Chapter 2

Describing Motion

Chapter 2 Overview

In chapter 2, we will try to accomplish two primary goals.

1. Understand and describe the motion of objects.
   - Define concepts like speed, velocity, acceleration, and the difference between them.
   - Solve problems involving uniform acceleration.
2. Develop some tools and skills we will use during the rest of the semester.
   - Solving problems with equations.
   - Relating equations to conceptual ideas
   - Using vectors
   - Interpreting graphs
   - Solving problems involving ratios or scaling.

Because we will be learning these new skills, we'll spend more time in chapter 2 than in most subsequent chapters.

Terminology

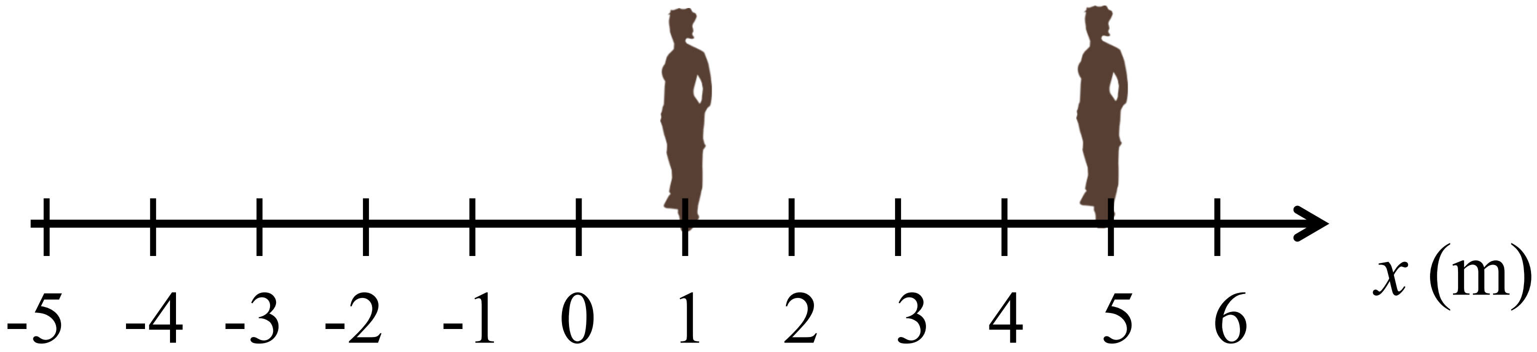
- In order to describe motion, we must provide clear definitions of our terms.
- The meanings of some terms as used in physics are related to, but not identical to, the meanings in everyday use.
- Precise and specialized meanings make the terms more useful in describing motion.
- We will define:
  - Distance and Displacement
  - Average and instantaneous speed
  - Average and instantaneous velocity
  - Average and instantaneous acceleration

Distance and Displacement

- Distance: how far you have traveled
  - Used to define speed
- Displacement: how far you are from where you started.
  - Used to define velocity
  - One of the differences between speed and velocity
  - Technically: how far from the origin.

If you run around a track and end up back where you started, the distance you have traveled is 400 m, but your displacement is zero meters.

Displacement along the x axis is written as: $x_{\text{final}} - x_{\text{initial}} = \Delta x$



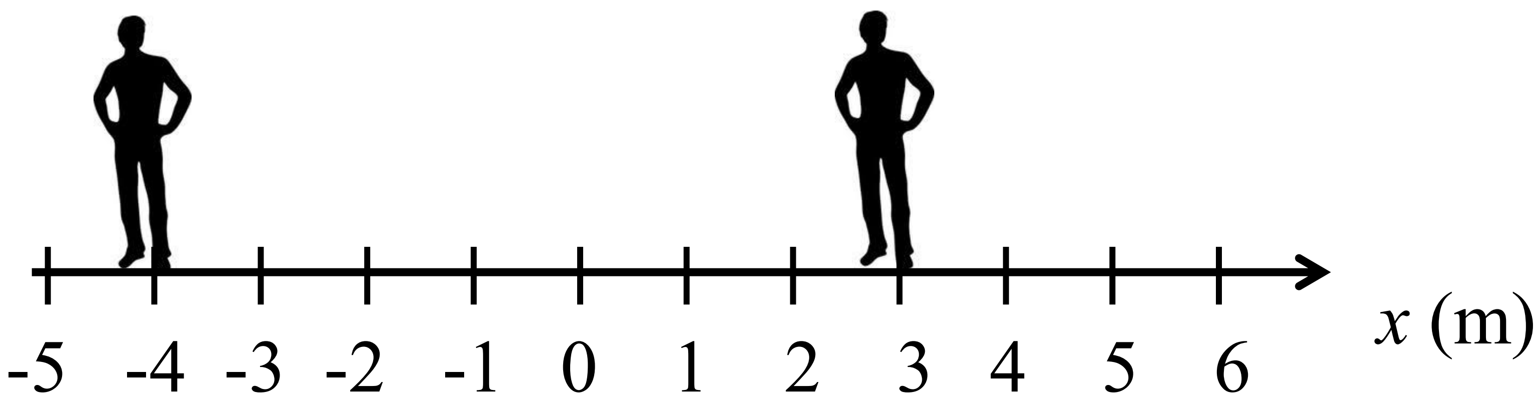
Start here

$x_{\text{initial}} = 1$

End here

$x_{\text{final}} = 5$

$\Delta x = 4$ m



End here

$x_{\text{final}} = -4$

Start here

$x_{\text{initial}} = 3$

$\Delta x = -7$ m

Interactive Question

You walk from one place to another place. When you arrive at your destination, the *distance* you have traveled will always be:

A) greater than
B) equal to
C) smaller than
D) either greater than or equal to
E) either smaller than or equal to

your *displacement* from your initial position.

Average speed

The average speed (*s*) is the distance traveled (*d*) divided by the time it takes to travel that distance (*t*) .

$$\text{Average Speed} = s = \frac{d}{t}$$

- The distance is how far you have actually traveled, not how far you are from where you started.
- The units are distance/time:
  - e.g. mile/hr, km/hr, m/s

Throughout this class will use these kind of mathematical equations to answer questions and solve problems.

Problem: If you run for 43 minutes at an average speed of 2.22 m/s. How far will you run?

Given: Want:

What principle and equation relates average speed to distance?

Problem: You drive from Norman to Enid, a distance of 117 miles, in exactly 2 hours. Then you drive from Enid to Stillwater, a distance of 65 miles in 63 minutes.

a) What was your average speed from Norman to Enid?

b) What was your average speed from Enid to Stillwater?

c) What was your average speed for the whole trip?

Why can’t I simply average speeds?

Imagine that I want to travel a total of 2 km and I want to average a speed of 2km/hour

For the first km I travel at a speed of 1 km/hour

How fast must I travel the second km to average 2 km/hour?

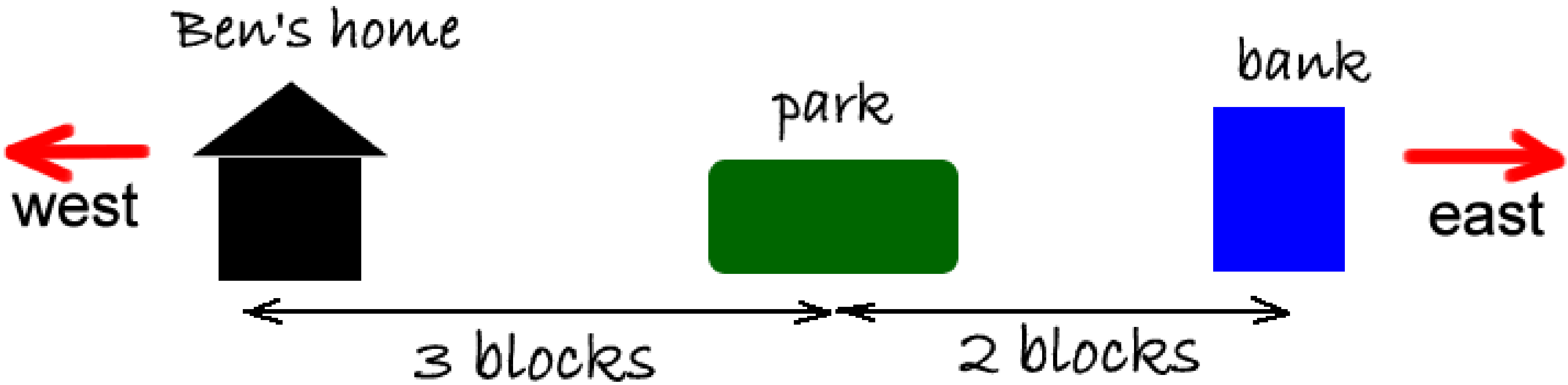
Wrong way: $2\ \text{km/hr} = \dfrac{1\frac{km}{hr}+x}{2}$ x=3 km/hour

Note: If I want to travel 2 km with an average speed of 2 km/hr, I have 1 hour to make the trip

During first km, I had a speed of 1 km/hr so I used up my entire hour. Therefore I cannot average 2 km/hour for the entire trip

Interactive Question

Ben leaves his home and walks to the bank, then back home in a total of 30 minutes. What is his average speed?



