share this with the more interested students.

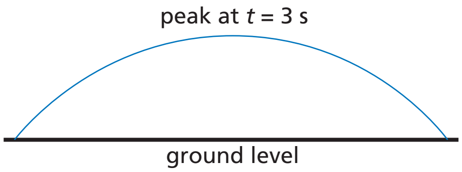
The vertical position of the ball may be obtained from the same equation as above

$$s = v_i t + \tfrac{1}{2}at^2$$

and substituting times of 1-6 s into the equation. The vertical and horizontal positions at the various times would be as follows:

Time (*t*) in seconds	Vertical distance in meters	Horizontal distance in meters
0	0	0
1	25	10
2	40	20
3	45	30
4	40	40
5	25	50
6	0	60

Plotting the points will give a parabola with a trajectory similar to the sketch below.



2.a)

To find the vertical and horizontal components of the ball's initial velocity

$v_{\text{vertical}} = v(\sin\theta) =$

$(50 \text{ m/s})(\sin 30^{\circ}) = 25 \text{ m/s}$

$v_{\text{horizontal}} = v(\cos\theta) =$

$(50 \text{ m/s})(\cos 30^{\circ}) = 43.3 \text{ m/s}$

2.b)

$v_{\text{vertical}} = 15 \text{ m/s}$

$v_{\text{horizontal}} = 43 \text{ m/s}$

2.c)

$v_{\text{vertical}} = -24 \text{ m/s}$

$v_{\text{horizontal}} = 43 \text{ m/s}$

2.d)

50 m/s at an angle of 30° below the horizontal (found from using the Pythagorean theorem).

NOTES

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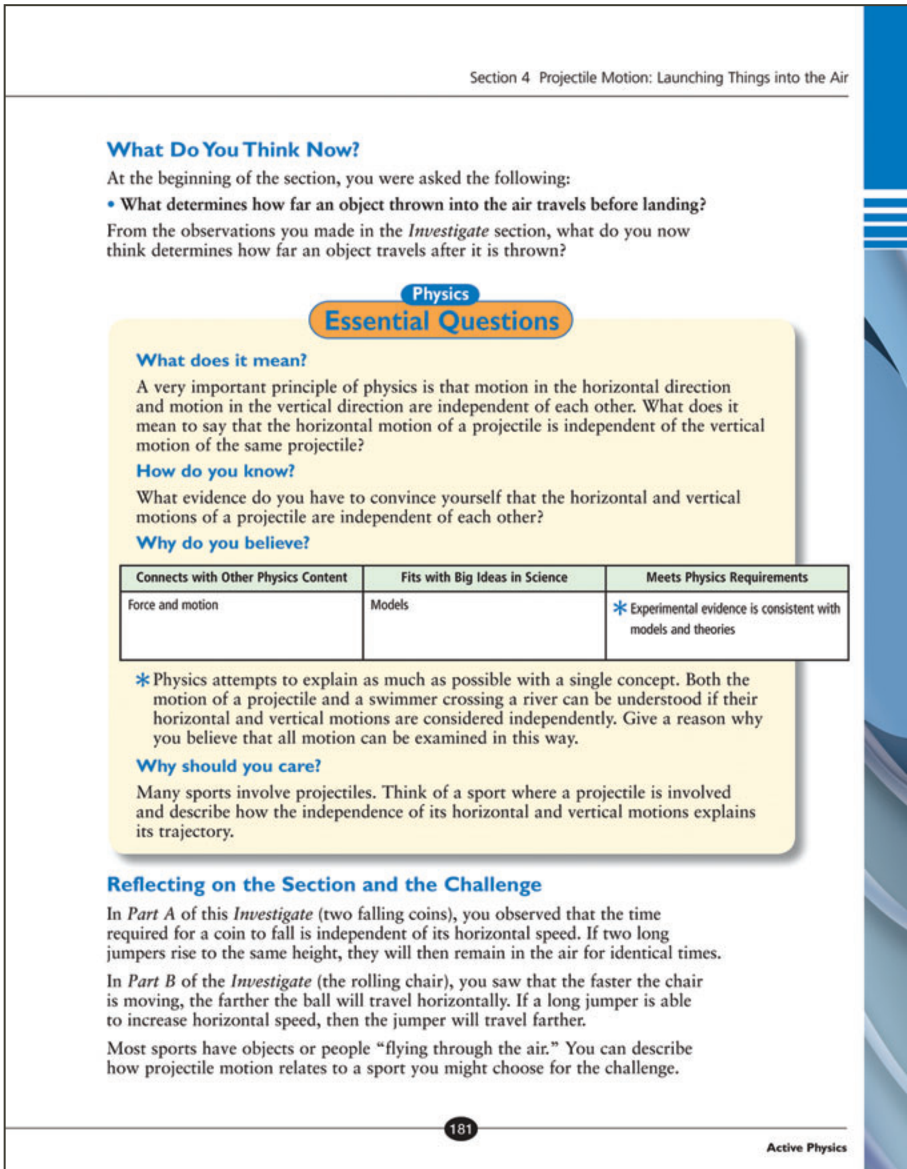
NOTES

