Table of Contents

End Of Slide

Chapter menu

Resources

Objectives

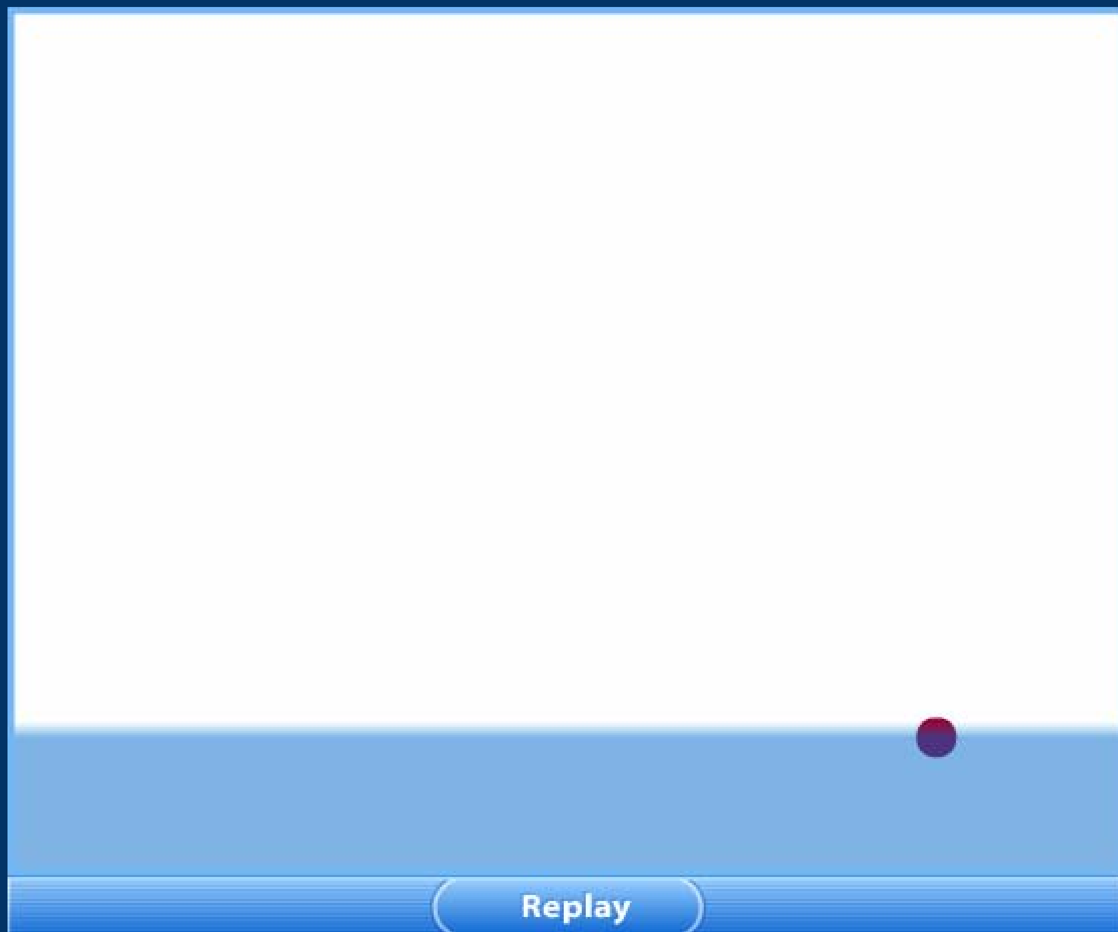
- **Describe** motion in terms of frame of reference, displacement, time, and velocity.
- **Calculate** the displacement of an object traveling at a known velocity for a specific time interval.
- **Construct** and **interpret** graphs of position versus time.

End Of Slide

One Dimensional Motion

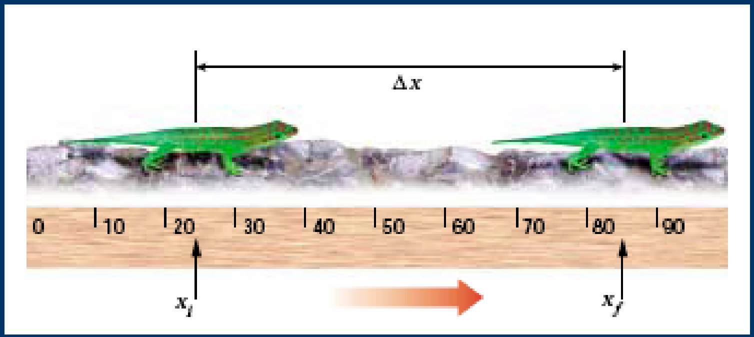
- To simplify the concept of motion, we will first consider motion that takes place in **one direction.**
- One example is the motion of a commuter train on a straight track.
- To measure motion, you must choose a **frame of reference.** A frame of reference is a system for specifying the precise location of objects in space and time.

Frame of Reference



Displacement

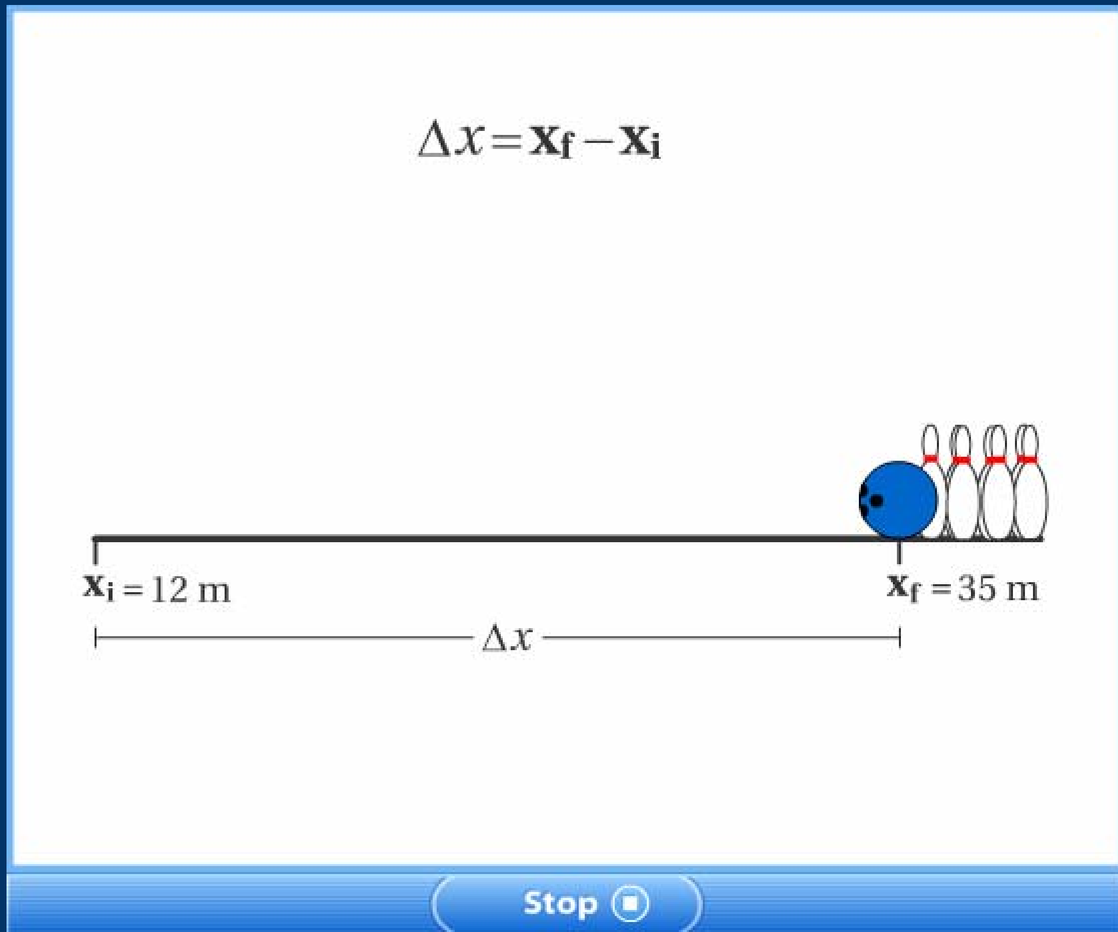
- **Displacement** is a **change in position.**
- Displacement is not always equal to the distance traveled.
- The SI unit of displacement is the **meter, m.**



