Chapter 2

Motion in One Dimension

Dr: H.Alsamamra

Dynamics

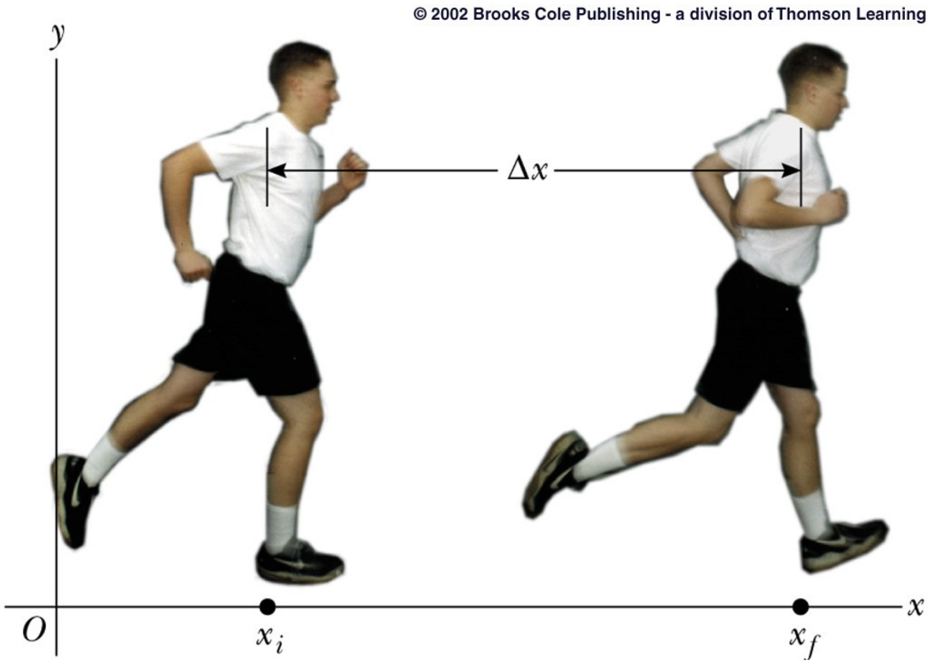
- The branch of physics involving the motion of an object and the relationship between that motion and other physics concepts
- ***Kinematics*** is a part of dynamics
  - In kinematics, you are interested in the *description* of motion
  - *Not* concerned with the cause of the motion

Quantities in Motion

- Any motion involves three concepts
  - Displacement
  - Velocity
  - Acceleration
- These concepts can be used to study objects in motion

Position

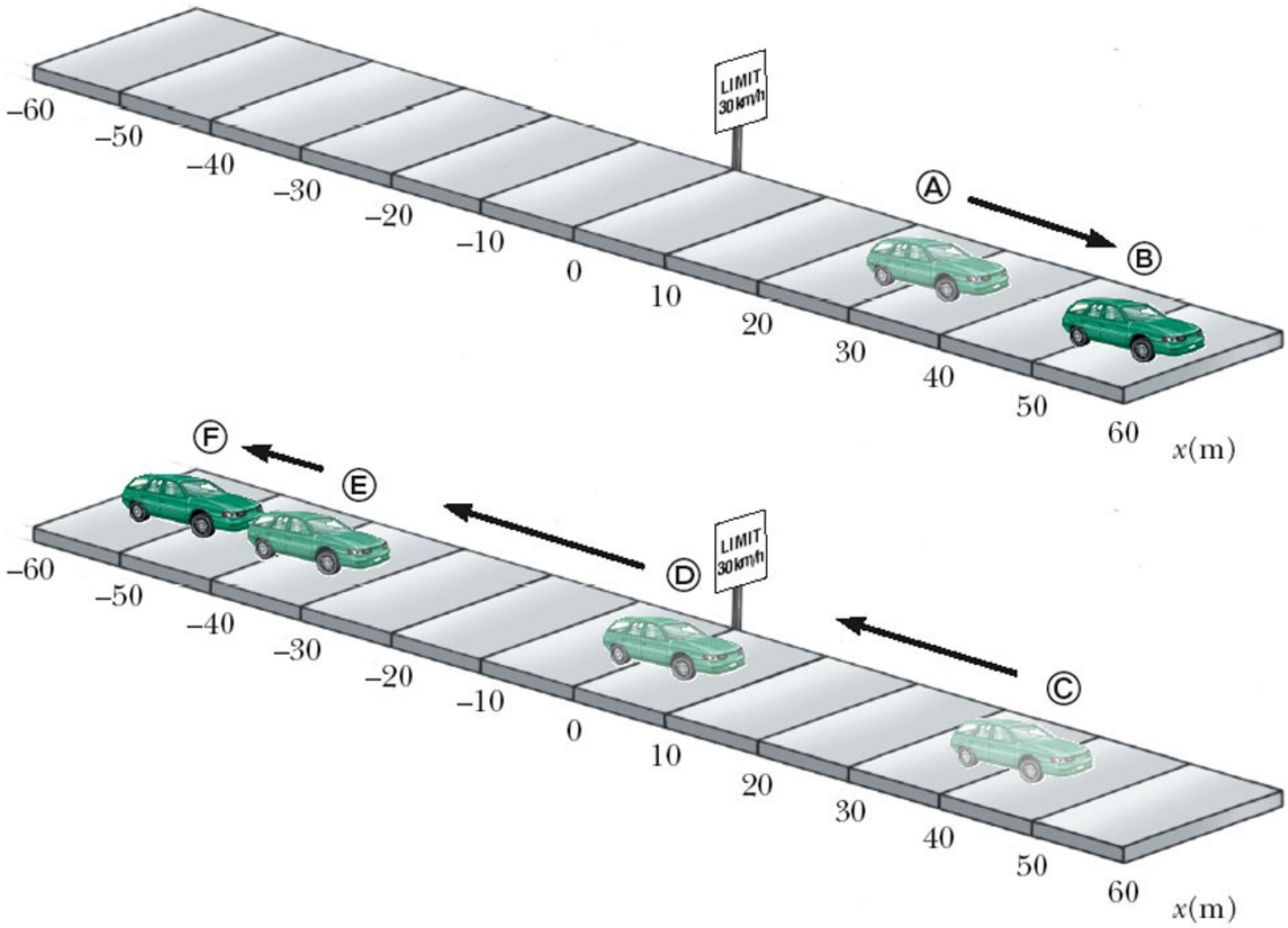
- Defined in terms of a **frame of reference**
  - One dimensional, so generally the x- or y-axis
  - Defines a starting point for the motion



2.1 Displacement

- Defined as the change in position
  - $\Delta x \equiv x_f - x_i$
    - x_f stands for final and x_i or x_o stands for initial
  - May be represented as Δy if vertical
  - Units are meters (m) in SI, centimeters (cm) in cgs or feet (ft) in US Customary

Displacements



© 2006 Brooks/Cole - Thomson

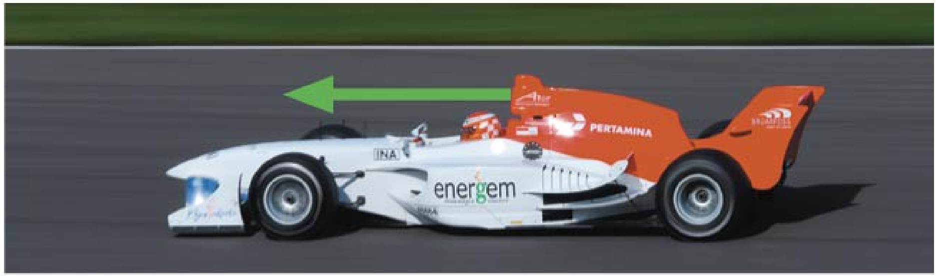
Vector and Scalar Quantities

- Vector quantities need both magnitude and direction to completely describe them

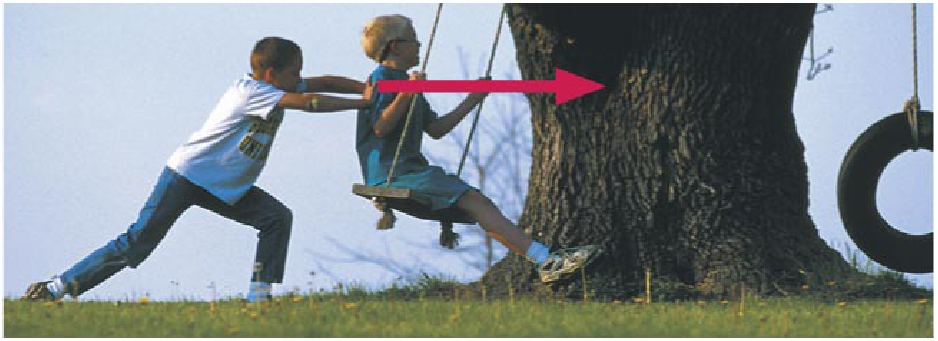
- Scalar quantities are completely described by magnitude only

Vectors

A quantity that requires both a magnitude and a direction can be represented by a *vector*. Graphically, we represent a vector by an arrow.



The velocity of this car is **100 m/s** (magnitude) to the **left** .



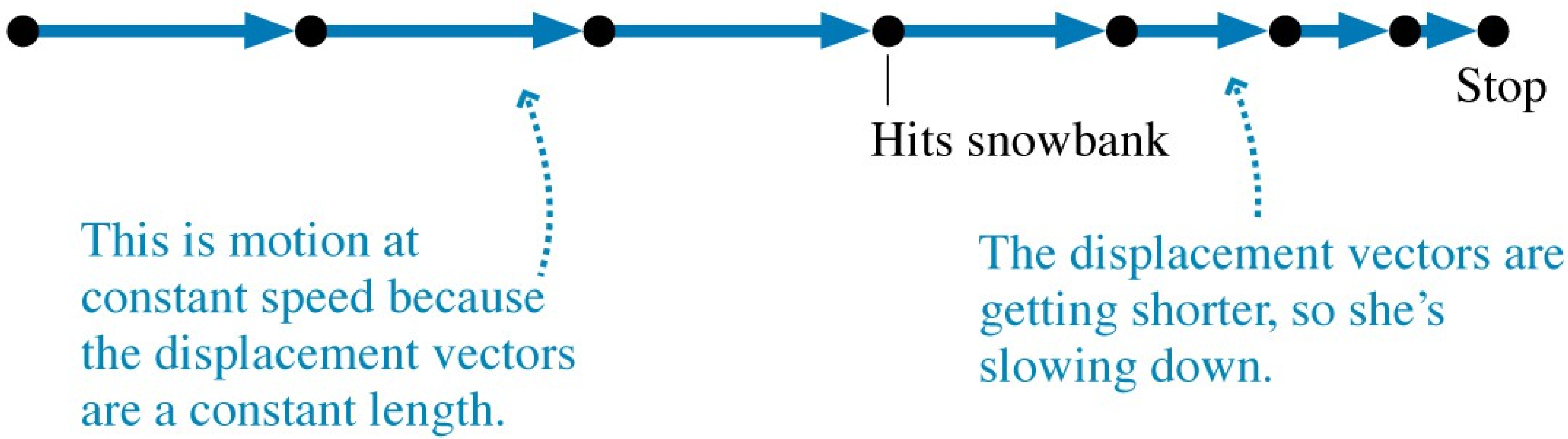
This boy pushes on his friend with a force of **25 N** to the **right**.