A) 0 blocks/min

B) 1/3 block/min

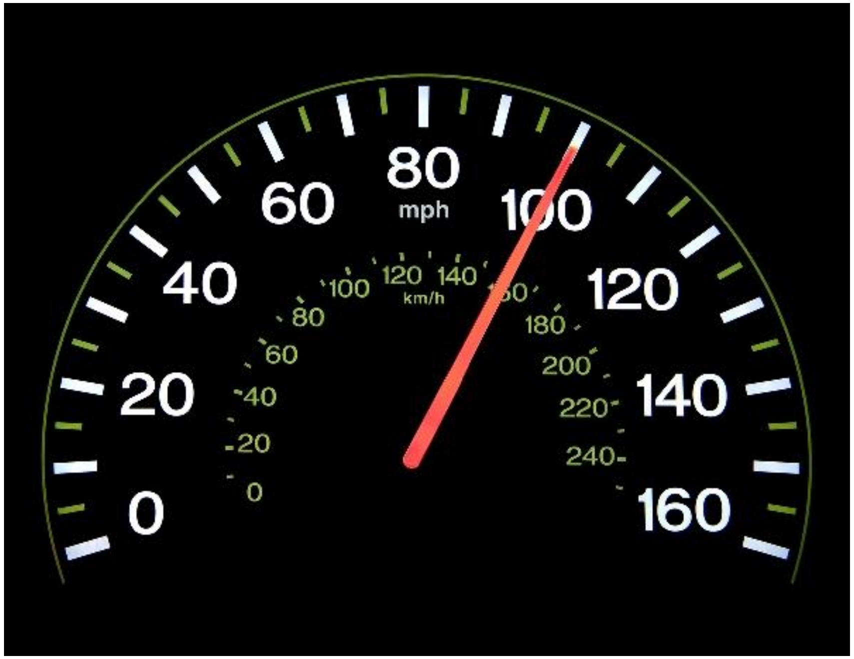
C) 1/6 block/min

D) 2/15 block/min

E) 10 blocks/min

Instantaneous speed

The instantaneous speed is your speed at a certain moment in time.



Your speedometer shows your instantaneous speed. It tells you how fast you are going at one instance, but not necessarily how far you will travel in a period of time (which is your average speed.)

Interactive Question

Can the average speed ever be the same as the instantaneous?

A) No.

B) Yes, it is always the same.

C) Yes, if the speed never changes.

Vectors

- We will encounter two kinds of physical quantities, vectors and scalars.
- Scalars are just numbers with units.
  - Instantaneous speed is a scalar (e.g. 50 mi/hr)
- Vectors have a magnitude (a number with units) and a direction in space (e.g. north, east, up, 15º south of west).
  - A vector is represented as a bold face letter or a letter with an arrow over it, or both:

    $\mathbf{v} \qquad \vec{v} \qquad \vec{\mathbf{v}}$

  - Two vectors are identical only if *both* the magnitude *and* the direction are the same.
  - To specify a vector, you must give both a magnitude (like 50 mi/hr) and a direction.

Interactive Question

Which of the following is a vector quantity?

A) The age of the earth.
B) The mass of a football.
C) The earth's pull on your body.
D) The temperature of an iron bar.
E) The number of people attending an OU football game.

- Vectors are drawn as an arrow with the length of the arrow proportional to the magnitude and the direction of the arrow pointing in the direction of the vector.

This is the vector **A**

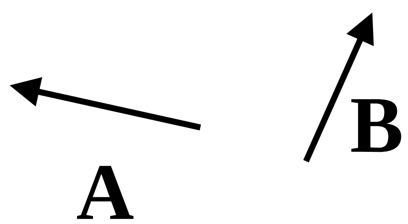
- Vectors do not have a specific location

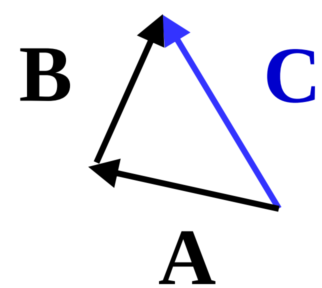
Vectors **B** and **C** are identical

Vectors **D** and **E** are not identical to **B** or **C**

Addition of Vectors

Vectors are not added or subtracted like scalars. To add two vectors, put the tail of one vector on the tip of the other and draw the resultant.



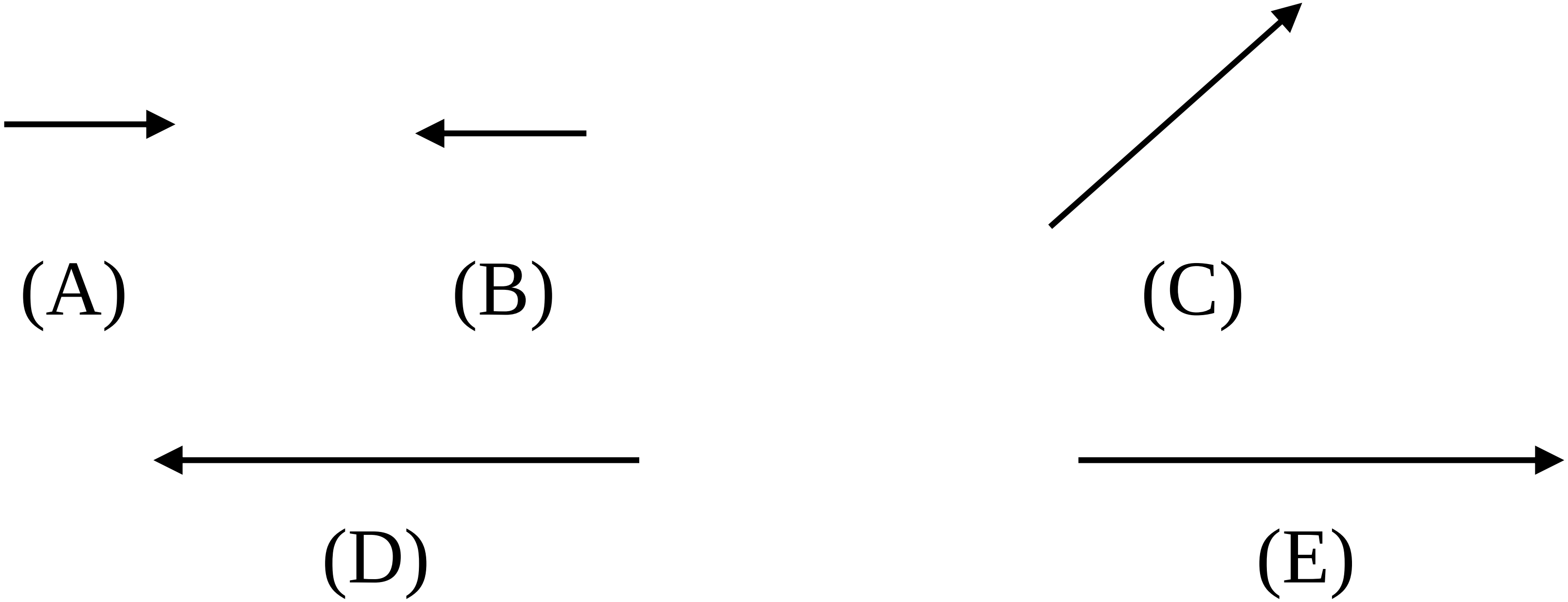


$\mathbf{C} = \mathbf{A} + \mathbf{B}$

It's easy to show that **A** + **B** = **B** + **A**. Try drawing them!