$$\Delta x = x_f - x_i$$

displacement = final position – initial position

Displacement



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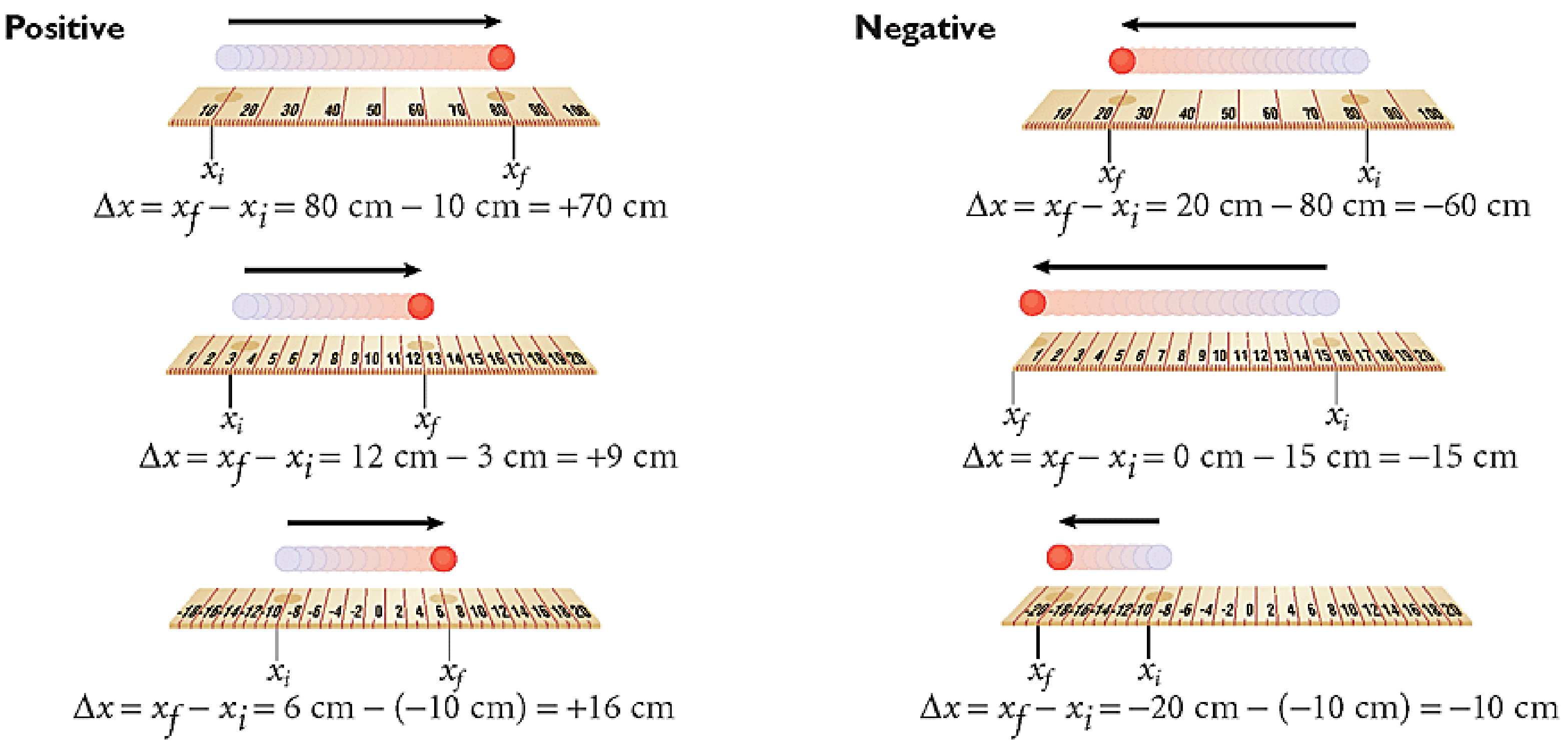
Positive and Negative Displacements



Average Velocity

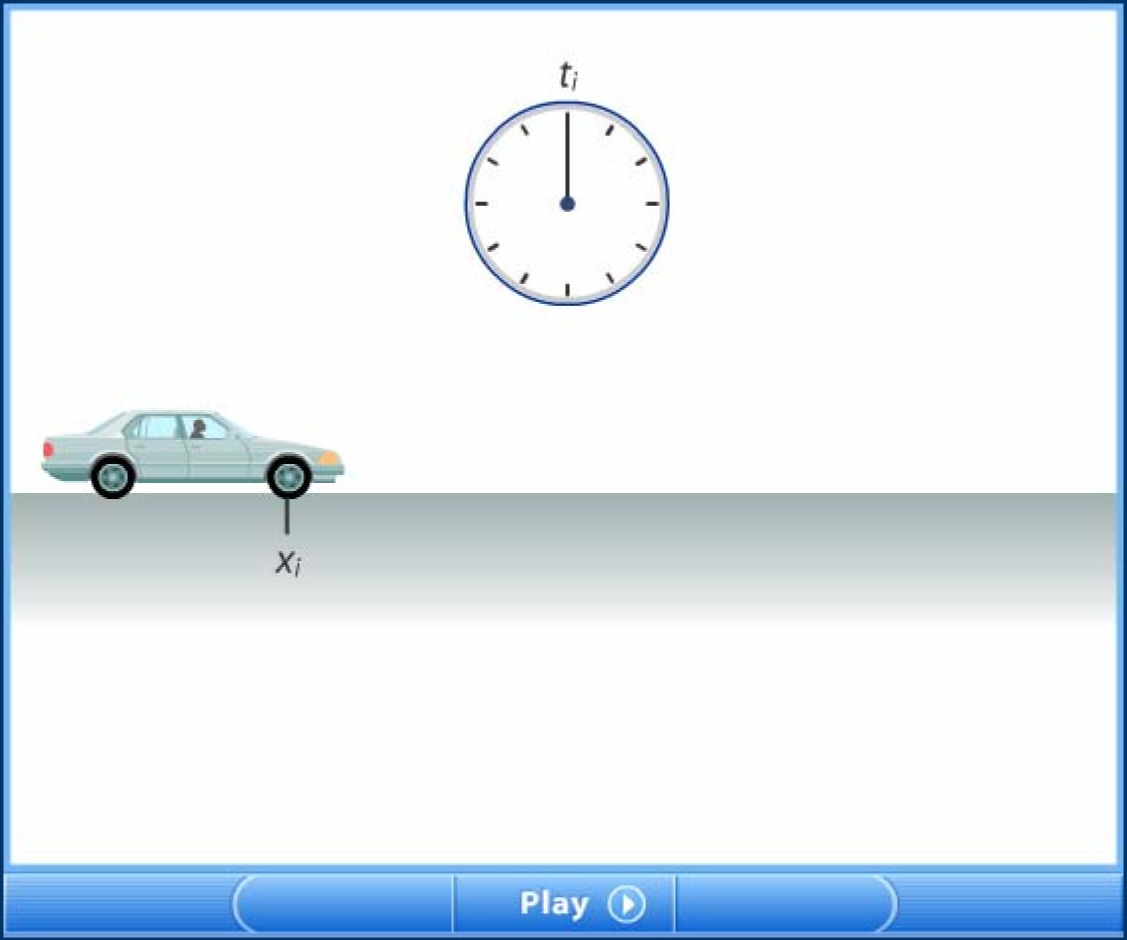
- **Average velocity** is the total **displacement** divided by the **time interval** during which the displacement occurred.

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

$$\text{average velocity} = \frac{\text{change in position}}{\text{change in time}} = \frac{\text{displacement}}{\text{time interval}}$$

- In SI, the unit of velocity is **meters per second,** abbreviated as **m/s.**

Average Velocity



Velocity and Speed

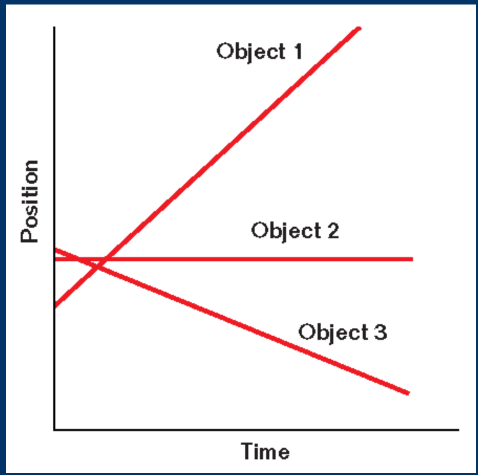
- **Velocity** describes motion with both a **direction** and a **numerical value** (a magnitude).
- **Speed** has no direction, only magnitude.
- **Average speed** is equal to the total **distance traveled** divided by the **time interval.**

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time of travel}}$$

Interpreting Velocity Graphically

- For any **position-time graph,** we can determine the **average velocity** by drawing a straight line between any two points on the graph.

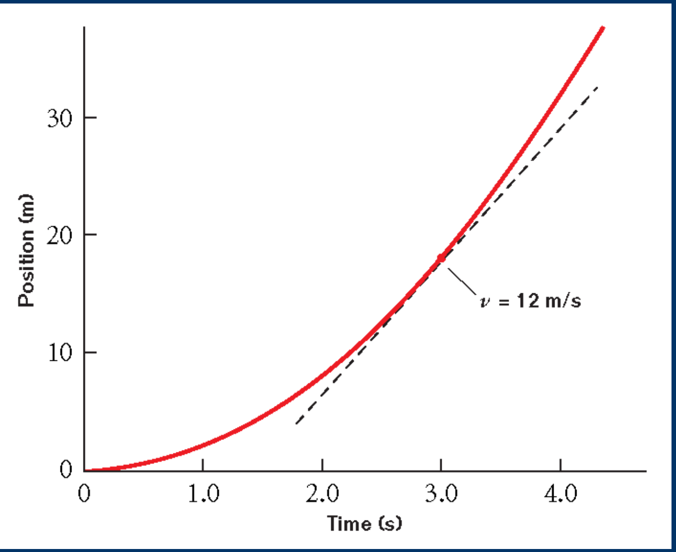
- If the velocity is **constant**, the graph of position versus time is a **straight line.** The slope indicates the velocity.
  - **Object 1:** positive slope = positive velocity
  - **Object 2:** zero slope= zero velocity
  - **Object 3:** negative slope = negative velocity