Displacement Vectors

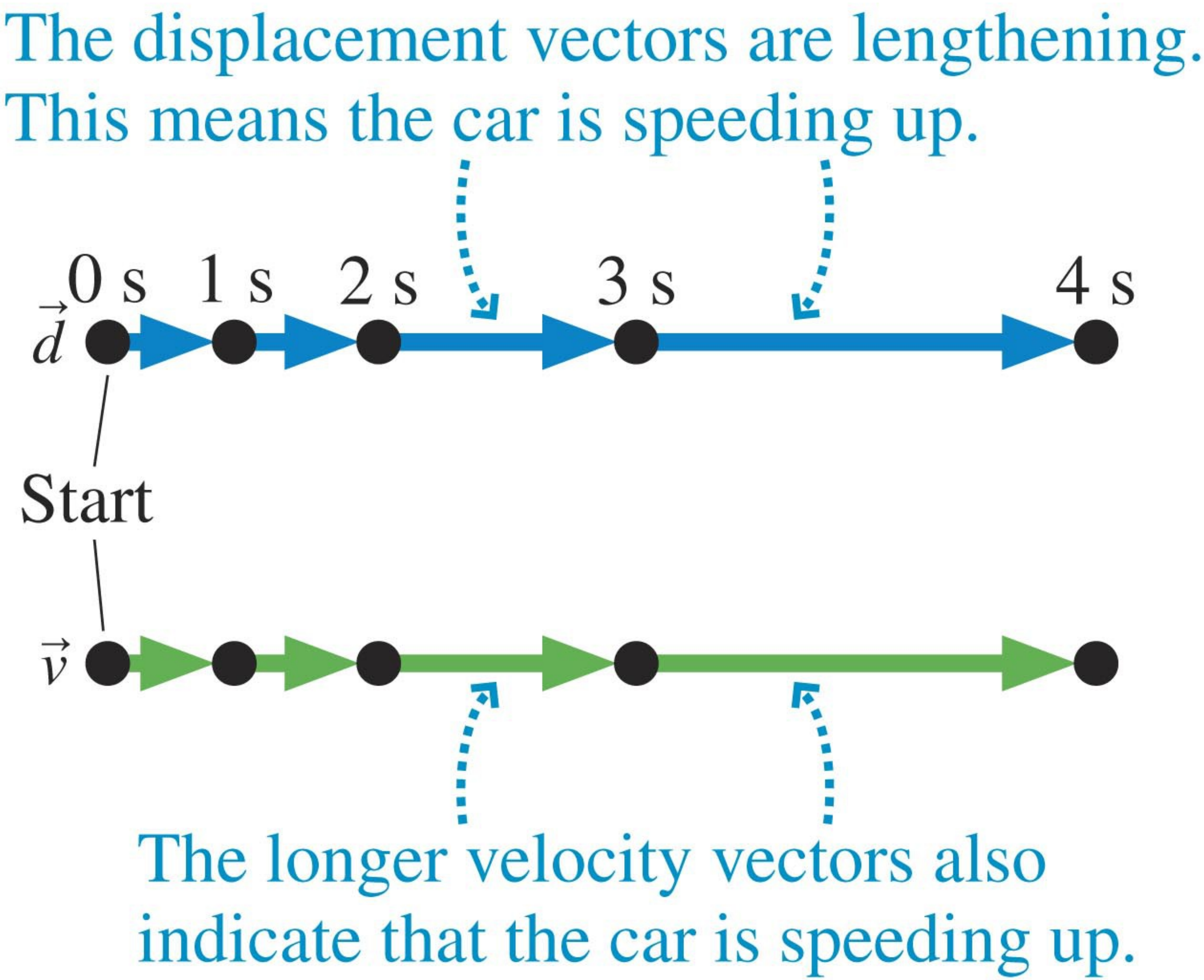
A *displacement vector* starts at an object's initial position and ends at its final position. It doesn't matter what the object did in between these two positions.

Exercise

An object is sliding along a smooth, icy road on her sled when she suddenly runs headfirst into a large, very soft snowbank that gradually brings her to a halt. Draw a motion diagram for Alice. Show and label all displacement vectors.

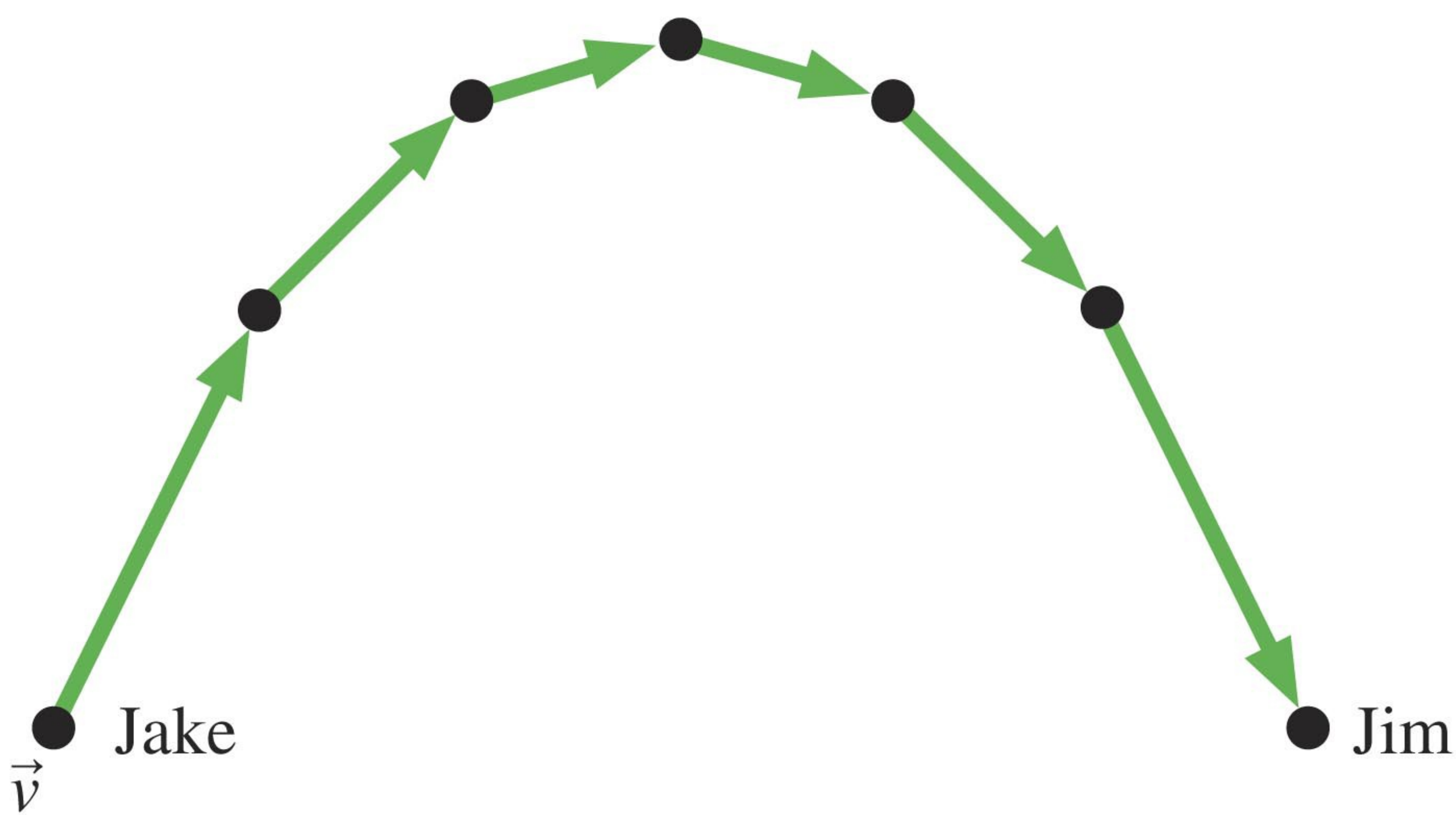


Velocity Vectors



Example: Velocity Vectors

Jake throws a ball at a 60° angle, measured from the horizontal. The ball is caught by Jim. Draw a motion diagram of the ball with velocity vectors.



Displacement Isn’t Distance

- The displacement of an object is not the same as the distance it travels
  - Example: Throw a ball straight up and then catch it at the same point you released it
    - *The distance is twice the height*
    - *The displacement is zero*

2.2 Velocity

- The **average speed** of an object is defined as the total distance traveled divided by the total time elapsed.

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$

$$v = \frac{d}{t}$$

- *Speed is a scalar quantity*

Speed, cont

- Average speed totally ignores any variations in the object's actual motion during the trip
- The *total distance* and the *total time* are all that is important
- SI units are m/s

Velocity

- It takes time for an object to undergo a displacement
- The **average velocity** is the rate at which the displacement occurs

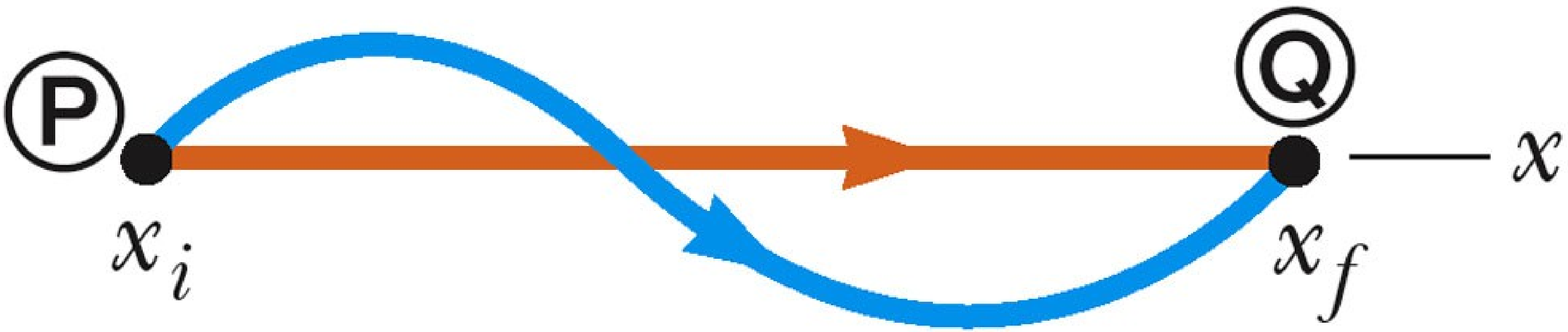
$$v_{average} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

- generally use a time interval, so let $t_i = 0$

Velocity continued

- Direction will be the **same** as the direction of the displacement (time interval is always positive)
  - + or - is sufficient (based on frame of reference)
- Units of velocity are m/s (SI), cm/s (cgs) or ft/s (US Cust.)
  - Other units may be given in a problem, but generally will need to be converted to these

Speed vs. Velocity



© 2006 Brooks/Cole - Thomson

- Cars on both paths have the same average velocity since they had the same displacement in the same time interval
- *The car on the blue path will have a greater average speed since the distance it traveled is larger while the time is kept constant for both.*

Reading Quiz

If Sam walks 100 m to the right, then 200 m to the left, his net displacement vector points

A. to the right.

B. to the left.

C. has zero length.

D. Cannot tell without more information.

Answer

If Sam walks 100 m to the right, then 200 m to the left, his net displacement vector points

A. to the right.

B. to the left.

C. has zero length.

D. Cannot tell without more information.

Reading Quiz

Velocity vectors point

A. in the same direction as displacement vectors.

B. in the opposite direction as displacement vectors.

C. perpendicular to displacement vectors.

D. in the same direction as acceleration vectors.

E. Velocity is not represented by a vector.

Answer

Velocity vectors point

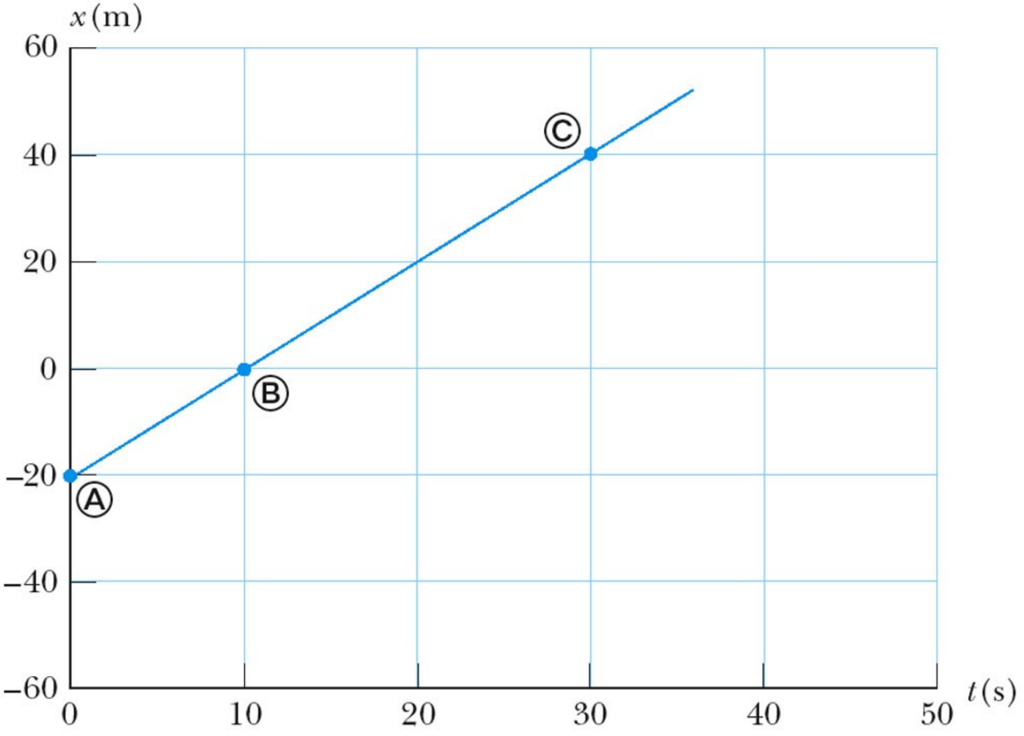
A. **in the same direction as displacement vectors.**
B. in the opposite direction as displacement vectors.
C. perpendicular to displacement vectors.
D. in the same direction as acceleration vectors.
E. Velocity is not represented by a vector.

