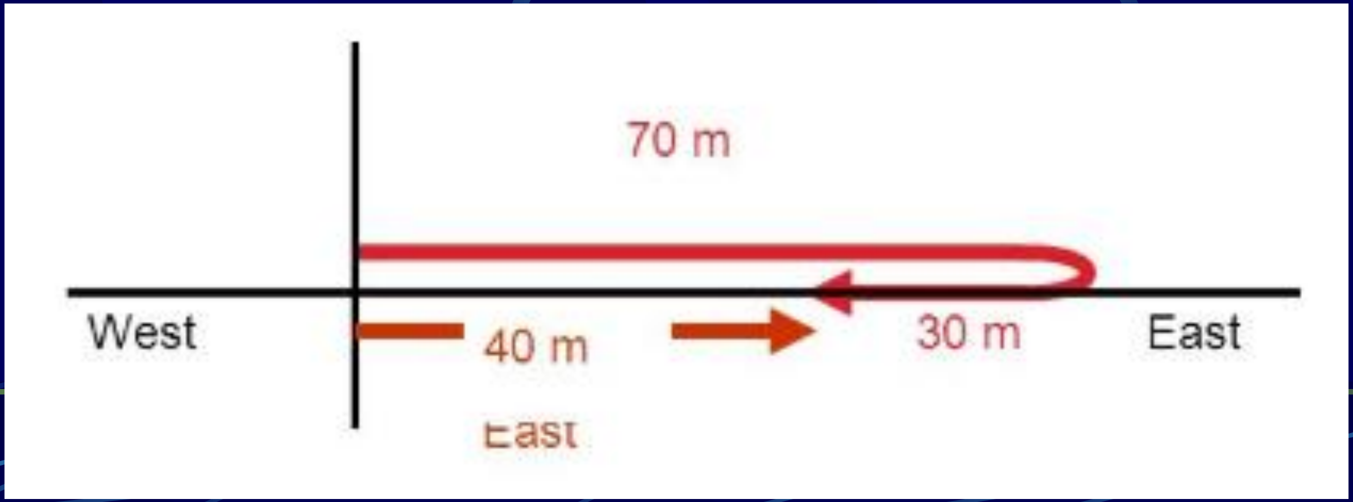
Chapter 2
Describing Motion

Lecture PowerPoint

Motion

- ***Motion*** is a change in an object’s position relative to a reference point
  - Distance: total amount traveled
  - Displacement: distance and direction of the object’s change in position



Distance and Displacement

- 1. Chance drives his scooter 7 kilometers north. He stops for lunch and then drives 5 kilometers east. What distance did he cover? What was his displacement?
- 2. Anthony walks to the pizza place for lunch. He walks 1 km east, then 1 km south and then 1 km east again. What distance did he cover? What has his displacement?
- 3. Jose buys a new moped. He travels 3 km south, then 4 k m east, then 10 km north, and finally 8 km west. How far does he need to go to get back to where he started?

Practice

- 1. On his fishing trip Justin rides in a boat 12 km south. The fish aren't biting so they go 4 km west. They then follow a school of fish 1 km north. What distance did they cover? What was their displacement?
- 2. Tara goes on a camel safari in Africa. She travels 5 km north, then 3 km east and then 1 km north again. What distance did she cover? What was her displacement?
- 3. Alex goes cruising on his dirt bike. He rides 700 m north, 300 m east, 400 m north, 600 m west, 1200 m south, 300 m east, and finally 100 m north. What distance did he cover? What was his displacement?

Why do we need clear, precise definitions?

What's the difference between:

- ***average speed*** and ***instantaneous speed***?
- ***speed*** and ***velocity***?
- speed and ***acceleration***?

Speed

- ***Speed*** is how fast an object changes its location.
  - Speed is always some distance divided by some time.
  - The ***units*** of speed may be miles per hour, or meters per second, or kilometers per hour, or inches per minute, etc.
- ***Average speed*** is total distance divided by total time.

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time of travel}} = \frac{d_{final} - d_{initial}}{\text{time of travel}}$$

- Practice: A car traveling at a constant speed covers a distance of 750 m in 25 s. What is the car's speed?

Speed White Boarding

- ***Speed*** = d / t (units of length) / (units of time)

$$Speed = \frac{d}{t} \quad \frac{\text{(units of length)}}{\text{(units of time)}}$$

1. A passenger elevator travels from the first floor to the 60th floor, a distance of 210 m, in 35 seconds. What is the elevator's speed?
2. A motorcycle is moving at a constant speed of 40 km/h. How long does it take the motorcycle to travel a distance of 10 km?
3. How far does a car travel in 0.75 h if it is moving at a constant speed of 88 km/h?

Speed Practice Problems

- Due Tomorrow

Average Speed

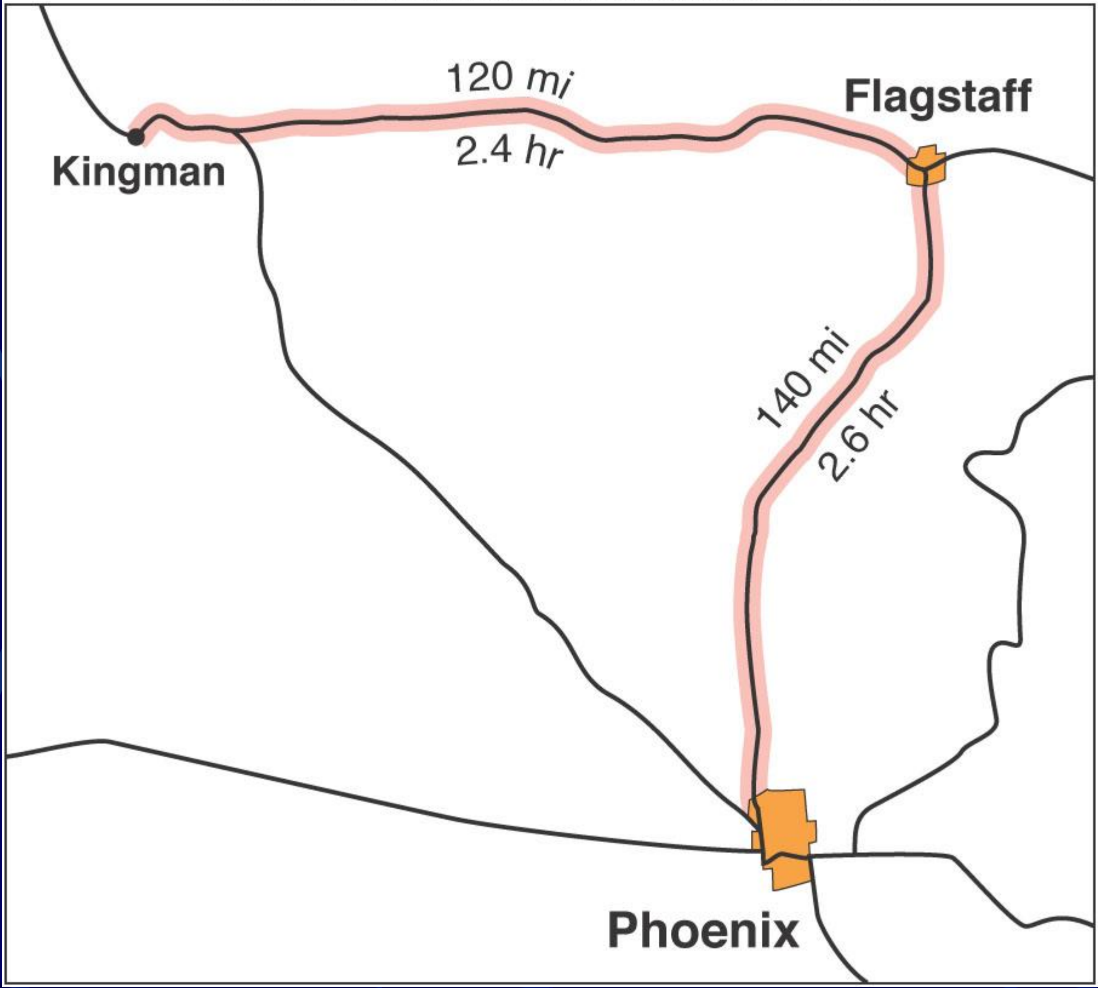
Kingman to Flagstaff:
120 mi ÷ 2.4 hr
= 50.0 mph

Flagstaff to Phoenix:
140 mi ÷ 2.6 hr
= 53.8 mph

Total trip:
120 mi + 140 mi
= 260 mi

2.4 hr + 2.6 hr
= 5.0 hr

260 mi ÷ 5.0 hr
= 52.0 mph

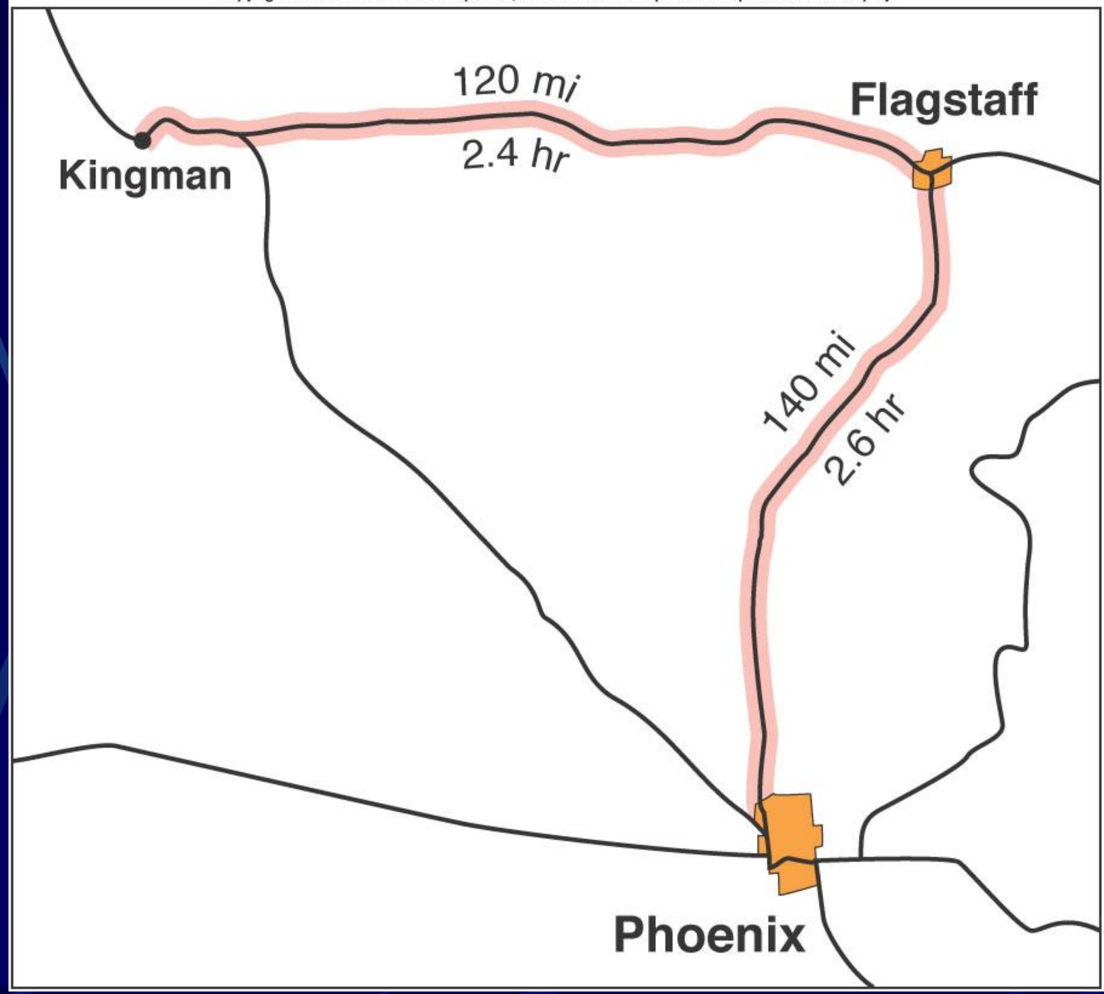


Average Speed

Kingman to Flagstaff:
120 mi ÷ 2.4 hr
= 50.0 mph

Flagstaff to Phoenix:
140 mi ÷ 2.6 hr
= 53.8 mph

Note: the average speed for the whole trip (52.0 mph) is not the average of the two speeds (51.9 mph). Why?