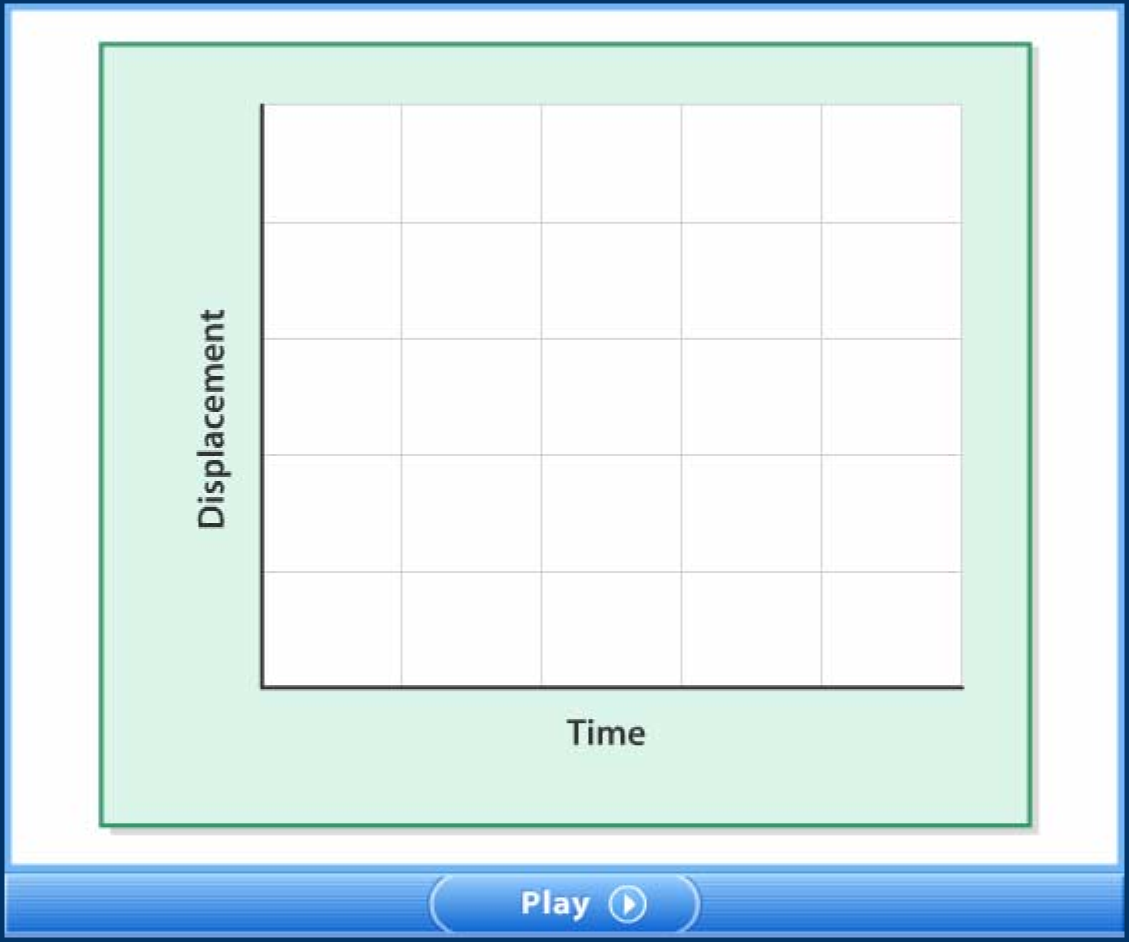
Interpreting Velocity Graphically, *continued*

The **instantaneous velocity** is the velocity of an object at some instant or at a specific point in the object's path.

The instantaneous velocity at a given time can be determined by measuring the slope of the line that is tangent to that point on the position-versus-time graph.



Sign Conventions for Velocity



Objectives

- **Describe** motion in terms of changing velocity.
- **Compare** graphical representations of accelerated and nonaccelerated motions.
- **Apply** kinematic equations to **calculate** distance, time, or velocity under conditions of constant acceleration.

Changes in Velocity

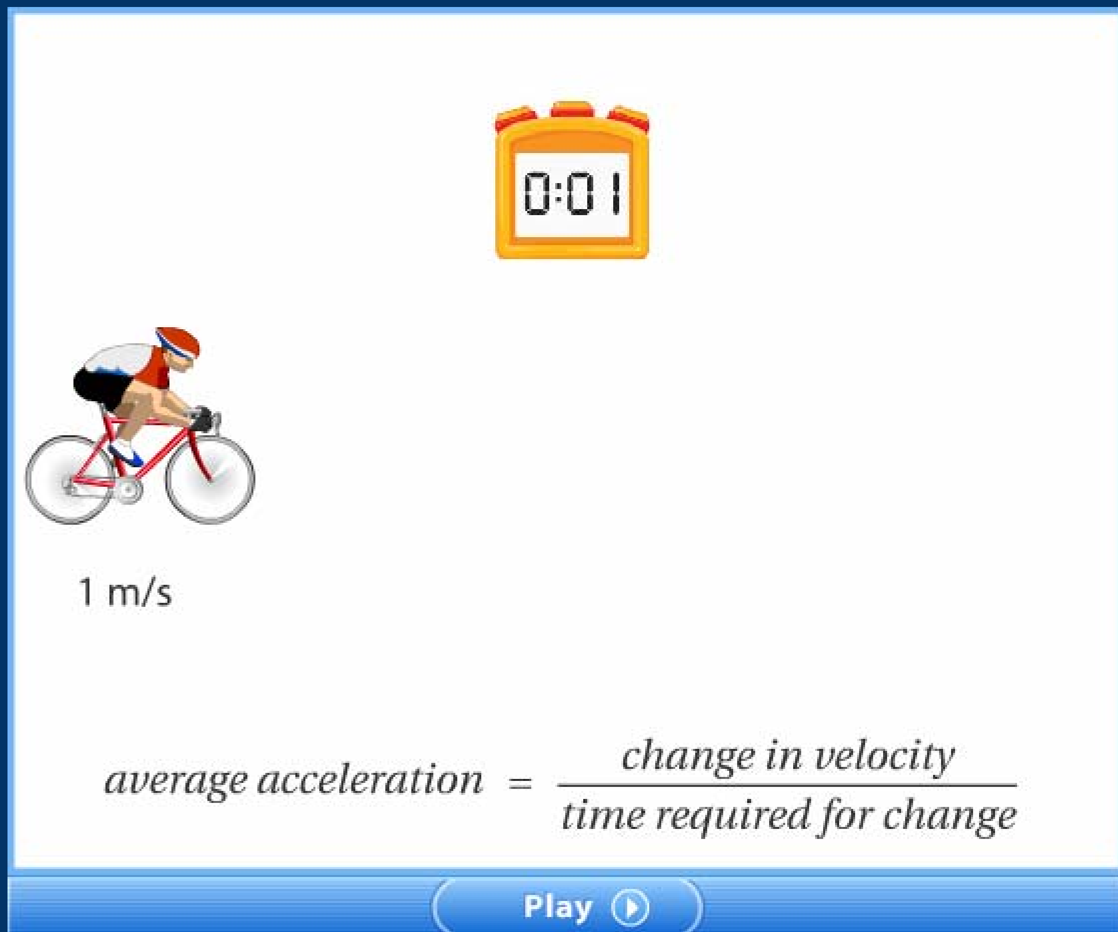
- **Acceleration** is the rate at which velocity changes over time.

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time required for change}}$$

- An object accelerates if its **speed, direction, or both** change.
- Acceleration has direction and magnitude. Thus, acceleration is a **vector** quantity.

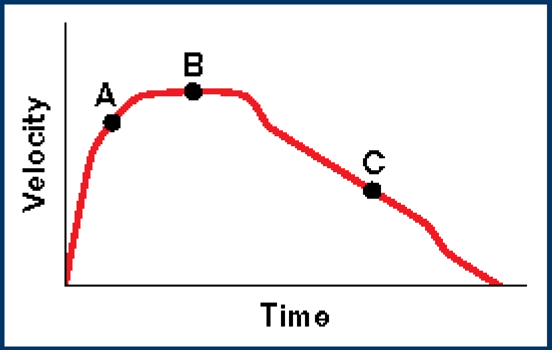
Acceleration



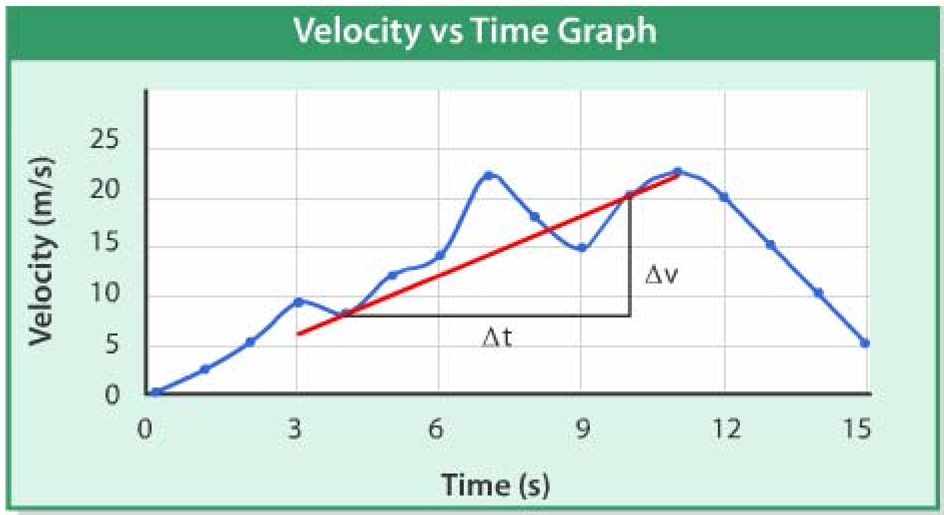
End Of Slide

Changes in Velocity, *continued*

- Consider a train moving to the right, so that the displacement and the velocity are positive.
- The slope of the velocity-time graph is the average acceleration.
  - When the velocity in the positive direction is increasing, the **acceleration is positive**, as at **A.**
  - When the velocity is constant, there is **no acceleration**, as at **B.**
  - When the velocity in the positive direction is decreasing, the **acceleration is negative**, as at **C.**