Graphical Interpretation of Velocity

- Velocity can be determined from a position-time graph
- Average velocity equals the slope of the line joining the initial and final positions
- An object moving with a constant velocity will have a graph that is a straight line

Average Velocity, Constant

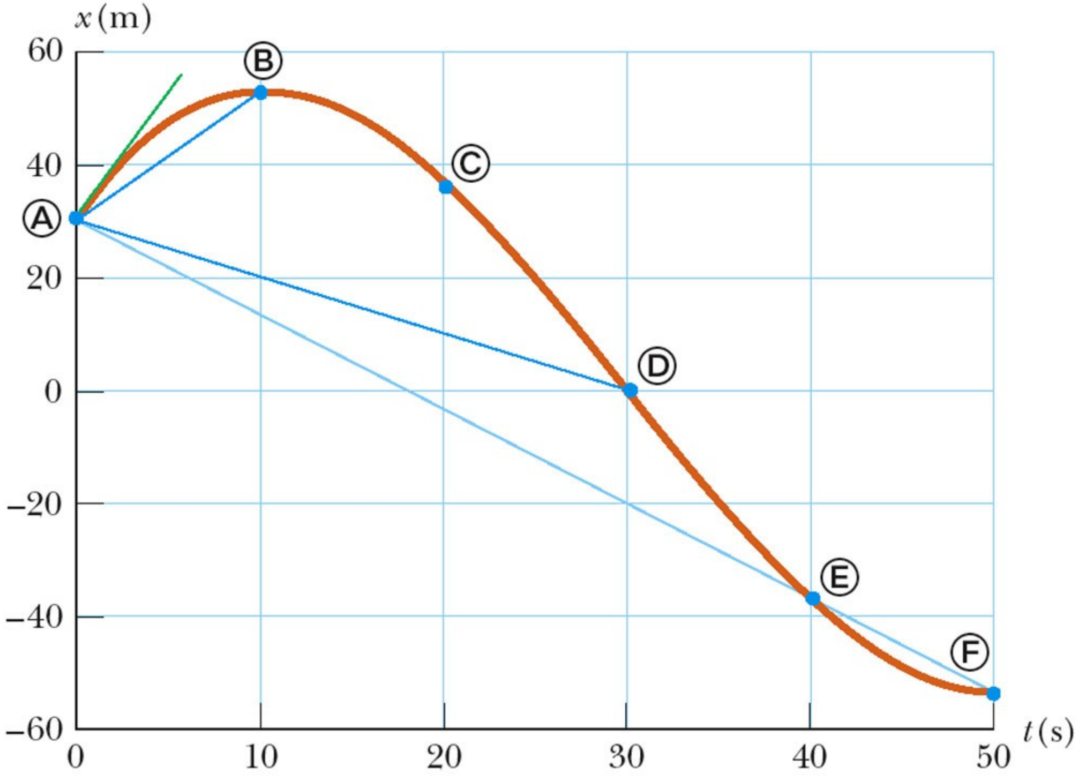
- The straight line indicates constant velocity
- The slope of the line for a displacement vs time graph is the value of the average velocity



© 2006 Brooks/Cole - Thomson

Average Velocity, Non Constant

- The motion is non-constant velocity
- The average velocity is the slope of the blue line joining two points
- V_{AB} is the average velocity between points A and B.
- V_{AD} is the average velocity between points A and D.



© 2006 Brooks/Cole - Thomson

Checking Understanding

Maria is at position x = 23 m. She then undergoes a displacement Δx = –50 m. What is her final position?

A. –27 m

B. –50 m

C. 23 m

D. 73 m

Answer

Maria is at position $x = 23$ m. She then undergoes a displacement $\Delta x = -50$ m. What is her final position?

A. –27 m

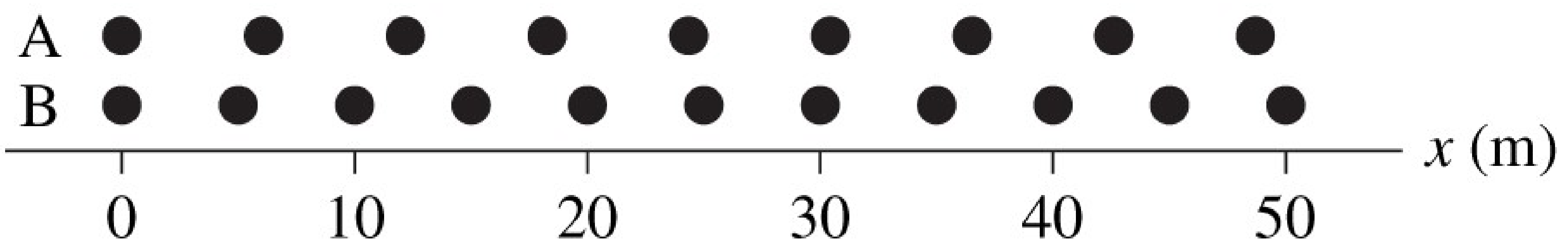
B. –50 m

C. 23 m

D. 73 m

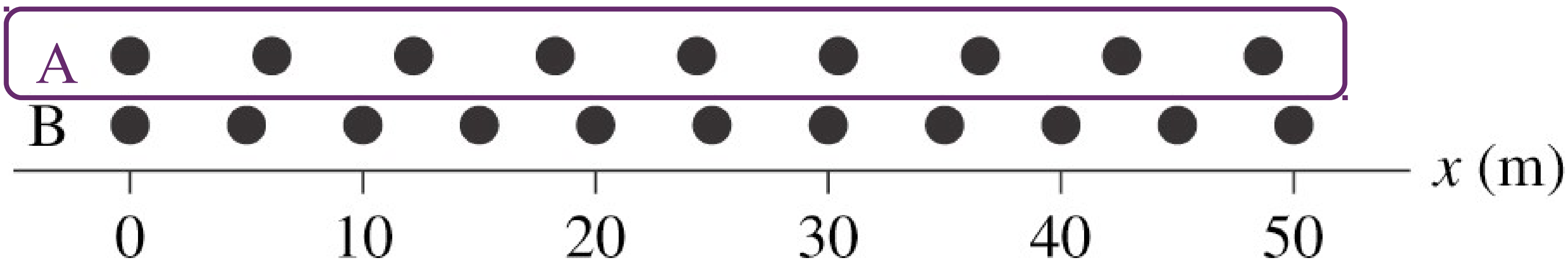
Checking Understanding

Two runners jog along a track. The positions are shown at 1 s time intervals. Which runner is moving faster?



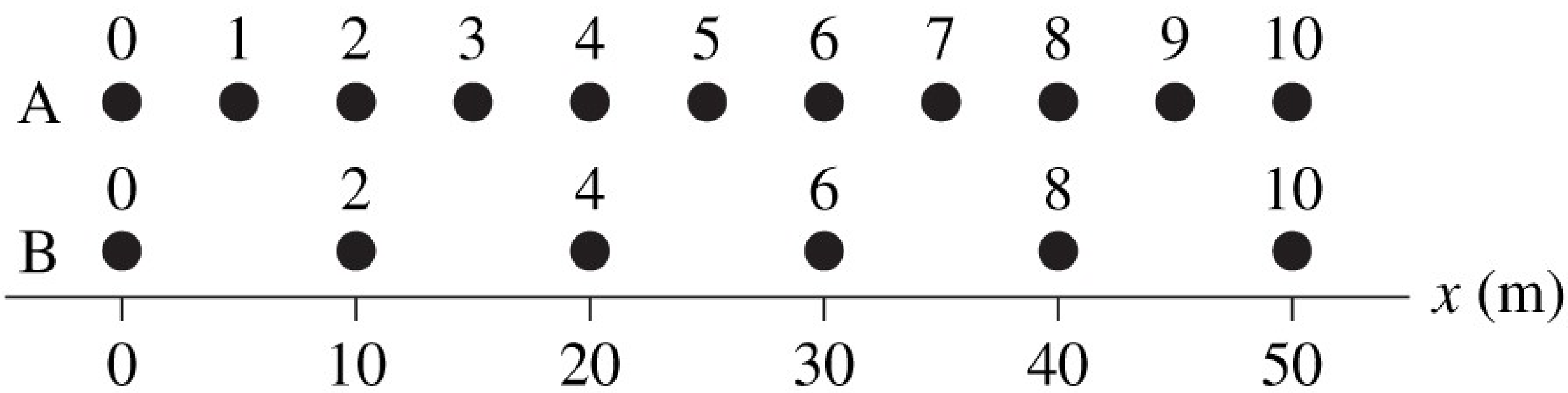
Answer

Two runners jog along a track. The positions are shown at 1 s time intervals. Which runner is moving faster?



Checking Understanding

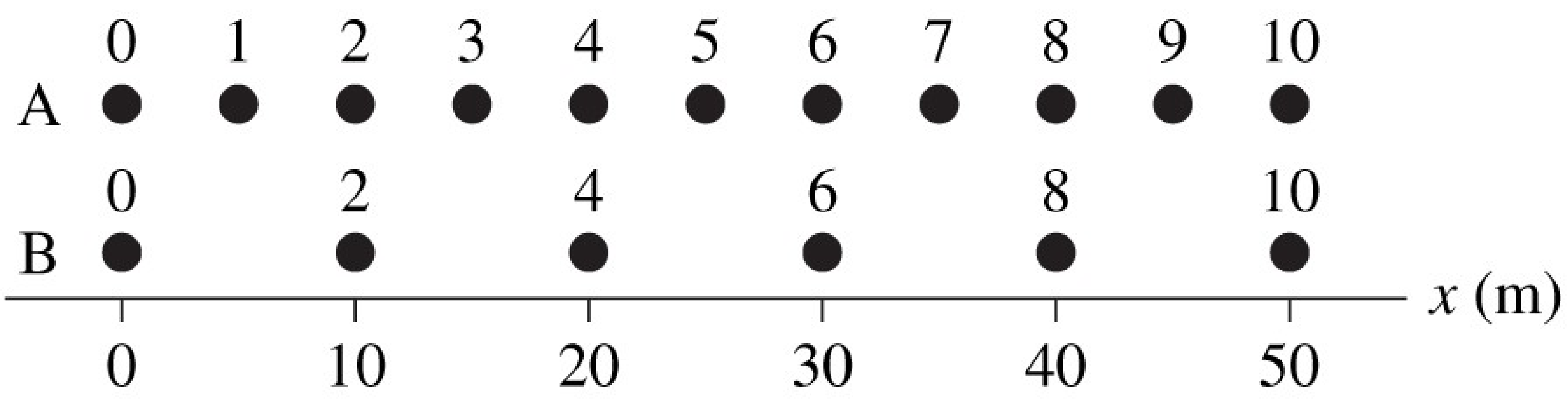
Two runners jog along a track. The times at each position are shown. Which runner is moving faster?



C. They are both moving at the same speed.

Answer

Two runners jog along a track. The times at each position are shown. Which runner is moving faster?