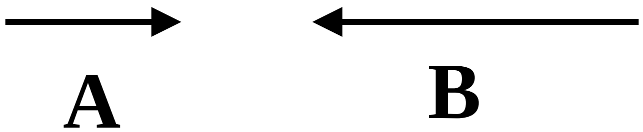
Interactive Question

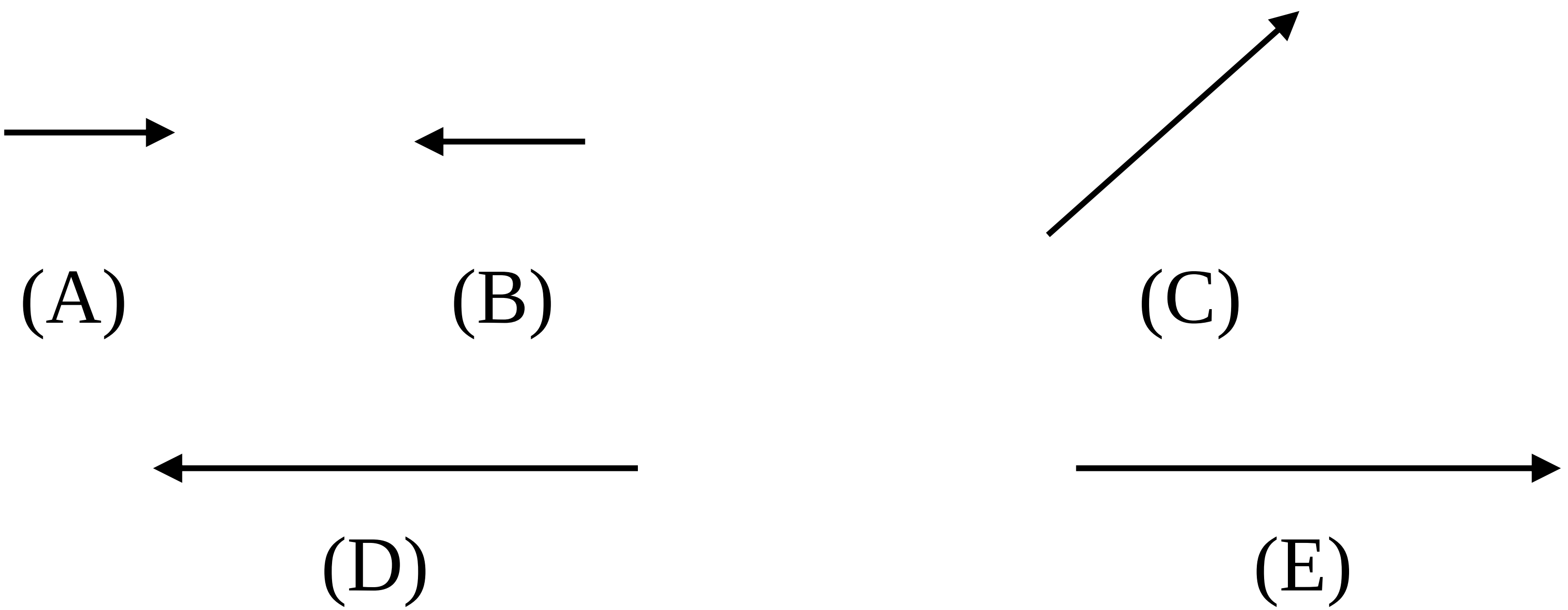
Vectors **A** and **B** are shown. Which vector best represents **A** + **B**?



Interactive Question

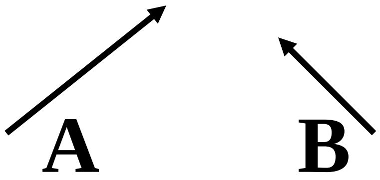
Vectors **A** and **B** are shown. Which vector best represents **A** + **B**?



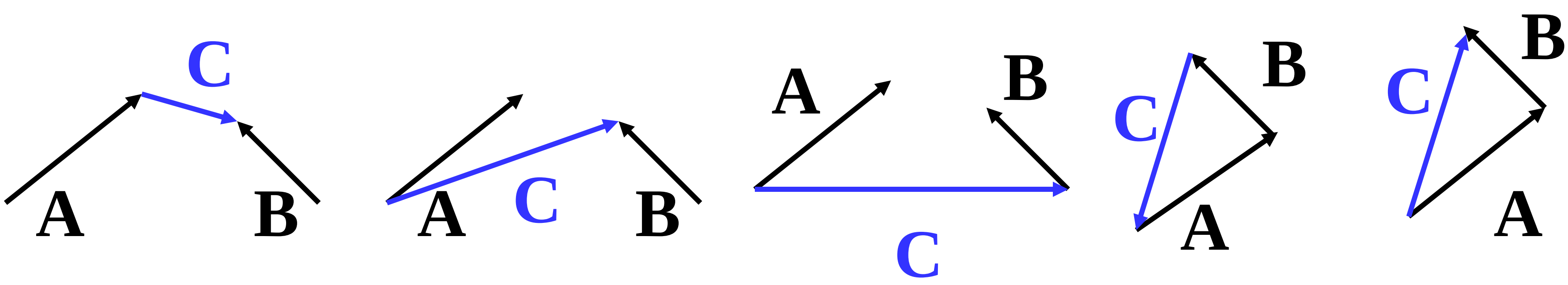


Interactive Question

Vectors **A** and **B** are shown below.



Which diagram below correctly shows the vector **C**, where **C** = **A** + **B**



(A) (B) (C) (D) (E)

Average and Instantaneous Velocity

Velocity differs from speed in two important ways:

1. Velocity is displacement/time
   (Recall speed is defined as distance/time)
2. Velocity is a vector
   To specify velocity, you must give both a magnitude and a direction.

- Average velocity is the total displacement that occurred during some time interval.
- Instantaneous velocity is the velocity at a specific instant of time.
- When discussing velocity and speed, I will always mean instantaneous unless I specifically say average. "velocity" = "instantaneous velocity"

Interactive Question

You jog around a 400 m track in 100 seconds, returning to the place where you started. Which of the following statements is true?

A) Your average speed and average velocity are the same, and neither is zero.
B) Your average speed and average velocity are the same, and both are zero.
C) Your average velocity is zero, and your average speed is 4 m/s.
D) Your average speed is zero, and your average velocity is 4 m/s.

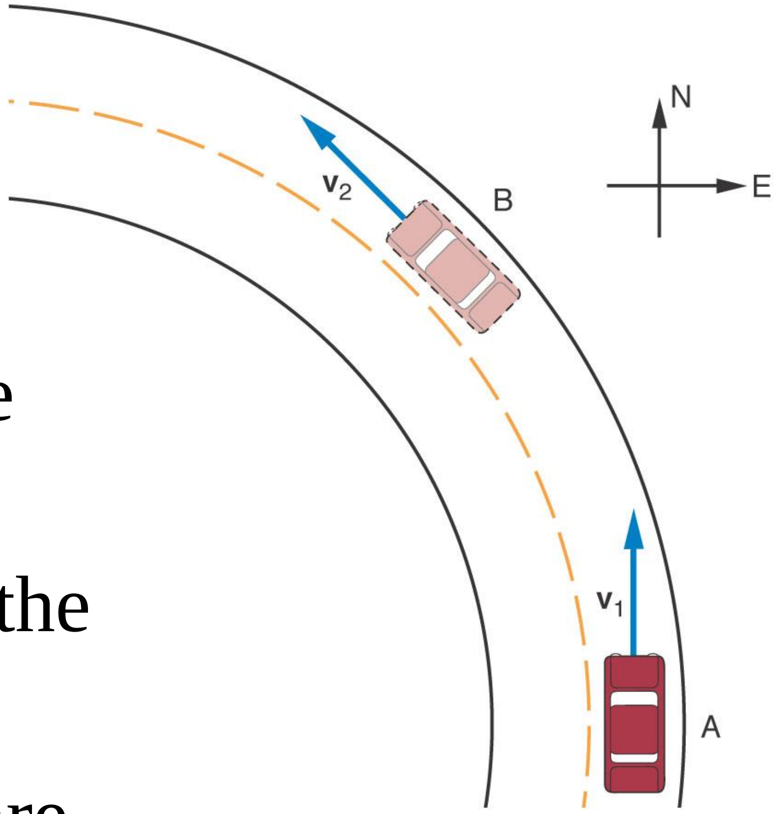
Interactive Question

There are many instruments and gauges in your car. If you want to know your instantaneous velocity which would you have to look at?