Speed (cont.)

- ***Rate*** is one quantity divided by another quantity.
  - For example: gallons per minute, pesos per dollar, points per game.
  - So average speed is the rate at which distance is covered over time.
- ***Instantaneous speed*** is the speed at that precise instant in time.
  - It is the rate at which distance is being covered at a given instant in time.
  - It is found by calculating the average speed, over a short enough time that the speed does not change much.

What does a car's speedometer measure?

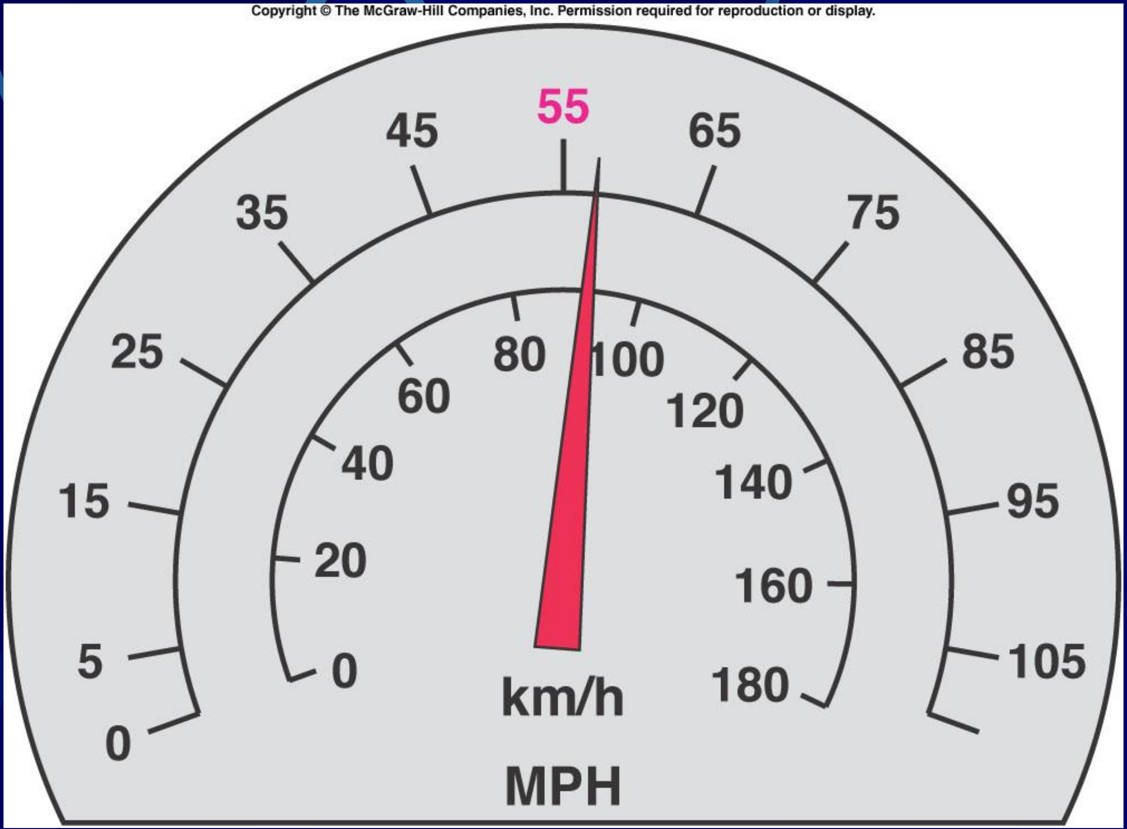
a) Average speed
b) Instantaneous speed
c) Average velocity
d) Instantaneous velocity

b) A speedometer measures ***instantaneous speed***.

(In a moment, we'll discuss why a speedometer doesn't measure ***velocity***.)

Instantaneous Speed

The speedometer tells us how fast we are going at a given instant in time.



Which quantity is the highway patrol more interested in?

a) Average speed
b) Instantaneous speed

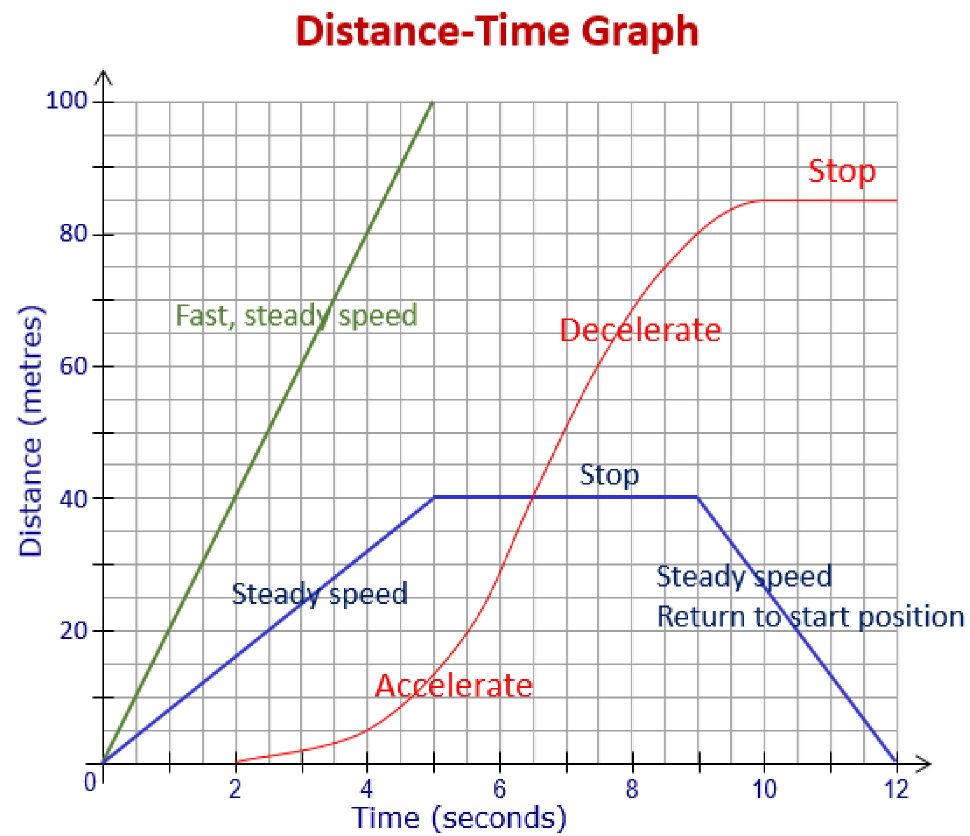
b) The speed limit indicates the maximum legal ***instantaneous*** speed.

In some cases, the highway patrol uses an ***average*** speed to prosecute for speeding. If your average speed ever exceeds the posted limit they can be 100% certain your instantaneous speed was over the posted limit.

Graphing Motion

- Shows the motion of an object over a period of time
- Time → x-axis
- Distance → y-axis

- **What does the slope of the line represent?**



The **green line** shows a fast, steady speed, moving from 0 to 100 m in 5 seconds.

The **blue line** shows a journey with a stop and a return to the starting position.

The **red line** shows a journey starting 2 seconds later than the other two, with an initial acceleration, then a deceleration and then a stop.

Distance vs. Time Graph

- Make a distance-time graph that shows the motion of both runners. What is the average speed of each runner? Which runner stops briefly? Over what time interval do they both have the same speed? Which runner traveled at a constant speed?

Time (s)	1	2	3	4
Sally's distance (m)	2	4	6	8
Alonzo's distance (m)	1	2	2	4

Graphing Motion WS

- Due Tomorrow

Distance vs. Time Graph

- Class Activity -

Velocity

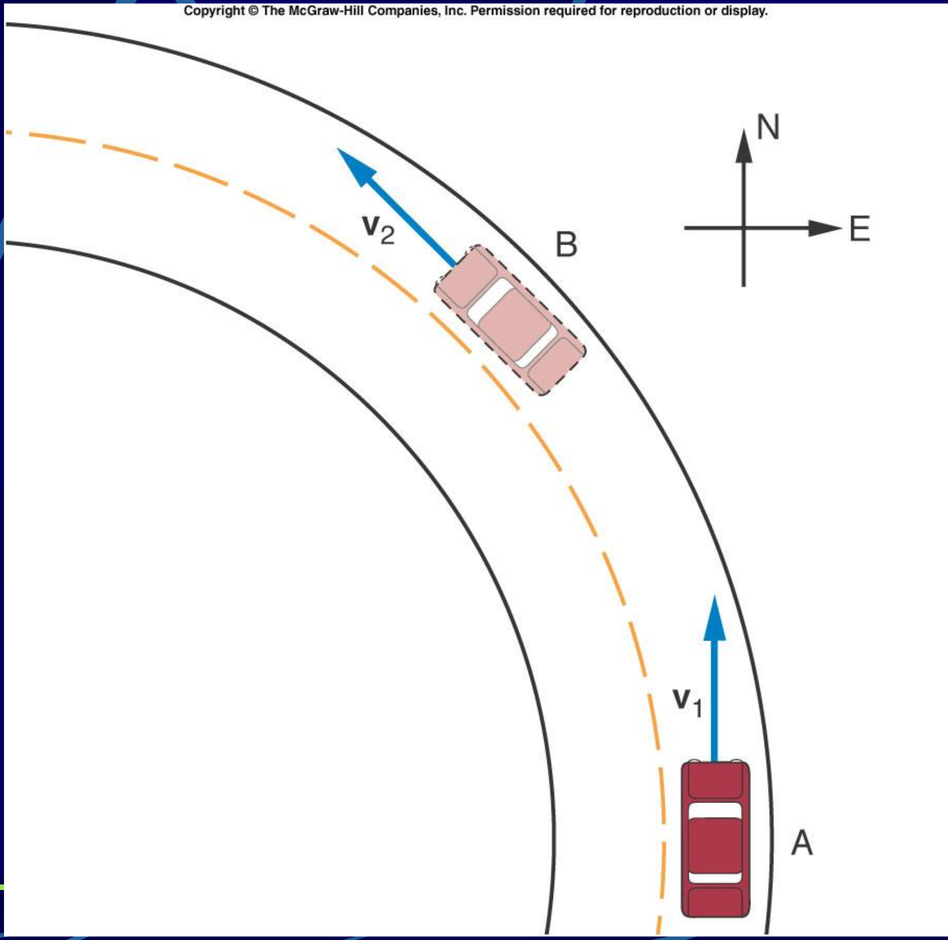
- ***Velocity*** involves direction of motion as well as how fast the object is going.
  - Velocity is a ***vector quantity***.
  - ***Vectors*** have both ***magnitude*** and ***direction***.
  - Velocity has a magnitude (the speed) and also a direction (which way the object is moving).
- A change in velocity can be a change in the object’s speed or direction of motion.
- A speedometer doesn’t indicate direction, so it indicates instantaneous speed but not velocity.
- Cars traveling in opposite directions on a road with the same speed, have different velocities.

A car goes around a curve at constant speed. Is the car's velocity changing?

a) Yes
b) No

a) At position A, the car has the velocity indicated by the arrow (vector) v_1.