C. They are both moving at the same speed.

Instantaneous Velocity

- The limit of the average velocity as the time interval becomes infinitesimally short, or as the time interval approaches zero

$$v \equiv \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

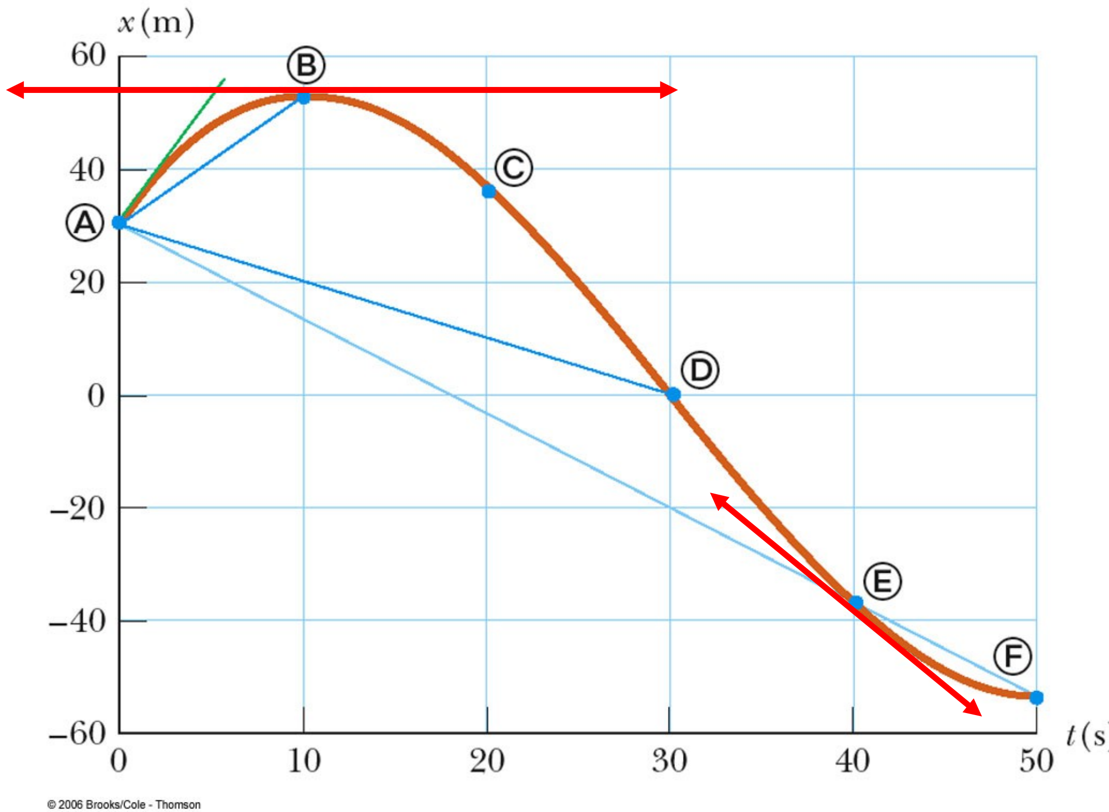
- The instantaneous velocity indicates what is happening at every point of time

Instantaneous Velocity on a Graph

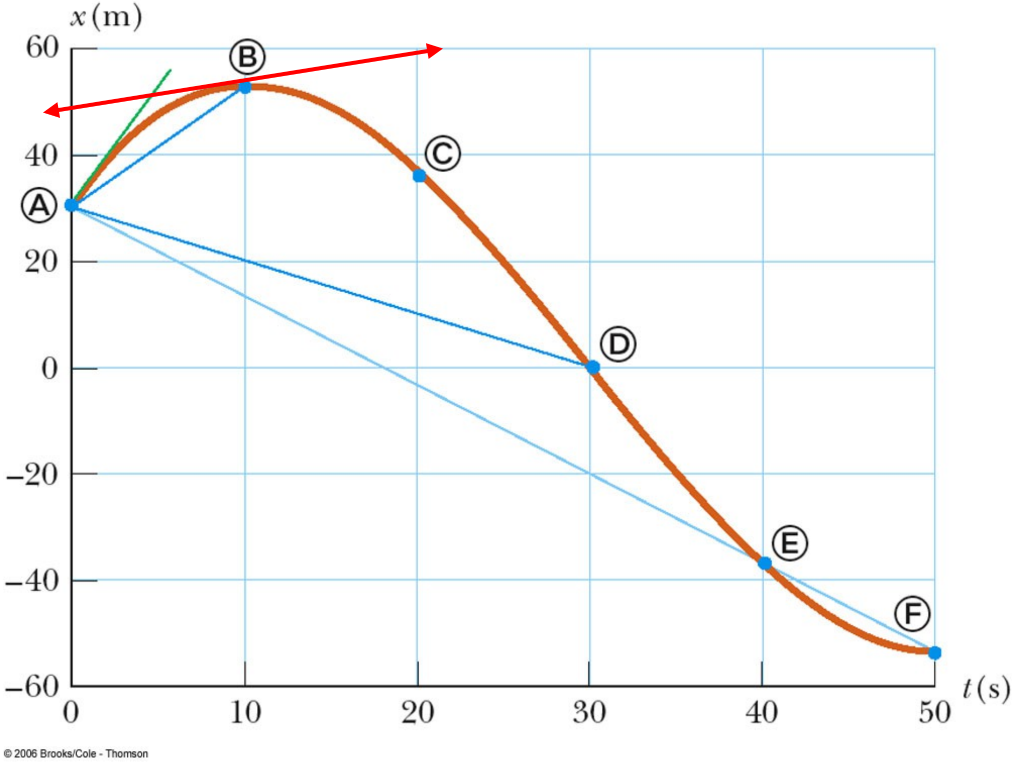
- The slope of the line tangent to the position-vs.-time graph is defined to be the instantaneous velocity at that time
  - The instantaneous speed is defined as the magnitude of the instantaneous velocity

Instantaneous Velocity on a Graph

- The slope of the line tangent to the position-vs.-time graph at a specific point on the curve is the instantaneous velocity. The slope at point B is different than at point E. Each of these points represents an instantaneous velocity value on the graph.



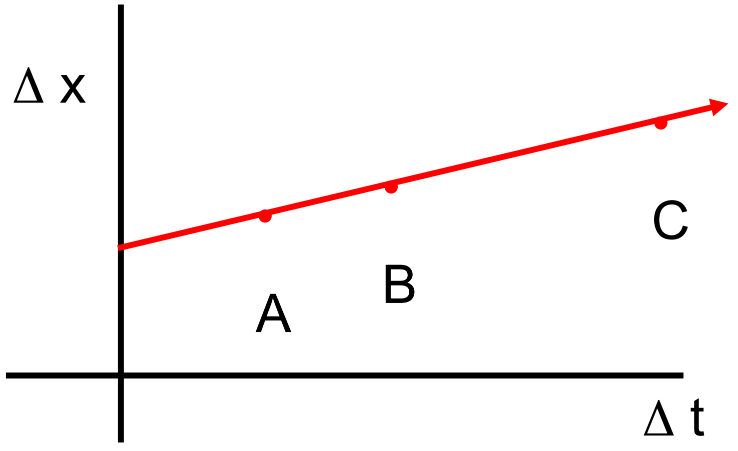
Instantaneous Velocity on a Graph



- The slope of AB is the average velocity between A & B.
- The slope of the tangent line at B is the instantaneous velocity at B and is determined using limits & calculus.

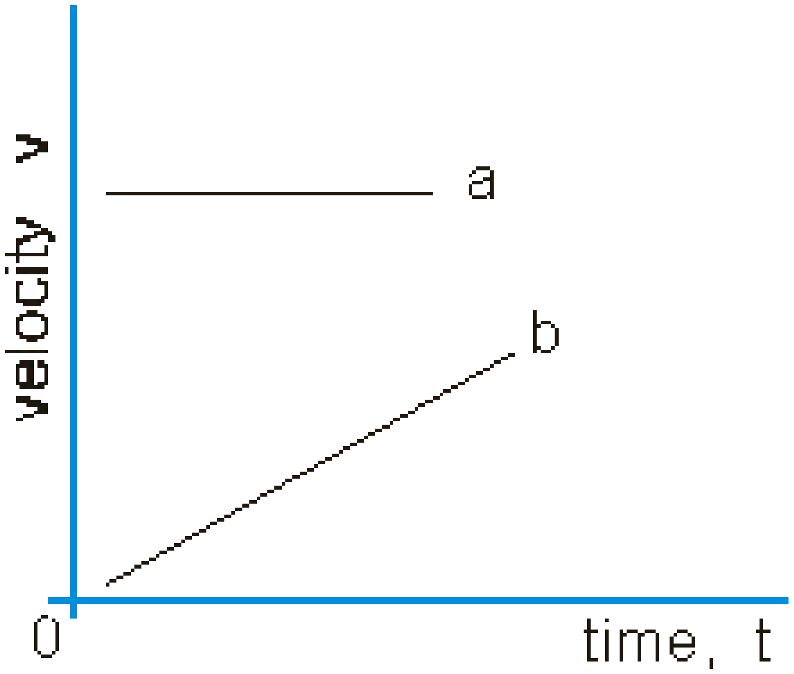
Constant Velocity

- Uniform velocity is constant velocity
- The instantaneous velocities are always the same
  - All the instantaneous velocities will also equal the average velocity



Velocity against Time Graphs

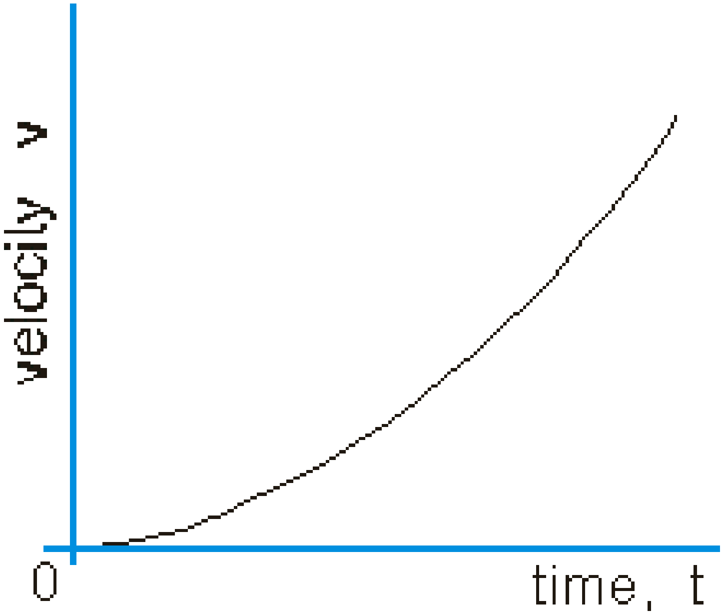
a) uniform velocity



Both graphs demonstrate a uniform velocity. The slope shown by a is 0. This means there is no acceleration. The velocity shown by b is uniform with acceleration present.

Velocity against Time Graphs

- b) uniform acceleration
- The slope of a v/t graph represents **acceleration.**



This graph illustrates non-uniform acceleration as velocity is not uniform.

2.3 Acceleration

- Changing velocity (non-uniform) means an acceleration is present. Changing velocity can occur due to a change in speed and/or direction.
- Acceleration is the rate of change of the velocity

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

- Units are m/s² (SI), cm/s² (cgs), and ft/s² (US Cust)

Average Acceleration

- Vector quantity
- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are in the opposite directions, the speed is decreasing

Average Acceleration

Velocity	Acceleration	Explanation
Positive	Positive	Going east while increasing speed
Positive	Negative	Going east while reducing speed
Positive	Zero	Going east with constant speed
Negative	Positive	Going west while reducing speed
Negative	Negative	Going west while increasing speed
Negative	Zero	Going west with constant speed
Zero	Positive	Starting at rest with increasing speed going east
Zero	Negative	Starting at rest with increasing speed going west

