Physics of Everyday Phenomena 9th edition Griffith Solutions Manual

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2 Describing Motion

1 Average and Instantaneous speed
2 Velocity
3 Acceleration
4 Graphing Motion
5 Uniform Acceleration
Everyday Phenomenon: Transitions in Traffic Flow
Everyday Phenomenon: The 100-Meter Dash

Care spent in developing the concepts of kinematics in this chapter will be rewarded in future chapters on dynamics. I personally think it important, though, to relate things to the upcoming idea of energy transfer. This helps connect concepts students generally otherwise see as completely discrete and unconnected.

Suggestions for using the PowerPoint Lectures, the Clicker Questions and the Videos

This chapter is long on material that is important as a foundation for the following chapters on kinematics. **Therefore, take your time.** Three to five 50 minute class periods should be devoted to this chapter. If possible incorporate some of the suggested activities.

The best classes get the students engaged and interested in the material. You might try using the Powerpoint lectures followed by an activity or demonstration. Then start the next class period with clicker questions about the previous material. Clicker questions are a great way for you as the instructor to see if the students 'got it' or not. If not, you might patiently revisit some of the material, or do an additional activity.

The rest of these paragraphs give some excellent ideas of how you can incorporate demonstrations and activities into your lecture and some discussion points for the classroom.

The video at the end of the chapter (video 2.1) would be helpful to show in class—both to get the students used to the idea that the videos are helpful to their understanding and as a starting point for some discussion. It goes into a lot of detail (in 5 minutes) regarding velocity and acceleration graphs.

Section 2.1
Lecture slides 1 - 13
Clicker question 2.1

Section 2.2
Lecture slides 14 -17
Clicker questions 2.2 and 2.3

Section 2.3
Lecture slides 18 - 26
Clicker questions 2.4 to 2.6

Section 2.4
Lecture slides 27- 44
Clicker questions 2.7 to 2.15

Section 2.5
Lecture slides 45 - 54
Clicker question 2.16
Video 2.1

Suggestions for Presentation

The concepts of speed (both average speed and then instantaneous speed) and acceleration can be easily demonstrated. Before any demonstrations, though, it is important to draw on your students' experience.

First provide the students with a set of distance-time graphs and have them predict what everyday motions would be represented by each graph. Before they have much experience with this notion, they will propose some interesting solutions, such as walking up a ramp to create a distance-time graph that has a constant positive slope.

Then ask questions about how to graph a constant speed, straight line trip between two familiar places. How does the distance travelled vary with time? How do they know (speedometer tells them how many miles per hour)? How does the speed vary with time (assuming they're on cruise control)? You can then introduce the velocity-time graphs using the same motions. Comparing the distance-time graph and velocity-time graph for familiar motions will help convince them that the area under the velocity-time graph yields distance travelled, and that the slope of the distance-time graph yields velocity. Turning around and going back to the point of origin means a negative velocity, etc. At this point, most will abandon the idea of walking up a ramp to make a graph, realizing that the graph is not the motion, but instead is a representation of it. You can extend this with acceleration-time graphs. It is probably helpful to use some of the graphs from the text. For example, ask what motion is represented by Figure 2.15, and then have students predict the distance-time graph for that motion and the acceleration-time graph for that motion, revealing that those are shown in Figures 2.14 and 2.16, respectively. You can even create "meaningless" graphs (e.g. distance-time with a

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single vertical line, or a circle) to get students engaged and thinking "outside the box."

It also helps to think "inside the box," specifically the Everyday Phenomenon Box 1.2, which relates the real-life situation of a 100-meter dash to the abstraction of its graph. Show a YouTube video of such a sprint first and have students analyze the motion verbally before graphing.

If you are fortunate enough to have a demonstration setup involving a fan cart, dynamics track, and motion sensor coupled to a computer, you can then demonstrate in real time both the motion of an object and the graphical representation of that motion. With the fan turned on, the cart will experience essentially constant acceleration; with the fan turned OFF, a gentle shove will give it essentially a constant velocity. Again, have students predict what the various graphs would look like for a demonstrated motion *before* running the demonstration. Then run the demonstration with the motion sensor so that they can *see* where their predictions fell short of the reality. In this way, students are more likely to make valuable conceptual shifts. Another interesting alternative is, assuming you have the equipment and space, to make the students "walk" the graphs while watching the output of the motion sensor, thus feeling the motion for themselves.

If such equipment is not available, a two-meter air track with photocell timers is also illustrative. One can even get by with a croquet ball rolling across a board or a small metal car on a track, a meter stick and a timer. The key point students must note is that a speed determination involves two measurements, distance and time. Show first for a body moving on a horizontal surface that the average speed is the same over various portions of its path. Though this is apparent without taking actual measurements, it will more likely be striking if measurements are taken.

To study acceleration, set the track or board at a small angle. About a 1/2 cm drop in 2.0 meters works well. With the body starting from rest, measure time successively to travel predetermined distances. Rather than using equal spatial distances, it is more instructive to choose distances that will involve equal time intervals such as 10, 40, 90 and 160 cm. It is good to try this in advance since some tracks may not be quite straight and will give you problems. It is a good idea to take more than one measurement for the time on each of the distances so that students can see what the uncertainties are. Since the instantaneous velocity is equal to the average velocity at the mid-point in the time interval, the acceleration in each interval is found from the changes in average velocity and corresponding changes in the time-midpoints (actually the change in time-midpoint is the same as the changes in the time interval itself. Students will probably find this reasonable without going into the rationale behind it). Typical values with such an air track timing by hand are as follows:

s (cm)	t (sec)	v_{av} (cm/s)	a (cm/s^2)
0	0		
	(1.4)	3.6	
10	2.8		2.4
	(4.2)	10.3	
40	5.7		2.1
	(7.2)	16.7	
90	8.7		2.7
	(10.1)	24.5	
160	11.6		

You may prefer to plot v vs. t to get the slope. The result will look better than getting a from successive interval data as above.

The nature of distance can be demonstrated by putting a golf ball into a cup. Students can easily see that one straight shot is equivalent to two or three bad putts before the ball enters the cup. Having established how distances combine, it is now easy to present the directional concepts of velocity and acceleration.

Most physicists and instructors of higher level physics classes are used to using displacement and discussing the vector nature of displacement. **The vector nature of displacement is not discussed in this text.** Instead vectors are not introduced until the difference between velocity and speed is discussed. Be aware that if you choose to use the term 'displacement' without explaining how it is different from 'distance,' students will most likely be confused. Students seem more comfortable with waiting to introduce velocity and speed before incorporating vectors.

Students may find the units of acceleration confusing when presented as m/s^2. You can start out with an example that gives mixed time units such as those in which car performance is expressed. A car which can start from rest and reach a velocity of 90 km/hr in 10 seconds, has an average acceleration of 9 km/hr-s which means that on the average the velocity increases by 9 km/hr each second. This can then be converted to the more useful equivalent form of 9000 m/hr-s = 2.5 m/s^2.

Debatable Issues

"*A radar gun used by a police officer measures your speed at a certain instant in time, whereas an officer in a plane measures the time it takes for you to travel the known distance between two stripes painted on the highway. What is the difference in nature*

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between these two types of measurement and which is the fairer basis for issuing a speeding ticket?"

Would your answer change if one stripe occurred before a rest area and the other occurred after the rest area? Which method would be better for picking out an erratic driver who sporadically zips past cars then lags a bit? The radar is determining an instantaneous velocity, while the airplane method figures average velocity. Which method would be better for filtering out the dangerous drivers in thick traffic, like that described in Everyday Phenomenon Box 1.1? Which would be easier to foil?

Answers to Questions

Q1 a. Speed is distance divided by time, so it will be measured in *boogles/bops*

b. Velocity has the same units as speed, so it will also be measured in *boogles/bops.*

c. Acceleration is change in velocity divided by time, so the units will be *boogles/bops*^{2}.

Q2 a. The unit system of inches and days would give velocity units of inches per day and acceleration of inches per day squared.

b. This would be a terrible choice of units! The distance part would be huge while the time part would be miniscule!

Q3 Since fingernails grow slowly, a unit such as mm/month may be appropriate.

Q4 a. The winner of a race must have the greater average speed, so the plodding tortoise is the leader here.

b. Since the hare has the higher average speed taken over short intervals, he is likely to have the greater instantaneous speed.

Q5 In England "doing 80" likely means driving at 80 km/hour which would be a reasonable highway speed. In the US it means 80 mi/hr. Stating a number without the proper units leaves us uncertain as to what it means.

Q6 A speedometer measures instantaneous speed; the speed that you are driving at a particular instant of time. You can note how it responds immediately as you speed up (accelerate) or slow down (brake).

Q7 In low density traffic, the speed is more likely to be constant, therefore the average and the instantaneous speed will be close for relatively long periods. In high density traffic, the speed is likely to be changing often so that only for short periods the instantaneous speed will equal the average.

Q8 The radar gun measures instantaneous speed - the speed at the instant the radar beam hits the car and is reflected from it. An airplane spotter measures average speed; timing a car between two points which are a known distance apart.

Q9 The vehicle density is the number of vehicles per mile, and is a property of several vehicles. It has nothing to do with vehicle weight.

Q10 When traffic is in a slowly moving jam, the average speeds of different vehicles are essentially the same, at least within a given lane.

Q11 At the front end of the traffic jam, the vehicle density is reduced due to the slower flow behind. Vehicles begin to accelerate and increase the distance between vehicles at the front end of the jam.

Q12 Yes, the velocity changes. The direction of motion has changed after the puck hits the wall, which represents a change in velocity since velocity involves both speed and direction.

Q13 a. Yes. As it moves in a circle the velocity of the ball at each instant is tangent to the circular path. Since this direction changes, the velocity changes even though the speed remains the same.

b. No. Since the velocity is changing, the acceleration is not zero.

Q14 a. No. The velocity changes because the speed and direction of the ball are changing.

b. No. The speed is constantly changing. At the turn-around points the speed is zero.

Q15 No. When a ball is dropped it moves in a constant direction (downwards), but the magnitude of its velocity (speed) increases as it accelerates due to gravity.

Q16 Yes. Acceleration is the change in velocity per unit time. Here the change in velocity is negative (the velocity decreases), so the acceleration is also negative and opposite to the direction of velocity. This is often called a deceleration.

Q17 No. In order to find the acceleration, you need to know the change in velocity that occurs during a time interval. Knowing the velocity at just one instant tells you nothing about the velocity at a later instant of time.

Q18 No. If the car is going to start moving, its acceleration must be non-zero. Otherwise the velocity would not change and it would remain at rest, or stopped.

Q19 No. As the car rounds the curve, the direction of its velocity changes. Since there is a change in velocity (direction even if not magnitude), it must have an acceleration.

Q20 The turtle. As long as the racing car travels with constant velocity (even as large a velocity as 100 MPH), its

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acceleration is zero. If the turtle starts to move at all, its velocity will change from zero to something else, and thus it does have an acceleration.

Q21 a. Yes. Constant velocity is represented by the horizontal line from t= 0 seconds to t = 2 seconds, which indicates the velocity does not change.

b. Acceleration is greatest between 2 and 4 sec where the slope of the graph is steepest.

Q22 a. Yes. The velocity is represented by the slope of a line on a distance-time graph. You can also see that sometime after pt. B the line has a negative slope indicating a negative velocity.

b. Greater. The instantaneous velocities can be compared by looking at their slopes. The steeper slope indicates the greater instantaneous velocity.

Q23 Yes. The velocity is constant during all three different time intervals, that is in each interval where there is a straight line. Note that while the velocities are constant in these intervals, they are not the same in each.

Q24 a. No. The car has a positive velocity during the entire time shown.

b. At pt. A. The acceleration is greatest since the slope between 0 and 2 sec. is greater than between 4 and 6 sec. Between 2 and 4 seconds the slope is zero so the velocity in that interval does not change.

Q25 Between 2 and 4 sec the car travels the greatest distance. Distance traveled can be determined from a velocity-time graph and is represented by the area under the curve, and between 2 and 4 sec. The area is the largest. The car travels the next greatest distance between 4 and 6 sec.

Q26 a. Yes, during the first part of the motion between 0 and 20 seconds where the instantaneous speed is greatest. The average speed for the entire trip must be less than during this interval since for the rest of the trip the speeds are less.

b. Yes. The velocity changes direction. Even if the magnitude of the velocity (speed) is the same, the different directions make the velocities different. Actually, the change is negative so the car decelerates.

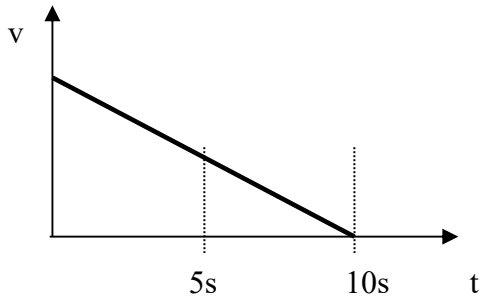
Q27 No. This relationship holds only when the acceleration is constant.

Q28 Velocity and distance increase with time when a car accelerates uniformly from rest as long as the acceleration is positive. As long as it accelerates *uniformly*, the acceleration is constant.

Q29 No. The acceleration is increasing. A constant acceleration is represented by a straight line. Here the curve shown has an increasing, or positive, slope.