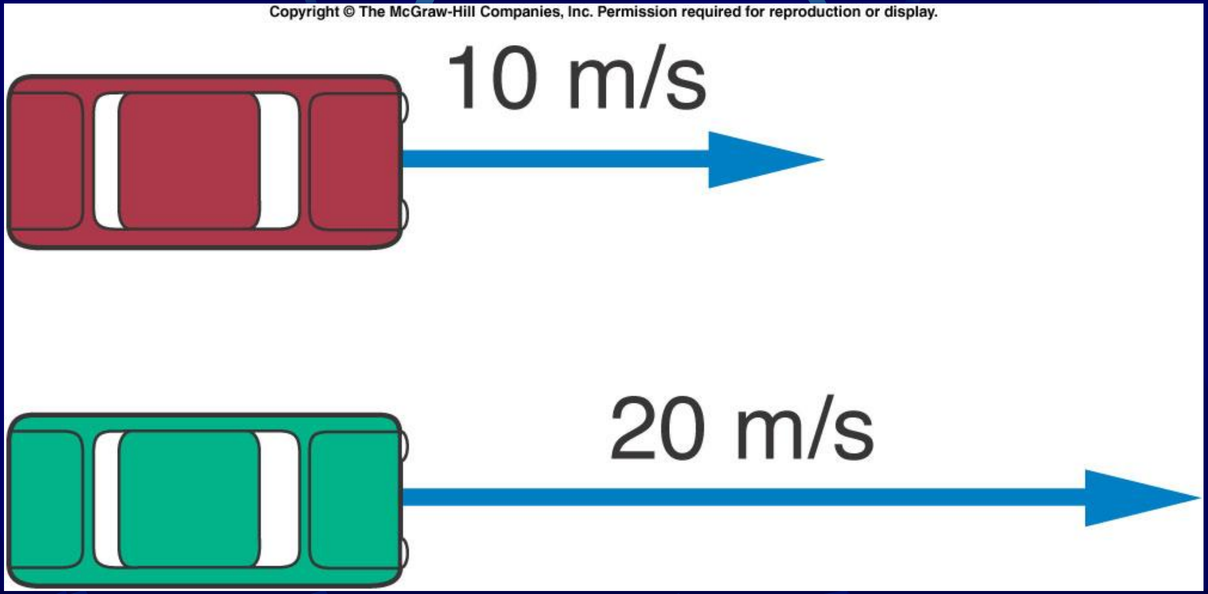
At position B, the car has the velocity indicated by the arrow (vector) v_2, with the same magnitude (speed) but a different direction.



Instantaneous Velocity

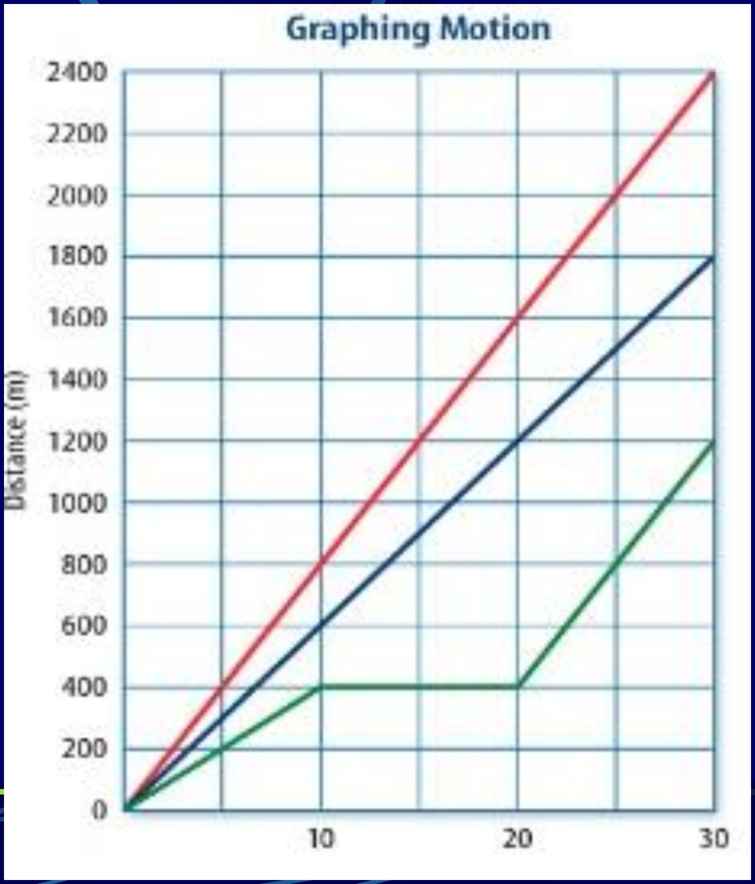
Instantaneous velocity is a vector quantity having:

- a size (magnitude) equal to the instantaneous speed at a given instant in time, and
- a direction equal to the direction of motion at that instant.



Velocity Practice

- Describe the velocity of an object that travels north 6.9 m in 3 s, then turns and travels south 2.8 m in 4 s.
- Using the graph below, what is the average speed of each runner?

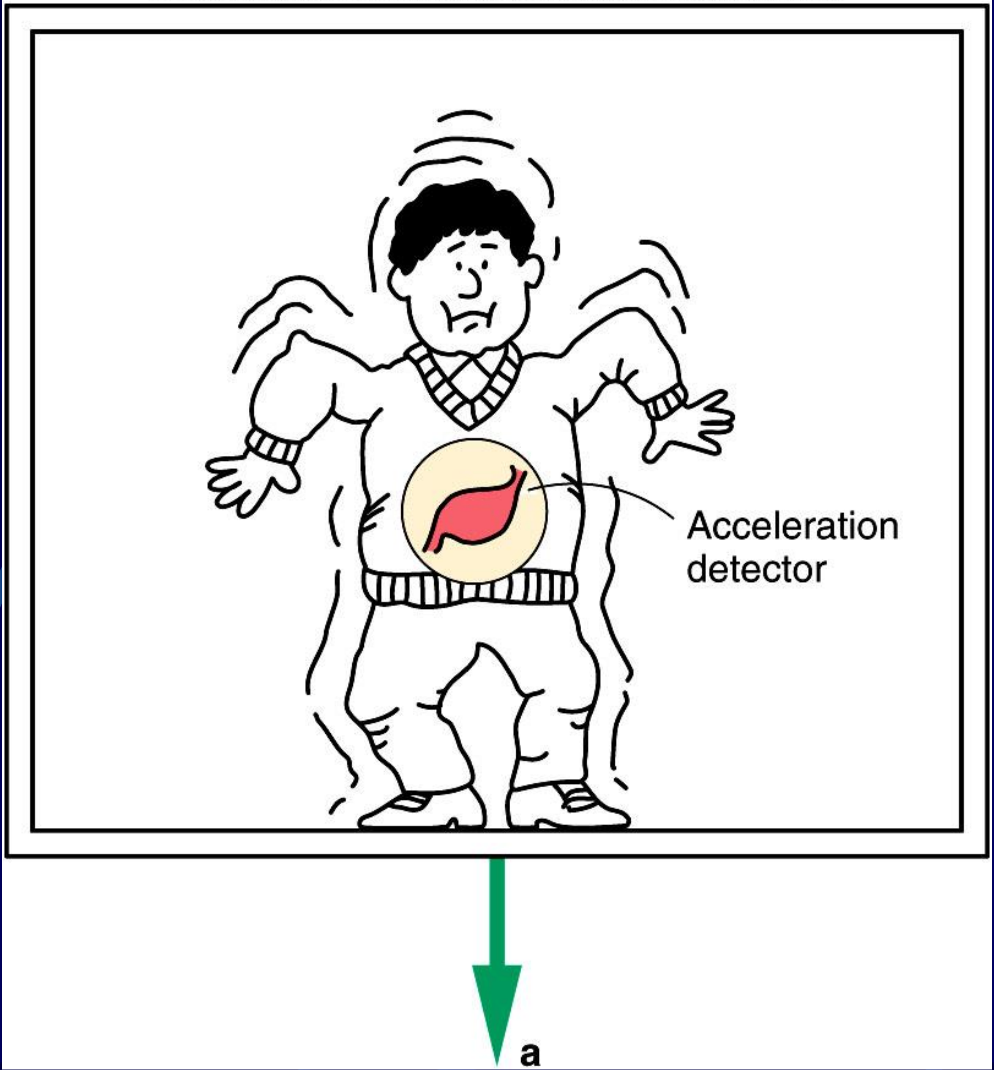


Acceleration

- ***Acceleration*** is the rate at which ***velocity*** changes.
  - Our bodies don't feel velocity, if the velocity is constant.
  - Our bodies feel ***acceleration***.
    - A car changing speed or direction.
    - An elevator speeding up or slowing down.
- ***Acceleration*** can be either a change in the object's speed or direction of motion.

Acceleration (cont.)

It isn't the fall that hurts; it's the sudden stop at the end!

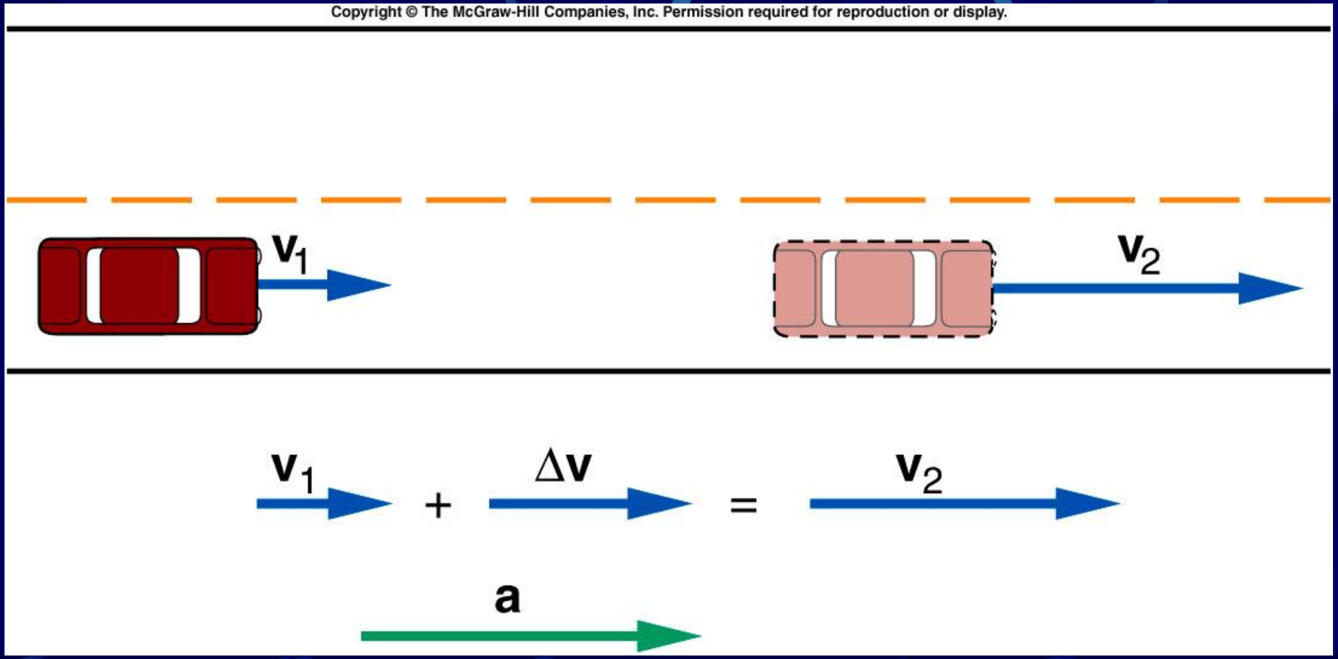


Acceleration (cont.)

- Acceleration is also a vector quantity, with magnitude and direction.
  - The direction of the acceleration vector is that of the *change* in velocity, $\Delta\mathbf{v}$.
  - Acceleration refers to *any* change in velocity.
  - We even refer to a *decrease* in velocity (a *slowing down*) as an acceleration.