Graphical Representations of Acceleration



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End Of Slide
Chapter menu
Resources

Velocity and Acceleration

v_i	a	Motion
+	+	speeding up
−	−	speeding up
+	−	slowing down
−	+	slowing down
− or +	0	constant velocity
0	− or +	speeding up from rest
0	0	remaining at rest

Motion with Constant Acceleration

- When velocity changes by the same amount during each time interval, **acceleration is constant.**
- The relationships between **displacement, time, velocity,** and **constant acceleration** are expressed by the equations shown on the next slide. These equations apply to any object moving with constant acceleration.
- These equations use the following symbols:

Δx = displacement
v_i = initial velocity
v_f = final velocity
Δt = time interval

Equations for Constantly Accelerated Straight-Line Motion

Form to use when accelerating object has an initial velocity	Form to use when accelerating object starts from rest
$\Delta x = \frac{1}{2}(v_i + v_f)\Delta t$	$\Delta x = \frac{1}{2}v_f\Delta t$
$v_f = v_i + a\Delta t$	$v_f = a\Delta t$
$\Delta x = v_i\Delta t + \frac{1}{2}a(\Delta t)^2$	$\Delta x = \frac{1}{2}a(\Delta t)^2$
$v_f^2 = v_i^2 + 2a\Delta x$	$v_f^2 = 2a\Delta x$

Sample Problem

Final Velocity After Any Displacement

A person pushing a stroller starts from rest, uniformly accelerating at a rate of 0.500 m/s^2. What is the velocity of the stroller after it has traveled 4.75 m?

Sample Problem, *continued*

1. Define

Given:

$v_i = 0$ m/s

$a = 0.500$ m/s^2

$\Delta x = 4.75$ m

Unknown:

$v_f = ?$

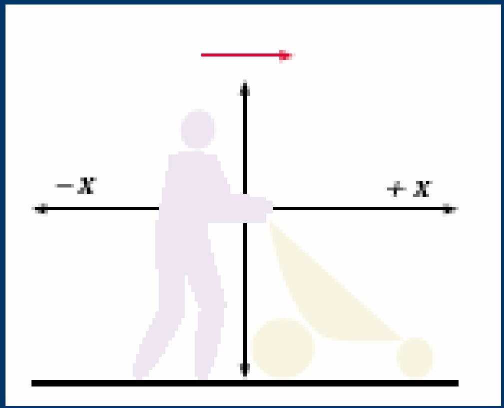


Diagram: Choose a coordinate system. The most convenient one has an origin at the initial location of the stroller, as shown above. The positive direction is to the right.

Sample Problem, *continued*

2. Plan

Choose an equation or situation: Because the initial velocity, acceleration, and displacement are known, the final velocity can be found using the following equation:

$$v_f^2 = v_i^2 + 2a\Delta x$$

Rearrange the equation to isolate the unknown: Take the square root of both sides to isolate v_f .

$$v_f = \pm\sqrt{v_i^2 + 2a\Delta x}$$

Sample Problem, *continued*

3. Calculate

Substitute the values into the equation and solve:

$$v_f = \pm\sqrt{(0 \text{ m/s})^2 + 2(0.500 \text{ m/s}^2)(4.75 \text{ m})}$$

$$\boxed{v_f = +2.18 \text{ m/s}}$$

***Tip:** Think about the physical situation to determine whether to keep the positive or negative answer from the square root. In this case, the stroller starts from rest and ends with a speed of 2.18 m/s. An object that is speeding up and has a positive acceleration must have a positive velocity. So, the final velocity must be positive.*

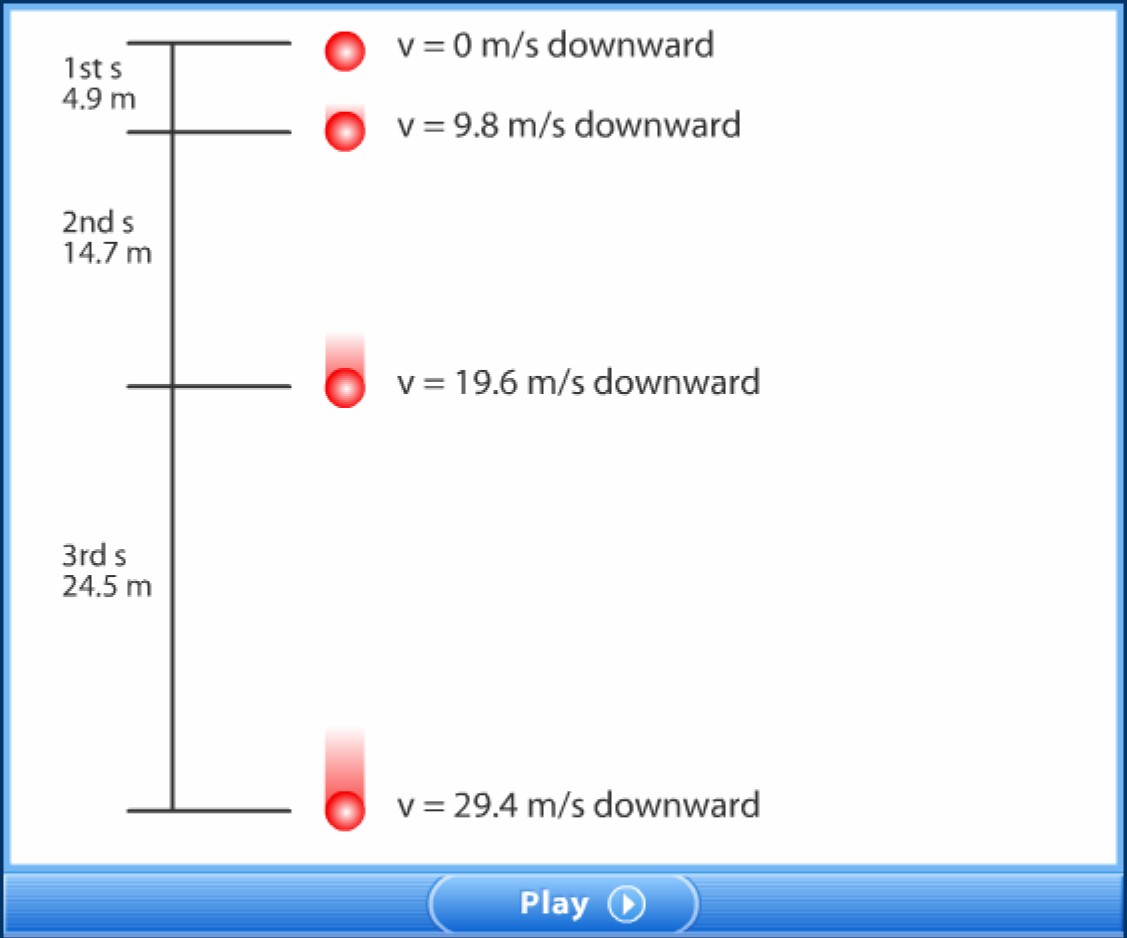
4. Evaluate

The stroller's velocity after accelerating for 4.75 m is 2.18 m/s to the right.

Objectives

- **Relate** the motion of a freely falling body to motion with constant acceleration.
- **Calculate** displacement, velocity, and time at various points in the motion of a freely falling object.
- **Compare** the motions of different objects in free fall.