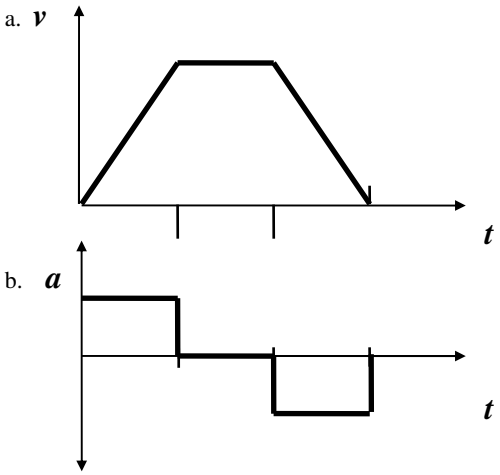
Q30 Yes. For uniform acceleration the acceleration is constant. Since acceleration does not change, the average acceleration equals this constant acceleration.

Q31 The distance covered during the first 5 sec is greater than the distance covered during the second 5 sec. Thus since distance = $v_o t + \frac{1}{2}at^2$, even though acceleration and time are the same for both intervals, the initial velocity at which the car starts the second interval is less than at the beginning of the first, so it will cover a shorter distance. Graphically, we see that during the first part of the trip, the area under the v-t graph is large, indicating a large distance.



Q32

Example plots are shown below assuming symmetric acceleration, but that need not be the case.



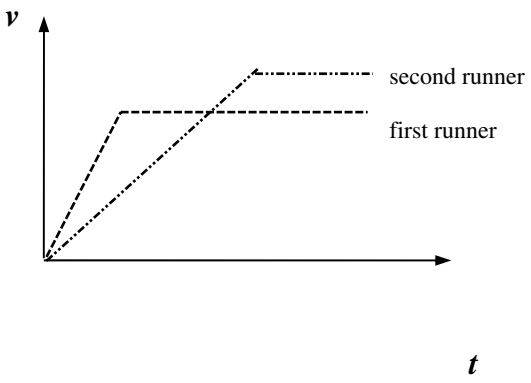
Q33 The second runner. If both runners cover the same distance in the same time interval, then their average velocity has to be the same and the area under the curves on a velocity-time graph are the same. If the first runner reaches maximum speed quicker, the only way the areas

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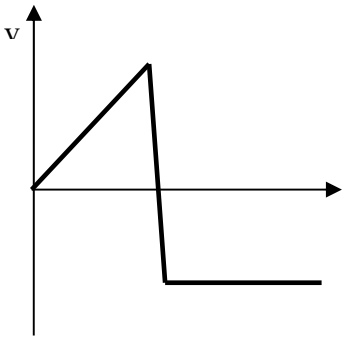
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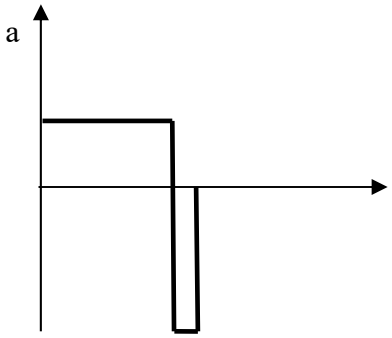
can be equal is if the second runner reaches a higher maximum speed which he then maintains over a shorter portion of the interval.

Q34



Q35



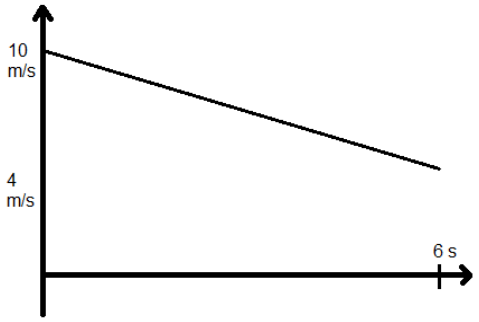


The area of the shaded region is = rectangle +triangle

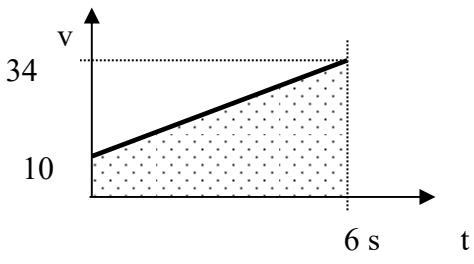
$= (6.0\,\text{s})(10\,\text{m/s}) + (6.0\,\text{s})(34\,\text{m/s} - 10\,\text{m/s})/2$

$= 132\,\text{m}$.

Q37 The speed after 6 seconds is $v = v_o + at = 10\text{m/s} + (-1\text{m/s}^2)(6\text{s}) = 4\text{m/s}$



Q36



Answers to Exercises

E1 59 MPH

E2 4.8 km/hr

E3 0.37 cm/day

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E4 170 mi

E5 360 s = 6 min

E6 7.14 hours

E7 7.02 km

E8 a. 0.028 km/s

b. 100.8 km/hr

E9 104.6 km/hr

E10 3 m/s^2

E11 26.8 m/s

E12 -2 m/s^2

E13 a. 24.4 m/s

b. 60.6 m

E14 a. 2.7 m/s

b.3.8 m

E15 a. 12 m/s

b. 110.0 m

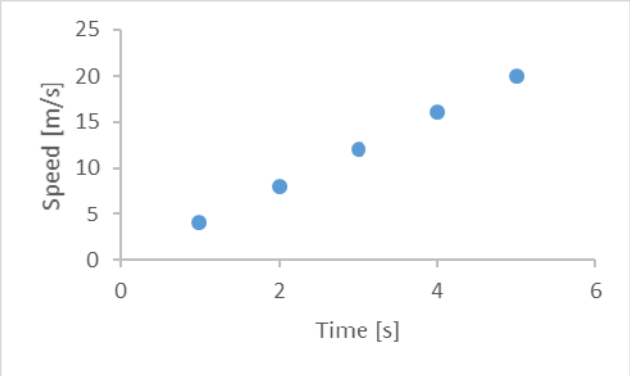
E16 a. 0.8 m/s

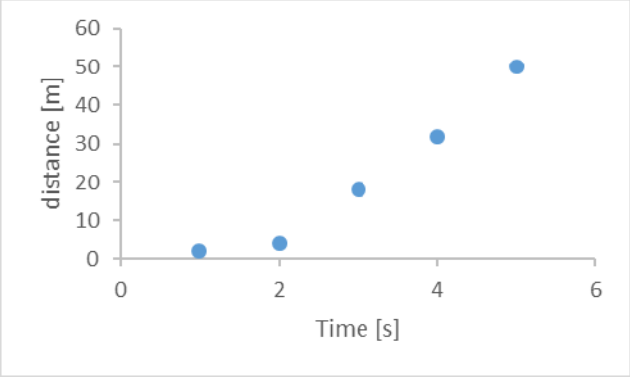
b. 4.8 m

E17 11.1 s

E18 a. Speed: 4 m/s, 8 m/s, 12 m/s, 16 m/s, 20 m/s

b. Distance: 2 m, 4 m, 18 m, 32 m, 50 m

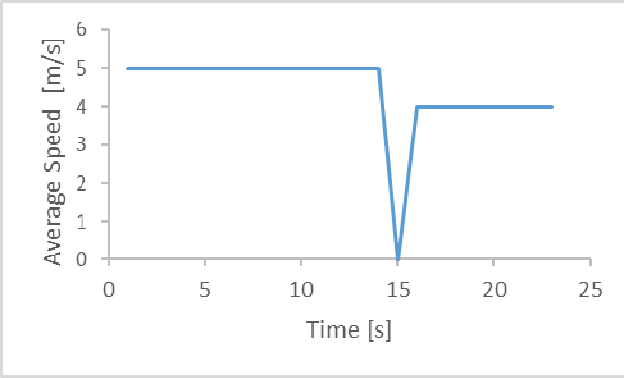




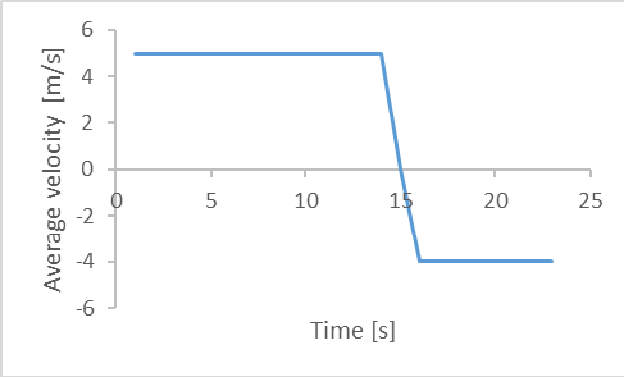
Answers to Synthesis Problems

SP1 a. 22s

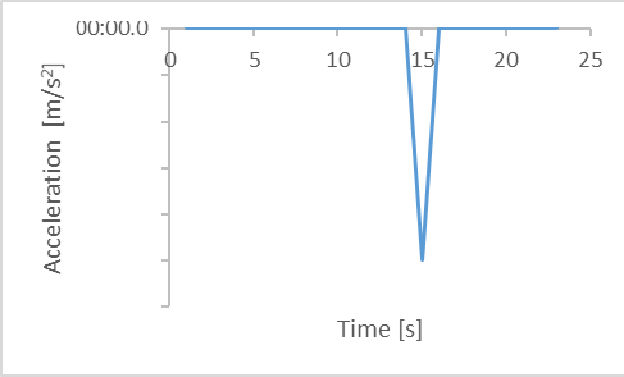
b.



c.



d.



SP2 a. 6 m/s^2

b. 1 m/s^2

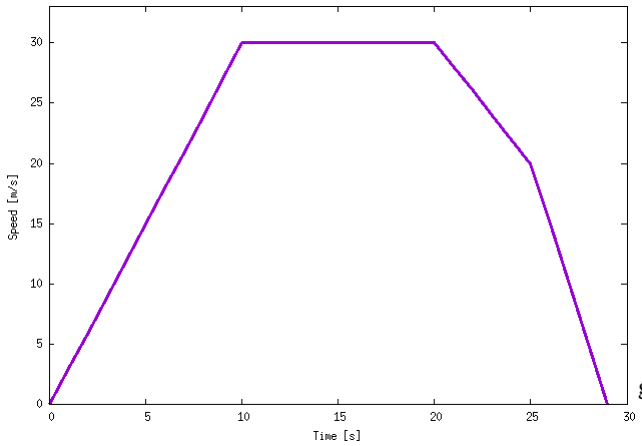
c. 2.25 m/s^2

d. No, because the car spends more time accelerating at 1 m/s^2 and only 1 second accelerating more quickly, the average acceleration is closer to 1 m/s^2.

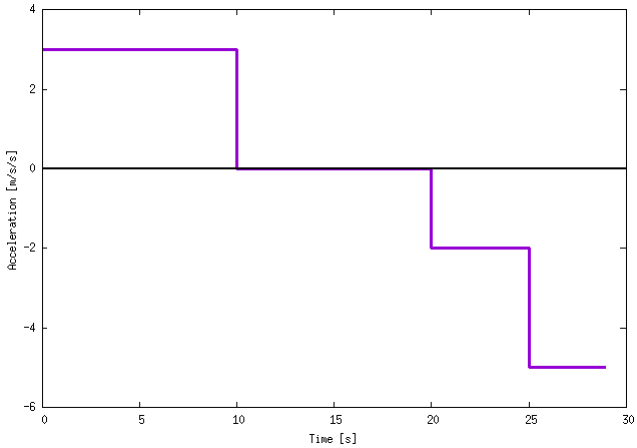
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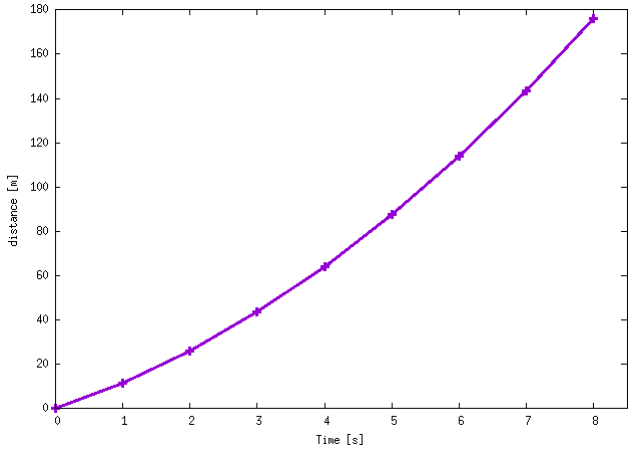
SP3 a.



b.



c. Yes. The car never has a negative velocity (that is, it never moves backwards), so its distance must increase.



Note the parabolic shape of this curve is not obvious over the given time span, but it is indeed a parabola!

SP4 a. 8 s

b. 176 m

c.

Time (s)	0	1	2	3	4	5	6	7	8
Distance (m)	0	11.5	26	43.5	64	87.5	114	143.5	176

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SP5

a.