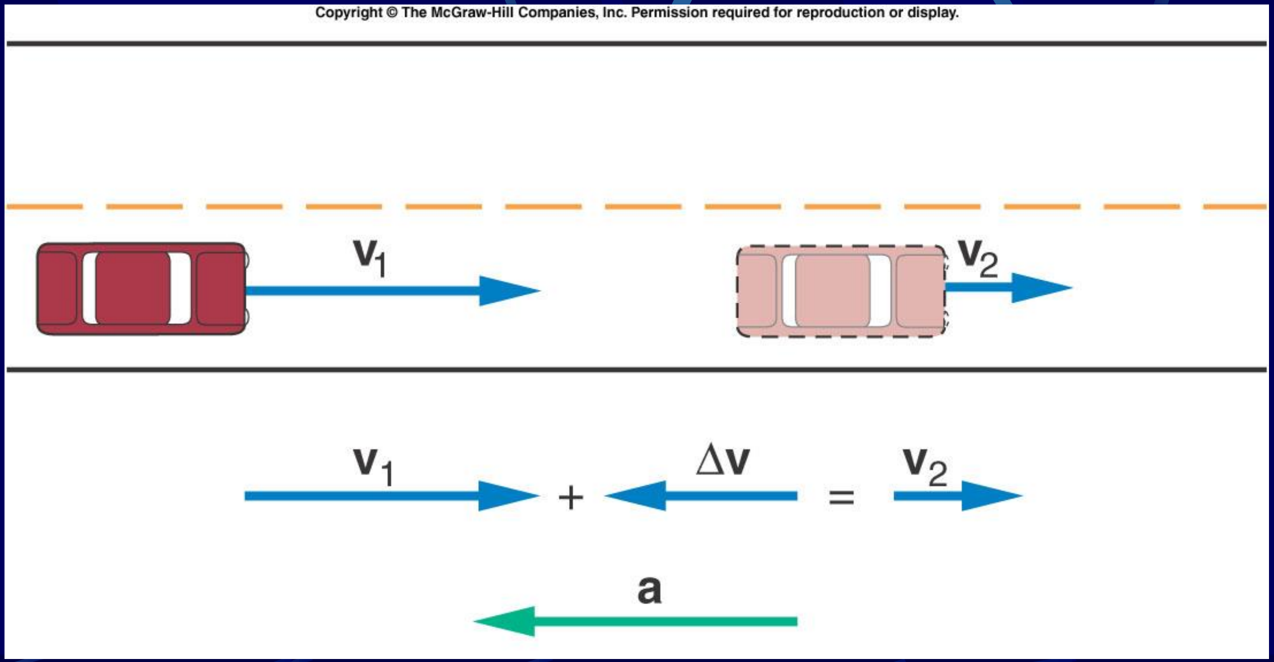
Acceleration (cont.)

- The direction of the acceleration vector is that of the *change* in velocity, $\Delta\mathbf{v}$.
- If velocity is ***increasing***, the acceleration is in the ***same*** direction as the velocity.



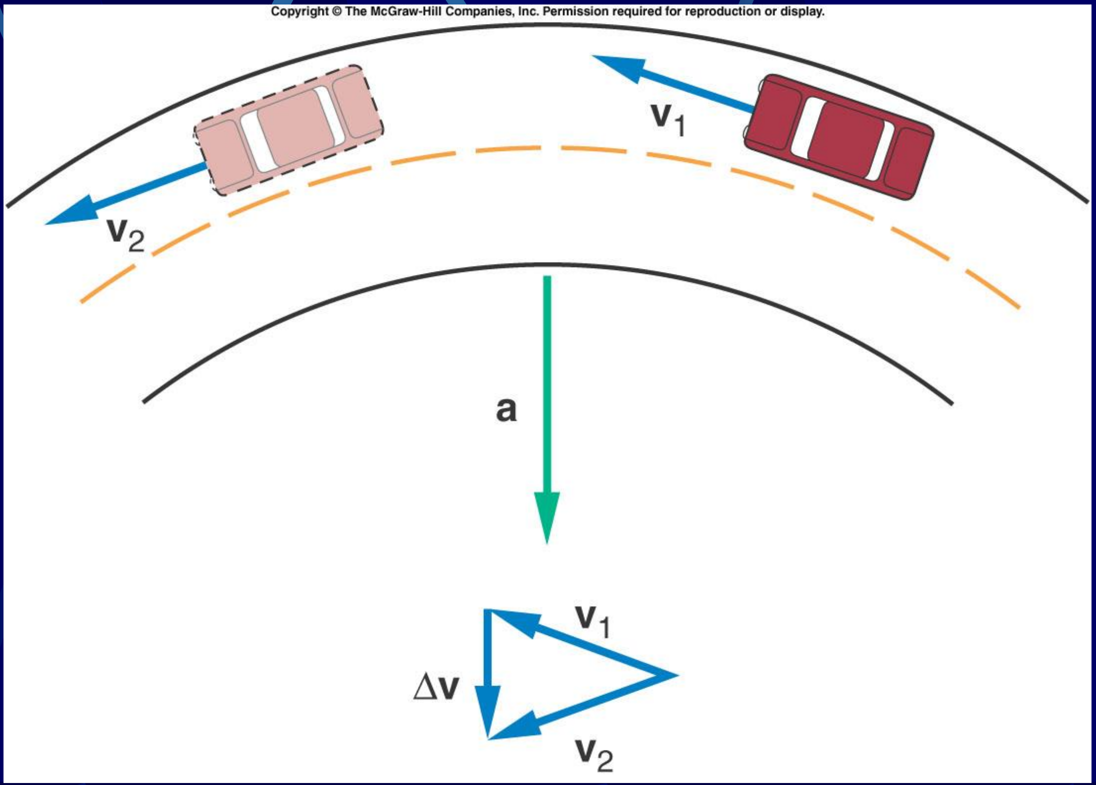
Acceleration (cont.)

- The direction of the acceleration vector is that of the *change* in velocity, $\Delta \mathbf{v}$.
- If velocity is ***decreasing***, the acceleration is in the ***opposite*** direction as the velocity.



Acceleration (cont.)

- The direction of the acceleration vector is that of the *change* in velocity, $\Delta \mathbf{v}$.
- If speed is constant but velocity ***direction*** is changing, the acceleration is ***at right angles to*** the velocity.



Average Acceleration

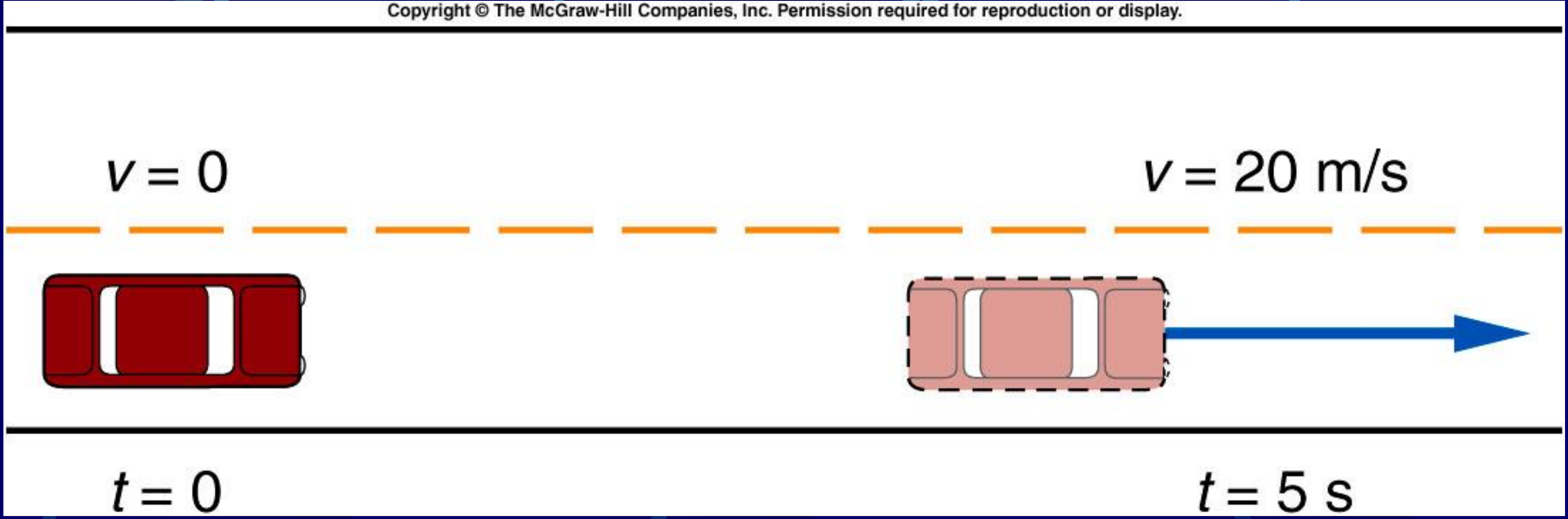
- ***Average acceleration*** is the change in velocity divided by the time required to produce that change.
  - The units of ***velocity*** are units of distance divided by units of time.
  - The units of ***acceleration*** are units of velocity divided by units of time.
  - So, the units of acceleration are units of (distance divided by time) divided by units of time (MUST BE THE SAME TIME UNIT):

Average Acceleration

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}}$$

$$\mathbf{a} = \frac{v_{final} - v_{initial}}{t}$$

Average Acceleration (cont.)



A car starting from rest, accelerates to a velocity of 20 m/s due east in a time of 5 s.

$$a = \frac{20\ \text{m/s}}{5\ \text{s}} = 4\ \text{m/s/s} = 4\ \text{m/s}^2$$

Instantaneous Acceleration

- ***Instantaneous acceleration*** is the acceleration at that precise instant in time.
  - It is the rate at which velocity is changing at a given instant in time.
  - It is found by calculating the average speed, over a short enough time that the speed does not change much.

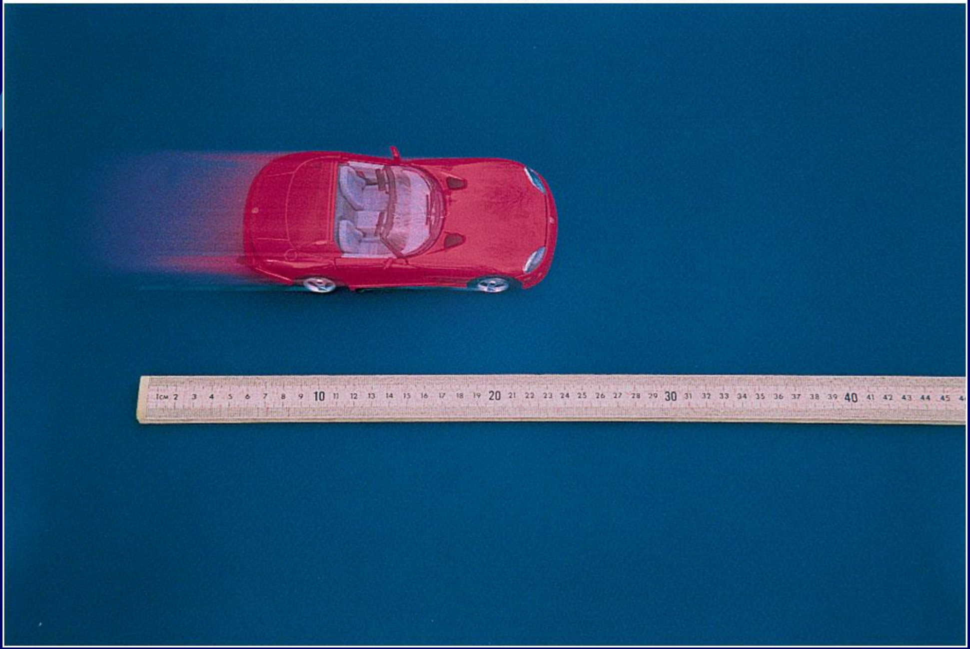
Practice Problems

- An airplane starts at rest and accelerates down the runway for 20 s. At the end of the runway, its velocity is 80 m/s north. What is its acceleration?
- A cyclist starts at rest and accelerates at 0.5 m/s^2 south for 20 s. What is the cyclist's final velocity?
- A ball is dropped and falls with an acceleration of 9.8 m/s^2 downward. It hits the ground with a velocity of 49 m/s downward. How long did it take the ball to fall to the ground?
- A car is traveling at 60 mph and comes to a complete stop in 30 seconds. What is its acceleration?

Graphing Motion

To describe the car's motion, we could note the car's position every 5 seconds.