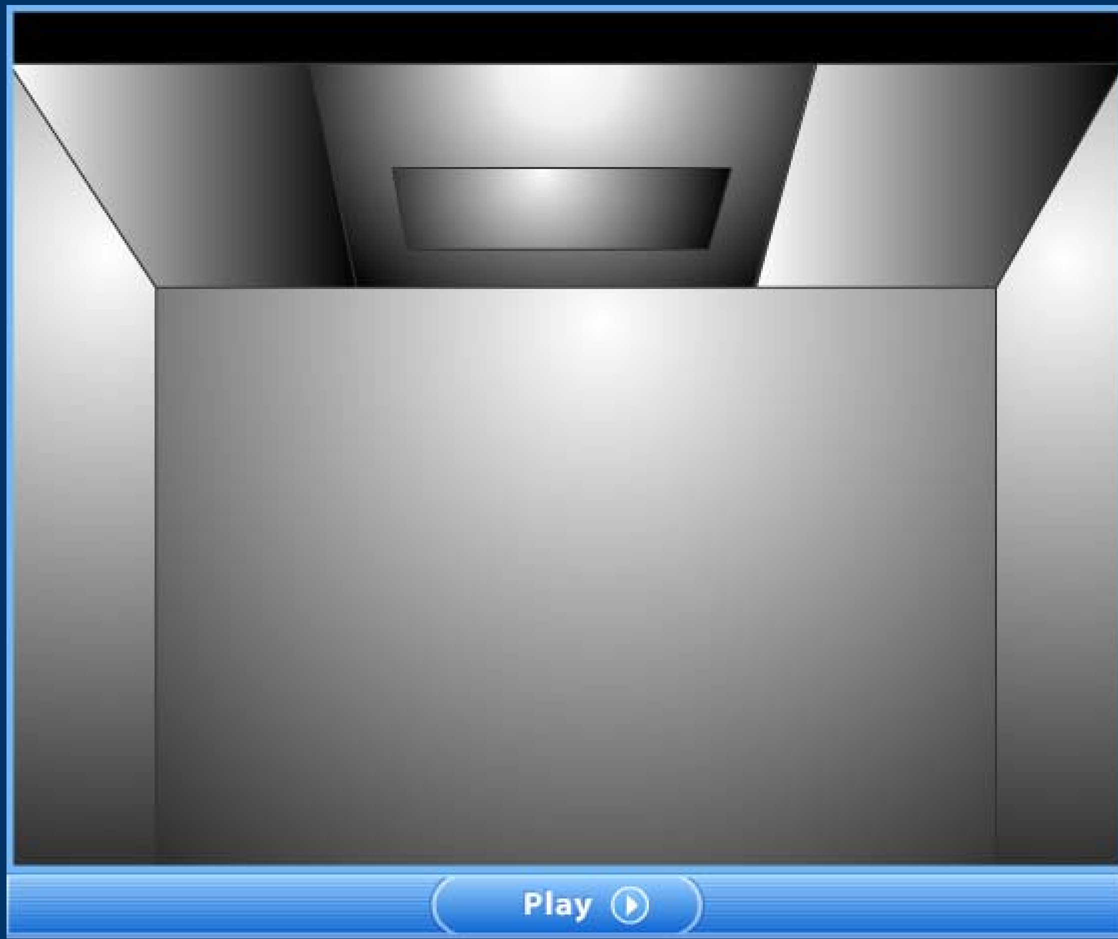
Free Fall


1st s
4.9 m
2nd s
14.7 m
3rd s
24.5 m
v = 0 m/s downward
v = 9.8 m/s downward
v = 19.6 m/s downward
v = 29.4 m/s downward
Play

Free Fall

- **Free fall** is the motion of a body when only the force due to gravity is acting on the body.
- The acceleration on an object in free fall is called the **acceleration due to gravity,** or **free-fall acceleration.**
- Free-fall acceleration is denoted with the symbols a_g (generally) or g (on Earth's surface).

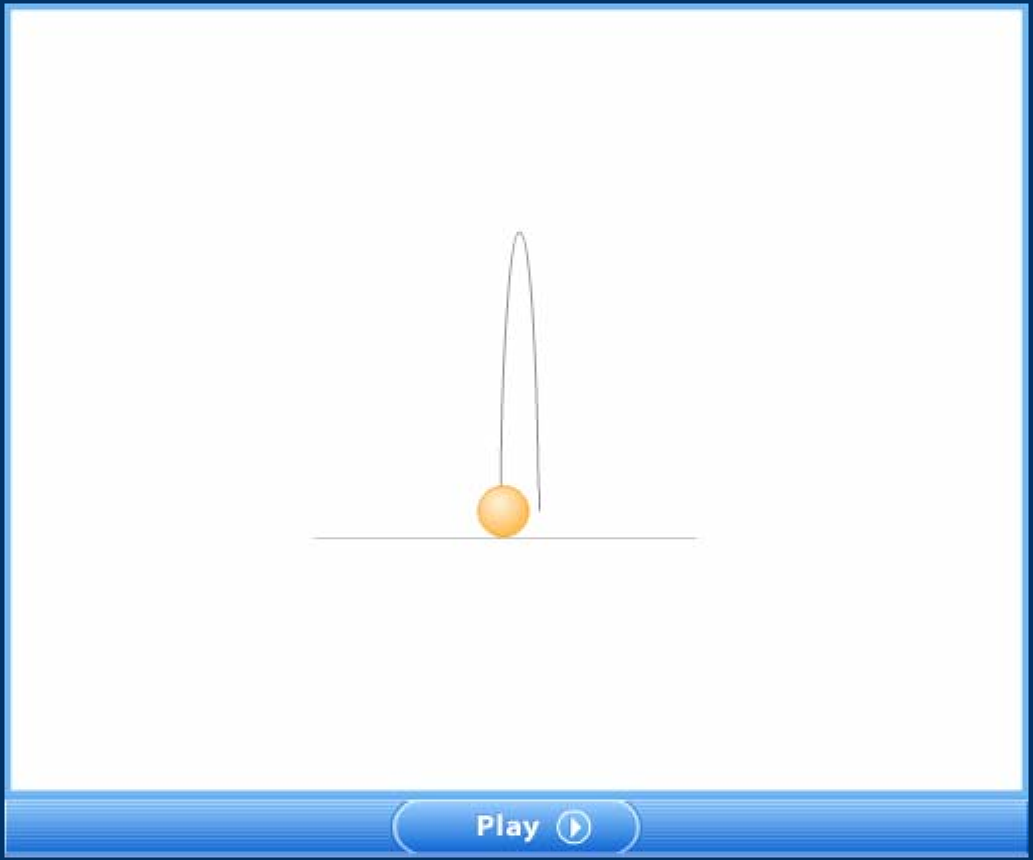
Free-Fall Acceleration



Free-Fall Acceleration

- Free-fall acceleration is the same for all objects, regardless of mass.
- This book will use the value **g = 9.81 m/s^2.**
- Free-fall acceleration on Earth's surface is –9.81 m/s^2 at **all points** in the object's motion.
- Consider a ball thrown up into the air.
  - **Moving upward:** velocity is decreasing, acceleration is –9.81 m/s^2
  - **Top of path:** velocity is zero, acceleration is –9.81 m/s^2
  - **Moving downward:** velocity is increasing, acceleration is –9.81 m/s^2

Velocity and Acceleration of an Object in Free Fall



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Sample Problem

Falling Object

Jason hits a volleyball so that it moves with an initial velocity of 6.0 m/s straight upward. If the volleyball starts from 2.0 m above the floor, how long will it be in the air before it strikes the floor?

End Of Slide

Sample Problem, *continued*

1. Define

Given:

$v_i = +6.0 \text{ m/s}$

$a = -g = -9.81 \text{ m/s}^2$

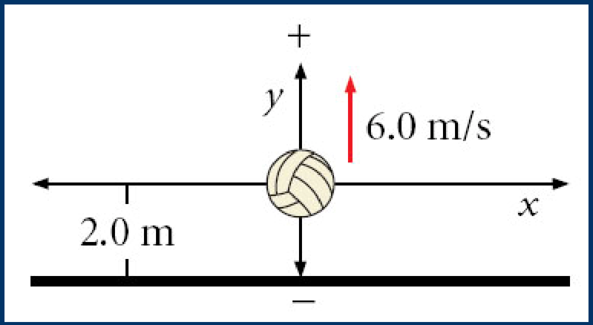
$\Delta y = -2.0 \text{ m}$

Unknown:

$\Delta t = ?$

Diagram:

Place the origin at the Starting point of the ball ($y_i = 0$ at $t_i = 0$).



Sample Problem, *continued*

2. Plan

Choose an equation or situation:

Both Δt and v_f are unknown. Therefore, first solve for v_f using the equation that does not require time. Then, the equation for v_f that does involve time can be used to solve for Δt.

$$v_f^2 = v_i^2 + 2a\Delta y \qquad v_f = v_i + a\Delta t$$

Rearrange the equation to isolate the unknown:

Take the square root of the first equation to isolate v_f. The second equation must be rearranged to solve for Δt.

$$v_f = \pm\sqrt{v_i^2 + 2a\Delta y} \qquad \Delta t = \frac{v_f - v_i}{a}$$

Sample Problem, *continued*

3. Calculate

Substitute the values into the equation and solve:

First find the velocity of the ball at the moment that it hits the floor.

$$v_f = \pm\sqrt{v_i^2 + 2a\Delta y} = \pm\sqrt{(6.0 \text{ m/s})^2 + 2(-9.81 \text{ m/s}^2)(-2.0 \text{ m})}$$

$$v_f = \pm\sqrt{36 \text{ m}^2/\text{s}^2 + 39 \text{ m}^2/\text{s}^2} = \pm\sqrt{75 \text{ m}^2/\text{s}^2} = -8.7 \text{ m/s}$$

Tip: *When you take the square root to find v_f, select the negative answer because the ball will be moving toward the floor, in the negative direction.*

Sample Problem, *continued*

Next, use this value of v_f in the second equation to solve for Δt.

$$\Delta t = \frac{v_f - v_i}{a} = \frac{-8.7\ \text{m/s} - 6.0\ \text{m/s}}{-9.81\ \text{m/s}^2} = \frac{-14.7\ \text{m/s}}{-9.81\ \text{m/s}^2}$$

$$\boxed{\Delta t = 1.50\ \text{s}}$$

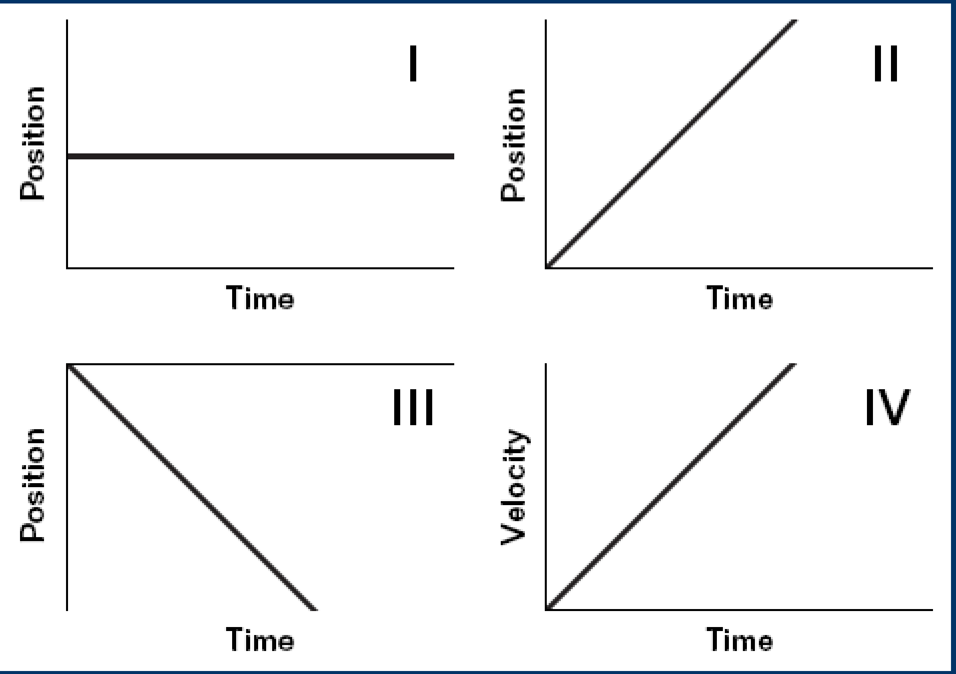
4. Evaluate

The solution, 1.50 s, is a reasonable amount of time for the ball to be in the air.