Time (s)	Distance (m)	
	Car A	Car B
1	2.1	7
2	8.4	14
3	18.9	21
4	33.6	28

b. Car A passes car B at between 3 and 4 seconds

c. To find a better time you could graph the distance versus time for each car and see where the two curves cross. To find the exact time when the distance is the same for both cars, note that then $d_A = d_B = \frac{1}{2} a_A t^2 = v_B t$. Thus $t_{meet} = 0$ s and $(2\ v_B/a_A) = 3.33$s

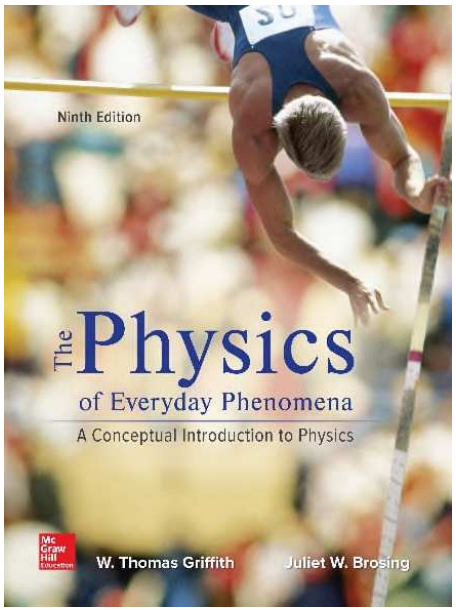
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The Physics of Everyday Phenomena

A Conceptual Introduction to Physics

Ninth Edition



W. Thomas Griffith
Juliet W. Brosing

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Chapter 2

Describing Motion

Lecture PowerPoint

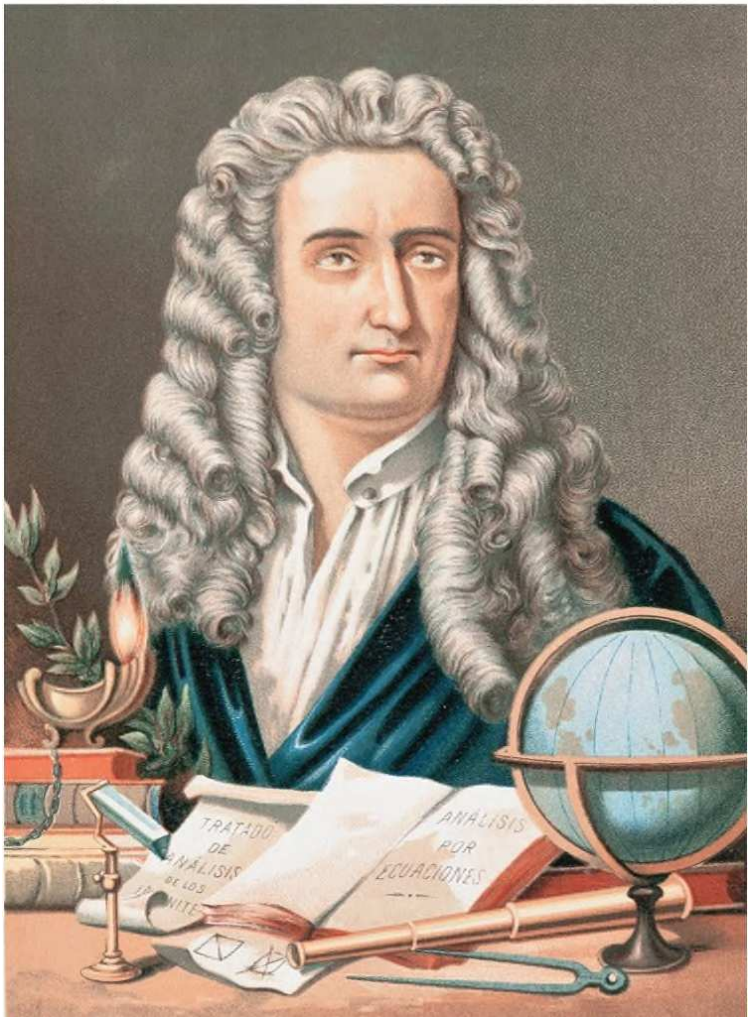
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Newton's Theory of Motion

To see well, we must stand on the shoulders of giants.

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First Things First

Before we can accurately describe motion, we must provide clear definitions of our terms.

The meanings of some terms as used in physics are different from the meanings in everyday use.

Precise and specialized meanings make the terms more useful in describing motion.

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Why do we need clear, precise definitions?

What's the difference between:

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

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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.

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

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Unit Conversion 1

Convert 70 kilometers per hour to miles per hour:

1 km = 0.6214 miles

1 mile = 1.609 km

$$70\ \frac{\cancel{\text{km}}}{\mathbf{h}} \times \frac{0.6214\ \mathbf{miles}}{1\ \cancel{\text{km}}} = \left(70 \times 0.6214\right)\frac{\mathbf{miles}}{\mathbf{h}}$$

$$= 43.5\ \frac{\text{mi}}{\text{h}}$$

$$= 43.5\ \text{MPH}$$

It is easier to multiply by 0.6214 than divide by 1.609… either will work on a calculator equally well.

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Unit Conversion 2

Convert 70 kilometers per hour to meters per second:

1 km = 1000 m

1 hour = 60 min

1 min = 60 sec

$$70\ \frac{\cancel{\text{km}}}{\mathbf{h}} \times \frac{1000\ \mathbf{m}}{1\ \cancel{\text{km}}} = (70 \times 1000)\frac{\mathbf{m}}{\mathbf{h}}$$

$$= 70{,}000\ \frac{\text{m}}{\text{h}}$$

$$70{,}000\ \frac{\mathbf{m}}{\cancel{\text{h}}} \times \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \times \frac{1\ \cancel{\text{min}}}{60\ \mathbf{s}} = \frac{70{,}000}{60 \times 60}\frac{\mathbf{m}}{\mathbf{s}}$$

$$= 19.4\ \text{m/s}$$

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Average Speed 1

Kingman to Flagstaff:

120 mi ÷ 2.4 hr = 50.0 mph

Flagstaff to Phoenix:

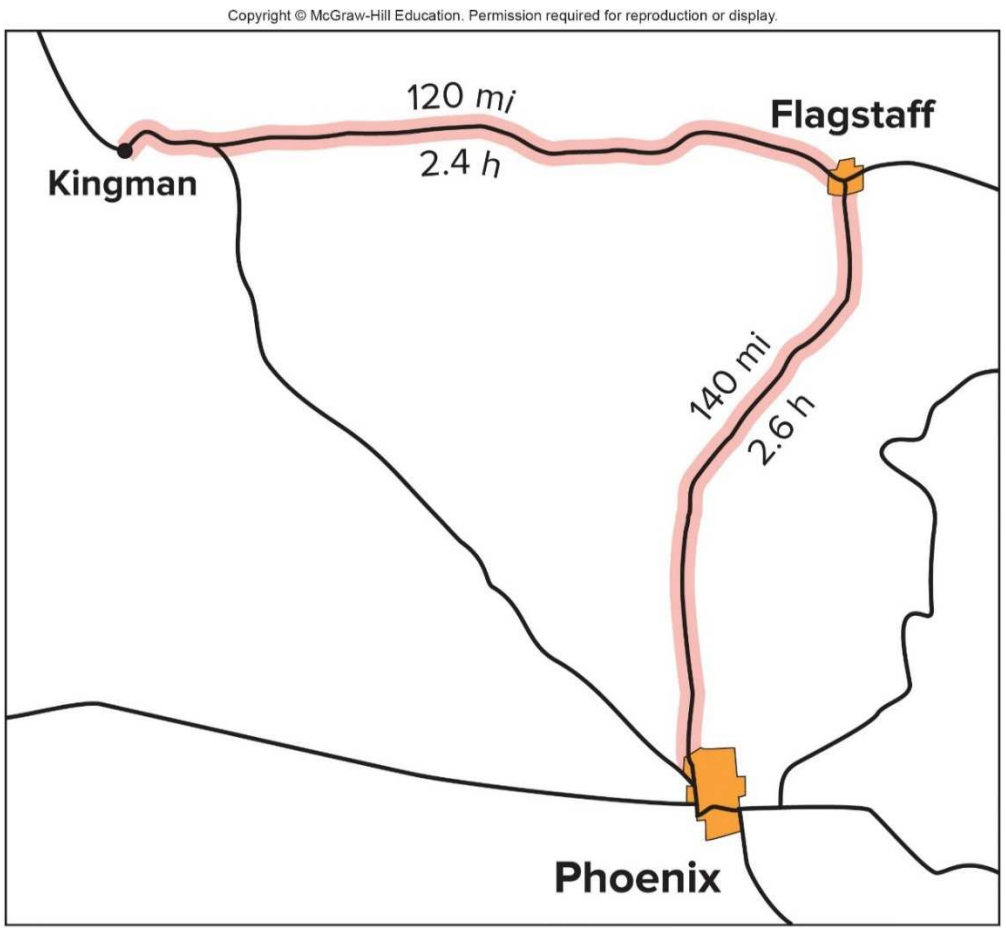
140 mi ÷ 2.6 hr = 53.8 mph

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



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Average Speed 2

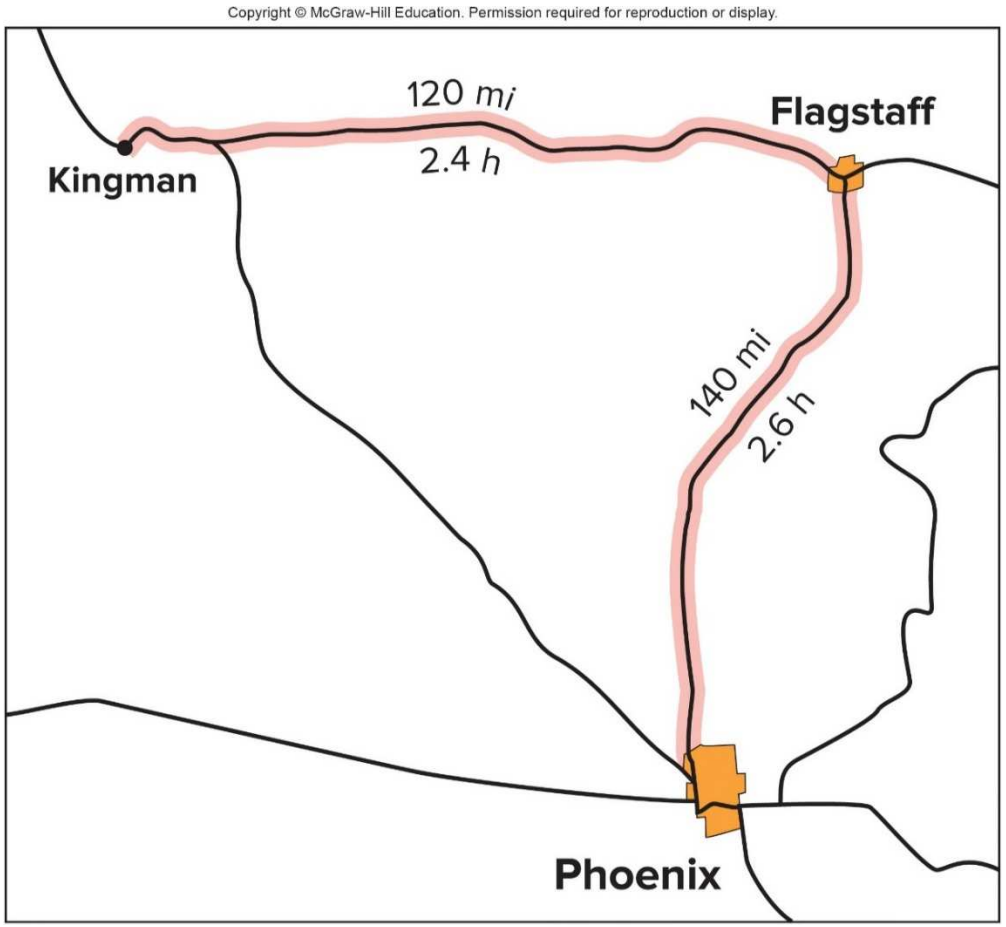
Kingman to Flagstaff:

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?



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Average Speed 3

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.