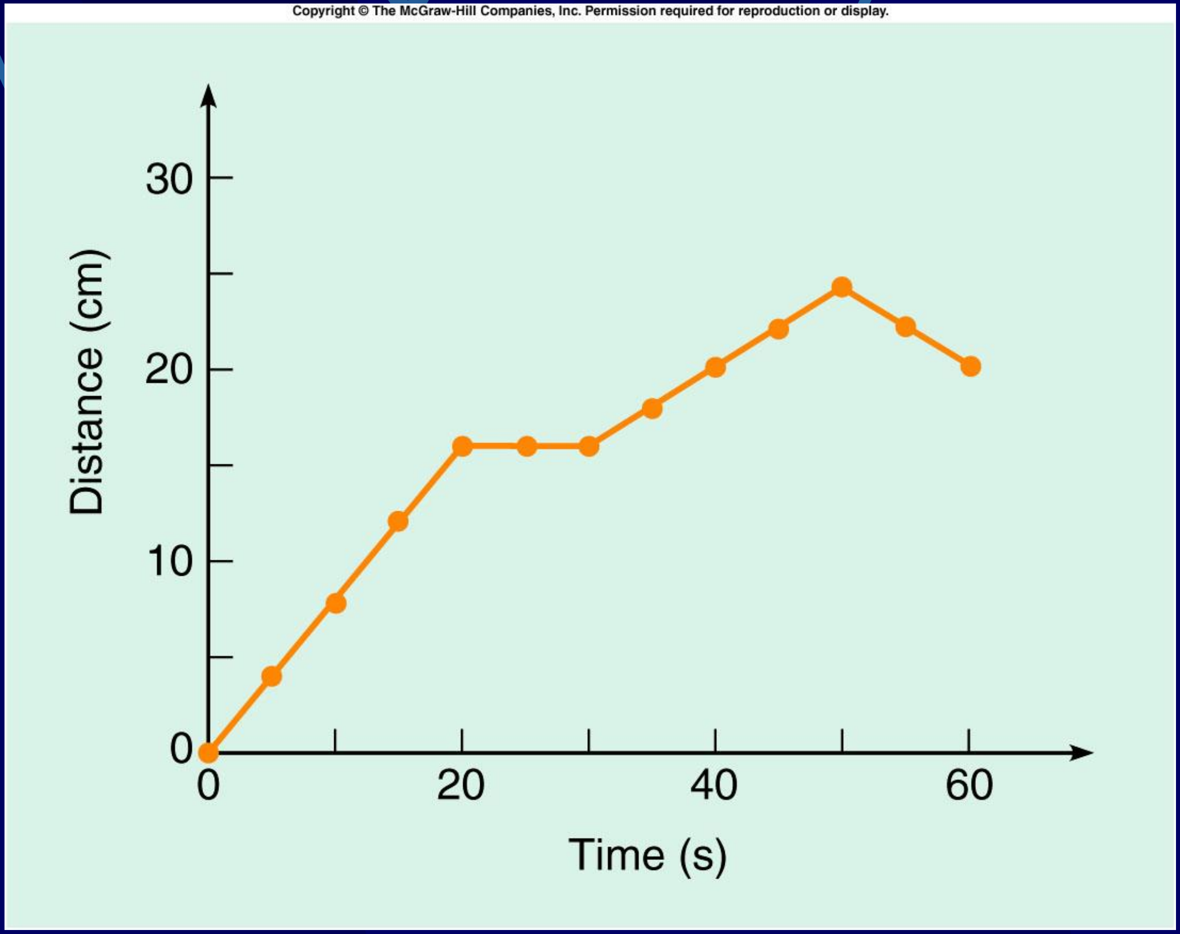
Time	Position
0 s	0.0 cm
5 s	4.1 cm
10 s	7.9 cm
15 s	12.1 cm
20 s	16.0 cm
25 s	16.0 cm
30 s	16.0 cm
35 s	18.0 cm



To graph the data in the table, let the horizontal axis represent ***time***, and the vertical axis represent ***distance***.

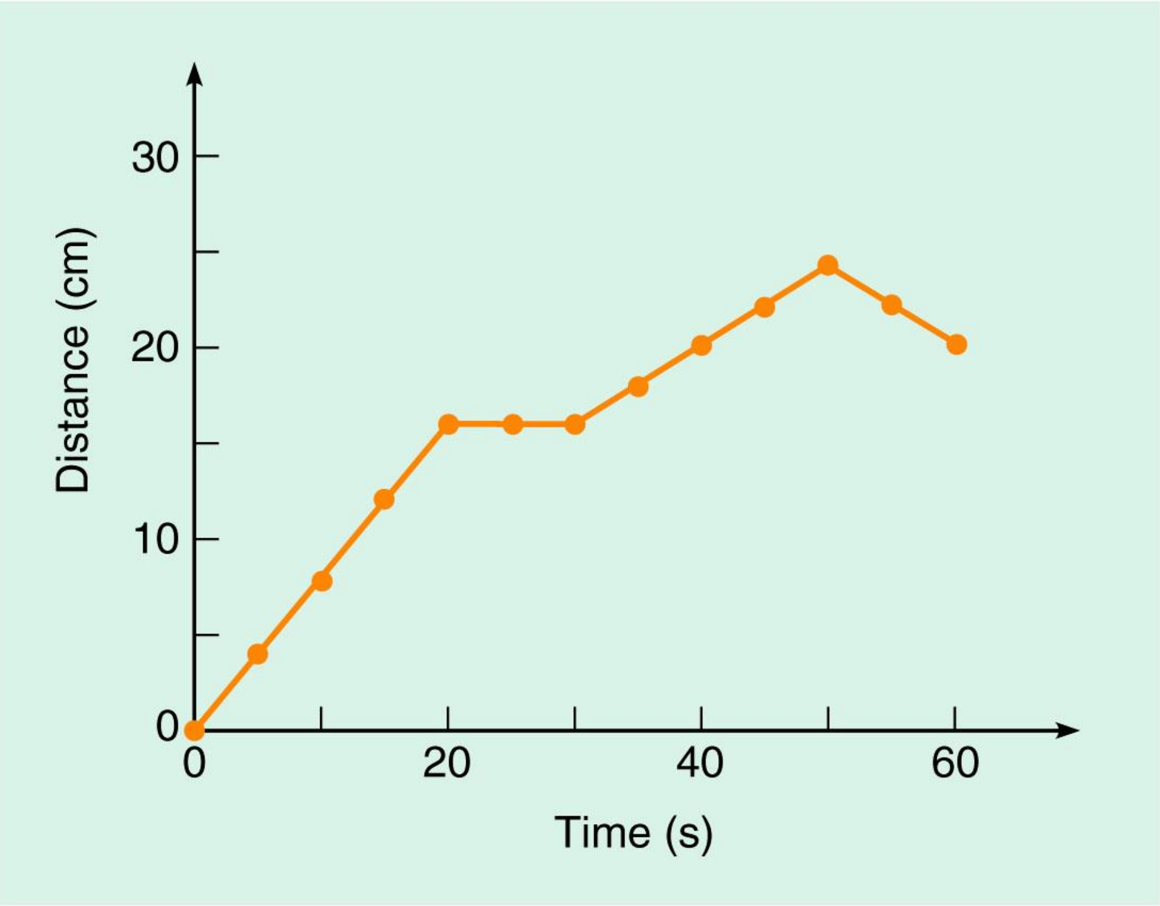
Each interval on an axis represents a fixed quantity of distance or time.

- The first data point is at 0 seconds and 0 cm.
- The second data point is at 5 seconds and 4.1 cm.
- Etc.



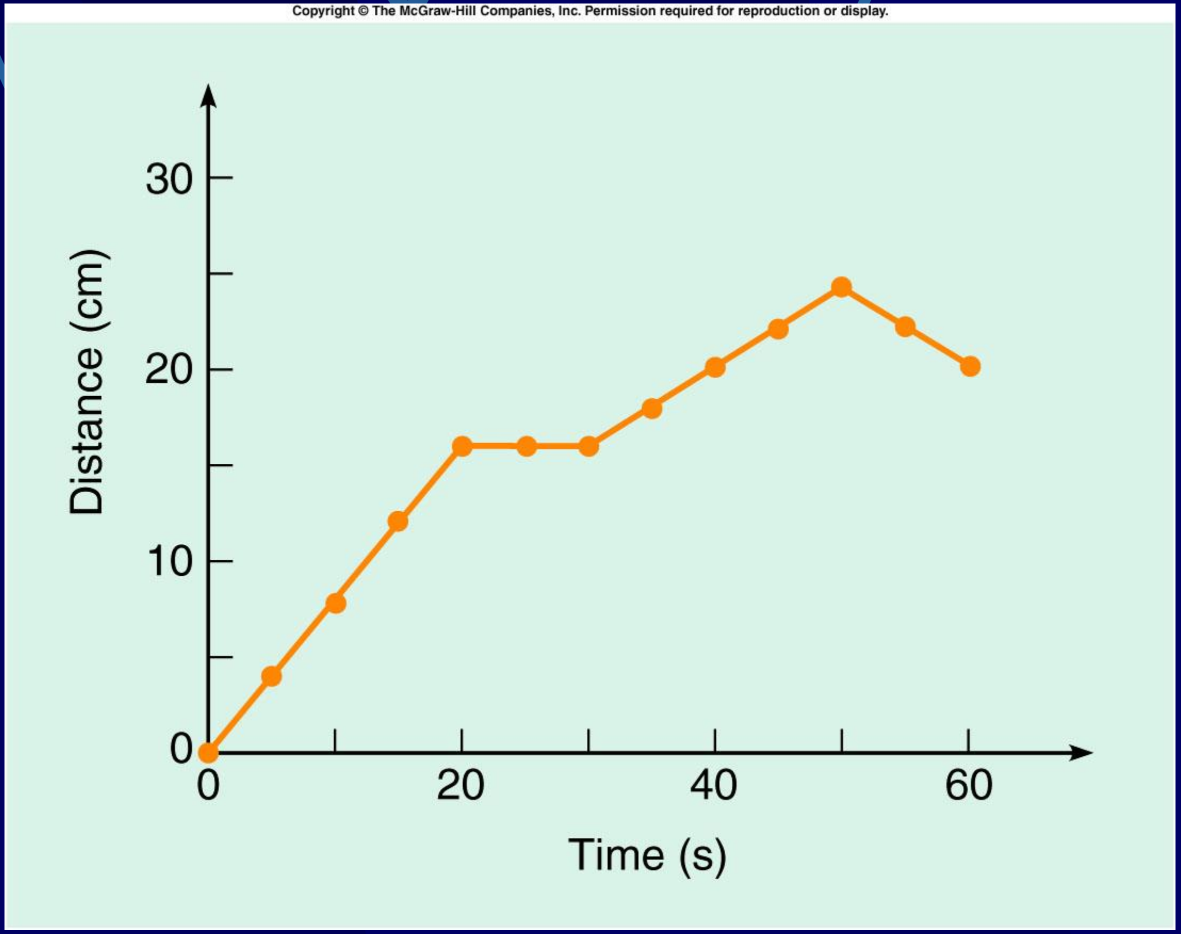
The graph displays information in a more useful manner than a simple table.

- When is the car moving the fastest?
- When is it moving the slowest?
- When is the car not moving at all?
- At what time does the car start moving in the opposite direction?



The ***slope*** at any point on the ***distance-versus-time*** graph represents the instantaneous ***velocity*** at that time.

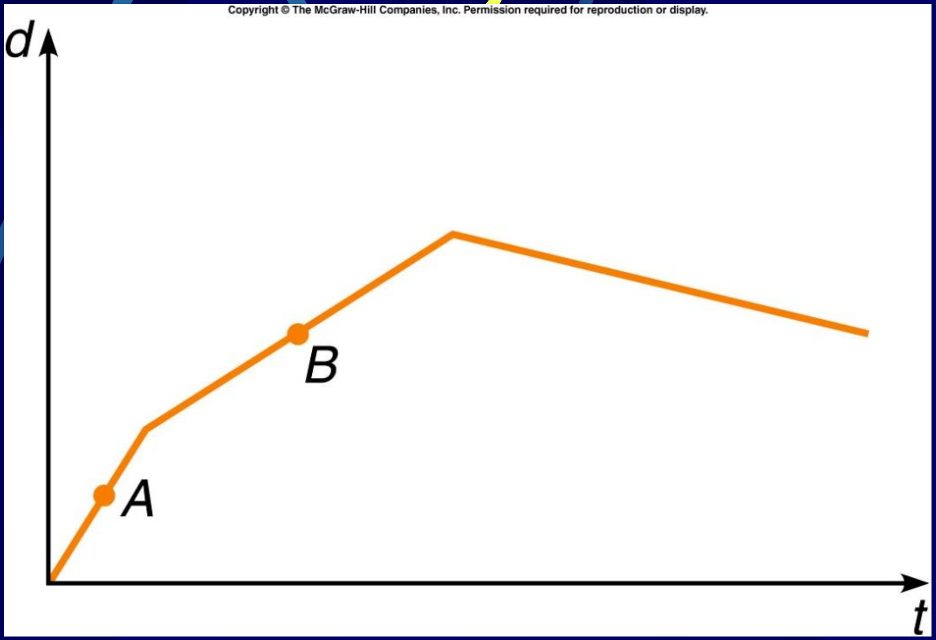
- ***Slope*** is change in vertical quantity divided by change in horizontal quantity.
- “rise over run”
- Similar to everyday meaning:
    - steepest “slope” is between 0 s and 20 s.
    - slope is zero (flat) between 20 s and 30 s
    - slope is negative between 50 s and 60 s



The graph shows the position of a car with respect to time. Does the car ever go backward (assume no u-turn)?