A) Your speedometer only
B) Your odometer only
C) Your compass only
D) Your speedometer and your odometer
E) Your speedometer and your compass

Interactive Question

A car goes around a corner at a constant speed of 30 mi/hr. Which of the following is true?



A) The speed is changing but the velocity is not.

B) The velocity is changing but the speed is not.

C) Both the speed and velocity are changing.

D) Neither the speed nor the velocity are changing.

Interactive Question

Which of the following is true?

A) The instantaneous speed will always equal the magnitude of the instantaneous velocity.

B) The average speed will always equal the magnitude of the average velocity.

C) The instantaneous speed can never equal the magnitude of the instantaneous velocity.

D) The average speed can never equal the magnitude of the average velocity.

Average and Instantaneous Acceleration

Acceleration is defined as the rate at which the velocity is changing:

Acceleration = (change in velocity)/(elapsed time)

- Acceleration is a vector.
  - Acceleration has both a magnitude and direction.
  - An object is accelerating if it *changes speed and/or direction*.

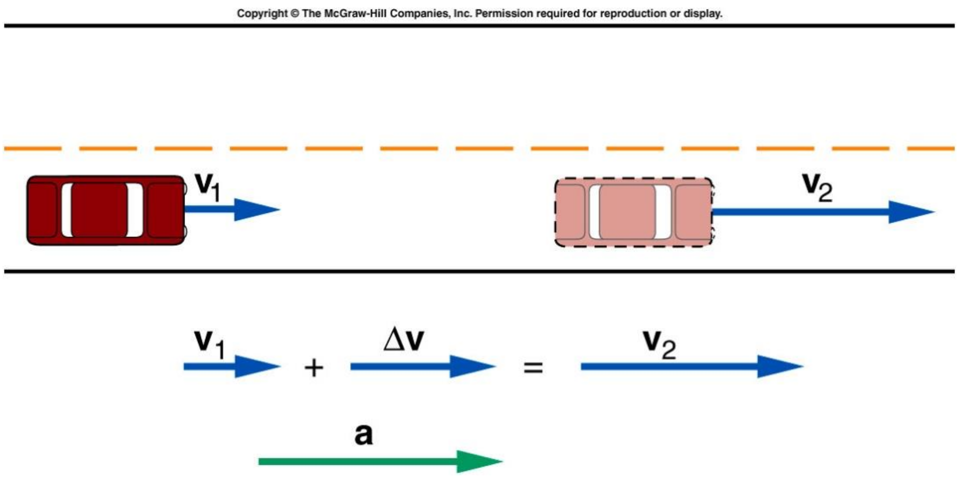
$$\mathbf{a} = \frac{\mathbf{v}_{\text{final}} - \mathbf{v}_{\text{initial}}}{t} = \frac{\Delta \mathbf{v}}{t}$$

- Average acceleration is the change in velocity that occurred during some time interval.
- Instantaneous acceleration is the change in velocity at a specific instant of time.

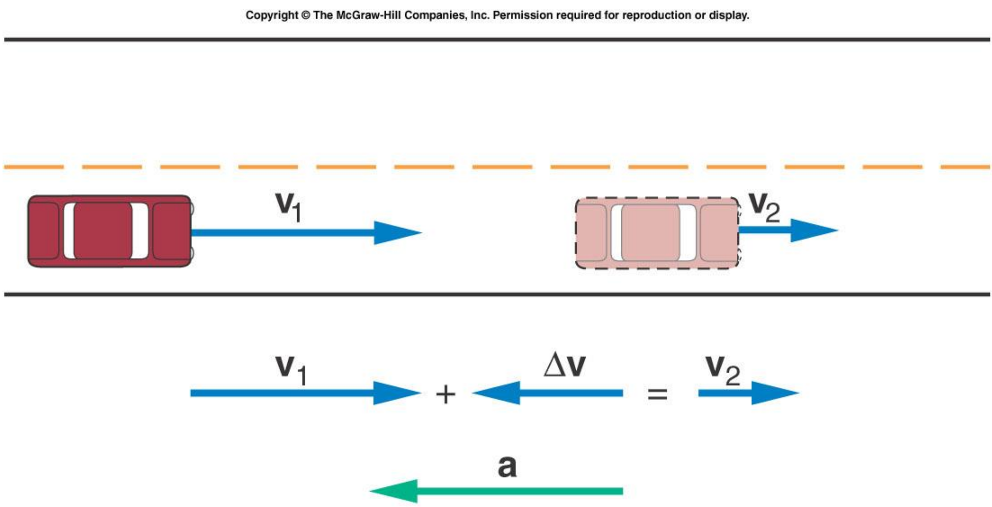
Direction of Acceleration

- The direction of the acceleration vector is that of the *change* in velocity, $\Delta\mathbf{v}$. Note $\mathbf{v}_{\text{final}} = \mathbf{v}_{\text{initial}} + \Delta\mathbf{v}$

- If velocity is *increasing*, the acceleration is in the *same* direction as the velocity.



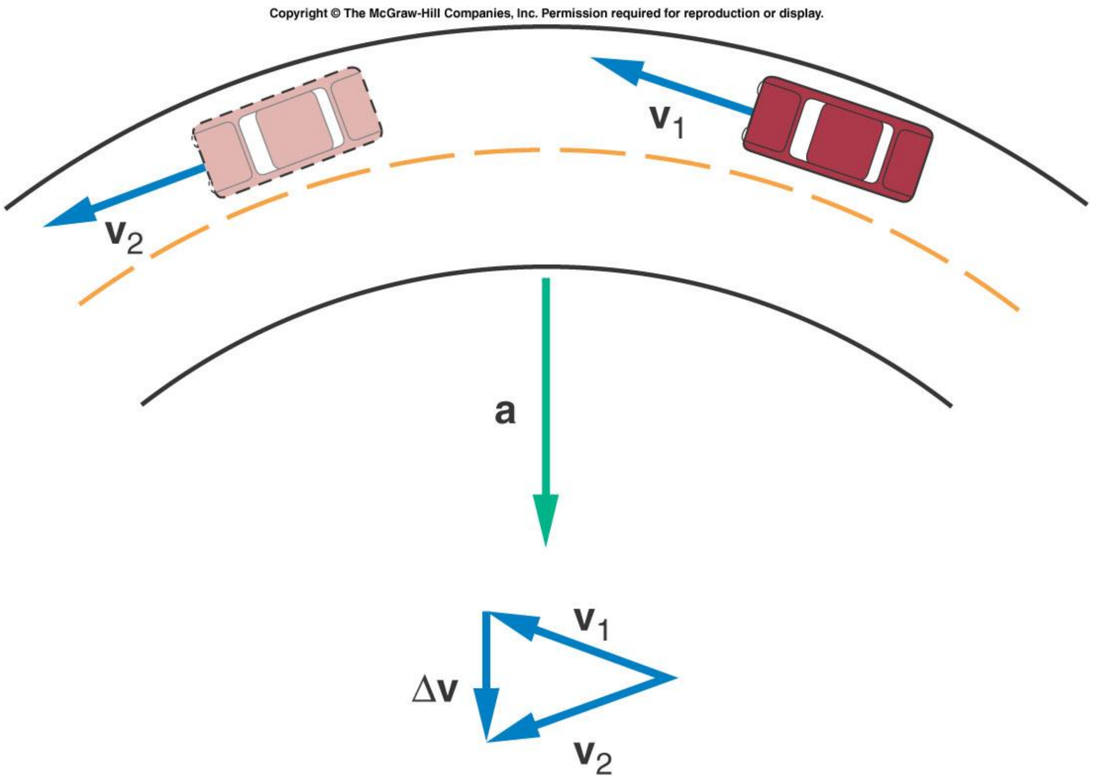
- If velocity is *decreasing*, the acceleration is in the *opposite* direction as the velocity.