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What does a car's speedometer measure?

a) Average speed

b) Instantaneous speed

c) Average velocity

d) Instantaneous velocity

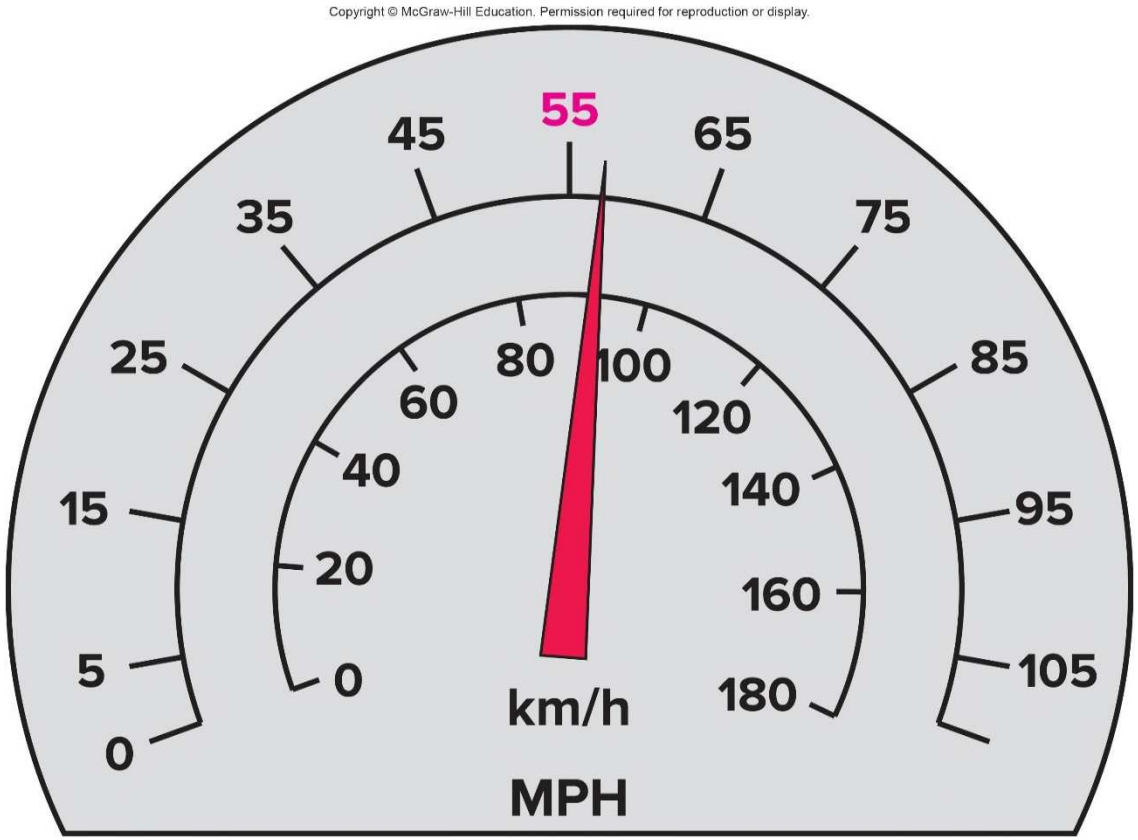
b) A speedometer measures ***instantaneous speed***.

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

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Instantaneous Speed

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



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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.

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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 OR both.

A speedometer doesn't indicate direction, so it indicates instantaneous speed but not velocity.

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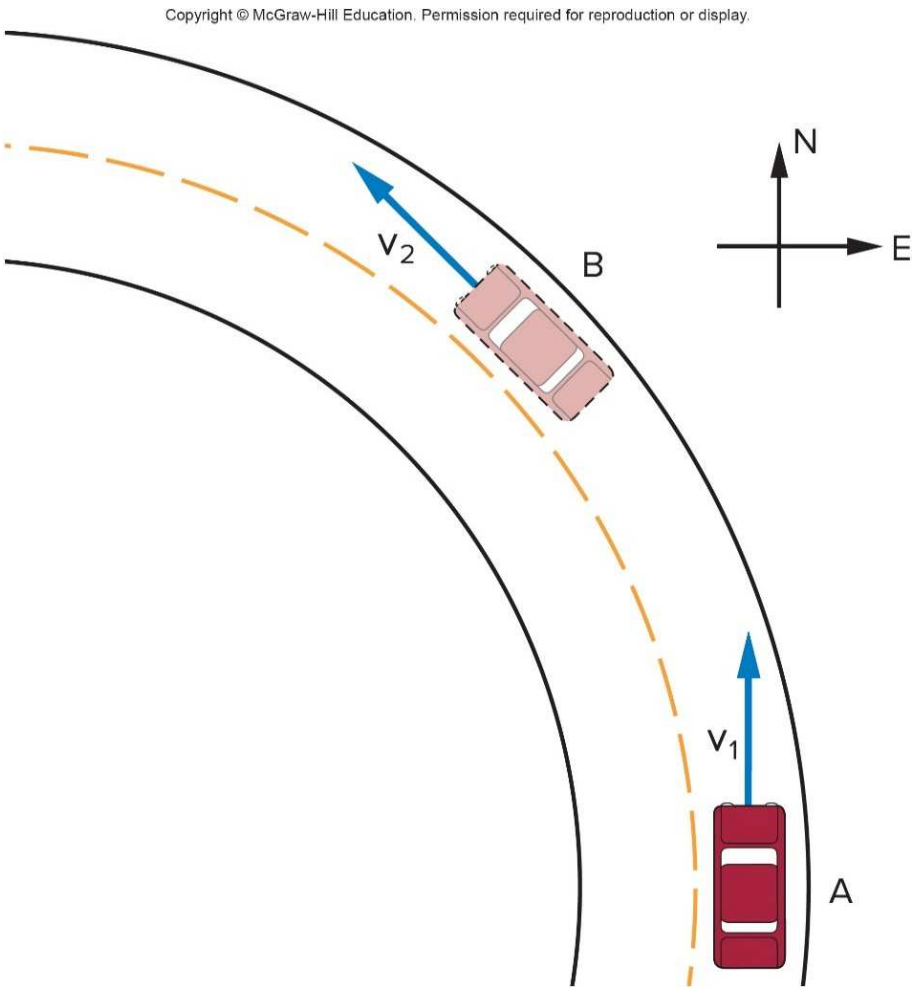
A car goes around a curve at constant speed. Is the car's velocity changing?

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.



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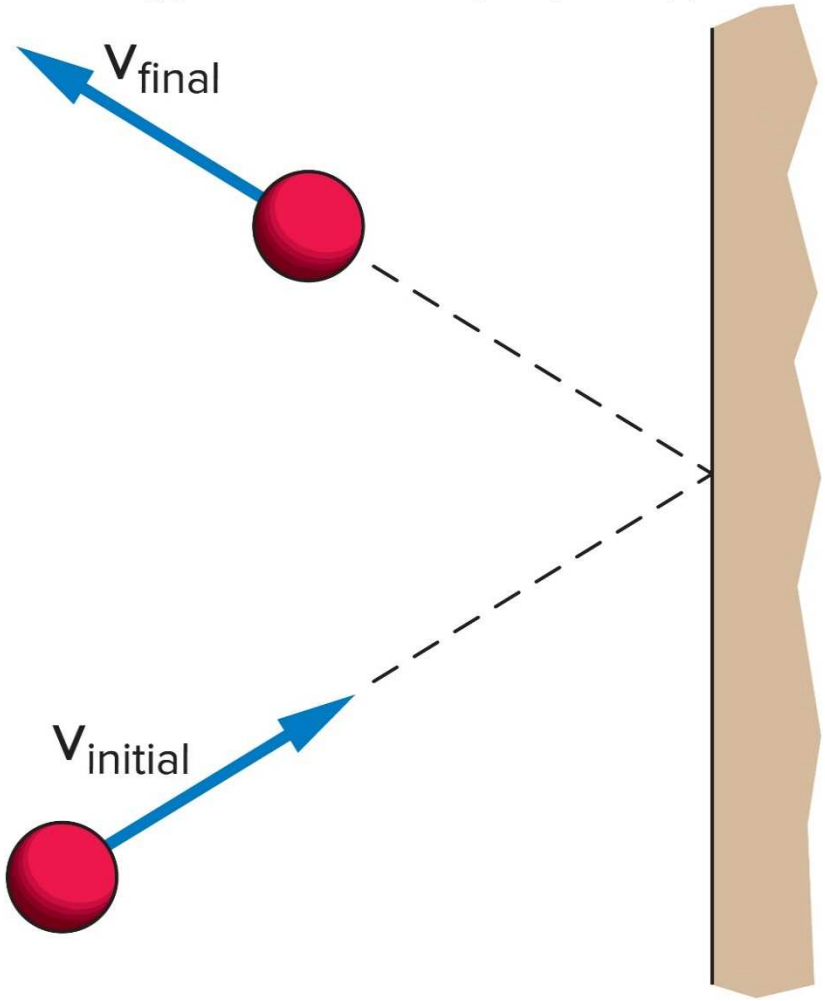
Changing Velocity

A force is required to produce a change in either the magnitude (speed) or direction of velocity.

For the car to round the curve, friction between the wheels and the road exerts a force to change the car's direction.

For a ball bouncing from a wall, the wall exerts a force on the ball, causing the ball to change direction.

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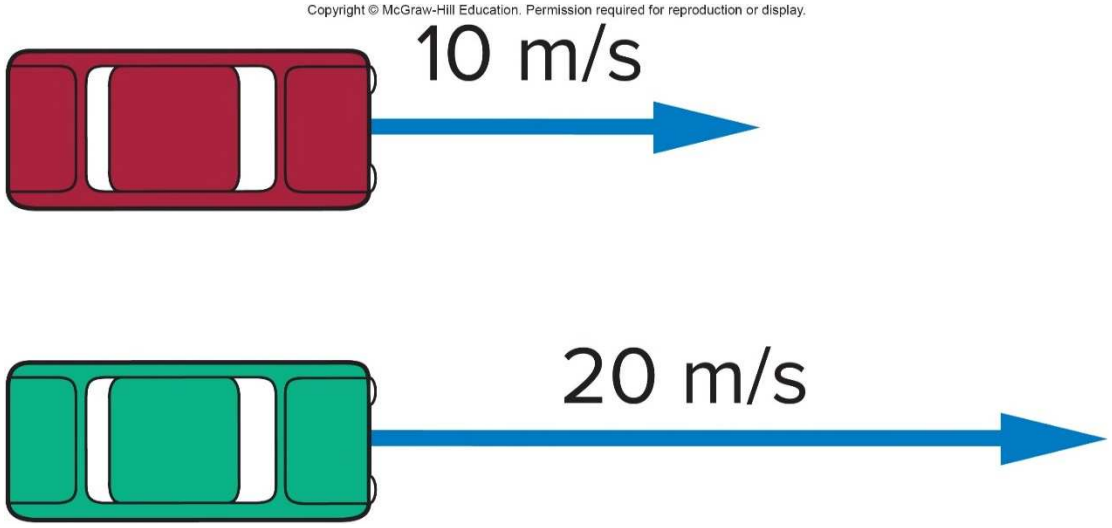
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Instantaneous Velocity

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.

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Acceleration 1

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.

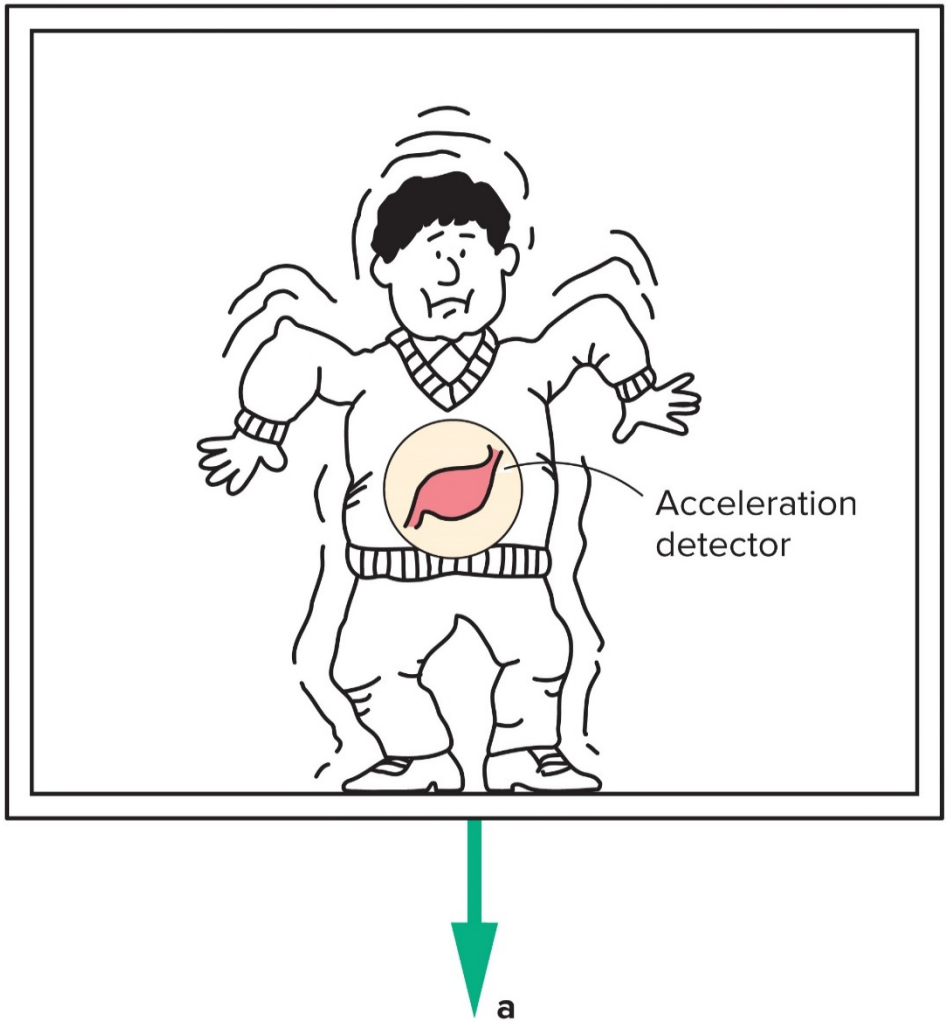
Acceleration can be either a change in the object's speed or direction of motion.

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Acceleration 2

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

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Acceleration 3

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.