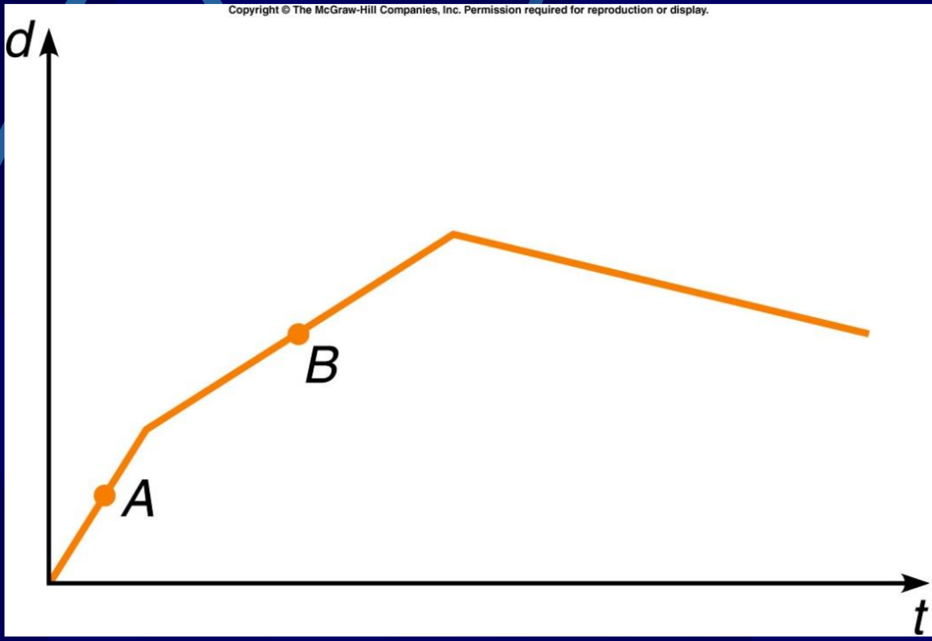
a) Yes, during the first segment (labeled A).
b) Yes, during the second segment (labeled B).
c) Yes, during the third segment (not labeled).
d) No, never.

c) The distance traveled is ***decreasing*** during the third segment, so at this time the car is moving backward (in reverse).



Is the instantaneous velocity at point A greater or less than that at point B?

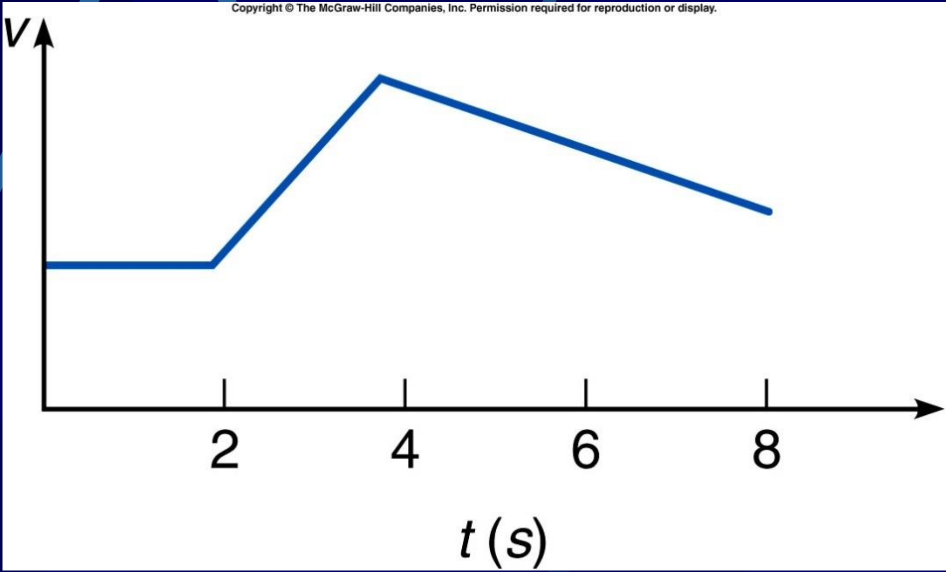
a) Greater than
b) Less than
c) The same as
d) Unable to tell from this graph



a) The instantaneous velocities can be compared by looking at their slopes. The ***steeper slope*** indicates the ***greater instantaneous velocity***, so the velocity at A is greater.

In the graph shown, is the velocity constant for any time interval?

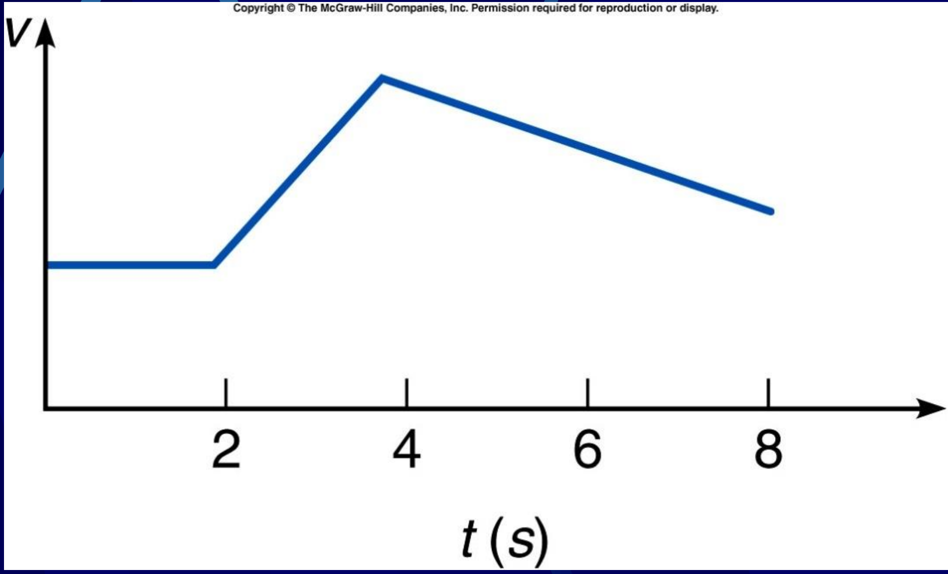
a) Yes, between 0 s and 2 s.
b) Yes, between 2 s and 4 s.
c) Yes, between 4 s and 8 s.
d) Yes, between 0 s and 8 s.
e) No, never.



a) The velocity is constant between 0 s and 2 s. The velocity is not changing during this interval, and the graph is flat, it has a slope of zero.

In the graph shown, during which time interval is the acceleration greatest?

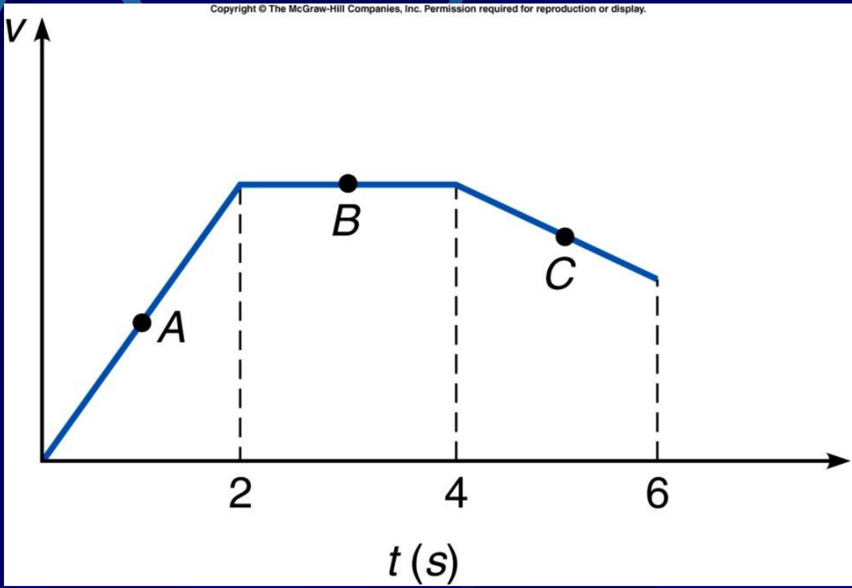
a) Between 0 s and 2 s.
b) Between 2 s and 4 s.
c) Between 4 s and 8 s.
d) The acceleration does not change.



b) The graph is steepest and has the greatest slope between 2 s and 4 s, the velocity is changing fastest during this interval making the acceleration the greatest.

A car moves along a straight road as shown. Does it ever go backward (assume no u-turn)?

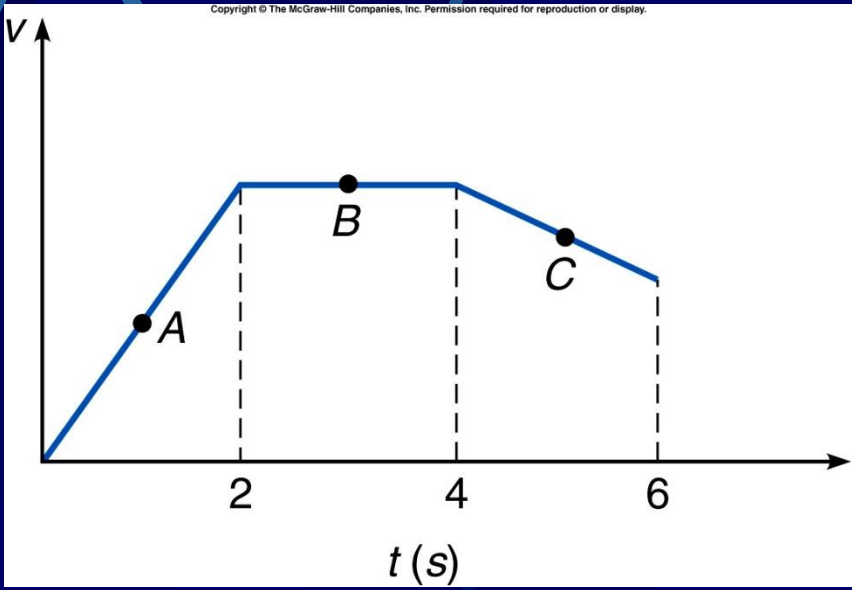
a) Yes, between 0 s and 2 s.
b) Yes, between 2 s and 4 s.
c) Yes, between 4 s and 6 s.
d) No, never.



d) Although the velocity is decreasing between 4 s and 6 s, the velocity is still positive and in the same direction (it is not negative), so the car is not moving backward.

At which point is the magnitude of the acceleration the greatest?