What Do You Think Now?

At this point, the students should know that the horizontal velocity of a projectile determines the range. It should be clear to them that the vertical velocity does not determine how far an object will travel. You might want to share the answers in the *Physicist's Response* with your class.

Providing a platform for recalling previously learned concepts that will strengthen their confidence and problem-solving skills.



What Do You Think Now?

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

- **What determines how far an object thrown into the air travels before landing?**

From the observations you made in the *Investigate* section, what do you now think determines how far an object travels after it is thrown?

Physics Essential Questions

What does it mean?

A very important principle of physics is that motion in the horizontal direction and motion in the vertical direction are independent of each other. What does it mean to say that the horizontal motion of a projectile is independent of the vertical motion of the same projectile?

How do you know?

What evidence do you have to convince yourself that the horizontal and vertical motions of a projectile are independent of each other?

Why do you believe?

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

* Physics attempts to explain as much as possible with a single concept. Both the motion of a projectile and a swimmer crossing a river can be understood if their horizontal and vertical motions are considered independently. Give a reason why you believe that all motion can be examined in this way.

Why should you care?

Many sports involve projectiles. Think of a sport where a projectile is involved and describe how the independence of its horizontal and vertical motions explains its trajectory.

Reflecting on the Section and the Challenge

In *Part A* of this *Investigate* (two falling coins), you observed that the time required for a coin to fall is independent of its horizontal speed. If two long jumpers rise to the same height, they will then remain in the air for identical times.

In *Part B* of the *Investigate* (the rolling chair), you saw that the faster the chair is moving, the farther the ball will travel horizontally. If a long jumper is able to increase horizontal speed, then the jumper will travel farther.

Most sports have objects or people "flying through the air." You can describe how projectile motion relates to a sport you might choose for the challenge.

Reflecting on the Section and the Challenge

Have your students list sporting events that involve projectile motion (long jump, high jump, hurdles, shot put, discus, javelin, hammer throw, baseball, tennis, golf, badminton). Ask them to consider if some of these events have greater dependence on knowledge and technique and less dependence on physical ability than other events. Events involving projectile motion may have high potential to be improved through physics-based help. You may wish to point out that Carl Lewis, one of the fastest men in the world, is one of the world's greatest long jumpers. Jesse Owens' 1936 Olympics performance in the sprints and the long jump also makes a very good story.

Physics Essential Questions

What does it mean?

All objects dropped from a certain height will hit the ground at the same time. This happens regardless of whether the object has a horizontal speed.

How do you know?

When the two coins left the table, the dropped coin and the forward-moving coin hit the ground at the same time. The conclusion is that the forward motion did not affect the vertical motion.

Why do you believe?

A bullet can travel much faster than the coin, but the horizontal motion is still independent of the vertical motion.

Why should you care?

A fast sprinter is also a good broad jumper. The jumper tries to gain maximum height so that the horizontal speed can allow him to travel as far as possible for as long a time as possible.

Physics to Go

1.

Students provide a sketch that should show one coin dropping nearly vertically and the other arcing outward.

2.

Students provide a sketch that should be similar to the first one but with a longer range for the projected coin.