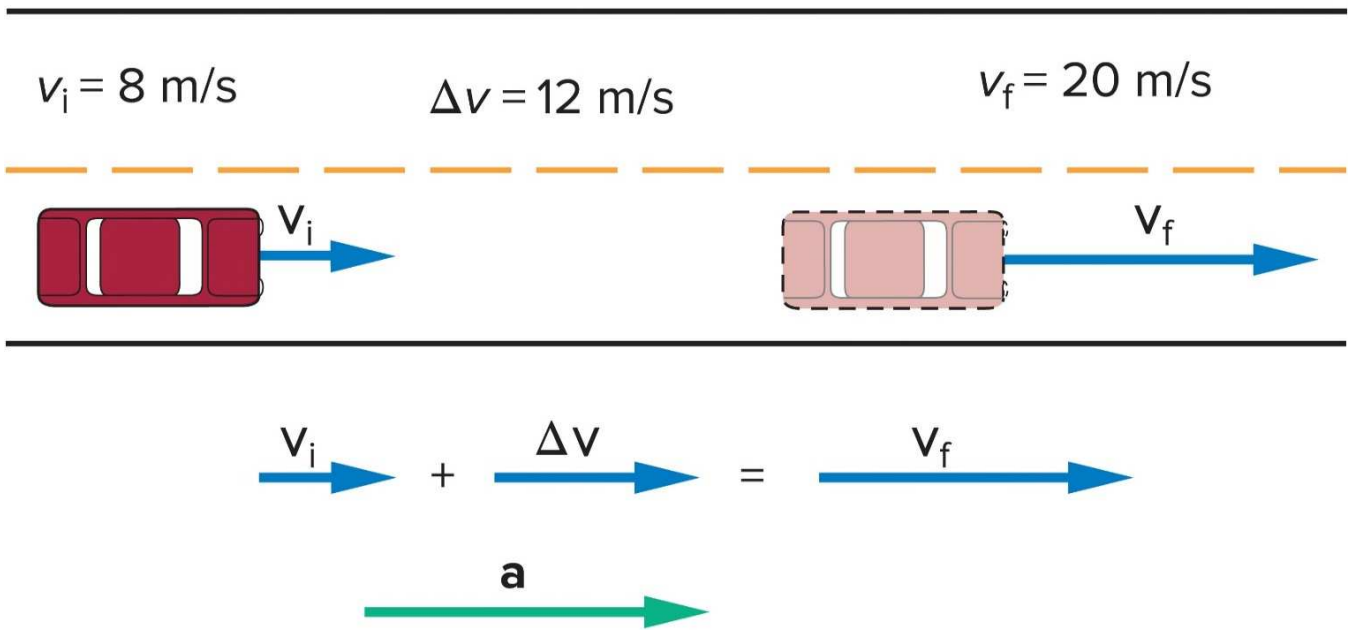
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Acceleration 4

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.

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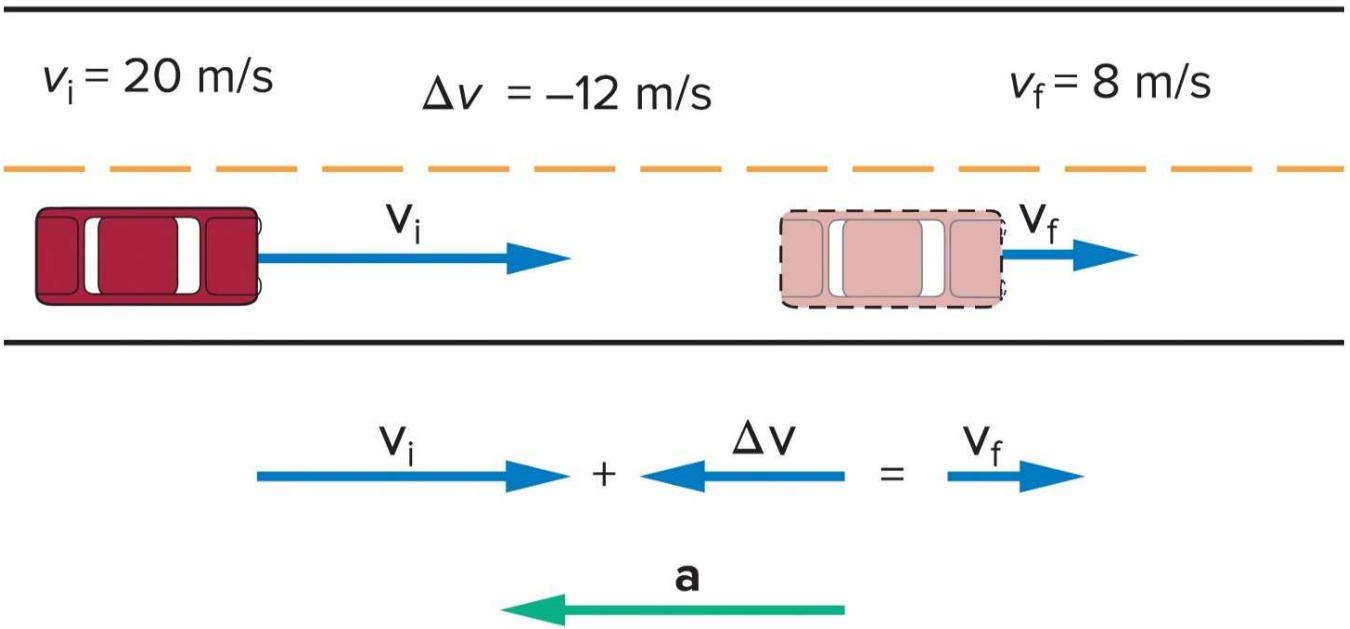
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Acceleration 5

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.

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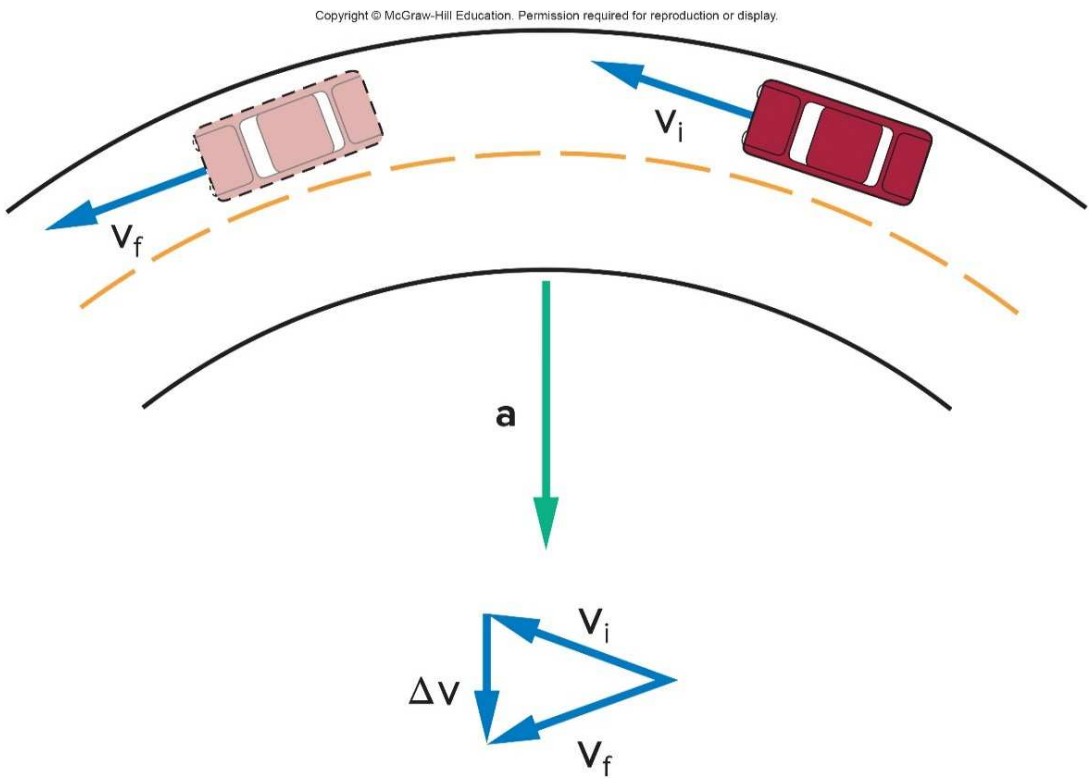


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Acceleration 6

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.



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Average Acceleration 1

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:

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

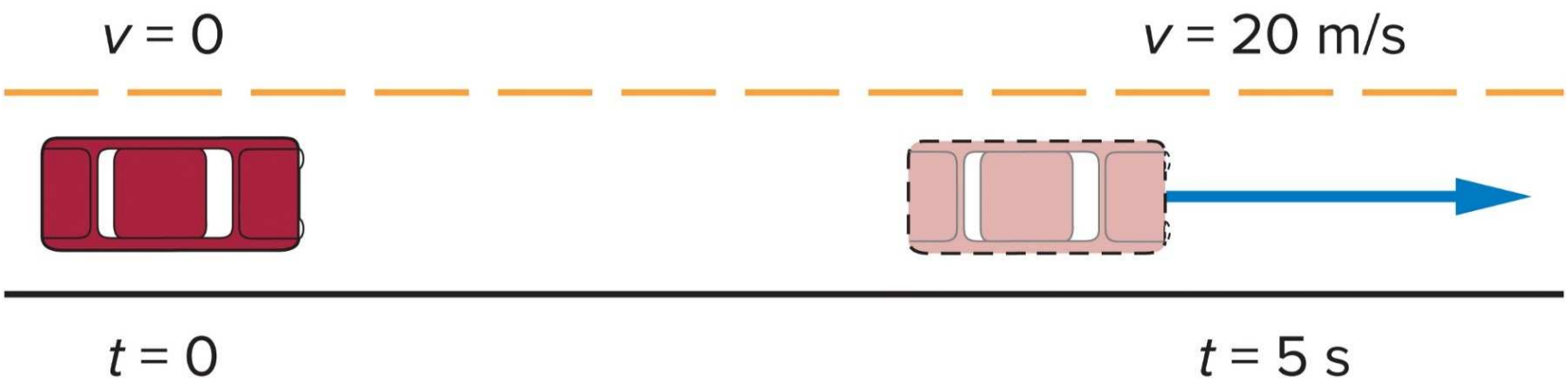
$$\mathbf{a} = \frac{\Delta \mathbf{v}}{t}$$

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

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Average Acceleration 2

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

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

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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.

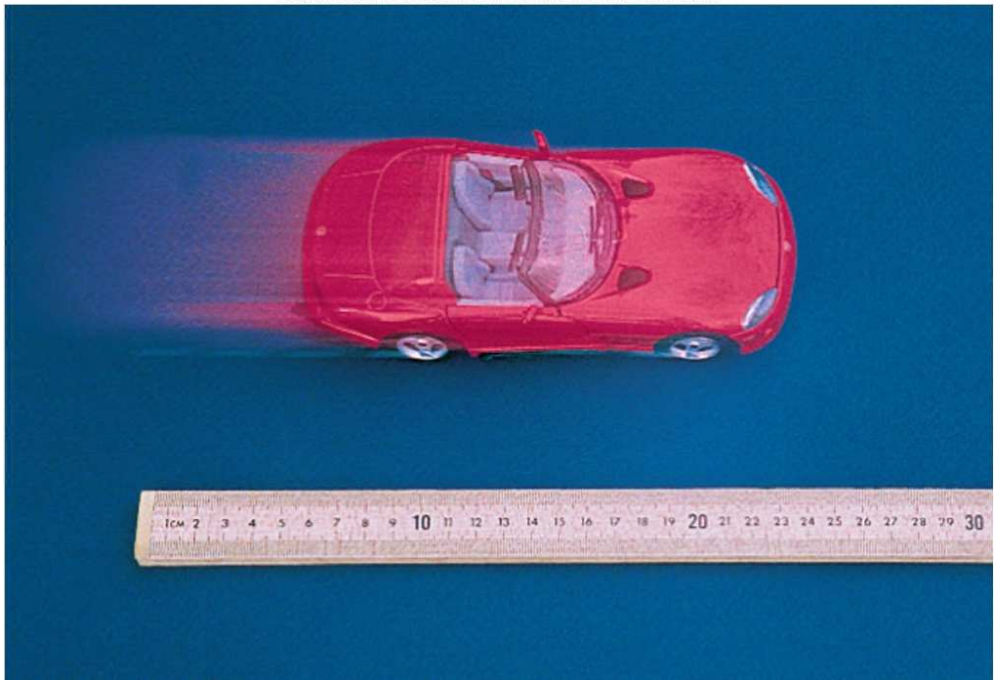
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Graphing Motion