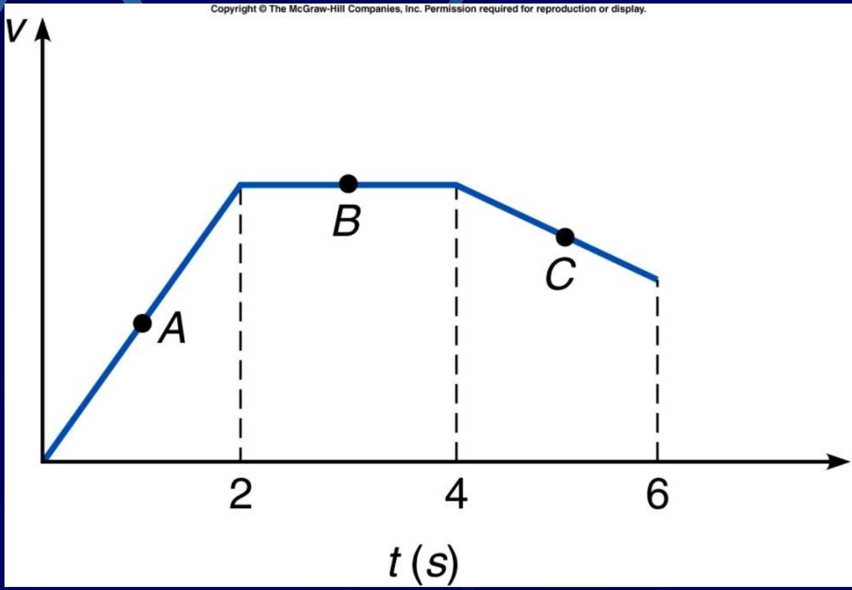
a) Point A
b) Point B
c) Point C
d) The acceleration does not change.



a) The magnitude of the acceleration is greatest when the velocity is changing the fastest. This is where the graph of velocity and time is steepest (has the greatest slope).

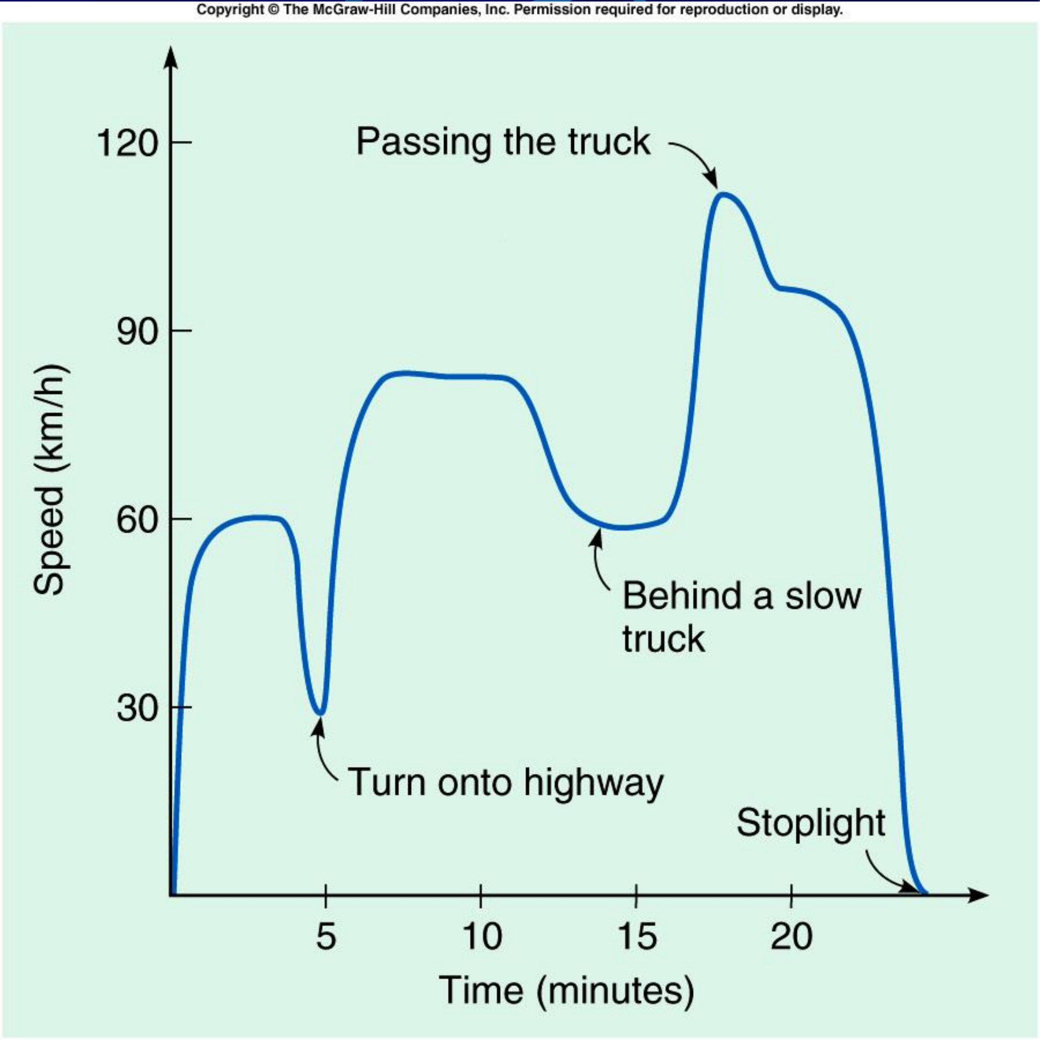
During which time interval is the distance traveled by the car the greatest?

a) Between 0 s and 2 s.
b) Between 2 s and 4 s.
c) Between 4 s and 6 s.
d) It is the same for all time intervals.



b) The distance traveled is greatest when the area under the velocity curve is greatest. This occurs between 2 s and 4 s.

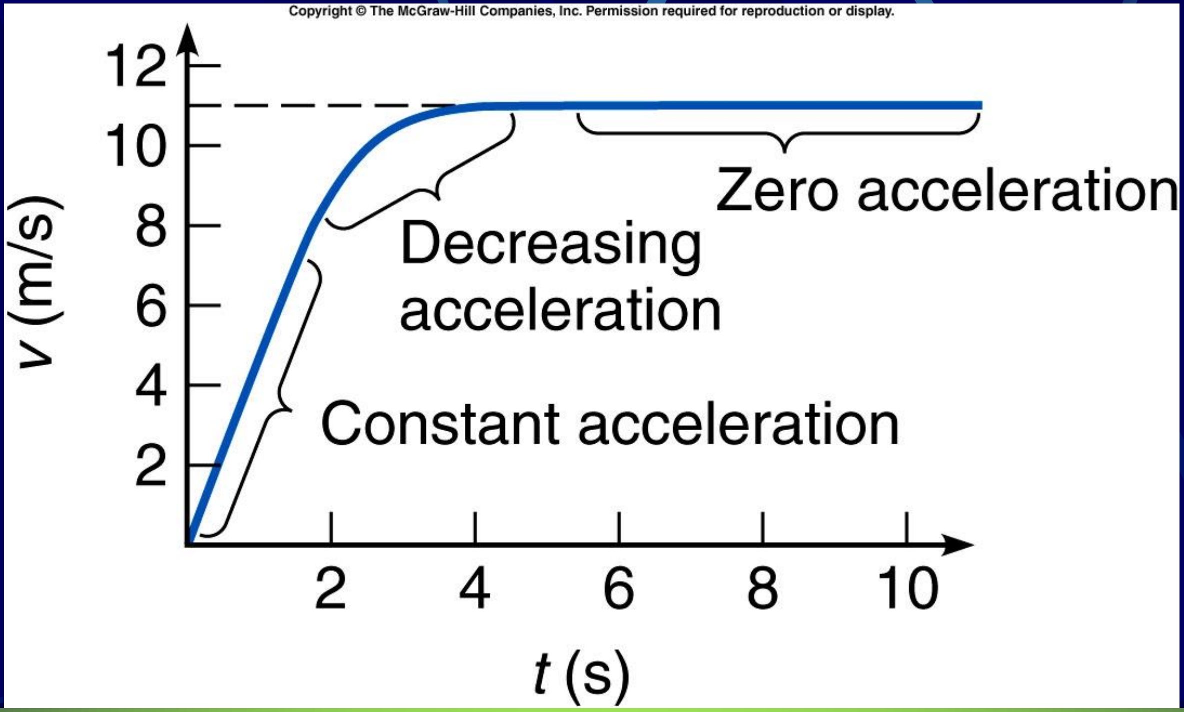
For example: a car traveling on a local highway



- A steep slope indicates a rapid change in velocity (or speed), and thus a large acceleration.
- A horizontal line has zero slope and represents zero acceleration.

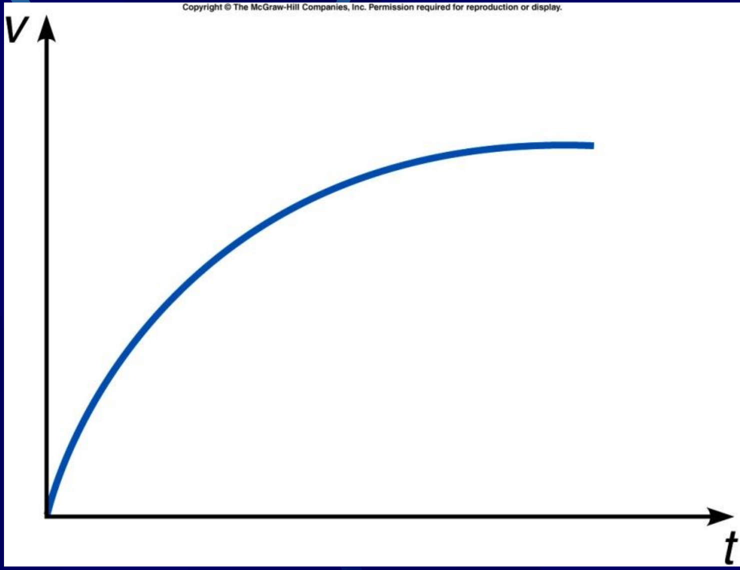
For example: the 100-m Dash

- The runner wants to reach top speed as soon as possible.
- The greatest acceleration is at the beginning of the race.
- For the remaining portion of the race, the runner continues at a constant speed (the top speed) so acceleration is zero.



The velocity graph of an object is shown. Is the acceleration of the object constant?

a) Yes.
b) No.
c) It is impossible to determine from this graph.



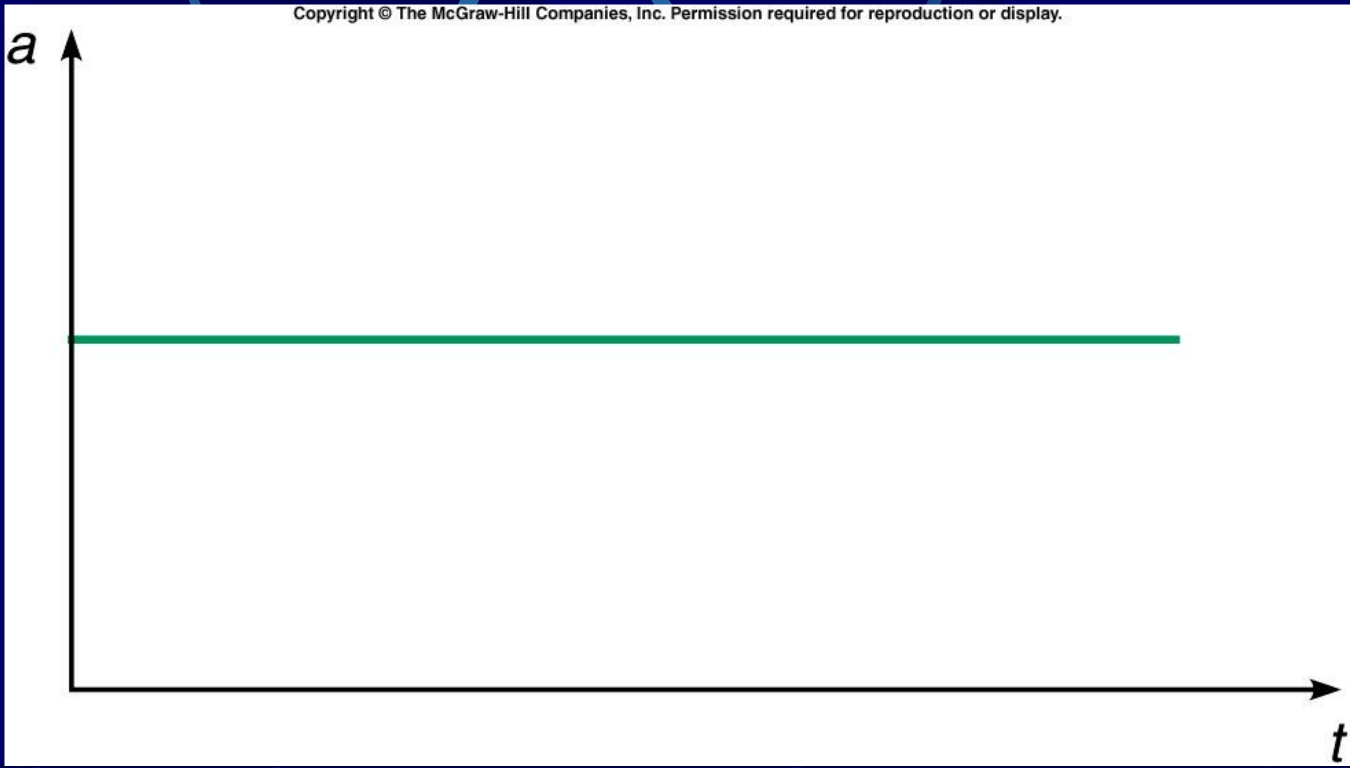
b) The slope of the velocity curve gradually decreases with time, so the acceleration is decreasing. Initially the velocity is changing quite rapidly, but as time goes on the velocity reaches a maximum value and then remains constant.