Acceleration and Turning

- If speed is constant but the *direction* of the velocity is changing, then the acceleration is *at right angles* (perpendicular) to the velocity.

$$\mathbf{v}_1 + \Delta\mathbf{v} = \mathbf{v}_2$$



- You actually feel acceleration, not velocity.

Interactive Question

In which of the following cases is the acceleration zero?

A) a car increases its speed from 0 mph to 30 mph
B) a car decreases its speed from 15 mph to 5 mph
C) a car goes around a curve at a speed of 30 mph
D) a car backs out of a drive at 10 mph
E) None of the above

Think of examples of the following:

a) **v**>0 and **a**=0

b) **v**<0 and **a**=0

c) **v**>0 and **a**>0

d) **v**<0 and **a**>0

e) **v**=0 and **a** non 0

f) speed constant and **a** non 0

g) **v** constant and **a** non 0

Problem: A car starts from rest and accelerates to a velocity of 20 m/s due east in a time of 5 s. What was the magnitude and direction of the average acceleration of the car?

Given:

Want:

Problem: You are driving 35 mi/hr in the positive x direction when a dog runs across your path. You slam on your brakes and in 2.0 seconds slow to 10 mi/hr. What was your average acceleration in m/s^2?

Given:

Interactive Question

Which of the following is true?

A) An object with negative acceleration is always slowing down.

B) An object with positive acceleration is always speeding up.

C) An object moving in the negative direction with negative acceleration is speeding up.

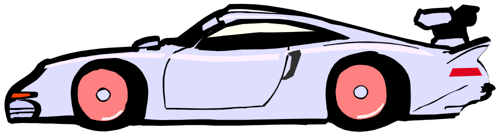
D) An object moving in the negative direction with positive acceleration is speeding up.

E) None of the above are true.

Problem: A sports car can accelerate at an average rate of 4.5 m/s^2. It starts at rest and accelerates in the negative x direction. After 8.0 seconds what is its velocity?

Given:

$+x$ $\longrightarrow$



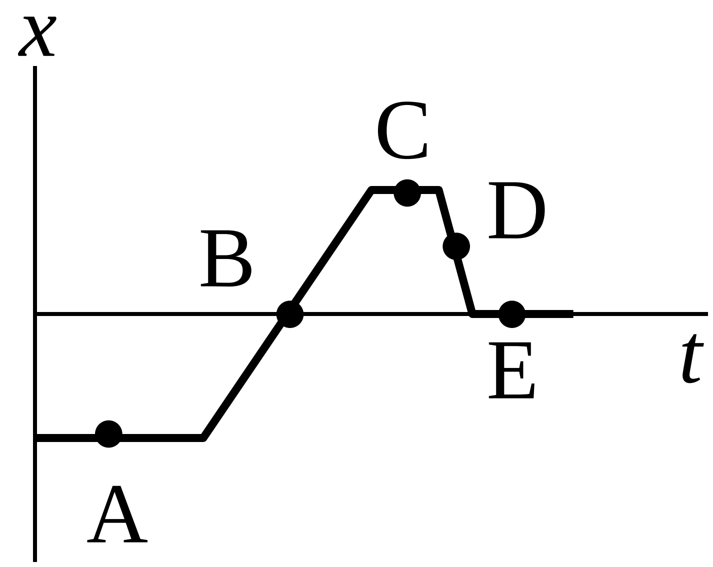
Want:

Analyzing Motion on a Graph

- Graphs are a good way to analyze motion.
- Look carefully at what the axes on the graph represent.
- Look carefully at what is constant, and what is changing linearly (at a constant rate).
- Determine what the slope represents.
  - Slope is defined as the change in the vertical axis divided by the change in the horizontal axis.
    - Example: If the vertical axis is displacement x and the horizontal axis is the time t, then the slope is $\Delta x/\Delta t = v$ (the slope is the velocity).
    - If the vertical axis is velocity v, and the horizontal axis is time, t, then the slope is given by $\Delta v/\Delta t = a$, (the slope is the acceleration).

Interactive Question

Consider the plot of x vs t at the right, at which point(s) is the motion slowest?



A) A

B) B

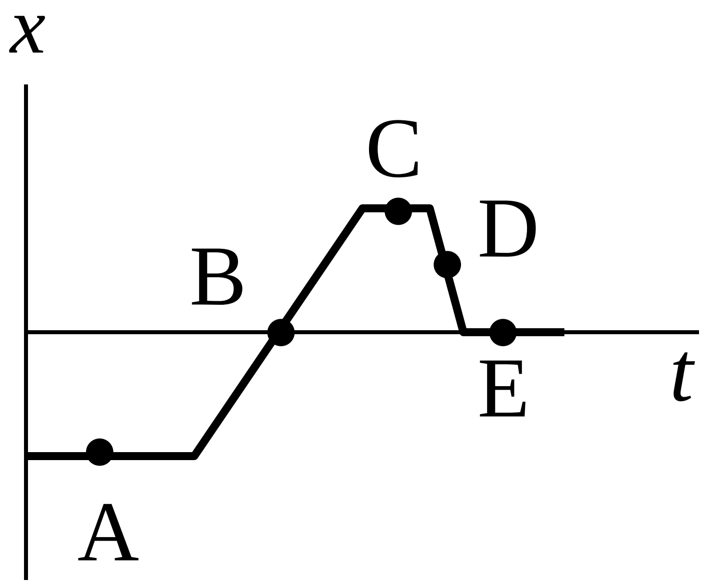
C) D

D) E

E) More than one of the above answers

Interactive Question

Consider the plot of x vs t at the right, at which point(s) is the object moving at a constant non-zero velocity?



A) A and C

B) A, C and D

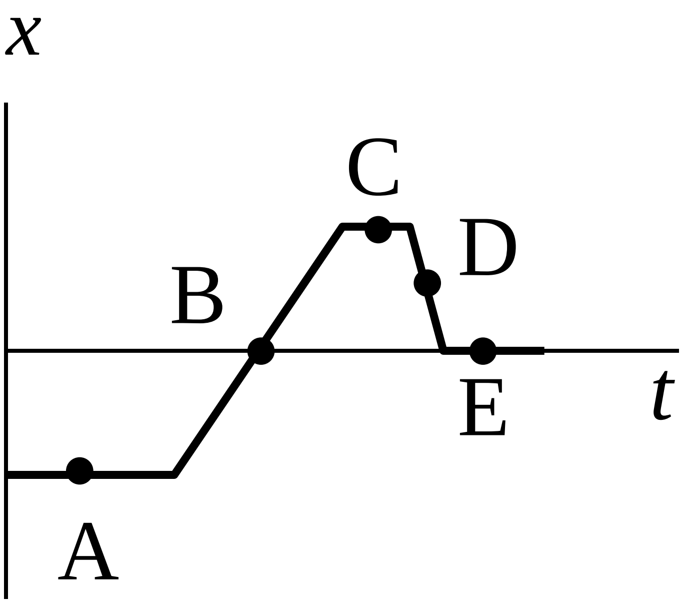
C) C only

D) D only

E) B and D

Interactive Question

Consider the plot of x vs t at the right, at which point(s) is the object moving in the negative x direction?



A) A

B) B

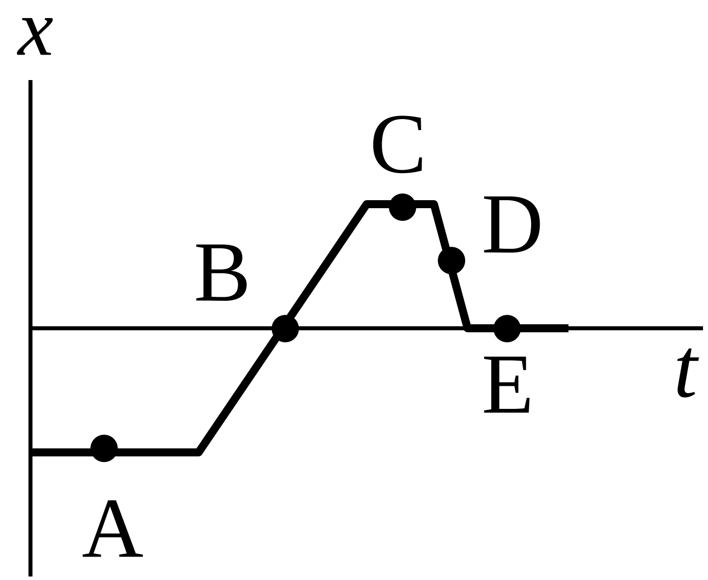
C) C

D) D

E) E

Interactive Question

Consider the plot of x vs t at the right, at which point(s) is the object turning around?