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

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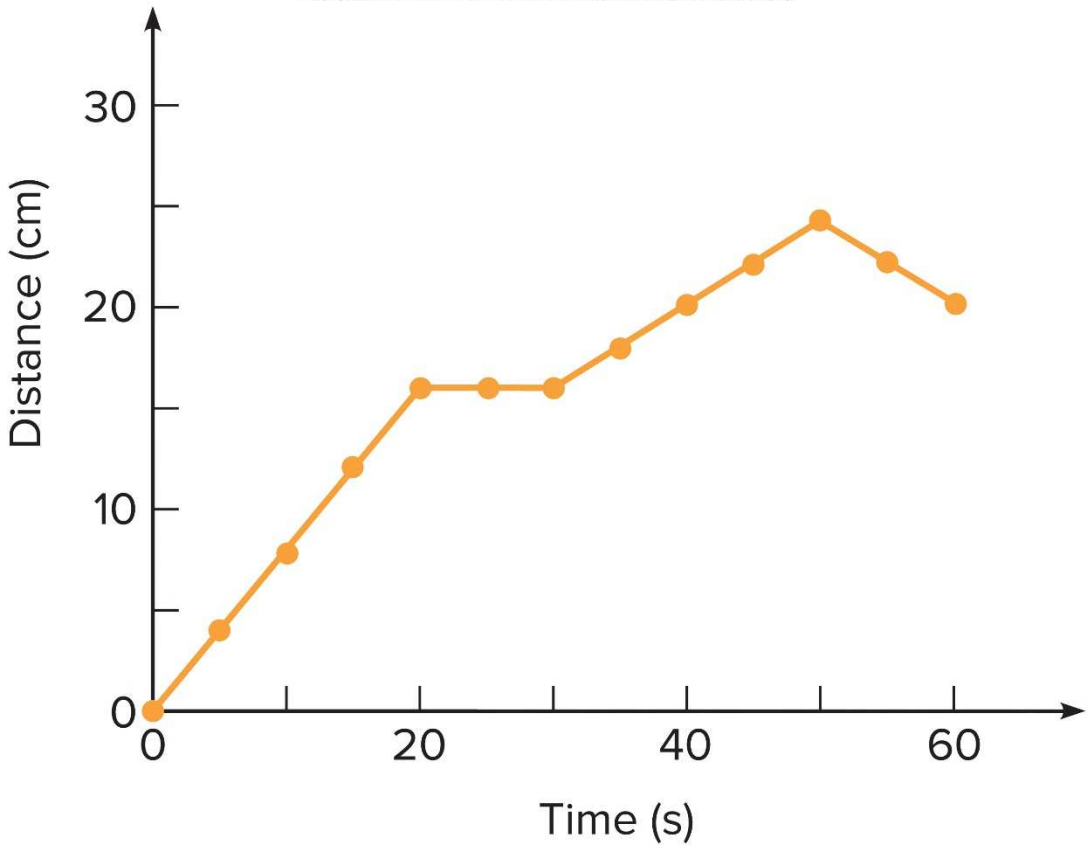
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To graph the data in the table, let the horizontal axis represent ***time***, and the vertical axis represent ***distance***.

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.

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The graph displays information in a more useful manner than a simple table. It is much easier to determine the answers to the following questions with a graph.

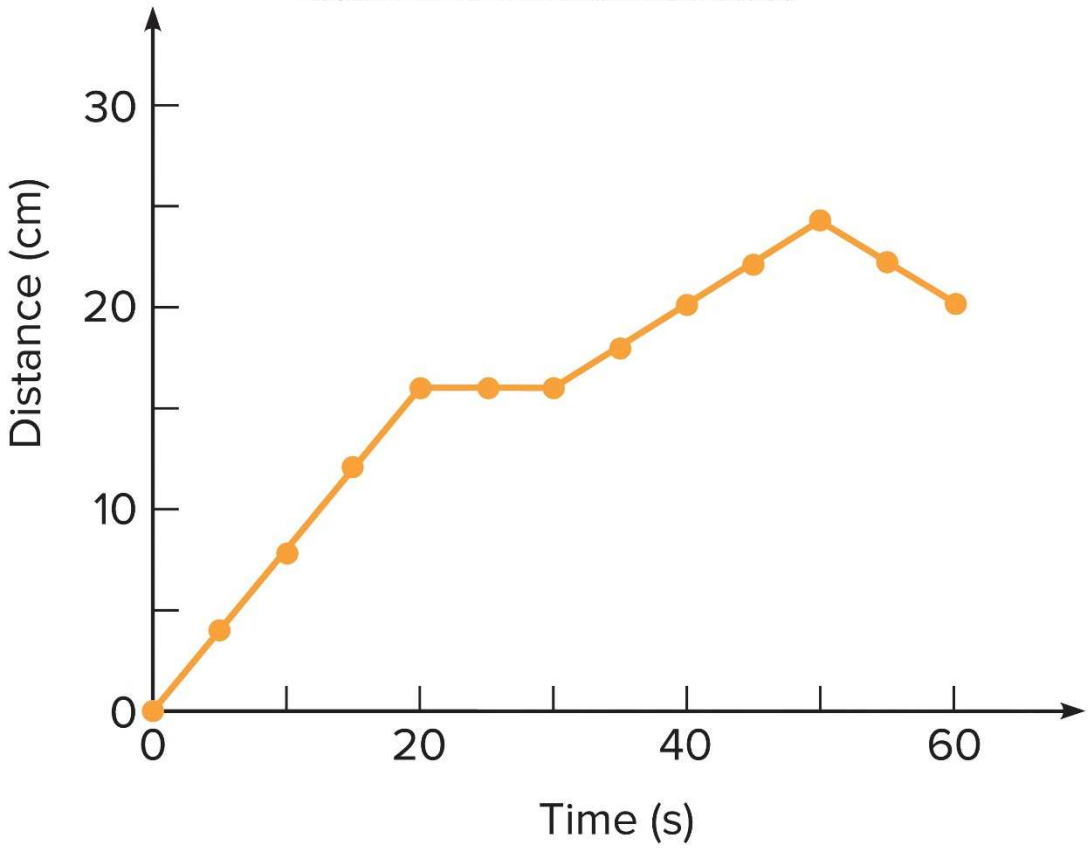
When is the car moving the fastest?

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?

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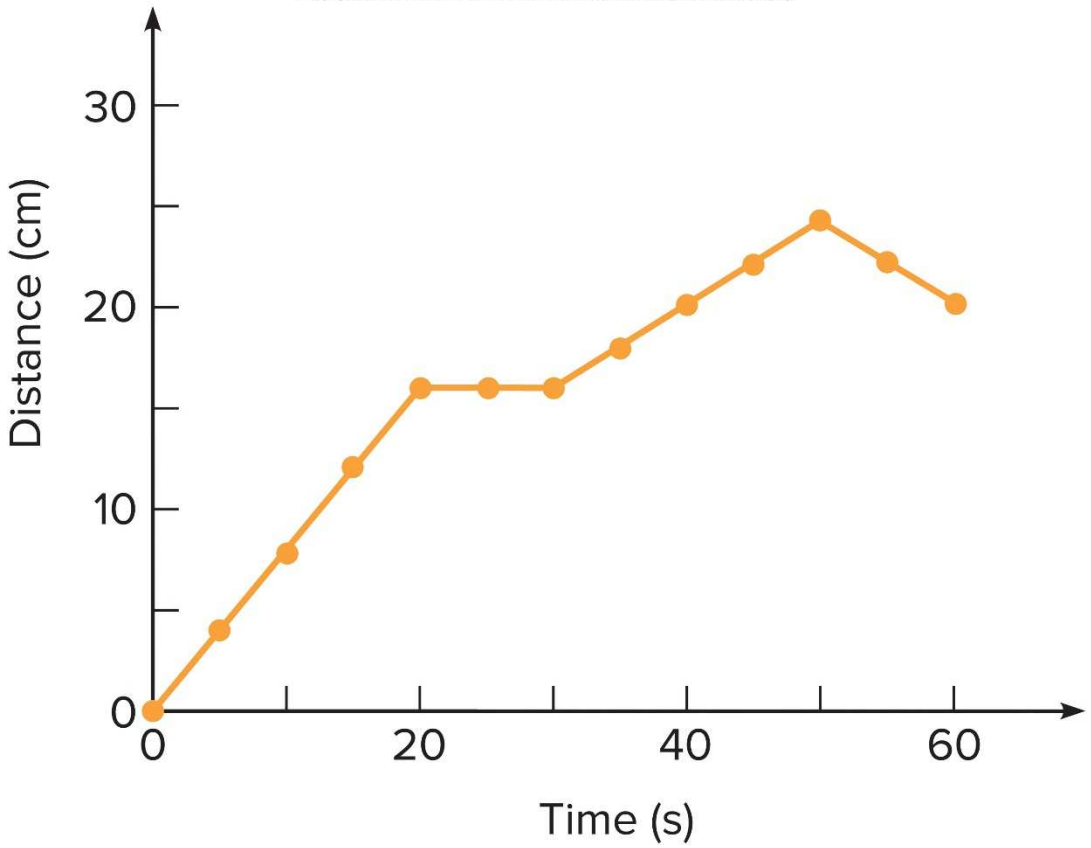
The ***slope*** at any point on the ***distance-versus-time*** graph represents the instantaneous ***velocity*** at that time. 1

Slope is change in vertical quantity divided by change in horizontal quantity.

"rise over run"

- steepest "slope" is between 0 s and 20 s, this is where it is moving the fastest.
- slope is zero (flat) between 20 s and 30 s, here it is not moving. Notice that the value of the distance doesn't change.

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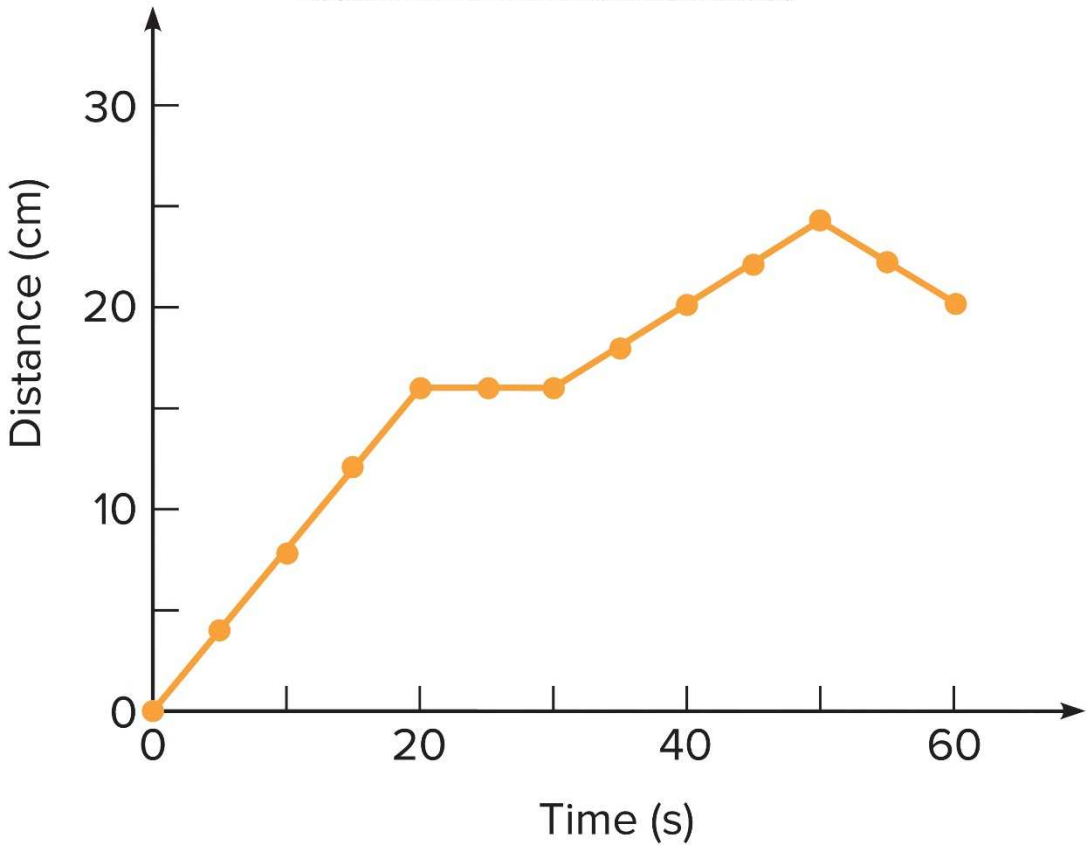
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The ***slope*** at any point on the ***distance-versus-time*** graph represents the instantaneous ***velocity*** at that time. 2

At what time does the car start moving in the opposite direction?

- The slope is negative between 50 s and 60 s. This would imply the velocity is negative, it has thus changed direction. Note that the value for the distance has decreased.