Uniform Acceleration

- ***Uniform Acceleration*** is the simplest form of acceleration.
  - It occurs whenever there is a constant force acting on an object.
  - Most of the examples we consider will involve constant acceleration.
    - A falling rock or other falling object.
    - A car accelerating at a constant rate.
  - The acceleration does not change as the motion proceeds.

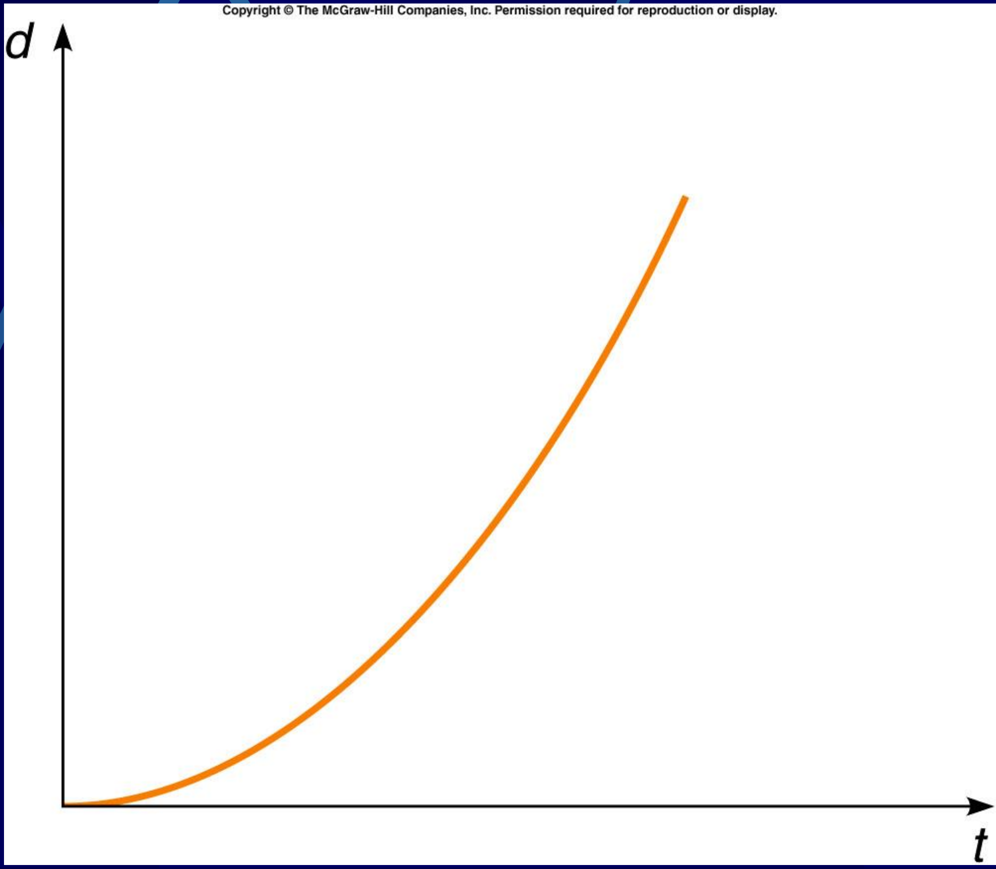
The acceleration graph for uniform acceleration is a horizontal line. The acceleration does not change with time.

- For example, a car moving along a straight road and accelerating at a constant rate.



The distance graph for uniform acceleration has a constantly increasing slope, due to a constantly increasing velocity. The distance covered grows more and more rapidly with time.

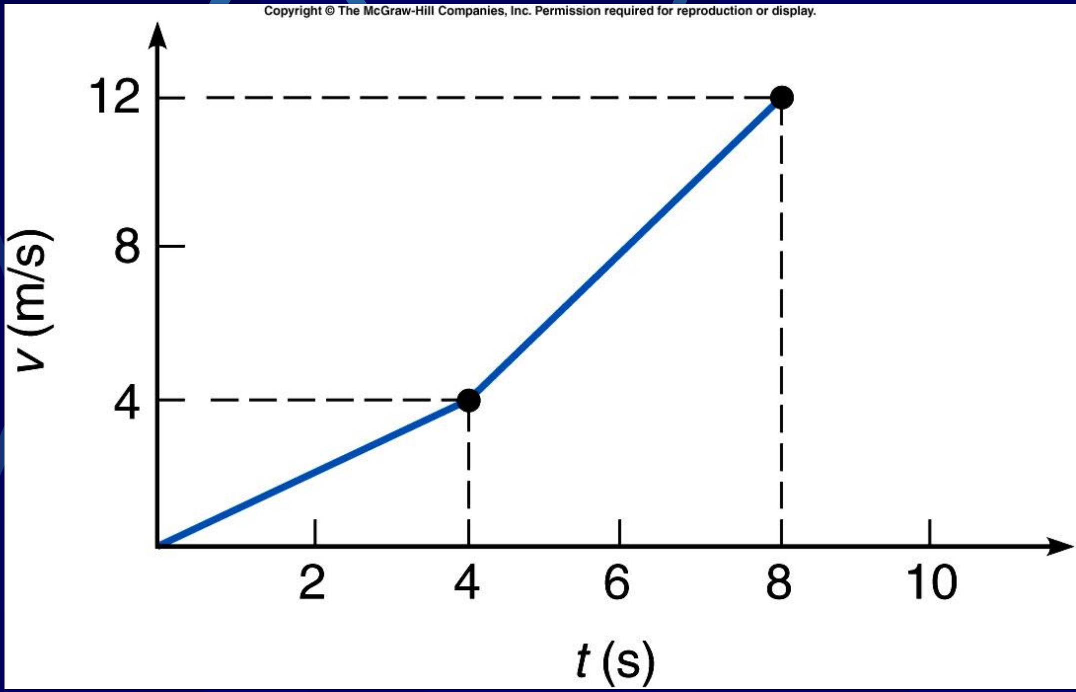
- The distance at any instant is velocity times the time at that instant.
- The total distance covered is average velocity times the total elapsed time.



The velocity of a car increases with time as shown. What is the average acceleration between 0 s and 4 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

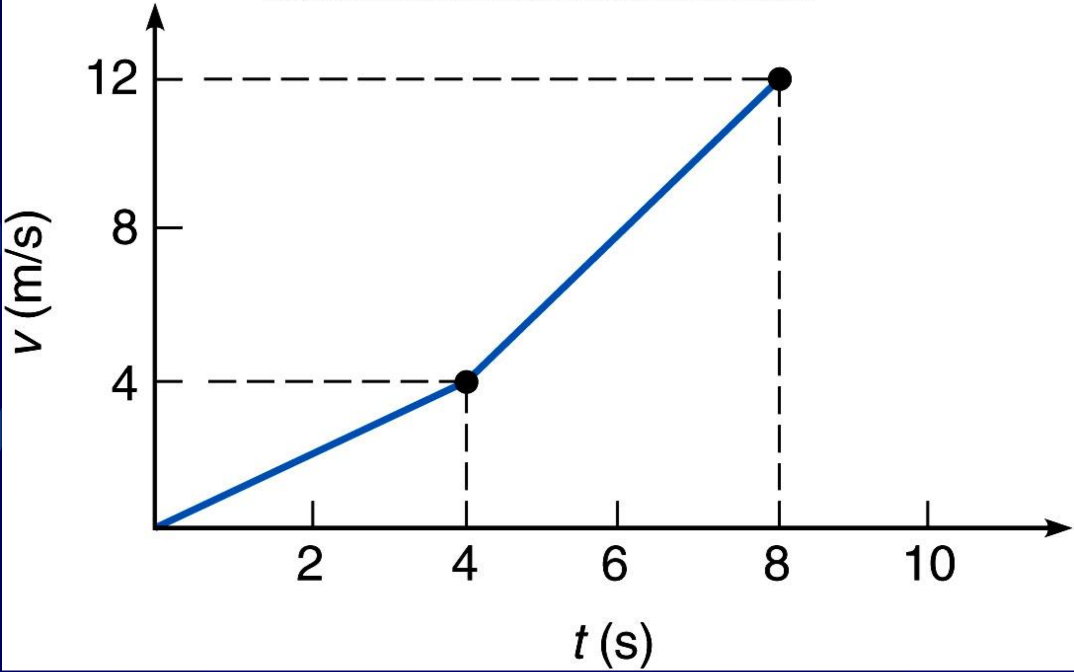
e) 4 m/s ÷ 4 sec = 1 m/s^2



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

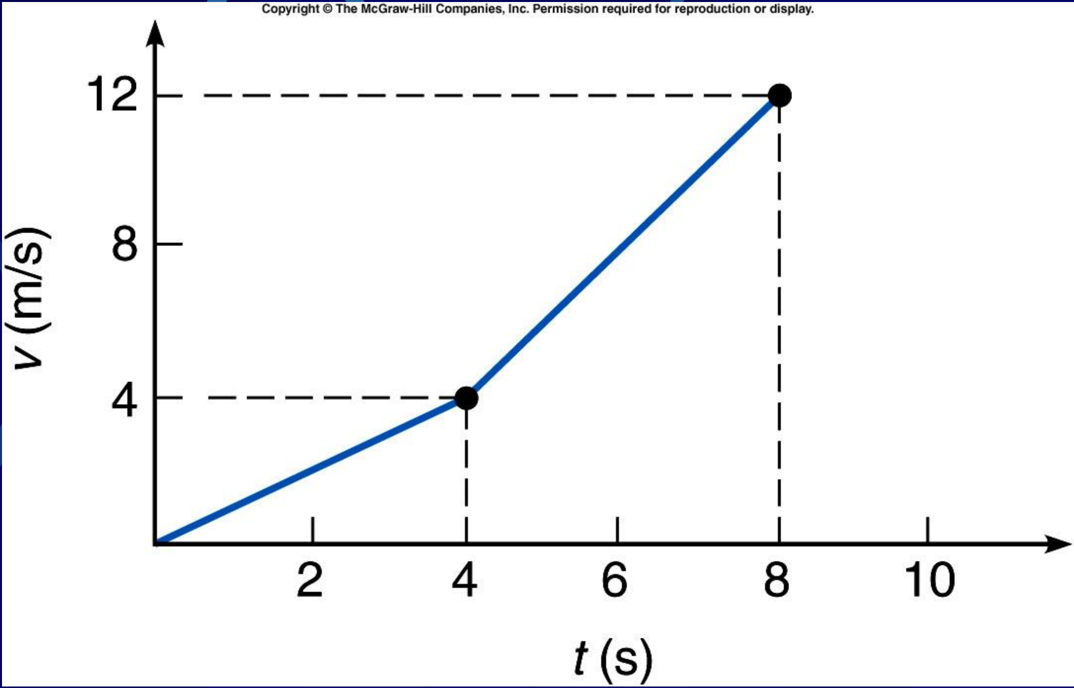
c) (12-4) m/s ÷ (8-4) sec = 2 m/s^2



The velocity of a car increases with time as shown. What is the average acceleration between 0 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

d) 12 m/s ÷ 8 sec = 1.5 m/s^2



The velocity of a car increases with time as shown.

Why is the average of the average accelerations from 0 to 4 sec and 4 to 8 sec the same as the average acceleration from 0 to 8 sec?