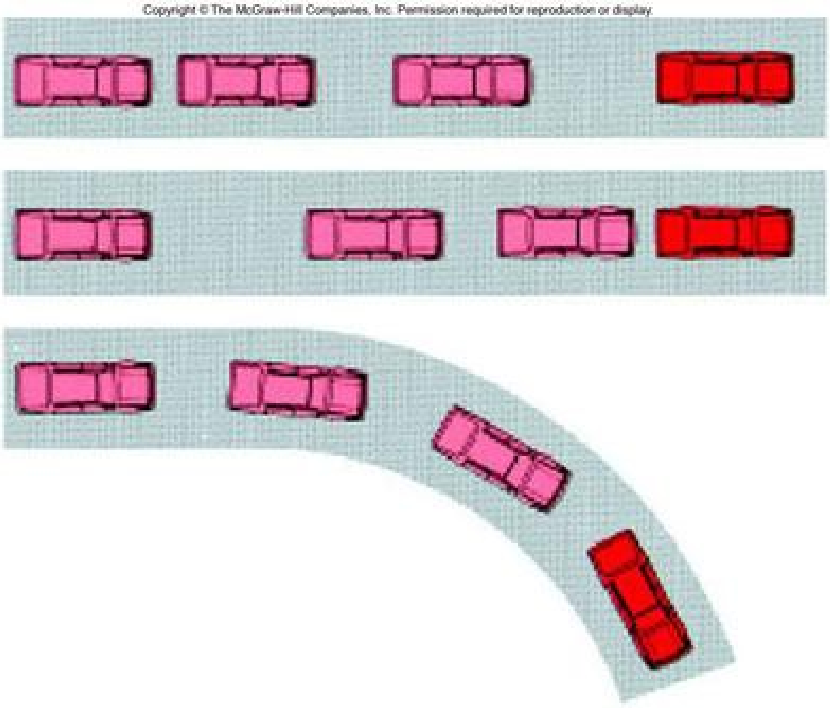
2-3. Acceleration

3 Types of Acceleartion

Speeding Up

Slowing Down

Turning



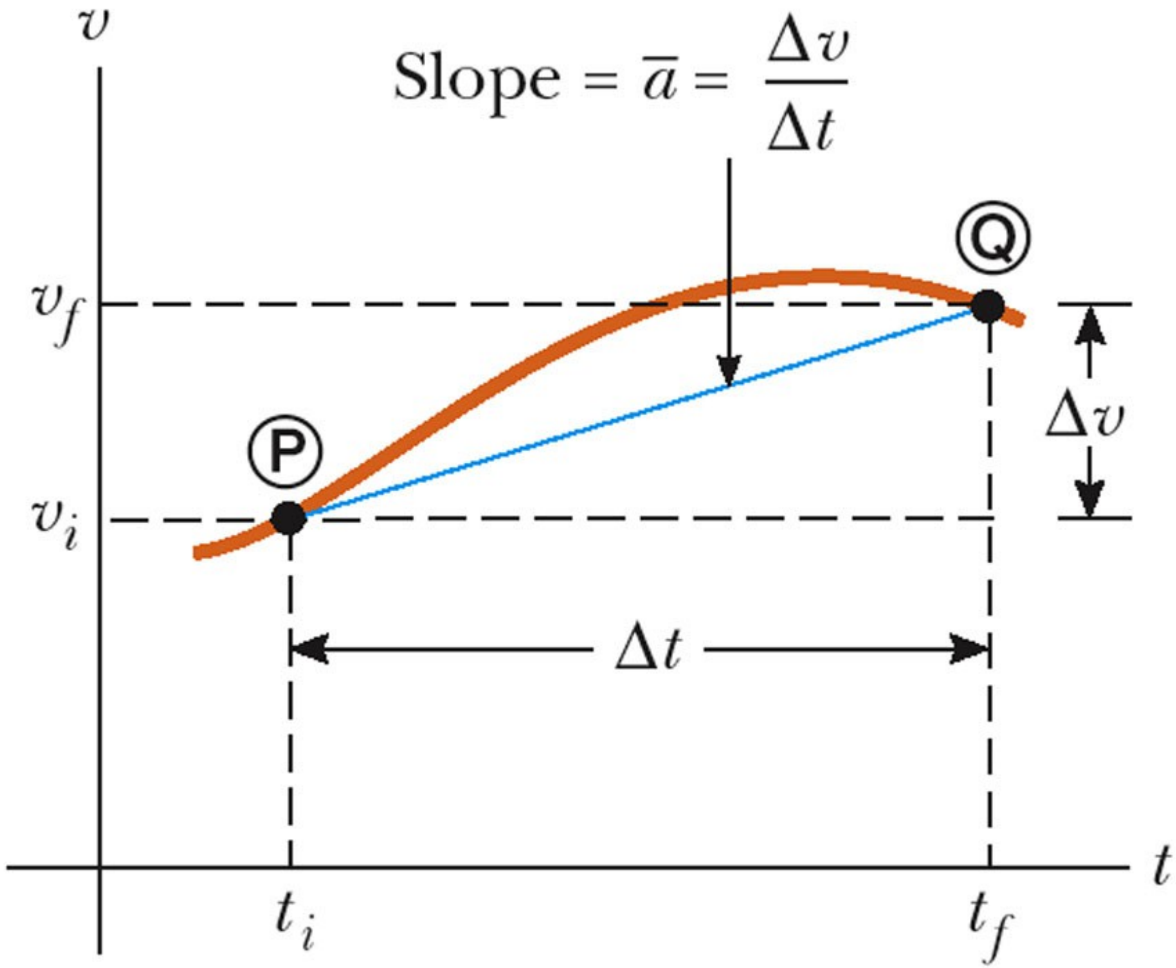
Instantaneous and Constant Acceleration

- The limit of the average acceleration as the time interval goes to zero
- When the instantaneous accelerations are always the same, the acceleration will be constant
  - The instantaneous accelerations will all be equal to the average acceleration

Graphical Interpretation of Acceleration

- Average acceleration is the slope of the line connecting the initial and final velocities on a velocity-time graph
- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph

Average Acceleration

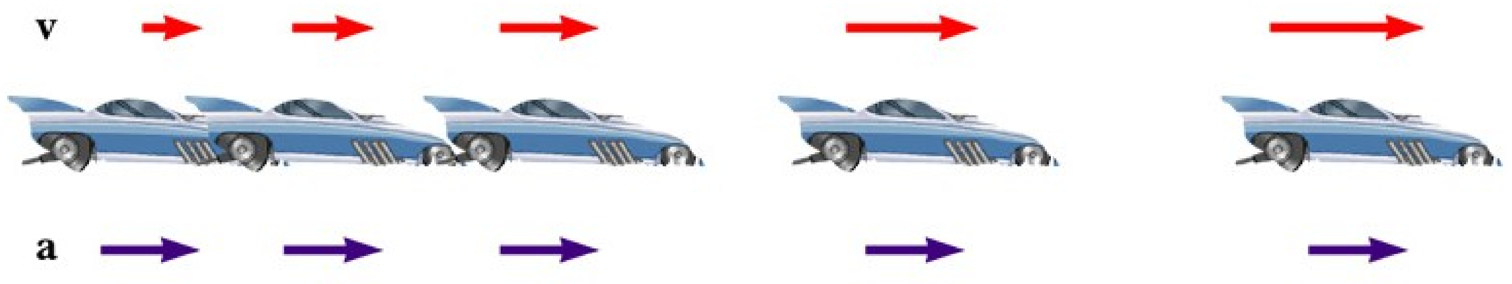


© 2006 Brooks/Cole - Thomson

Relationship Between Acceleration and Velocity

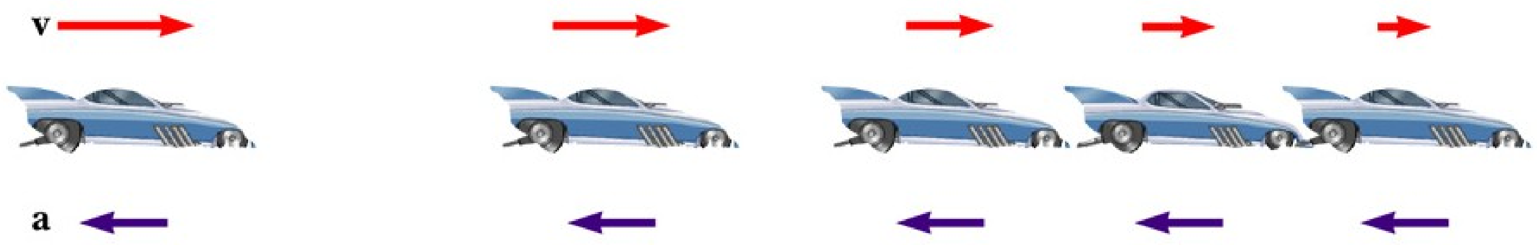
- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero

Relationship Between Velocity and Acceleration



- Velocity and acceleration are in the same direction
- Acceleration is constant (blue arrows maintain the same length)
- Velocity is increasing (red arrows are getting longer)
- Positive velocity and positive acceleration

Relationship Between Velocity and Acceleration



- Acceleration and velocity are in opposite directions
- Acceleration is constant (blue arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter)
- Velocity is positive and acceleration is negative

Check Understanding

The slope at a point on a position-versus-time graph of an object is

A. the object's speed at that point.
B. the object's average velocity at that point.
C. the object's instantaneous velocity at that point.
D. the object's acceleration at that point.
E. the distance traveled by the object to that point.

Answer

The slope at a point on a position-versus-time graph of an object is

A. the object's speed at that point.
B. the object's average velocity at that point.
C. the object's instantaneous velocity at that point.
D. the object's acceleration at that point.
E. the distance traveled by the object to that point.

Check Understanding

The area under a velocity-versus-time graph of an object is

A. the object's speed at that point.
B. the object's acceleration at that point.
C. the distance traveled by the object.
D. the displacement of the object.
E. This topic was not covered in this chapter.

Check Understanding

A 1kg ball and a 100 kg ball are dropped from a height of 10 m at the same time. In the absence of air resistance

A. the 1kg ball hits the ground first.
B. the 100 kg ball hits the ground first.
C. the two balls hit the ground at the same time.
D. There's not enough information to determine which ball wins the race.

Answer

A 1kg ball and a 100 kg ball are dropped from a height of 10 m at the same time. In the absence of air resistance

A. the 1kg ball hits the ground first.
B. the 100 kg ball hits the ground first.
C. **the two balls hit the ground at the same time.**
D. There's not enough information to determine which ball wins the race.

2.5 One-Dimensional motion with constant acceleration

- Used in situations with constant acceleration

$$v = v_o + at$$

$$\Delta x = \bar{v}t = \frac{1}{2}\left(v_o + v\right) t$$

$$\Delta x = v_o t + \frac{1}{2}at^2$$

$$v^2 = v_o^2 + 2a\Delta x$$

Notes on the equations

$$\Delta x = v_{average}\, t = \left(\frac{v_o + v_f}{2} \right) t$$

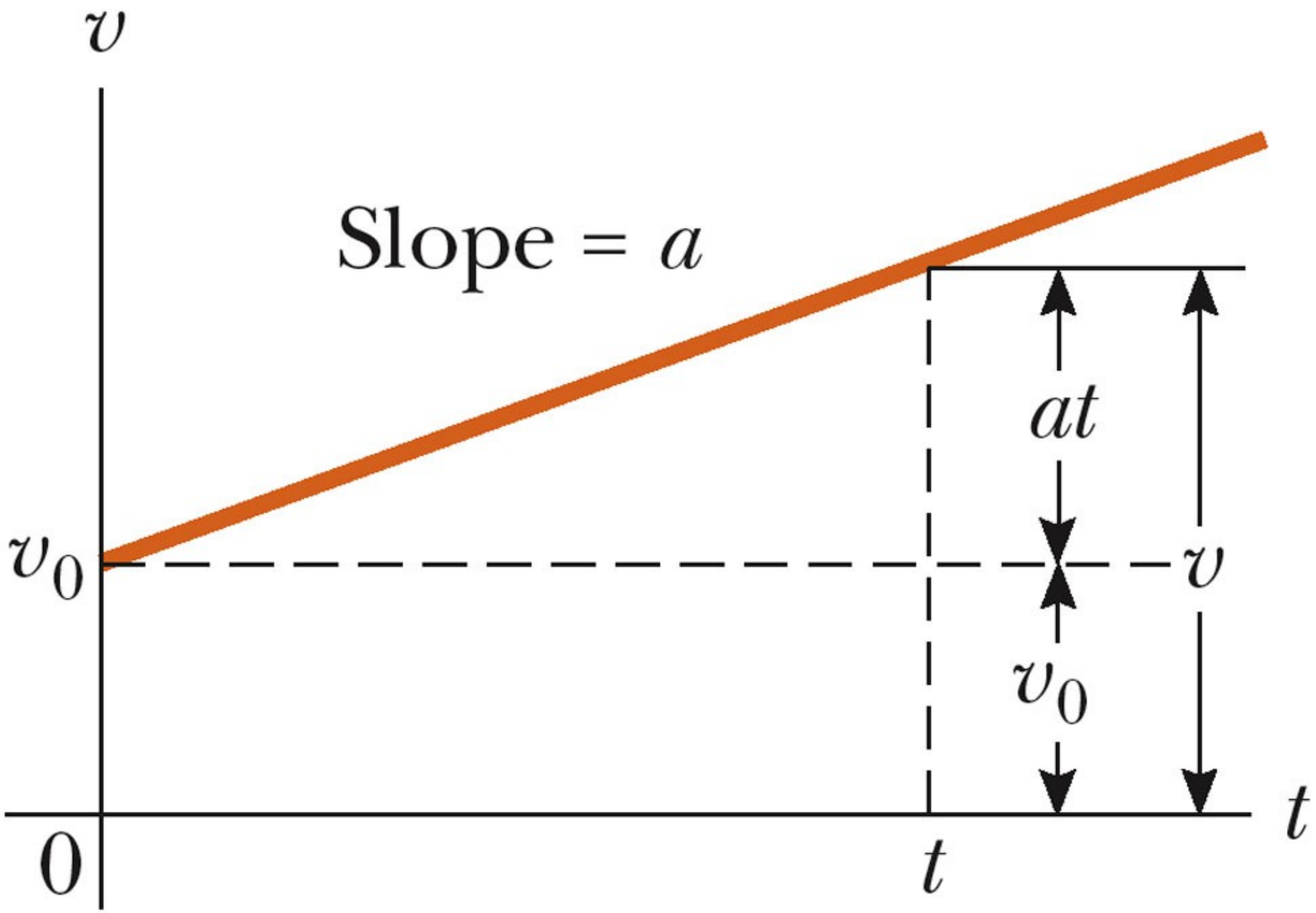
- Gives displacement as a function of velocity and time
- Use when you don’t know and aren’t asked for the acceleration

Notes on the equations

$$v = v_o + at$$

- Shows velocity as a function of acceleration and time
- Use when you don't know and aren't asked to find the displacement

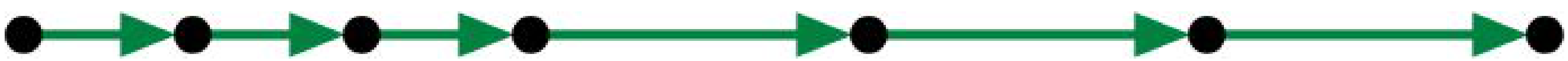
Graphical Interpretation of the Equation