Multiple Choice

Use the graphs to answer questions 1–3.

1. Which graph represents an object moving with a constant positive velocity?



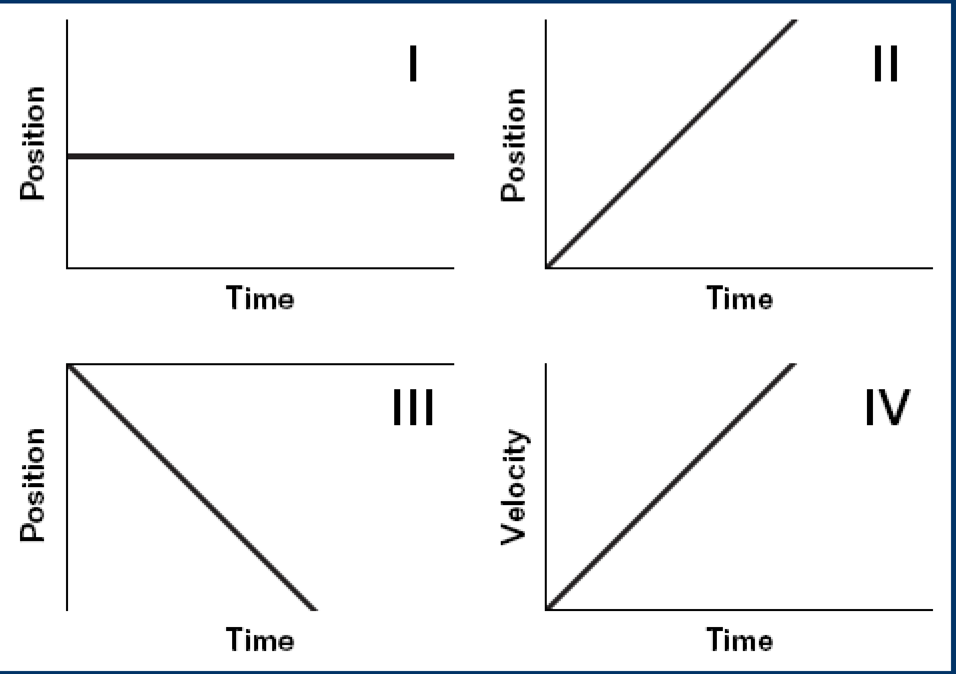
A. I
B. II
C. III
D. IV

Multiple Choice

Use the graphs to answer questions 1–3.

1. Which graph represents an object moving with a constant positive velocity?

A. I
B. II
C. III
D. IV



Multiple Choice, *continued*

Use the graphs to answer questions 1–3.

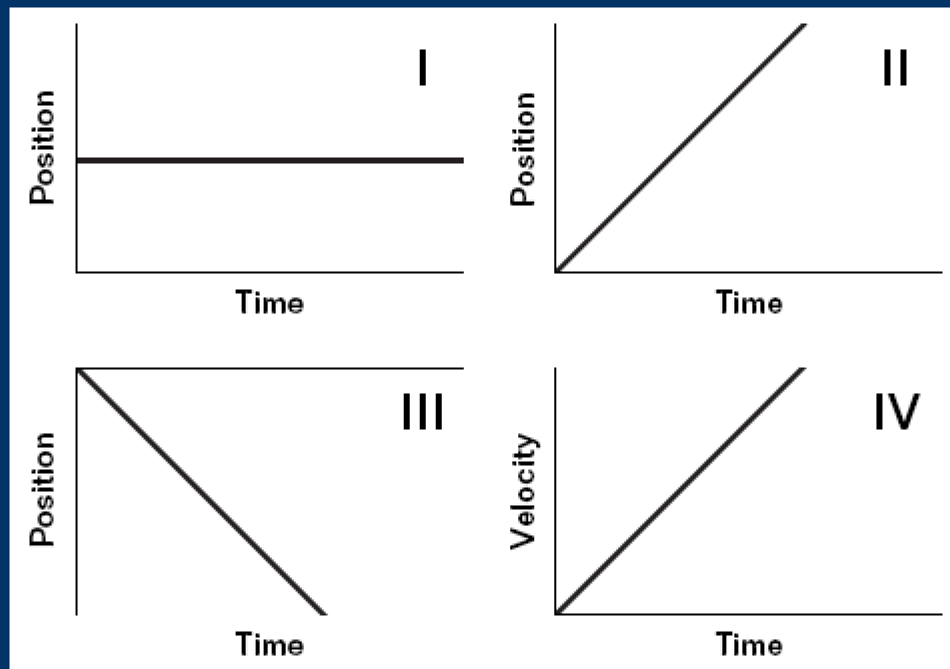
2. Which graph represents an object at rest?

F. I

G. II

H. III

J. IV

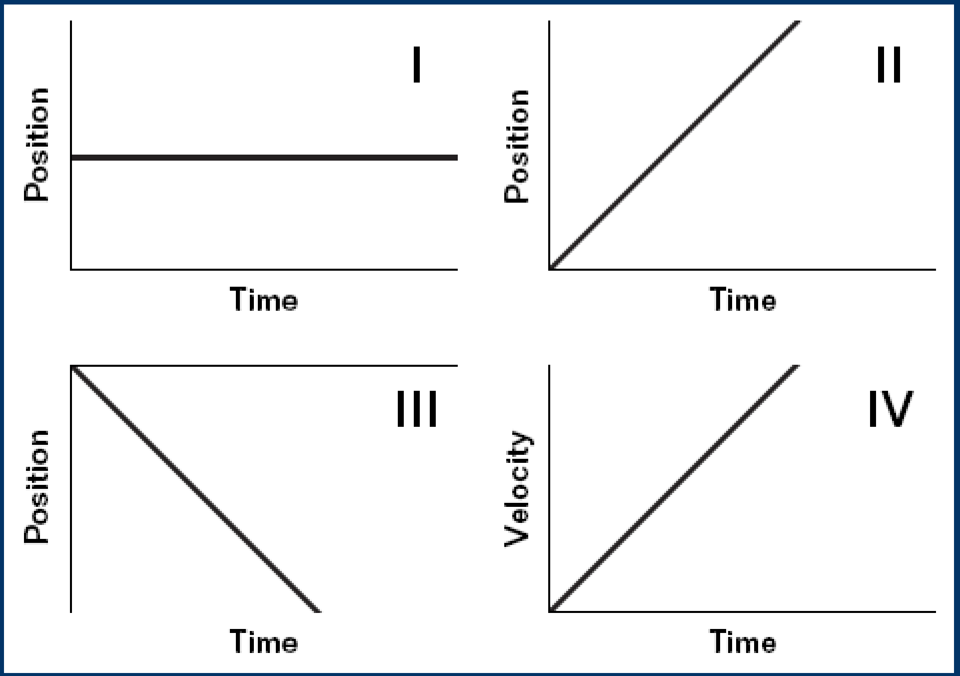


Multiple Choice, *continued*

Use the graphs to answer questions 1–3.

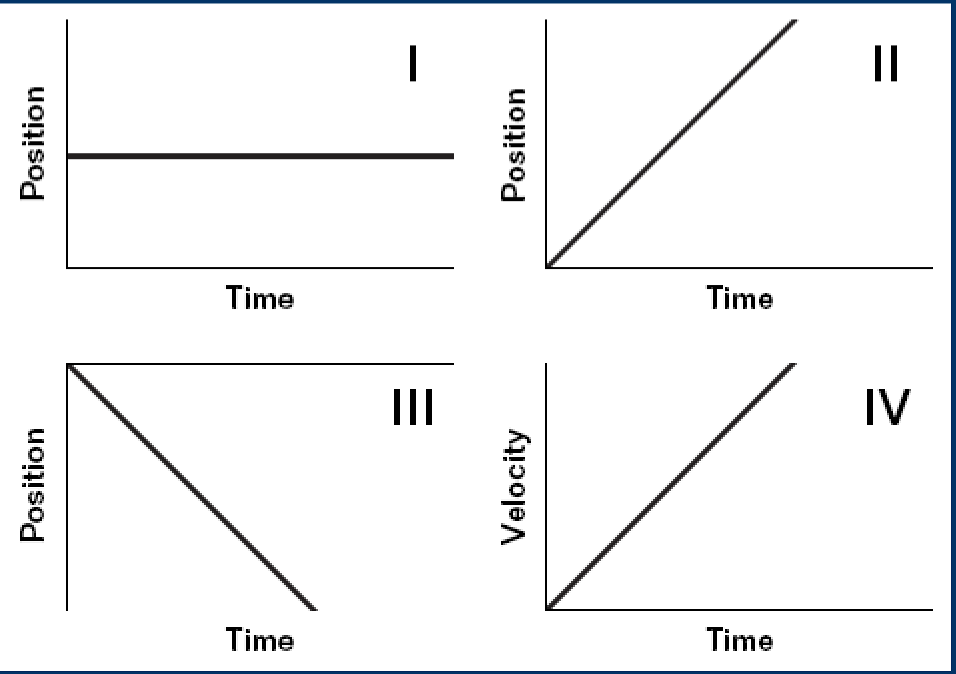
2. Which graph represents an object at rest?