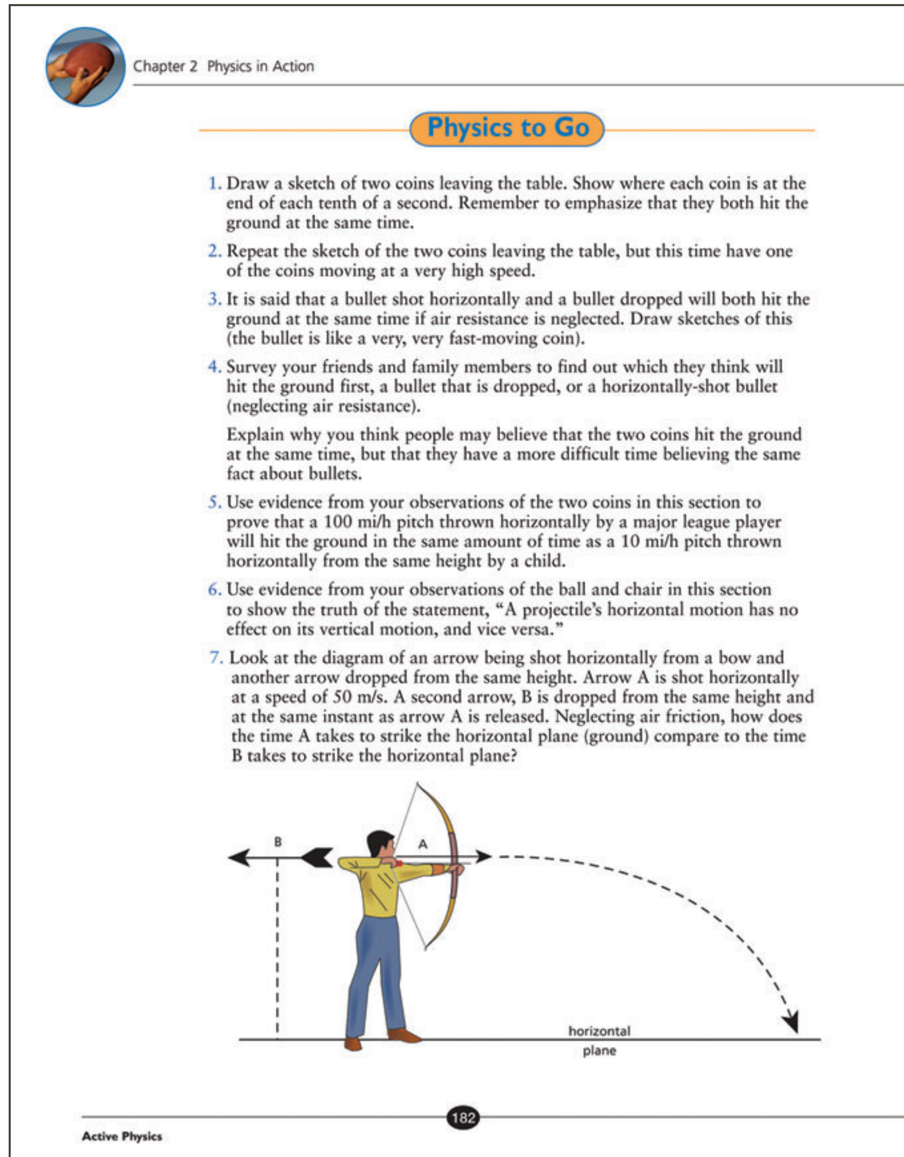
3.

Students provide sketch, similar to the others but with a very long range for the projected bullet. Some students may invoke the curvature of Earth's surface.

Note: Aiming a rifle horizontally is not the same as actually shooting horizontally. Actually shooting horizontally would involve bore sighting, or using a level on the barrel instead of the sight posts.

4.

Answers will vary, but most people would not believe a bullet fired horizontally and one dropped would strike the ground simultaneously on level ground. Encourage students to confront their own misconceptions when answering this question. Flying discs or other airfoil devices contribute to the misconception, but the largest factor is probably that the bullet lands so far away that it is not perceived to have hit the ground until significantly after the dropped bullet



Chapter 2 Physics in Action

Physics to Go

1. Draw a sketch of two coins leaving the table. Show where each coin is at the end of each tenth of a second. Remember to emphasize that they both hit the ground at the same time.

2. Repeat the sketch of the two coins leaving the table, but this time have one of the coins moving at a very high speed.

3. It is said that a bullet shot horizontally and a bullet dropped will both hit the ground at the same time if air resistance is neglected. Draw sketches of this (the bullet is like a very, very fast-moving coin).

4. Survey your friends and family members to find out which they think will hit the ground first, a bullet that is dropped, or a horizontally-shot bullet (neglecting air resistance).