A) A

B) B

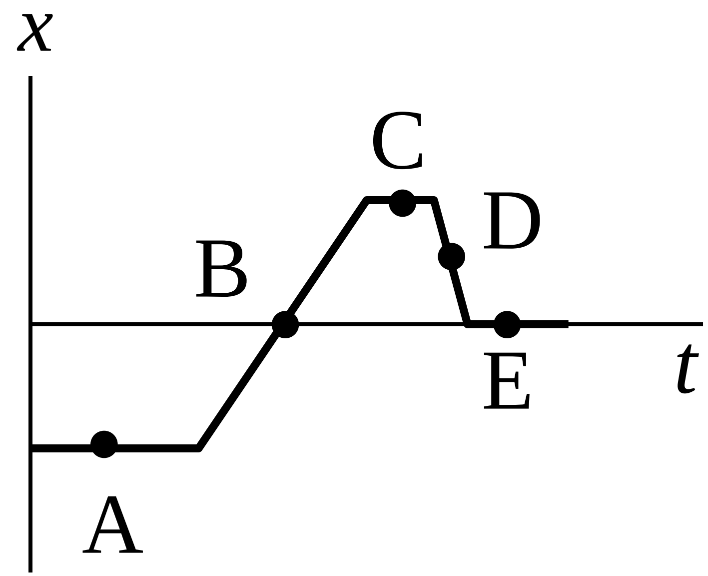
C) C

D) D

E) E

Interactive Question

Consider the plot of x vs t at the right, at which point(s) is the object moving the fastest?



A) A

B) B

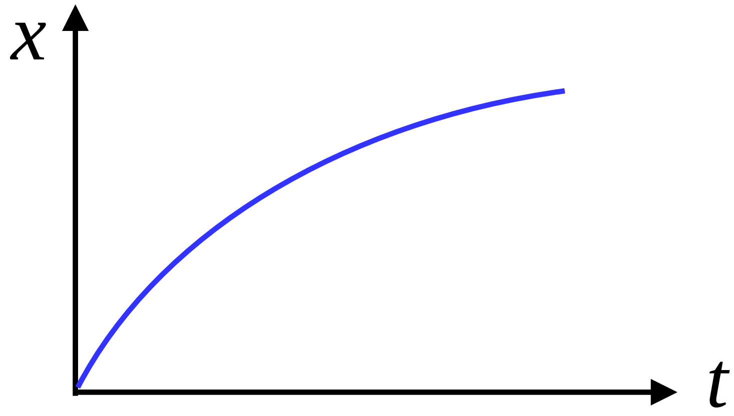
C) C

D) D

E) E

Interactive Question

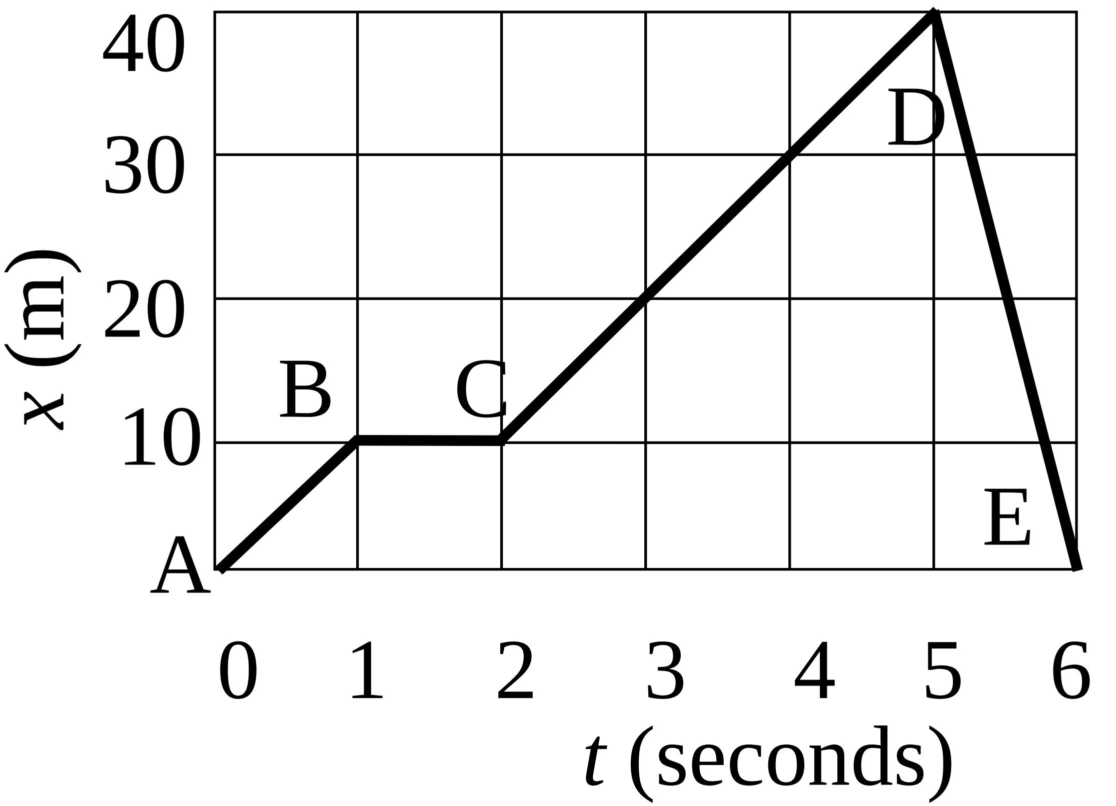
The graph for position vs. time is given for a car. What can you say about the velocity of the car over time?



A) it speeds up all the time
B) it slows down all the time
C) it moves at constant velocity
D) sometimes it speeds up and sometimes it slows
E) it turns around

Interactive Question

An object is moving along a straight line. The graph at the right shows its position from the starting point as a function of time.



What was the average velocity of the object during the first 4 seconds?

A) +6.0 m/s

B) +7.5 m/s

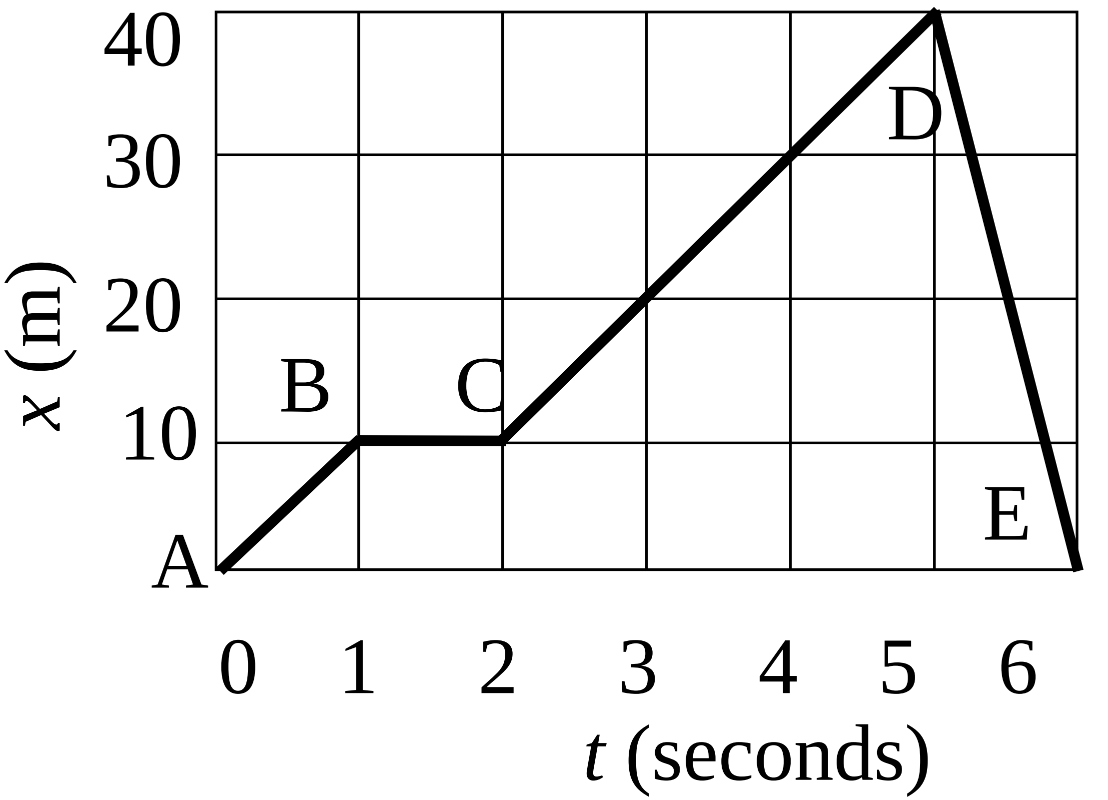
C) +8.0 m/s

D) +10.0 m/s

E) + 13.3 m/s

Interactive Question

An object is moving along a straight line. The graph at the right shows its position from the starting point as a function of time.