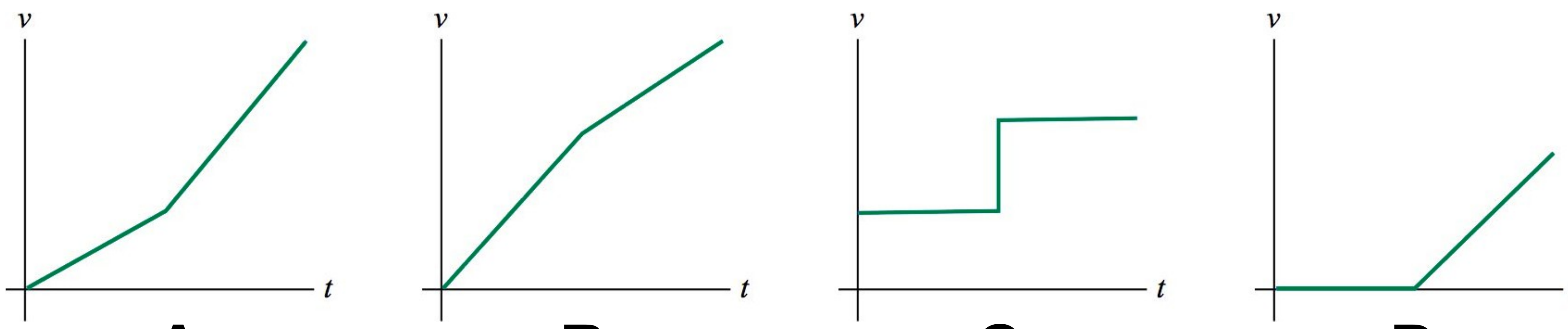
© 2006 Brooks/Cole - Thomson

Checking Understanding

Here is a motion diagram of a car moving along a straight stretch of road:



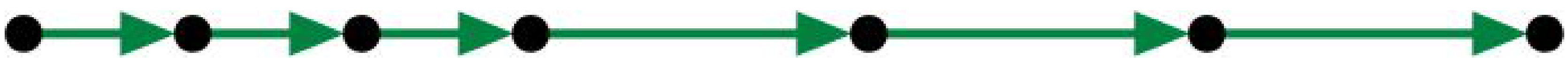
Which of the following velocity-versus-time graphs matches this motion diagram?



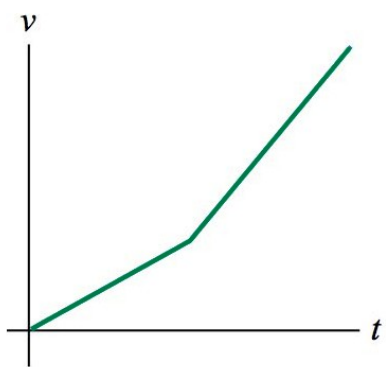
A. B. C. D.

Answer

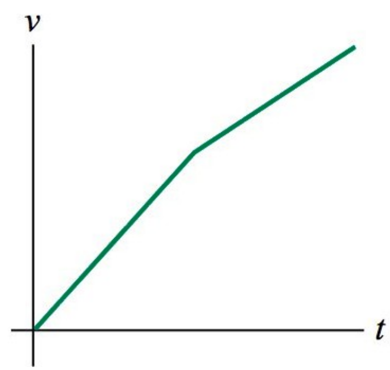
Here is a motion diagram of a car moving along a straight stretch of road:



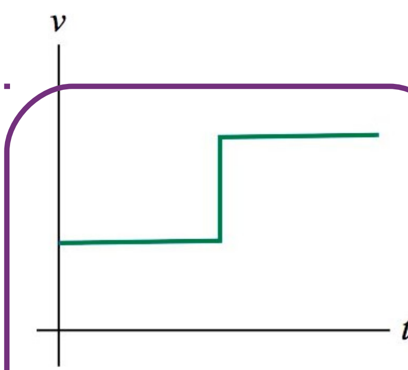
Which of the following velocity-versus-time graphs matches this motion diagram?



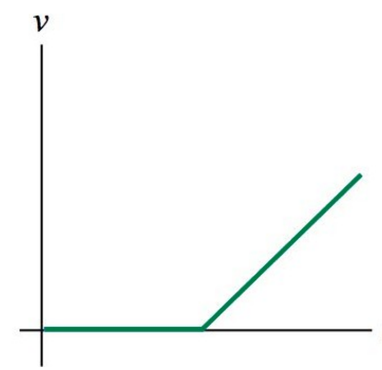
A.



B.



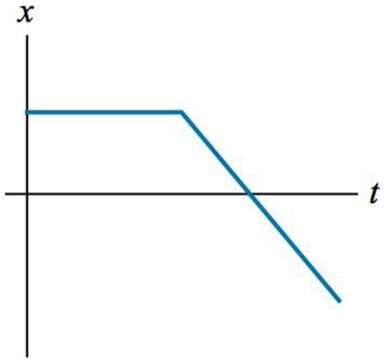
C.



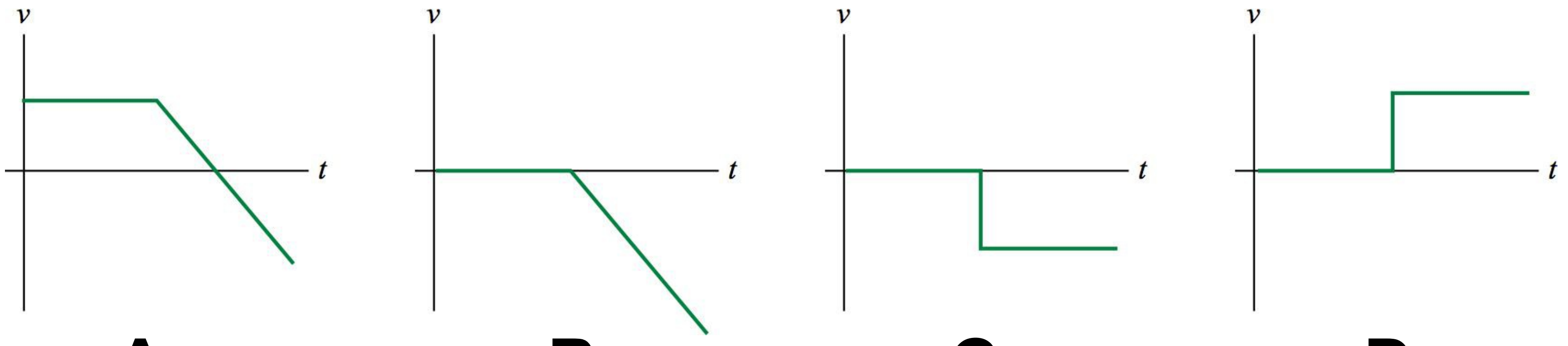
D.

Checking Understanding

A graph of position versus time for a basketball player moving down the court appears like so:



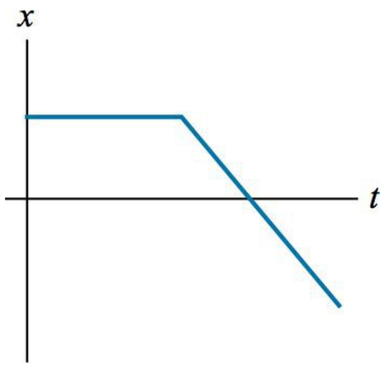
Which of the following velocity graphs matches the above position graph?



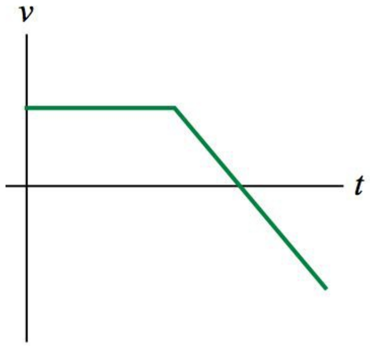
A. **B.** **C.** **D.**

Answer

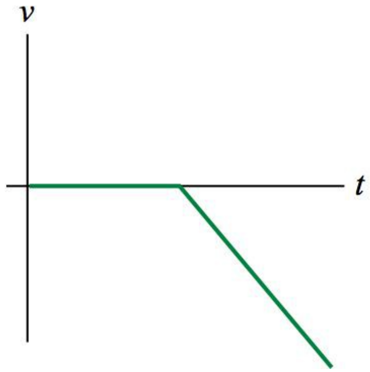
A graph of position versus time for a basketball player moving down the court appears like so:



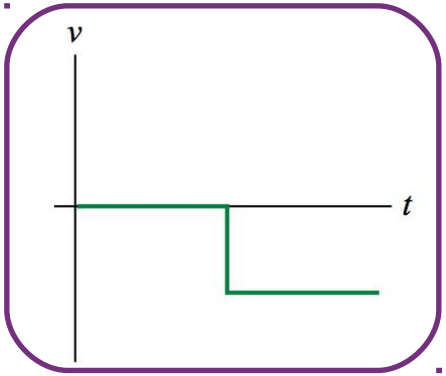
Which of the following velocity graphs matches the above position graph?



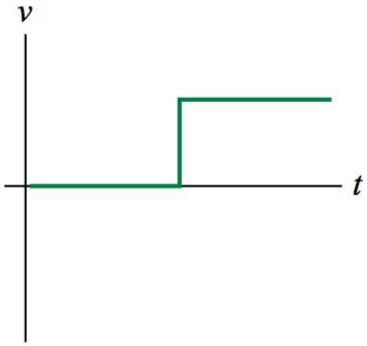
A.



B.



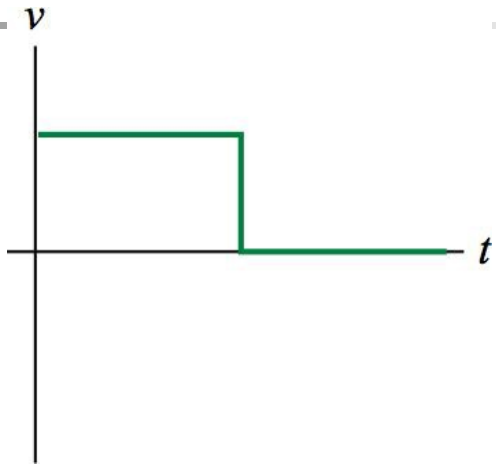
C.



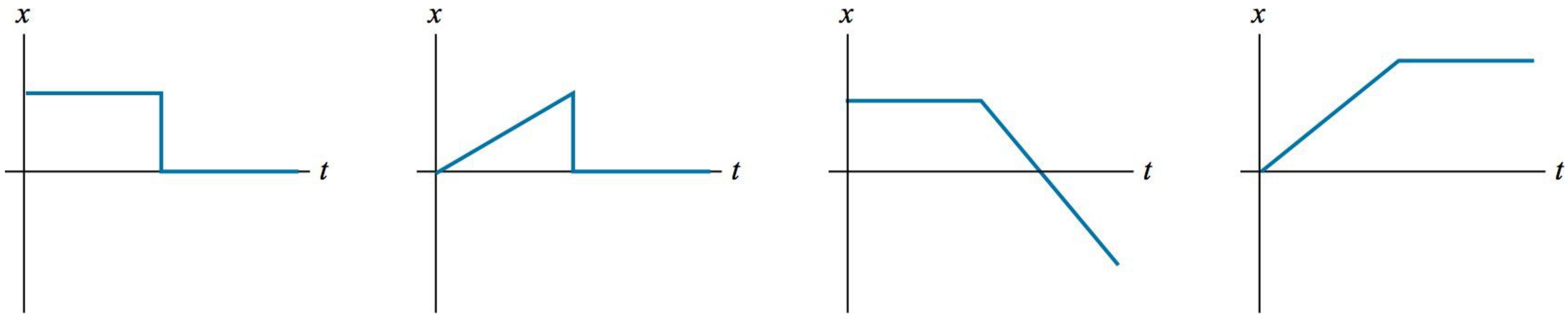
D.

Checking Understanding

A graph of velocity versus time for a hockey puck shot into a goal appears like so:



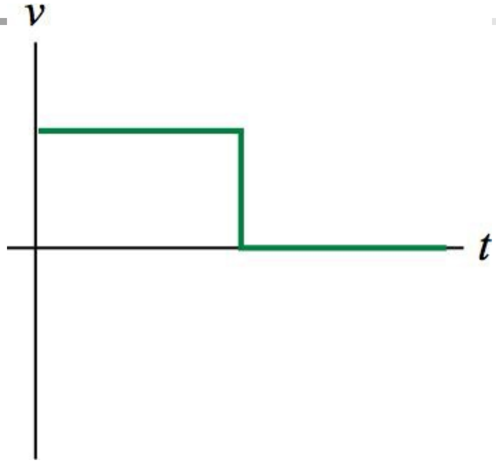
Which of the following position graphs matches the above velocity graph?