Explain why you think people may believe that the two coins hit the ground at the same time, but that they have a more difficult time believing the same fact about bullets.

5. Use evidence from your observations of the two coins in this section to prove that a 100 mi/h pitch thrown horizontally by a major league player will hit the ground in the same amount of time as a 10 mi/h pitch thrown horizontally from the same height by a child.

6. Use evidence from your observations of the ball and chair in this section to show the truth of the statement, "A projectile's horizontal motion has no effect on its vertical motion, and vice versa."

7. Look at the diagram of an arrow being shot horizontally from a bow and another arrow dropped from the same height. Arrow A is shot horizontally at a speed of 50 m/s. A second arrow, B is dropped from the same height and at the same instant as arrow A is released. Neglecting air friction, how does the time A takes to strike the horizontal plane (ground) compare to the time B takes to strike the horizontal plane?

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5.

The students should compare the coins that are flicked at different speeds hitting the ground at the same time as the dropped coin to the baseballs thrown at different speeds. They should make the logical jump that not only would a 100-mi/h and a 10-mi/h ball thrown horizontally hit the ground at the same time when released from the same height, but a dropped ball would also strike the ground at the same time.

6.

The ball would not have returned to the hands of the student riding in the chair if the horizontal and vertical motions were not independent of one another.

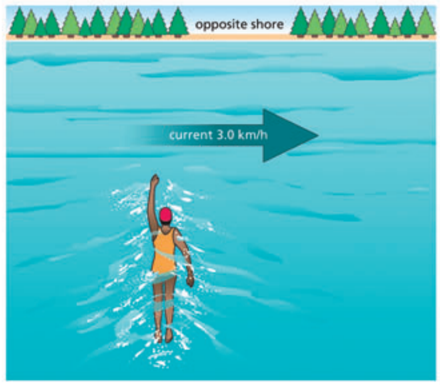
7.

The times are equal. The dropped arrow and the shot arrow hit the ground at the same time. The vertical motion is independent of the horizontal motion.

Section 4 Projectile Motion: Launching Things into the Air

Use a protractor for *Questions 8 – 10.*

8. A swimmer jumps into a river and swims directly for the opposite shore at 2.0 km/h as shown in the diagram. The current in the river is 3.0 km/h and flows from left to right in the diagram. What is the swimmer's velocity relative to the shore?



9. Active Physics Plus A football is thrown at 15 m/s at an angle of 37° in the horizontal direction.

a) What is its velocity in the horizontal direction?

b) How far in the horizontal direction has the football traveled in 2.0 s?

10. Active Physics Plus A shot put is released at 12 m/s at an angle of 45° in a horizontal direction.

a) What is its velocity in the horizontal direction?

b) How far in the horizontal direction has the shot put traveled in 0.5 s?

11. ***Preparing for the Chapter Challenge***
Write a script for a sports telecast that describes the motion of a baseball while it is pitched and then hit into the outfield.

Inquiring Further

Investigating more *x*- and *y*-components of motion

Ask another student to roll a marble slowly across the table in front of you. As the marble rolls by, apply a momentary force to it with a small object such as a block of wood. Make sure the force you apply is directly away from you and perpendicular to the initial velocity of the marble. If you define the *x*-direction to be along the initial velocity of the marble, then you can define the *y*-direction as the direction of the force you are applying. Investigate whether you can change the *x*-component of the marble's velocity by applying a force in the *y*-direction. Relate your observation to what you have learned about projectile motion.

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8.

Application of the Pythagorean theorem yields:

$(3.0\text{ km/h})^2 + (2.0\text{ km/h})^2 = v^2$

Therefore, $v = 3.6$ km/h

Therefore, using the tangent button on the calculator or a vector diagram, the angle is 34°, relative to the shoreline.

9.a)

To find the *x*-direction component of the velocity, make a scale diagram and measure the *x*-component. You can also use the cosine function:

$v_x = (15\text{ m/s})(\cos 37^\circ) = 12.0\text{ m/s}$

9.b)

If it travels horizontally at 12.0 m/s for 2.0 s, the distance traveled is

$v_x t = d = (12.0\text{ m/s})(2.0\text{ s}) = 24\text{ m}$

10.a)

To find the *x*-direction component of the velocity, make a scale diagram and measure the *x*-component. You can also use the cosine function:

$v_x = (12\text{ m/s})(\cos 45^\circ) = 8.5\text{ m/s}$

10.b)

If it travels horizontally at 8.5 m/s for 0.5 s, the distance traveled is:

$d = v_x t = (8.5\text{ m/s})(0.5\text{ s}) = 4.25\text{ m}$

Preparing for the Chapter Challenge

11.