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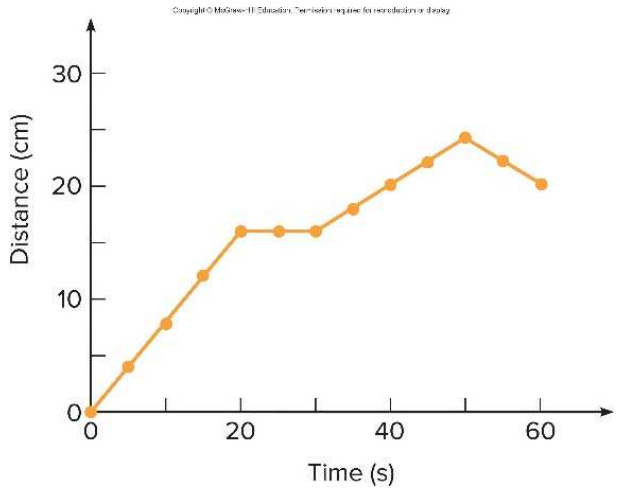


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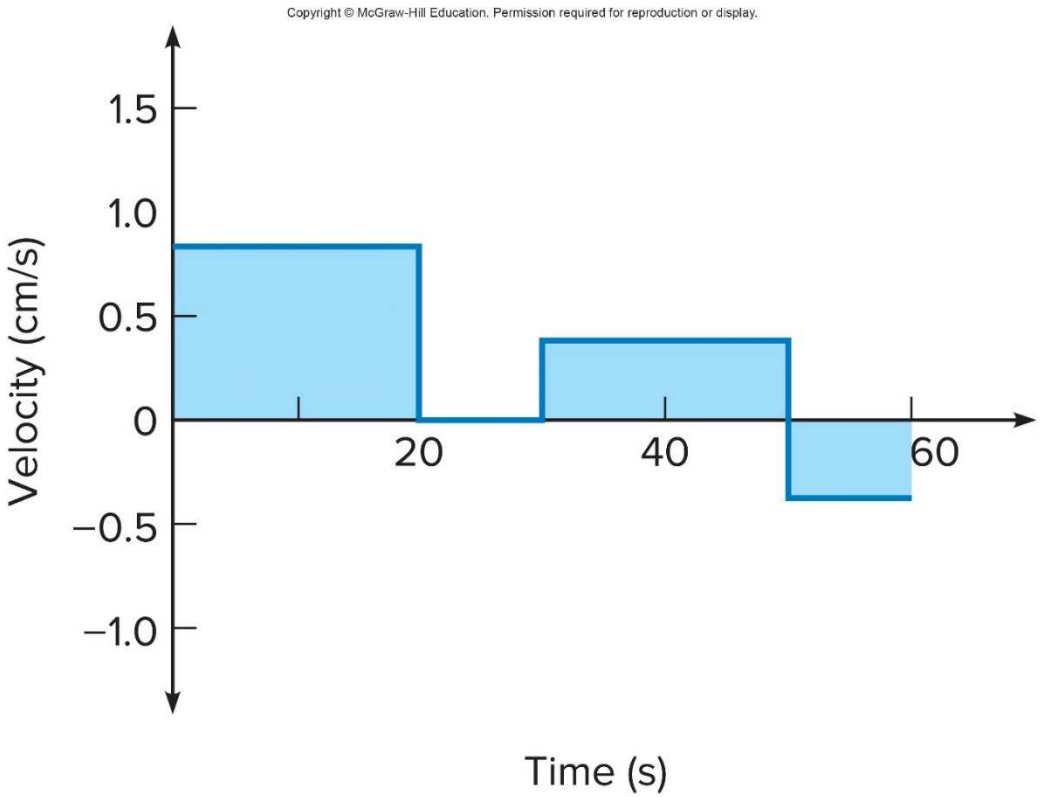
To summarize the car's velocity information, let the horizontal axis represent ***time***, and the vertical axis represent ***velocity***.

The velocity is constant wherever the slope of the distance-vs-time graph is constant.

The velocity changes only when the distance graph's slope changes.



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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).

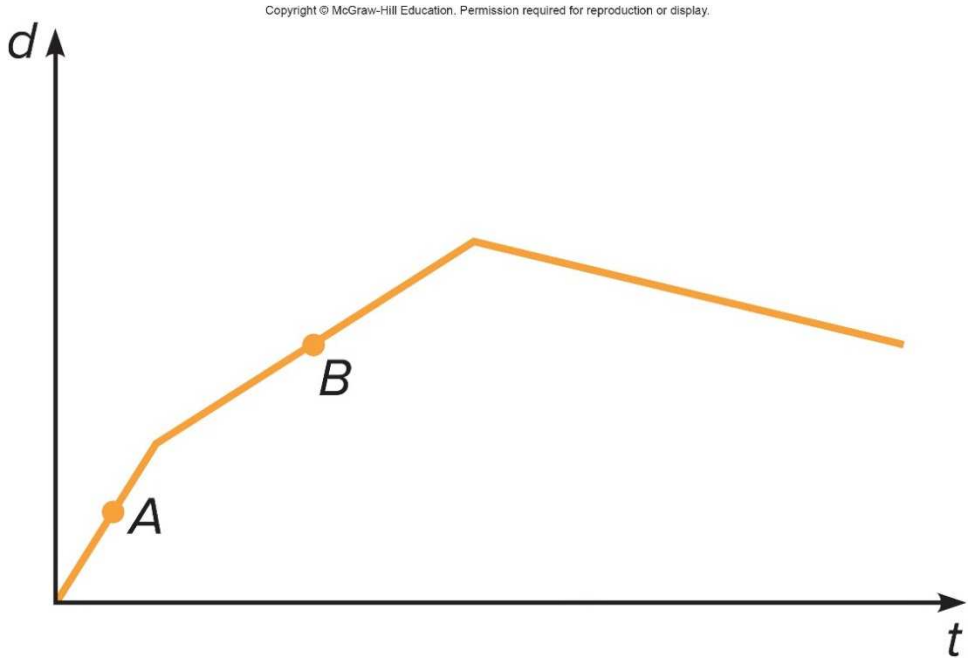
b) Yes, during the second segment (labeled B).

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).

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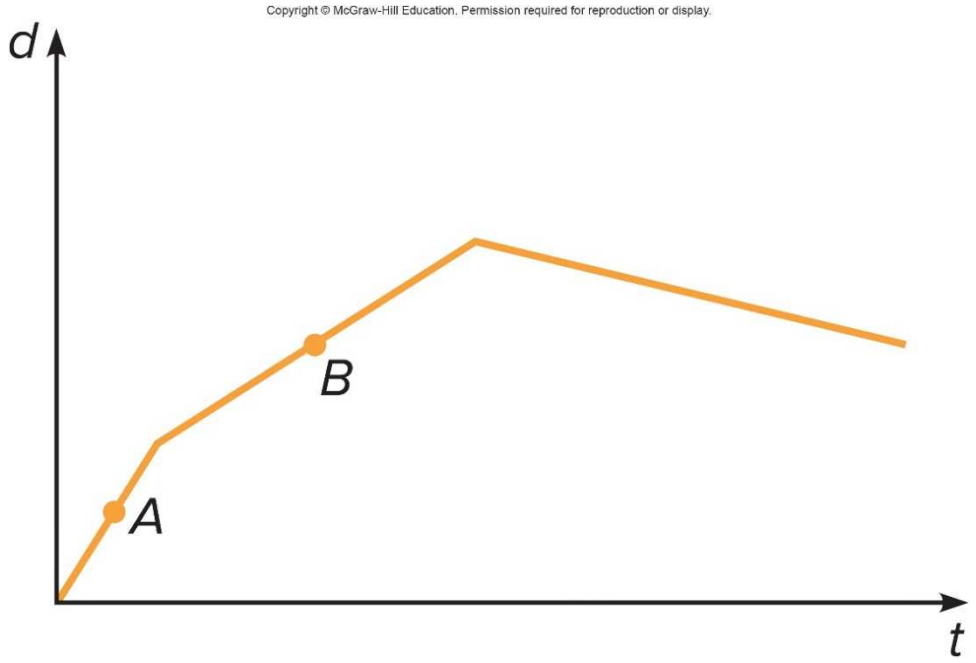
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Is the instantaneous velocity at point A greater or less than that at point B?

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.

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

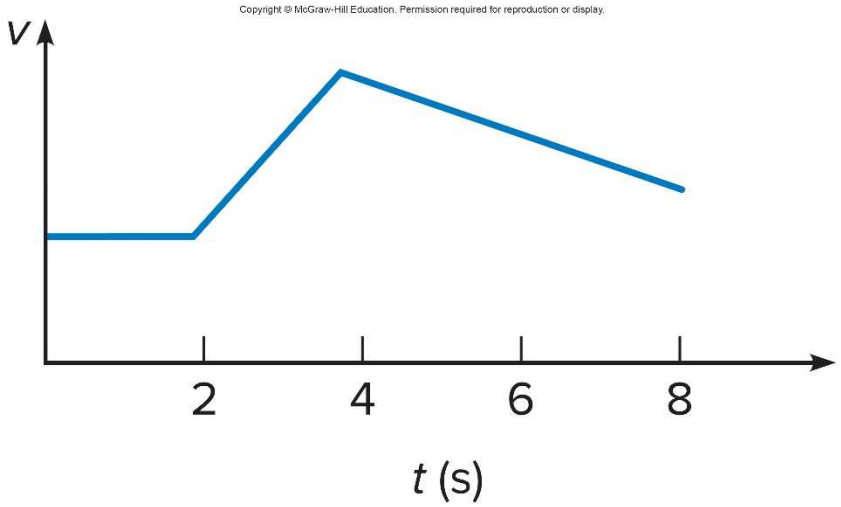
a) Yes, between 0 s and 2 s.

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.

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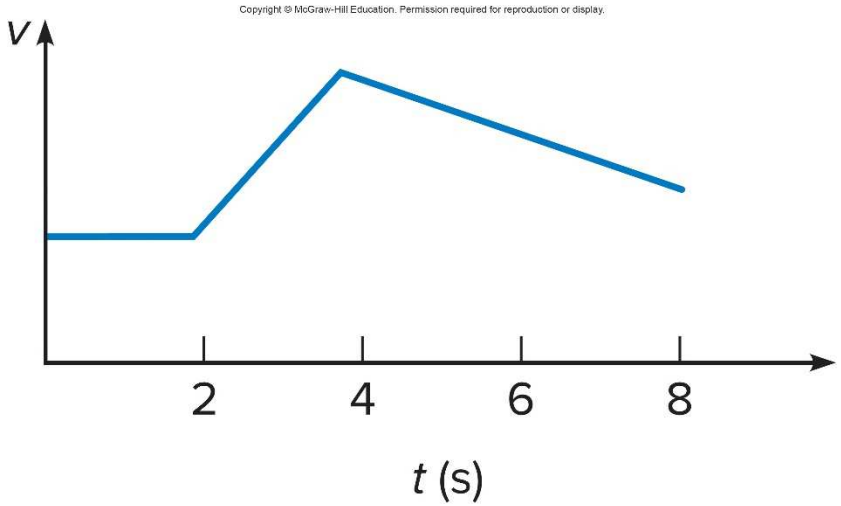
In the graph shown, during which time interval is the acceleration greatest?

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.

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

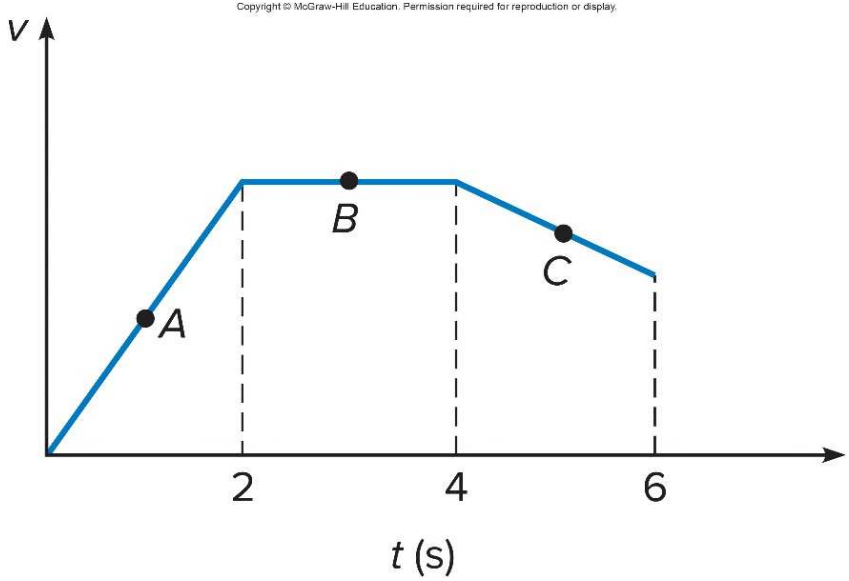
a) Yes, between 0 s and 2 s.

b) Yes, between 2 s and 4 s.

c) Yes, between 4 s and 6 s.

d) No, never.

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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.

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

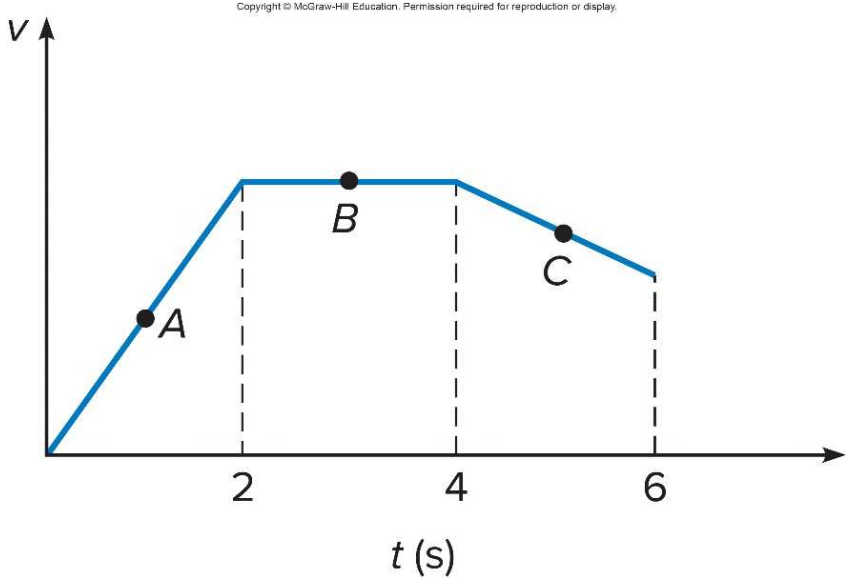
a) Point A

b) Point B

c) Point C

d) The acceleration does not change.