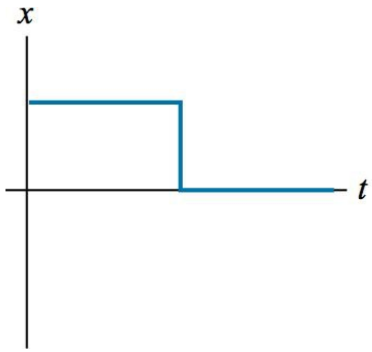
A. **B.** **C.** **D.**

Answer

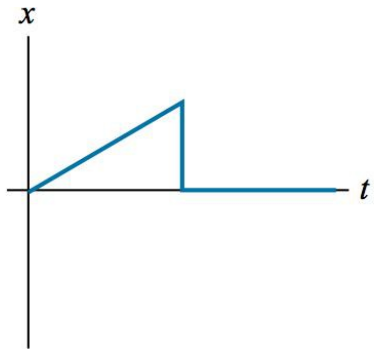
A graph of velocity versus time for a hockey puck shot into a goal appears like so:



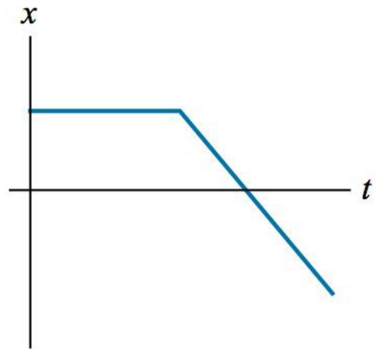
Which of the following position graphs matches the above velocity graph?



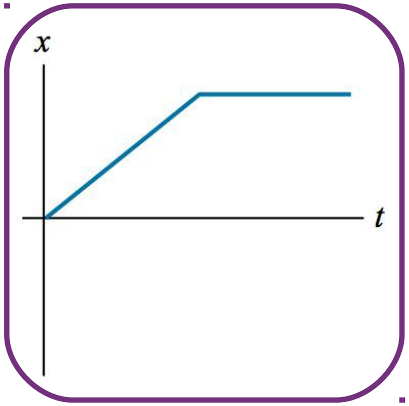
A.



B.



C.



D.

Notes on the equations

$$\Delta x = v_o t + \frac{1}{2} a t^2$$

- Gives displacement as a function of time, velocity and acceleration
- Use when you don't know and aren't asked to find the final velocity

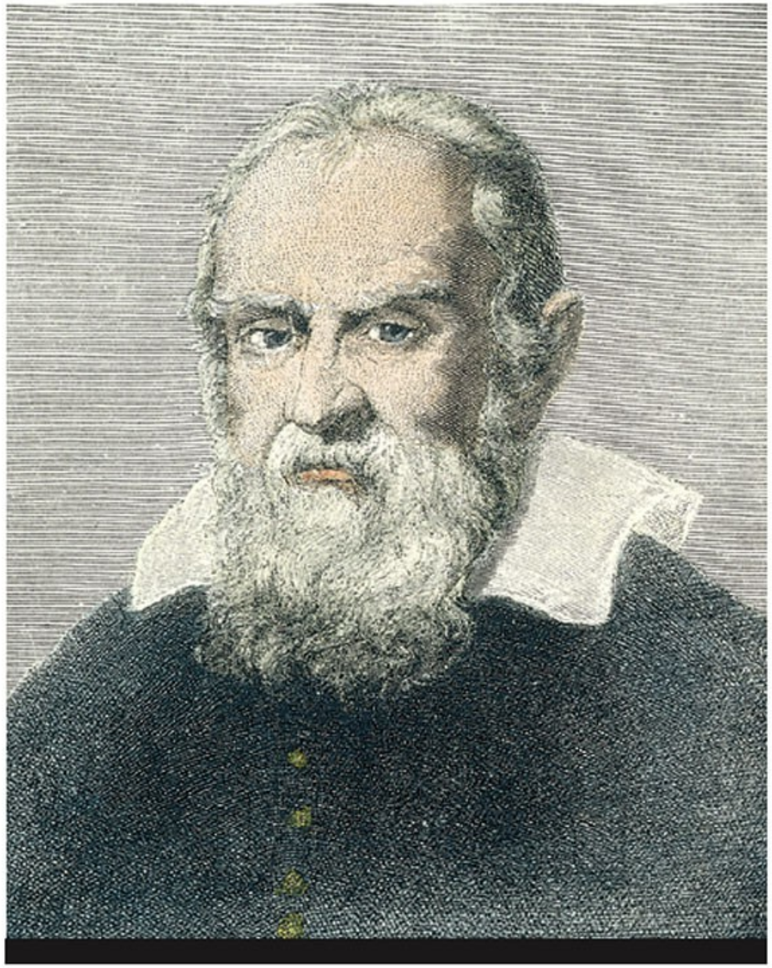
Notes on the equations

$$v^2 = v_o^2 + 2a\Delta x$$

- Gives velocity as a function of acceleration and displacement
- Use when you don't know and aren't asked for the time

Galileo Galilei

- 1564 - 1642
- Galileo formulated the laws that govern the motion of objects in free fall
- Also looked at:
  - Inclined planes
  - Relative motion
  - Thermometers
  - Pendulum



© 2006 Brooks/Cole - Thomson

2.6 Freely Falling Objects

- All objects moving under the influence of gravity only, are said to be in free fall
  - Free fall does not depend on the object’s original motion
- All objects falling near the earth’s surface fall with a constant acceleration
- The acceleration is called the acceleration due to gravity, and indicated by g

Acceleration due to Gravity

- Symbolized by *g*
- $g = 9.80 \text{ m/s}^2$
  - When estimating, use $g \approx 10 \text{ m/s}^2$
- *g* is always directed downward
  - toward the center of the earth
- Ignoring air resistance and assuming *g* doesn't vary with altitude over short vertical distances, free fall is constantly accelerated motion

The Acceleration due to Gravity (Acceleration of Free Fall)

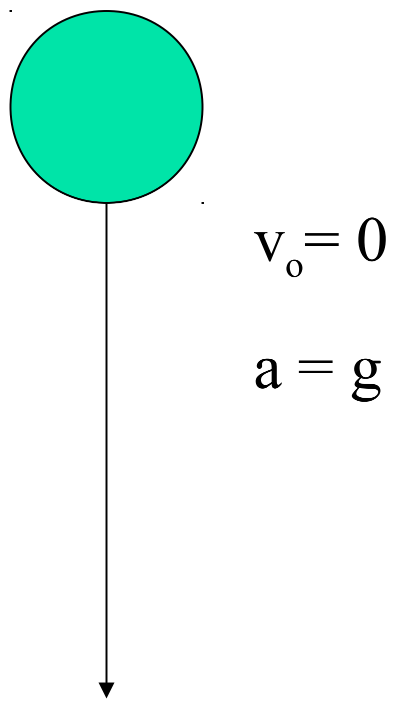
- Experiments show that, when *air resistance can be ignored*, all bodies **fall with the same acceleration.**
- This acceleration is given the symbol g.
- g = (about) **9.8** m/s^2
- The acceleration due to gravity is not *exactly* the same at all points on the earth's surface.

The Acceleration due to Gravity (Acceleration of Free Fall)

- Small variations in g are due to:
- i) altitude
- ii) latitude (**the earth is *not* a sphere**)
- iii) **the rotation of the earth.** The value of g is **less than** it would be if the earth did not rotate. The value of g is **reduced most** at places where the speed of circular motion is greatest; that is, on the **equator.**

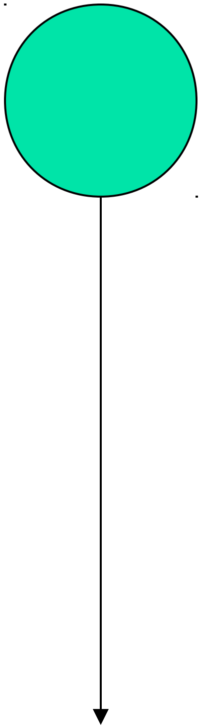
Free Fall – an object dropped

- Initial velocity is zero
- Let up be positive
- Use the kinematic equations
  - Generally use y instead of x since vertical
- Acceleration is *g* = -9.80 m/s²



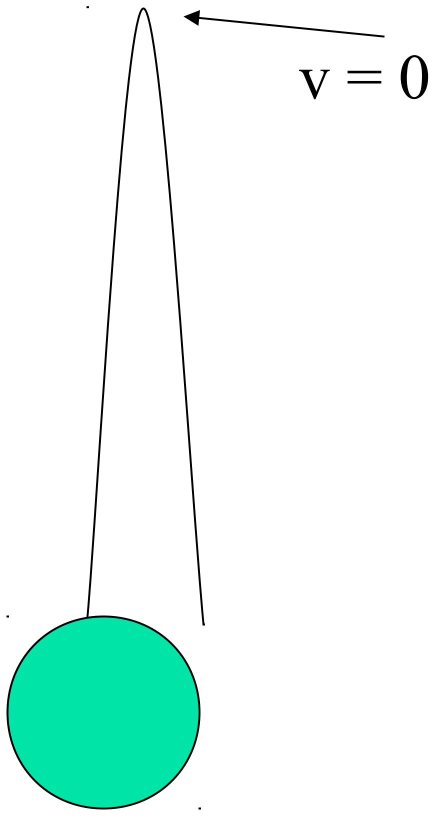
Free Fall – an object thrown downward

- $a = g = -9.80\ m/s^2$
- Initial velocity $\neq 0$
  - With upward being positive, initial velocity will be negative



Free Fall -- object thrown upward

- Initial velocity is upward, so positive
- The instantaneous velocity at the maximum height is zero
- a = *g* = -9.80 m/s^2 everywhere in the motion

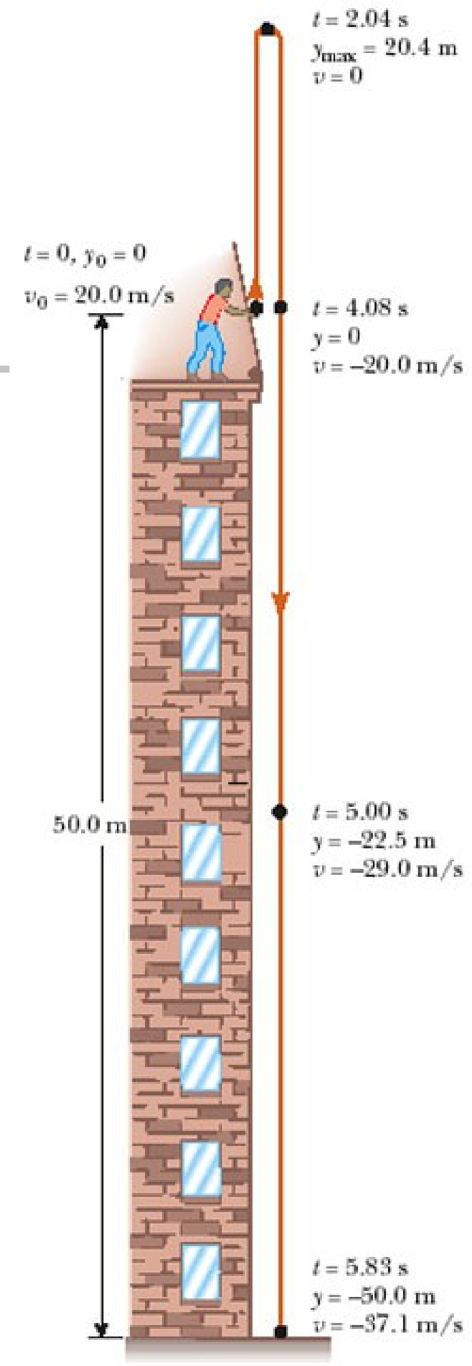


Thrown upward, cont.

- The motion may be symmetrical
  - Then $t_{up} = t_{down}$
  - Then $v = -v_o$
- The motion may not be symmetrical
  - Break the motion into various parts
    - Generally up and down

Non-symmetrical Free Fall

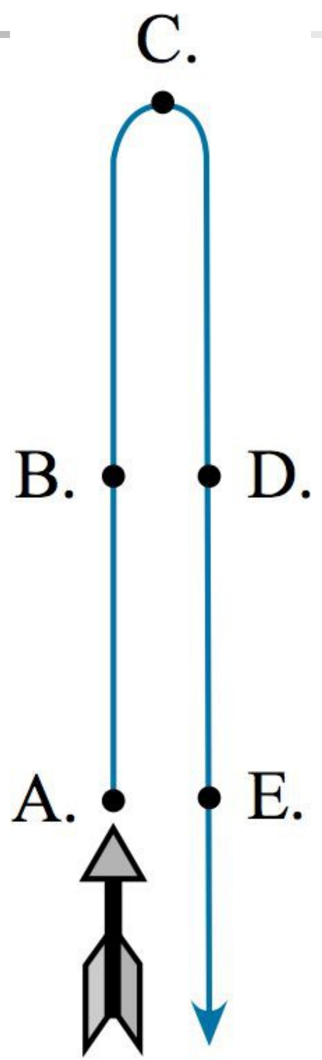
- Need to divide the motion into segments
- Possibilities include
  - Upward and downward portions
  - The symmetrical portion back to the release point and then the non-symmetrical portion



© 2006 Brooks/Cole - Thomson

Checking Understanding

An arrow is launched vertically upward. It moves straight up to a maximum height, then falls to the ground. The trajectory of the arrow is noted. Which choice below best represents the arrow's acceleration at the different points?