Answers will vary. A good answer will include the pitcher throwing the ball with an initial horizontal velocity that is immediately acted upon by gravity as it begins to fall in the vertical direction while maintaining its horizontal velocity. When the ball meets the bat, the force of the bat changes the ball's direction, accelerating it to a new velocity directed upward and horizontally toward the outfield. As the ball rises, it immediately begins to lose its vertical velocity because it is always being accelerated downward by the force of gravity. At the peak of the parabolic trajectory the vertical velocity is zero, after which the downward acceleration of the force of gravity causes the ball to reverse direction, and it begins to fall, gaining vertical speed. All along, the horizontal velocity of the ball has been the same until the ball reaches the level of the bat in the outfield where it will have the same velocity as when it left the bat. (Note: The above description

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is not descriptive of what occurs to a real baseball in air. The force of air resistance has a tremendous effect on both the ball's speed and its trajectory. For a more detailed description of the ball's true path, a student may want to read *The Physics of Baseball* by Robert Adair.)

Inquiring Further

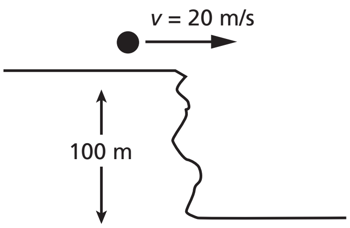
When doing this section, students will find that they cannot change the x component of the marble's speed with a force applied in the y direction. This is the same as the vertical force of gravity not having an effect on the horizontal motion of a projectile.

NOTES

SECTION 4 QUIZ

2-4c **Blackline Master**

Base your answers to Questions 1 and 2 on the diagram, which shows a ball projected horizontally with an initial velocity of 20 m/s off a cliff 100-m high (neglect air resistance).



1. Which of the following has no effect on how far the ball travels horizontally before it strikes the ground?

   a) the mass of the ball

   b) the height of the cliff

   c) the speed with which the ball is thrown

   d) the angle at which the ball is thrown

2. During the flight of the ball, what is the direction of its acceleration?

   a) downward　　b) upward

   c) westward　　d) eastward

3. A physics student is doing an experiment at the top of the school football bleachers, where she is going to throw an egg horizontally with a speed of 10 m/s. At the instant she throws the egg, she accidentally knocks over another egg which falls an equal distance to the ground. Which egg will hit the ground first?

   a) the dropped egg

   b) the thrown egg

   c) Both will hit the ground at the same time.

4. A ball is thrown horizontally at a speed of 20 m/s from the top of a cliff. As the speed of the ball is decreased, the time required for the ball to fall 30 m will

   a) decrease.

   b) increase.

   c) remain the same.

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5. A ball is tossed straight upward in an airplane doing 500 mi/h in a straight line at constant altitude. When the ball lands in the cabin its position relative to the person who tossed it will be

   a) farther toward the back of the cabin depending upon the plane's speed.

   b) farther toward the front of the cabin depending on the plane's speed.

   c) right back down on the person who tossed it straight upward.

   d) farther toward the back of the plane if the ball is light, but farther toward the front if the ball is heavy.

SECTION 4 QUIZ ANSWERS

1. a) Disregarding air resistance, the acceleration due to gravity is independent of the object's mass for objects that are much smaller than Earth.

2. a) The only force acting on the object is the force of gravity which will cause the object to accelerate downward.

3. c) Both eggs will strike the ground at the same time. The independence of right-angle motions indicates that the horizontal velocity now has an effect on the fall time.

4. c) The horizontal velocity does not affect the time it takes an object to fall a certain distance.

5. c) The ball will land right back in the person's hands. The initial forward motion of the ball was the same as the airplane before it was tossed. The ball retains that initial velocity as it is tossed, and matches the forward motion of the passenger and the plane as it rises and falls to land back in the passenger's hands. Mass has no effect because the ball, regardless of its mass, would have the same velocity as the plane. If this were done in an open convertible where wind resistance was a factor, a light object would be expected to land farther back due to the extra horizontal force of the wind.

NOTES