What was the instantaneous velocity of the object at $t = 4$ seconds?

A) +6.0 m/s

B) +8.0 m/s

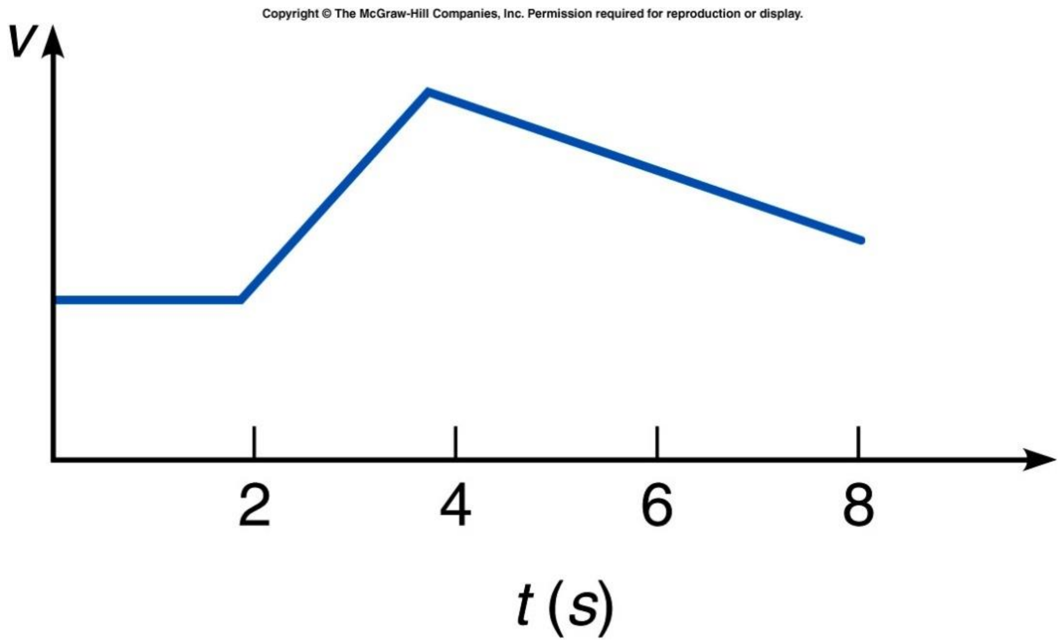
C) +10.0 m/s

D) + 13.3 m/s

E) +40 m/s

Interactive Question

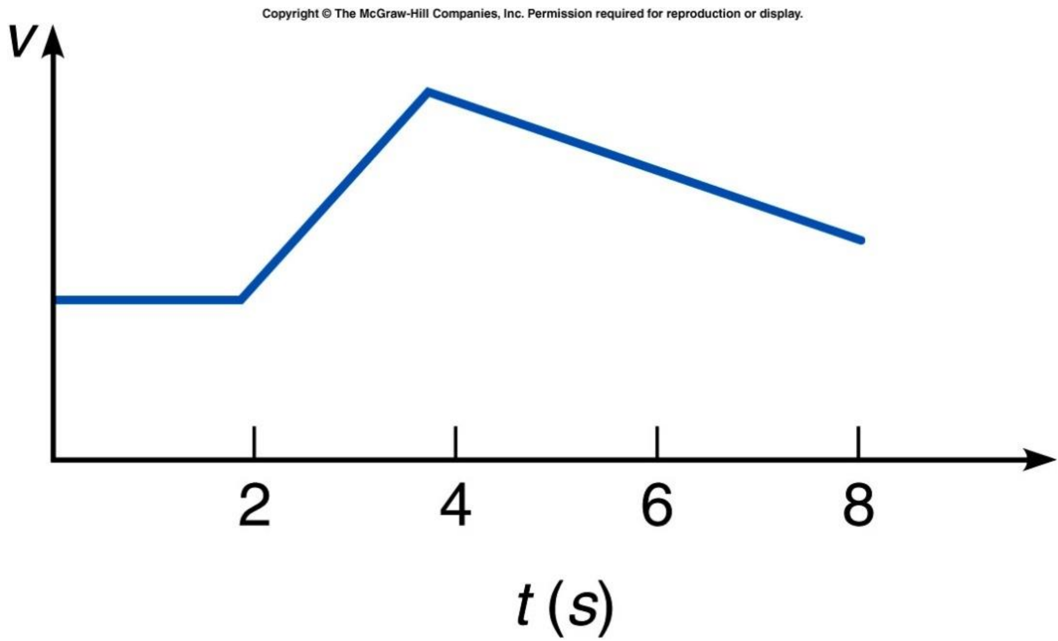
Consider this plot of velocity vs. time. Is the velocity constant during any time interval in this plot?



A) Yes, between 0 s and 2 s.
B) Yes, between 2 s and 4 s.
C) Yes, between 4 s and 8 s.
D) Yes, between 0 s and 8 s.
E) No, never.

Interactive Question

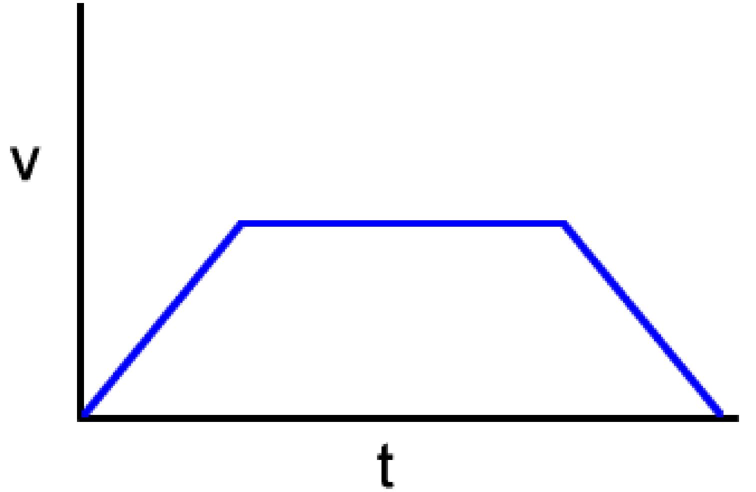
Consider this plot of velocity vs. time. During which time interval is the acceleration the greatest?



A) Between 0 s and 2 s.
B) Between 2 s and 4 s.
C) Between 4 s and 8 s.
D) The acceleration does not change.

Interactive Question

Which scenario is portrayed by the graph?



A) A car starts from rest and accelerates. It then travels at a constant velocity before slowing to a stop.

B) A car starts from rest and moves forward. It stops for a while before returning to its starting position.

C) A car travels at a constant velocity, then accelerates for a while, then returns to its initial constant velocity.

Interactive Question

The velocity of a car increases with time as shown. What is the average acceleration between 4 s and 8 s?