A. A = E > B = D; C = 0

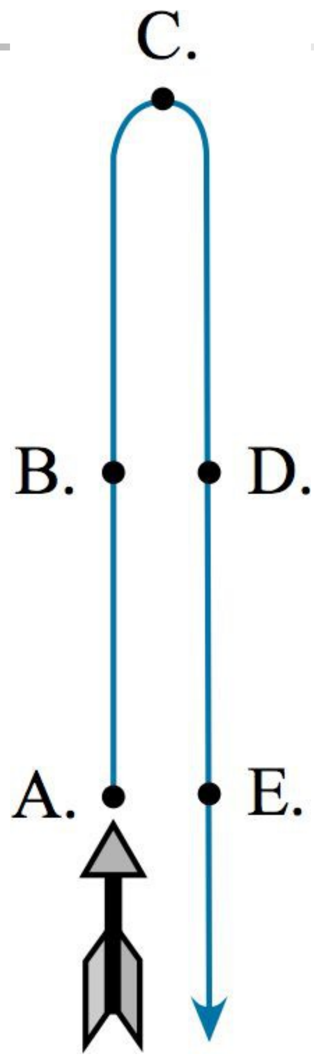
B. E > D > C > B > A

C. A = B = C = D = E

D. A > B > D > E; C = 0

Answer

An arrow is launched vertically upward. It moves straight up to a maximum height, then falls to the ground. The trajectory of the arrow is noted. Which choice below best represents the arrow's acceleration at the different points?



A. A = E > B = D; C = 0

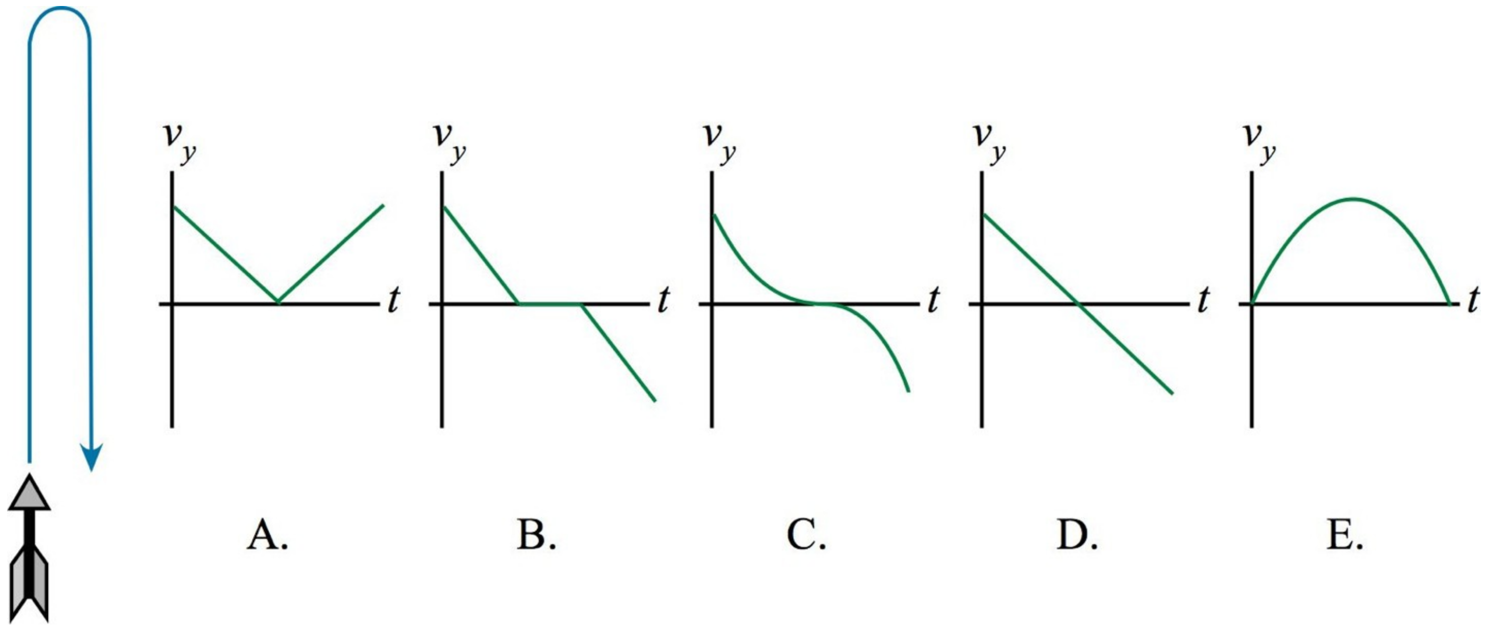
B. E > D > C > B > A

C. A = B = C = D = E

D. A > B > D > E; C = 0

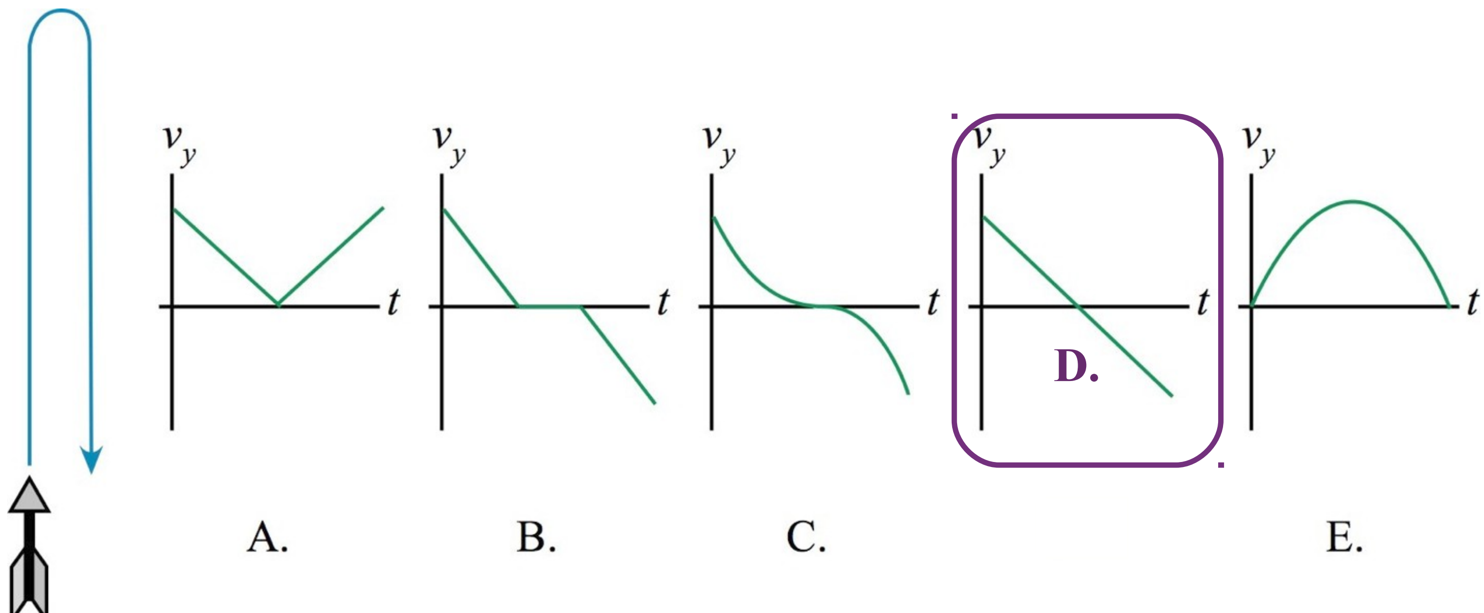
Checking Understanding

An arrow is launched vertically upward. It moves straight up to a maximum height, then falls to the ground. The trajectory of the arrow is noted. Which graph best represents the vertical velocity of the arrow as a function of time? Ignore air resistance; the only force acting is gravity.



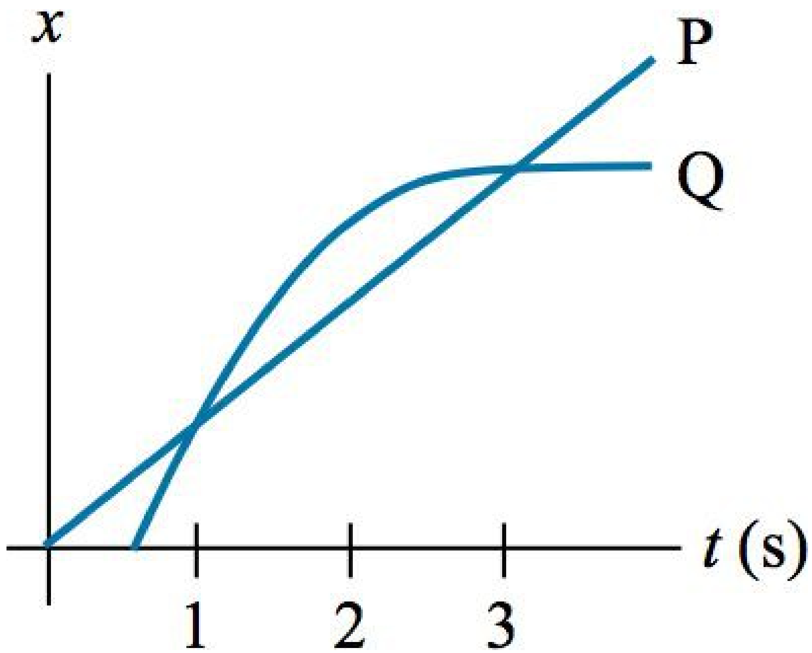
Answer

An arrow is launched vertically upward. It moves straight up to a maximum height, then falls to the ground. The trajectory of the arrow is noted. Which graph best represents the vertical velocity of the arrow as a function of time? Ignore air resistance; the only force acting is gravity.



Additional Question

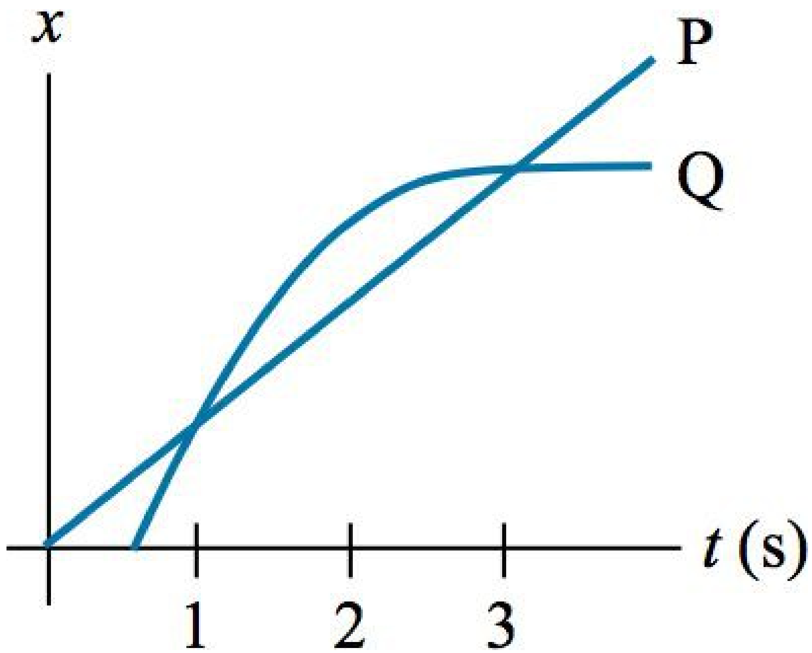
Masses P and Q move with the position graphs shown. Do P and Q ever have the same velocity? If so, at what time or times?



A. P and Q have the same velocity at 2 s.
B. P and Q have the same velocity at 1 s and 3 s.
C. P and Q have the same velocity at 1 s, 2 s, and 3 s.
D. P and Q never have the same velocity.

Answer

Masses P and Q move with the position graphs shown. Do P and Q ever have the same velocity? If so, at what time or times?



A. P and Q have the same velocity at 2 s.

B. P and Q have the same velocity at 1 s and 3 s.

C. P and Q have the same velocity at 1 s, 2 s, and 3 s.

D. P and Q never have the same velocity.