   F. I **H.** III
   G. II **J.** IV



Multiple Choice, *continued*

Use the graphs to answer questions 1–3.

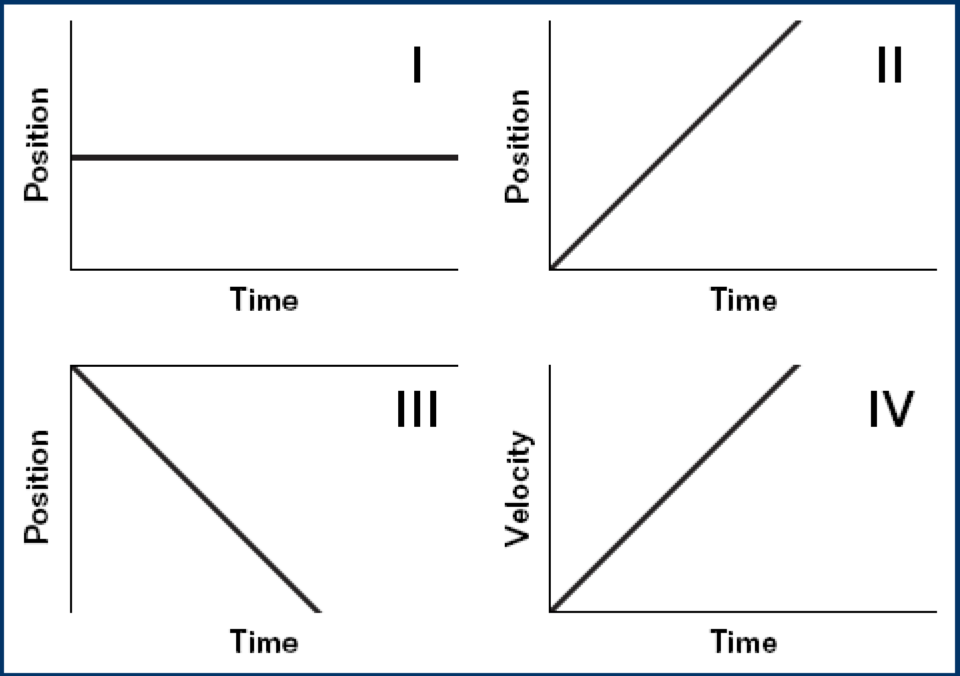


3. Which graph represents an object moving with a constant positive acceleration?

A. I
B. II
C. III
D. IV

Multiple Choice, *continued*

Use the graphs to answer questions 1–3.



3. Which graph represents an object moving with a constant positive acceleration?

A. I
B. II
C. III
D. IV

Multiple Choice, *continued*

4. A bus travels from El Paso, Texas, to Chihuahua, Mexico, in 5.2 h with an average velocity of 73 km/h to the south.What is the bus's displacement?

F. 73 km to the south

G. 370 km to the south

H. 380 km to the south

J. 14 km/h to the south

Multiple Choice, *continued*

4. A bus travels from El Paso, Texas, to Chihuahua, Mexico, in 5.2 h with an average velocity of 73 km/h to the south.What is the bus's displacement?

F. 73 km to the south

G. 370 km to the south

H. 380 km to the south

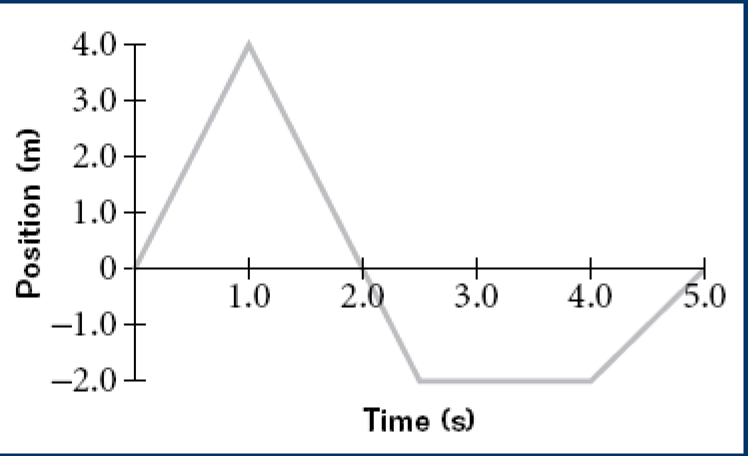
J. 14 km/h to the south

Multiple Choice, *continued*

Use the position-time graph of a squirrel running along a clothesline to answer questions 5–6.

5. What is the squirrel's displacement at time t = 3.0 s?

A. –6.0 m
B. –2.0 m
C. +0.8 m
D. +2.0 m



Multiple Choice, *continued*

Use the position-time graph of a squirrel running along a clothesline to answer questions 5–6.

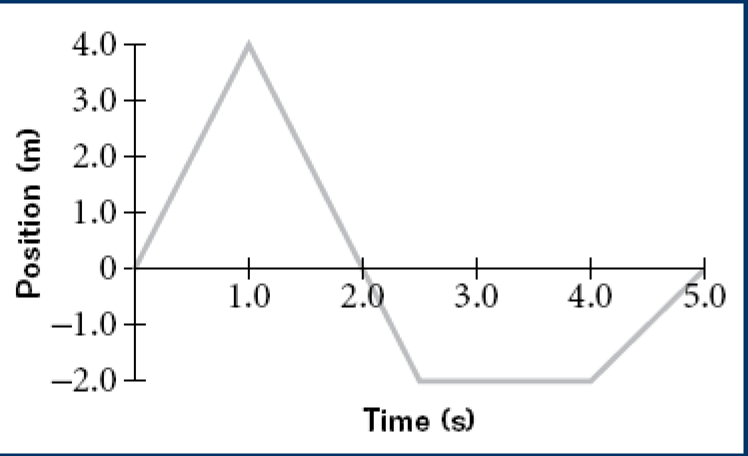
5. What is the squirrel's displacement at time t = 3.0 s?

A. –6.0 m

B. –2.0 m

C. +0.8 m

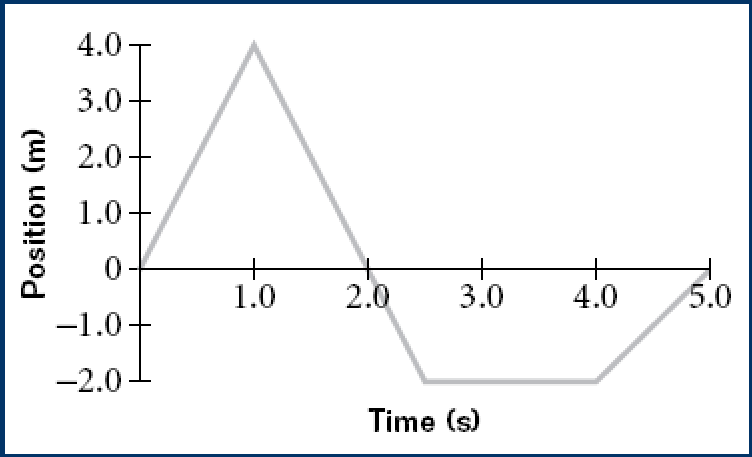
D. +2.0 m



Multiple Choice, *continued*

Use the position-time graph of a squirrel running along a clothesline to answer questions 5–6.

6. What is the squirrel's average velocity during the time interval between 0.0 s and 3.0 s?



F. –2.0 m/s

G. –0.67 m/s

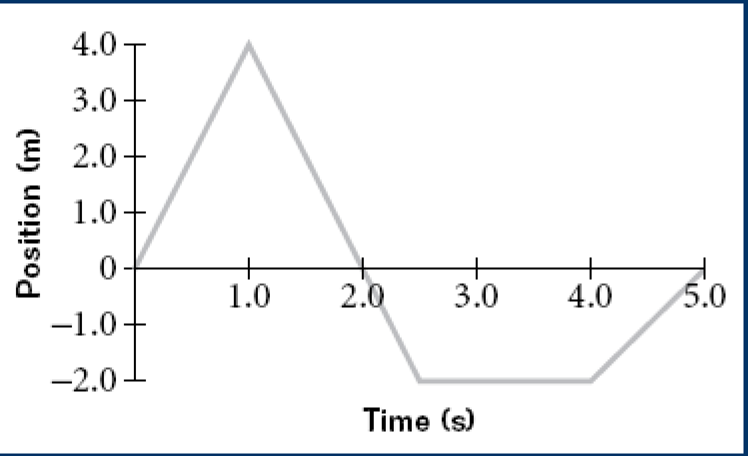
H. 0.0 m/s

J. +0.53 m/s

Multiple Choice, *continued*

Use the position-time graph of a squirrel running along a clothesline to answer questions 5–6.