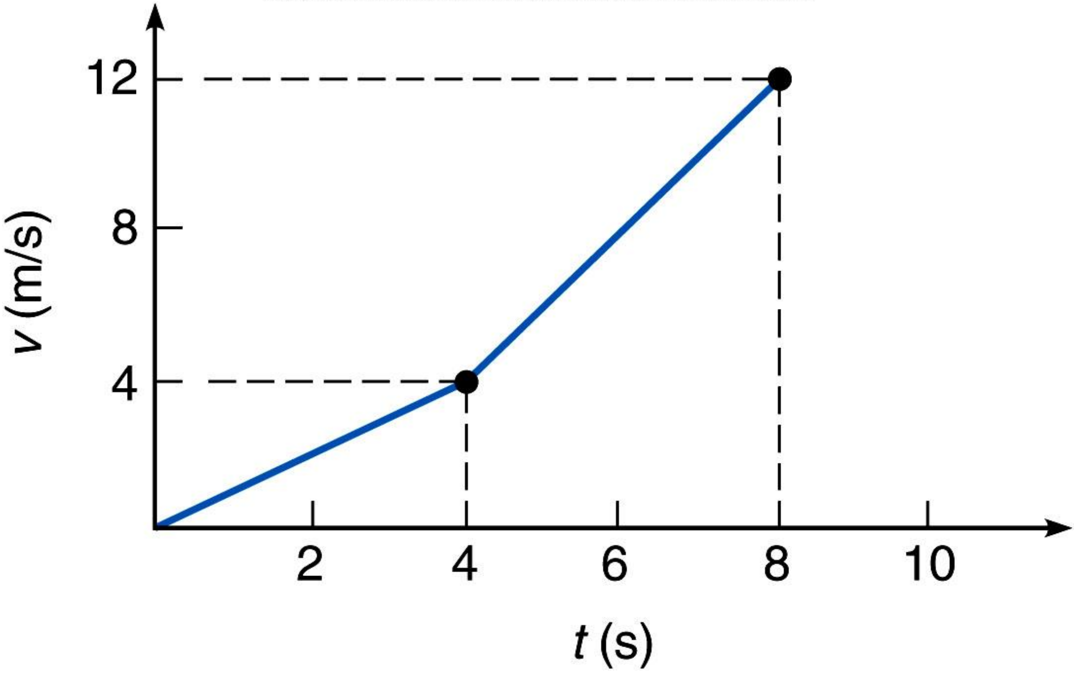
A) 4 m/s^2

B) 3 m/s^2

C) 2 m/s^2

D) 1.5 m/s^2

E) 1 m/s^2



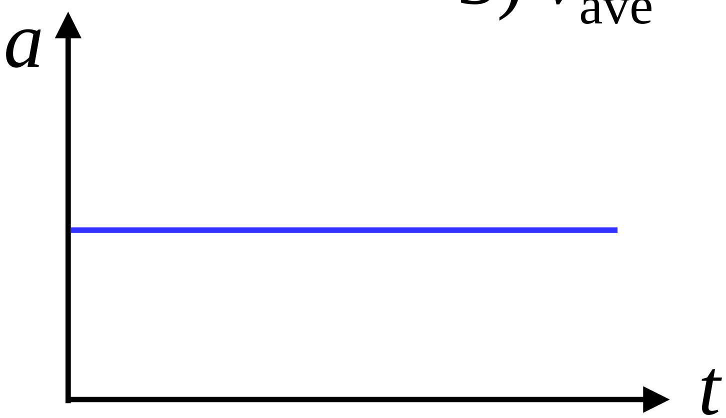
Uniform Acceleration

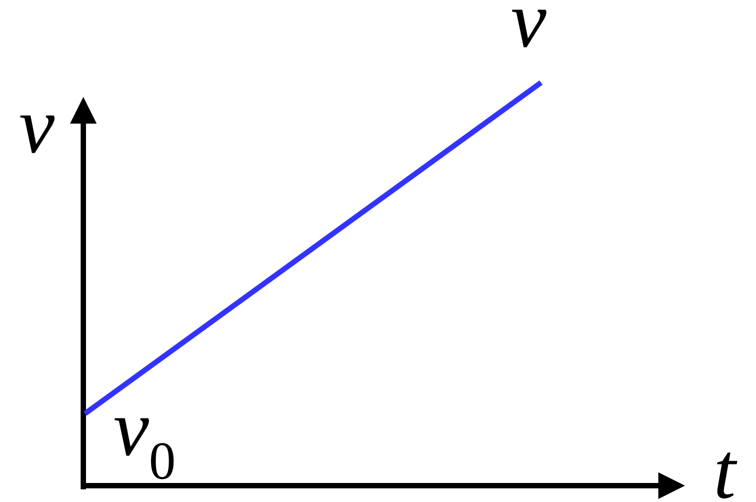
When the acceleration is constant or uniform, (which means that it does not change in magnitude or direction), then there are three equations we will use that describe the motion.

1) $v = v_0 + at$ 2) $d = v_0 t + (1/2)at^2$

v_0 is the initial velocity, and v is the final velocity after a time t has elapsed. d is the displacement during that time.

3) $v_{ave} = (v_0 + v)/2$





Problem: A roller coaster is traveling at 8.0 m/s when it comes to the top of a hill. It accelerates down the hill at 4.6 m/s^2 for 4.0 s. How far has it traveled in that time?

Given:

Want:

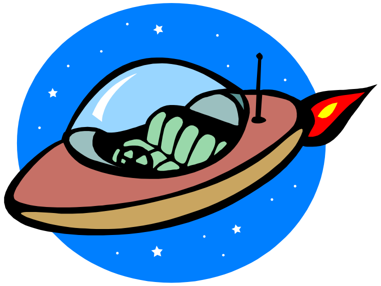
Problem: A train starts from rest and accelerates at a constant rate of 0.25 ft/s^2 over a distance of 1200 ft. How much time did this take?

Given:

Want:

This is a harder problem that requires two steps

Problem: A spacecraft is traveling with a speed of 3250 m/s, and it slows down by firing its retro rockets, so that it decelerates to a speed of 2050 m/s in 100 seconds. How far did it travel in that time?



Given:

Want:

Ratios and Scaling Problems

We look at how variables are related to each other to better understand the meaning of equations.

A worksheet on how to solve these types of problems can be found on the class web page

Suppose you have an equation like $A = B$. What happens to A if you double B?

Doubling B means to multiply B by 2

$2B = 2A$ (since $A = B$)

This is the same as multiplying both sides of the top equation by 2, so A doubles as well.

Suppose you have an equation like $A = B$. What happens to A if you increase B by 20%?

Increasing B by 20% meant to multiply B by 1.2

$1.2B = 1.2A$ (since $A = B$)

This is the same as multiplying both sides of the top equation by 1.2, so A increases by 20% as well.

Interactive Question

Consider the equation $A = 1/B$. What happens to A if you double B?

A) A doubles
B) A stays the same
C) A decreases to 1/2 its initial value
D) A decreases to $1/\sqrt{2}$ its initial value
E) A decreases to 1/4 its initial value

Interactive Question

Consider the equation $A = C/B$. What happens to A if you triple B?

A) A triples
B) A stays the same
C) A decreases to 1/3 its initial value
D) A decreases to $1/\sqrt{3}$ its initial value
E) A decreases to 1/9 its initial value

Interactive Question

Consider the equation $A = 1/B^2$. What happens to A if you double B?

A) A doubles
B) A stays the same
C) A decreases to 1/2 its initial value
D) A decreases to $1/\sqrt{2}$ its initial value
E) A decreases to 1/4 its initial value

Problem: Consider the equation $A = 1/B^2$. What happens to B if you double A?

Problem: Two cars start at rest and accelerate at the same rate. If the first car accelerates for three times the amount of time as the second car, how much faster is the first car going?

Problem: Two cars start at rest and accelerate at the same rate. If the first car accelerates for twice the amount of time as the second car, how much farther has the first car traveled?

Interactive Question

Two cars start from rest and each accelerates for the same amount of time. If the first car can accelerate at twice the rate of the second car, how much farther has the first car traveled?

A) The same distance
B) $\sqrt{2}$ times farther
C) Twice as far
D) Four times as far

Interactive Question

Two cars each drive for one hour. If the first car has an average speed that is three times that of the second car, how much distance does the second car travel compared with the first car?
(Hint: Be careful. Which car travels farther)

A) The same distance
B) 3 times farther
C) 1/3 times as far
D) 9 times farther
E) 1/9 as far

Problem: Two cars start from rest and accelerate at a constant rate. If the first car can accelerate at three times the rate of the second car, how much time more time does it take the second car to travel the same distance as the first car?

(Hint: since you want time, you will need to solve an equation for time.)