6. What is the squirrel's average velocity during the time interval between 0.0 s and 3.0 s?



F. –2.0 m/s

G. –0.67 m/s

H. 0.0 m/s

J. +0.53 m/s

Multiple Choice, *continued*

7. Which of the following statements is true of acceleration?

   A. Acceleration always has the same sign as displacement.

   B. Acceleration always has the same sign as velocity.

   C. The sign of acceleration depends on both the direction of motion and how the velocity is changing.

   D. Acceleration always has a positive sign.

Multiple Choice, *continued*

7. Which of the following statements is true of acceleration?

   A. Acceleration always has the same sign as displacement.

   B. Acceleration always has the same sign as velocity.

   C. The sign of acceleration depends on both the direction of motion and how the velocity is changing.

   D. Acceleration always has a positive sign.

Multiple Choice, *continued*

8. A ball initially at rest rolls down a hill and has an acceleration of 3.3 m/s^2. If it accelerates for 7.5 s, how far will it move during this time?

F. 12 m

G. 93 m

H. 120 m

J. 190 m

Multiple Choice, *continued*

8. A ball initially at rest rolls down a hill and has an acceleration of 3.3 m/s^2. If it accelerates for 7.5 s, how far will it move during this time?

F. 12 m

G. 93 m

H. 120 m

J. 190 m

Multiple Choice, *continued*

9. Which of the following statements is true for a ball thrown vertically upward?

   A. The ball has a negative acceleration on the way up and a positive acceleration on the way down.

   B. The ball has a positive acceleration on the way up and a negative acceleration on the way down.

   C. The ball has zero acceleration on the way up and a positive acceleration on the way down.

   D. The ball has a constant acceleration throughout its flight.

Multiple Choice, *continued*

9. Which of the following statements is true for a ball thrown vertically upward?

   A. The ball has a negative acceleration on the way up and a positive acceleration on the way down.

   B. The ball has a positive acceleration on the way up and a negative acceleration on the way down.

   C. The ball has zero acceleration on the way up and a positive acceleration on the way down.

   D. The ball has a constant acceleration throughout its flight.

Short Response

10. In one or two sentences, explain the difference between *displacement* and *distance traveled.*

Short Response

10. In one or two sentences, explain the difference between *displacement* and *distance traveled.*

Answer:

Displacement measures only the net change in position from starting point to end point. The distance traveled is the total length of the path followed from starting point to end point and may be greater than or equal to the displacement.

Short Response, *continued*

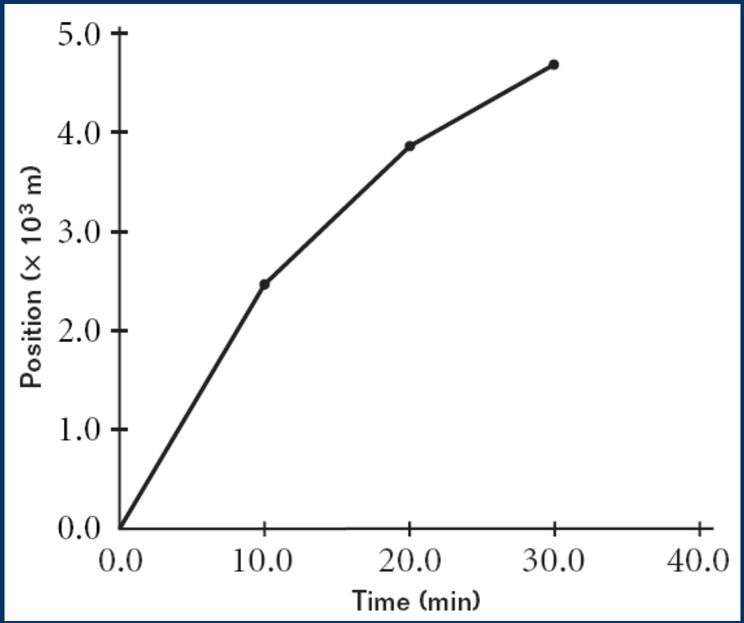
11. The graph shows the position of a runner at different times during a run. Use the graph to determine the runner's displacement and average velocity:

a. for the time interval from t = 0.0 min to t = 10.0 min

b. for the time interval from t = 10.0 min to t = 20.0 min

c. for the time interval from t = 20.0 min to t = 30.0 min

d. for the entire run



Short Response, *continued*

11. The graph shows the position of a runner at different times during a run. Use the graph to determine the runner's displacement and average velocity. *Answers will vary but should be approximately as follows:*

a. for t = 0.0 min to t = 10.0 min

Answer: +2400 m, +4.0 m/s

b. for t = 10.0 min to t = 20.0 min

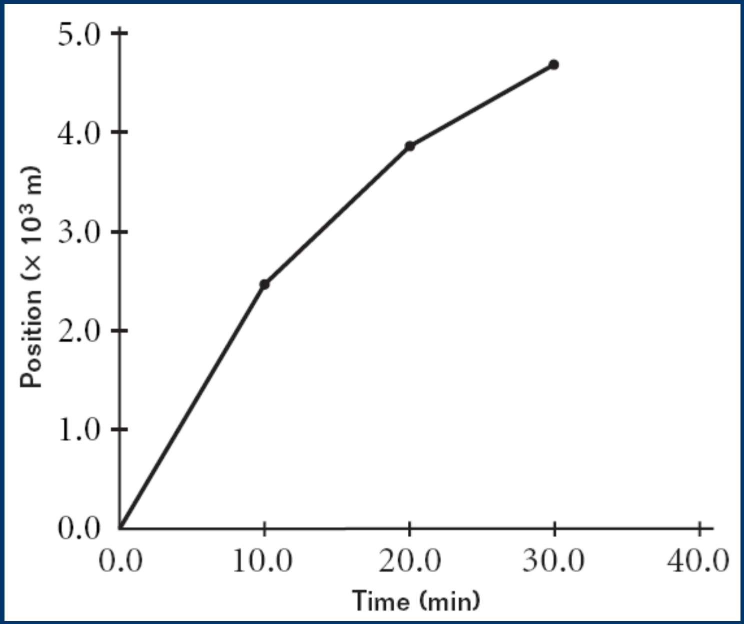
Answer: +1500 m, +2.5 m/s

c. for t = 20.0 min to t = 30.0 min

Answer: +900 m, +2 m/s

d. for the entire run

Answer: +4800 m, +2.7 m/s



Short Response, *continued*

12. For an object moving with constant negative acceleration, draw the following:

a. a graph of position vs. time

b. a graph of velocity vs. time

For both graphs, assume the object starts with a positive velocity and a positive displacement from the origin.

Short Response, *continued*

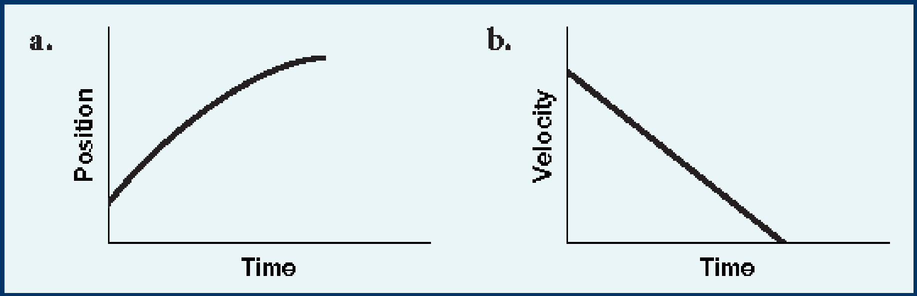
12. For an object moving with constant negative acceleration, draw the following:

a. a graph of position vs. time

b. a graph of velocity vs. time

For both graphs, assume the object starts with a positive velocity and a positive displacement from the origin.

Answers:



Short Response, *continued*

13. A snowmobile travels in a straight line. The snowmobile's initial velocity is +3.0 m/s.

a. If the snowmobile accelerates at a rate of $+0.50 \text{ m/s}^2$ for 7.0 s, what is its final velocity?

b. If the snowmobile accelerates at the rate of -0.60 m/s^2 from its initial velocity of +3.0 m/s, how long will it take to reach a complete stop?

Short Response, *continued*

13. A snowmobile travels in a straight line. The snowmobile's initial velocity is +3.0 m/s.

a. If the snowmobile accelerates at a rate of +0.50 m/s^2 for 7.0 s, what is its final velocity?

b. If the snowmobile accelerates at the rate of –0.60 m/s^2 from its initial velocity of +3.0 m/s, how long will it take to reach a complete stop?

Answers: **a.** +6.5 m/s
b. 5.0 s

Extended Response

14. A car moving eastward along a straight road increases its speed uniformly from 16 m/s to 32 m/s in 10.0 s.

a. What is the car's average acceleration?

b. What is the car's average velocity?

c. How far did the car move while accelerating?

Show all of your work for these calculations.

Extended Response

14. A car moving eastward along a straight road increases its speed uniformly from 16 m/s to 32 m/s in 10.0 s.

a. What is the car's average acceleration?

b. What is the car's average velocity?

c. How far did the car move while accelerating?

Answers: **a.** 1.6 m/s^2 eastward

b. 24 m/s

c. 240 m

Extended Response, *continued*

15. A ball is thrown vertically upward with a speed of 25.0 m/s from a height of 2.0 m.

a. How long does it take the ball to reach its highest point?

b. How long is the ball in the air?

Show all of your work for these calculations.

Extended Response, *continued*

15. A ball is thrown vertically upward with a speed of 25.0 m/s from a height of 2.0 m.

a. How long does it take the ball to reach its highest point?

b. How long is the ball in the air?

Show all of your work for these calculations.

Answers: **a.** 2.55 s

b. 5.18 s