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a) The magnitude of the acceleration is greatest when the velocity is changing the fastest. This is where the graph of velocity versus time is steepest (has the greatest slope), so point A.

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

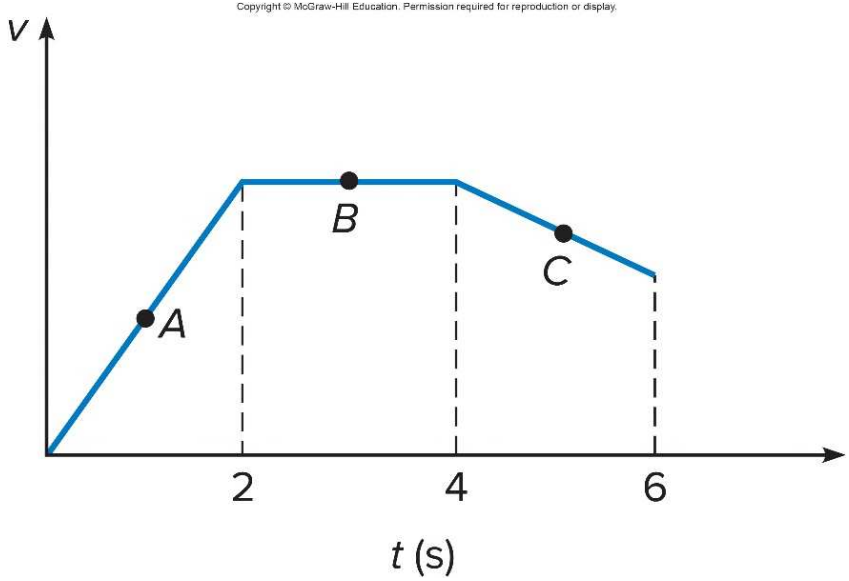
a) Between 0 s and 2 s.

b) Between 2 s and 4 s.

c) Between 4 s and 6 s.

d) It is the same for all time intervals.

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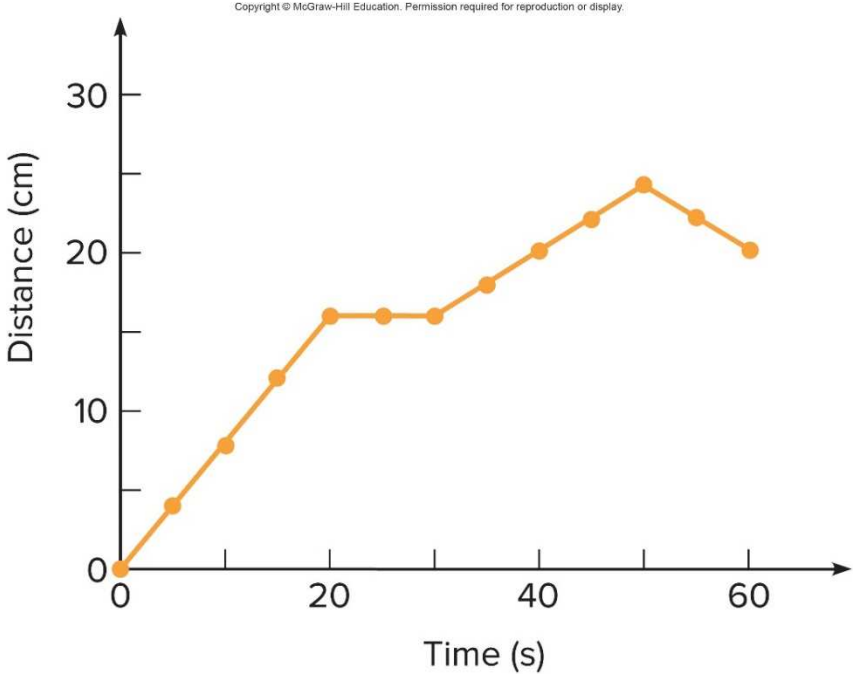


b) The distance traveled is greatest when the area under the velocity curve is greatest. This occurs between 2 s and 4 s.

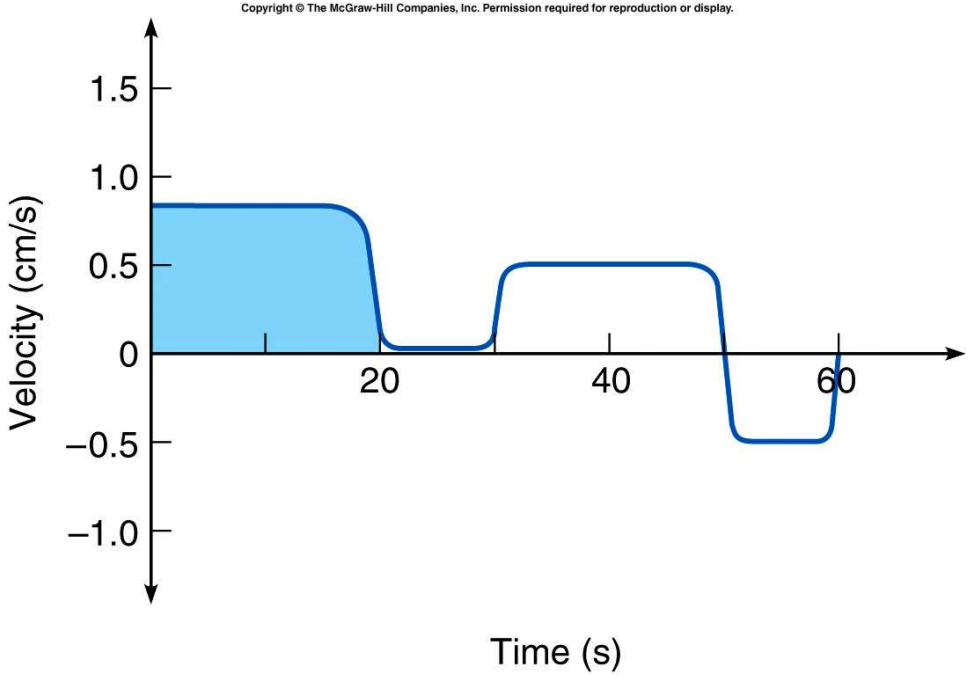
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What does the acceleration graph look like for the car motion we were examining earlier? Here are the position and velocity graphs.

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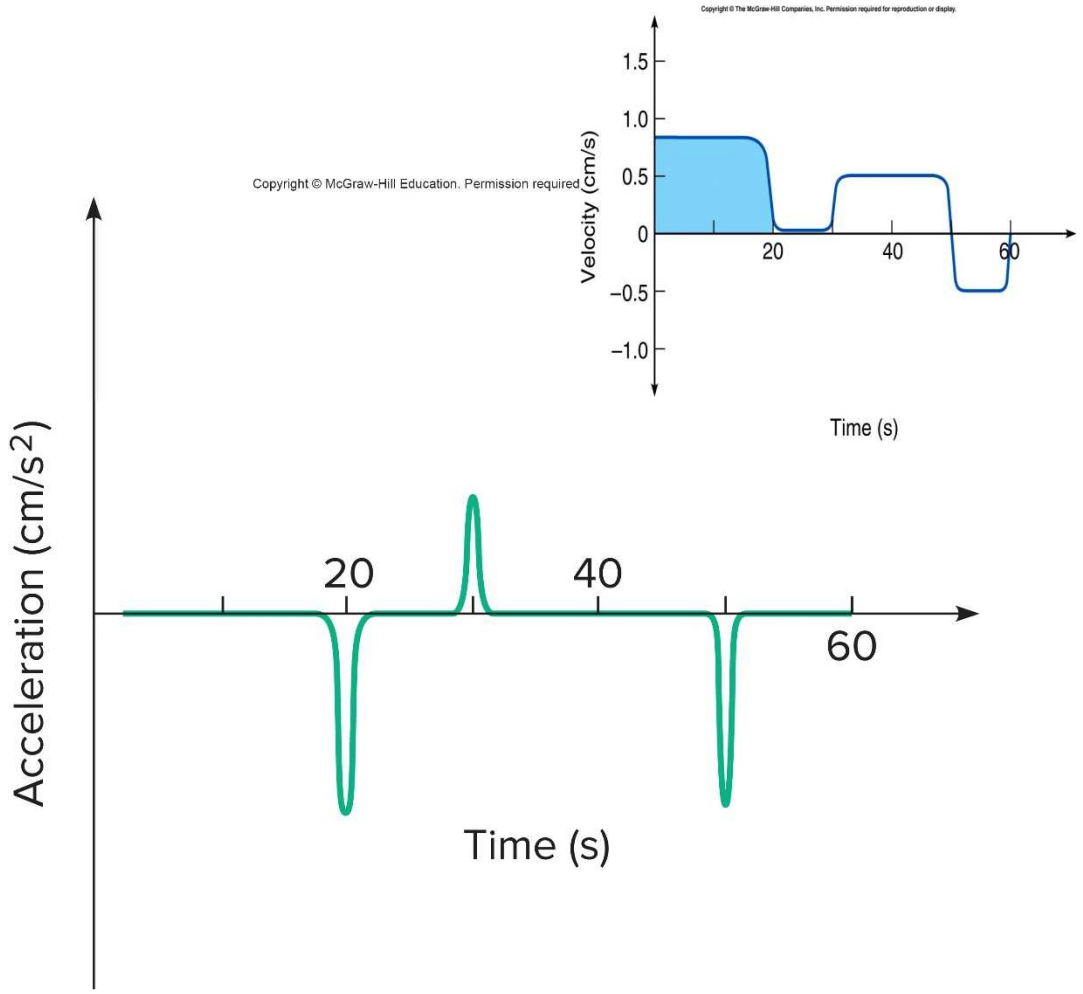
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A graph of the velocity graph's slope yields the acceleration-versus-time graph: let the horizontal axis represent ***time***, and the vertical axis represent ***acceleration***.

At 20 s a rapid decrease in velocity shows up here as a downward spike.

At 30 s the velocity increases from zero to a constant value, and shows up here as an upward spike.

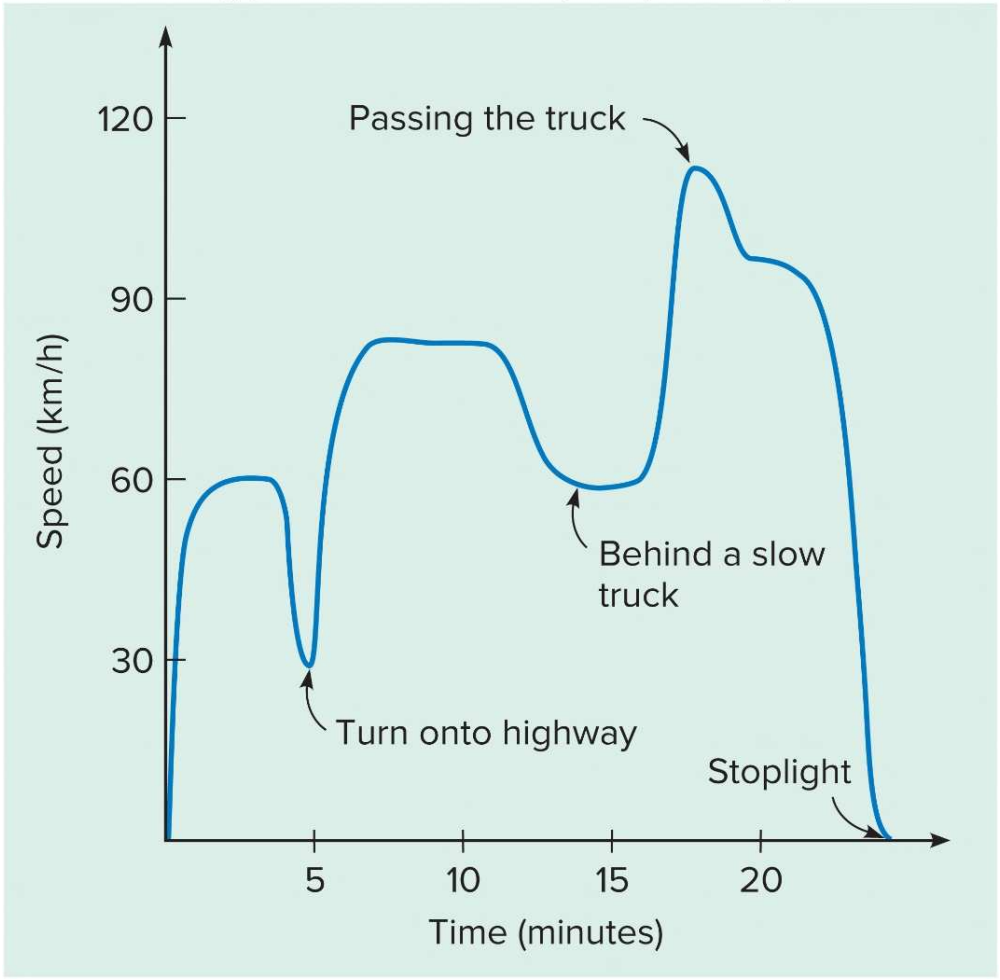
Etc.



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The graph of the speed of a car traveling on a local highway illustrates the relationship between acceleration and velocity.

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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, so the object is moving with constant velocity.

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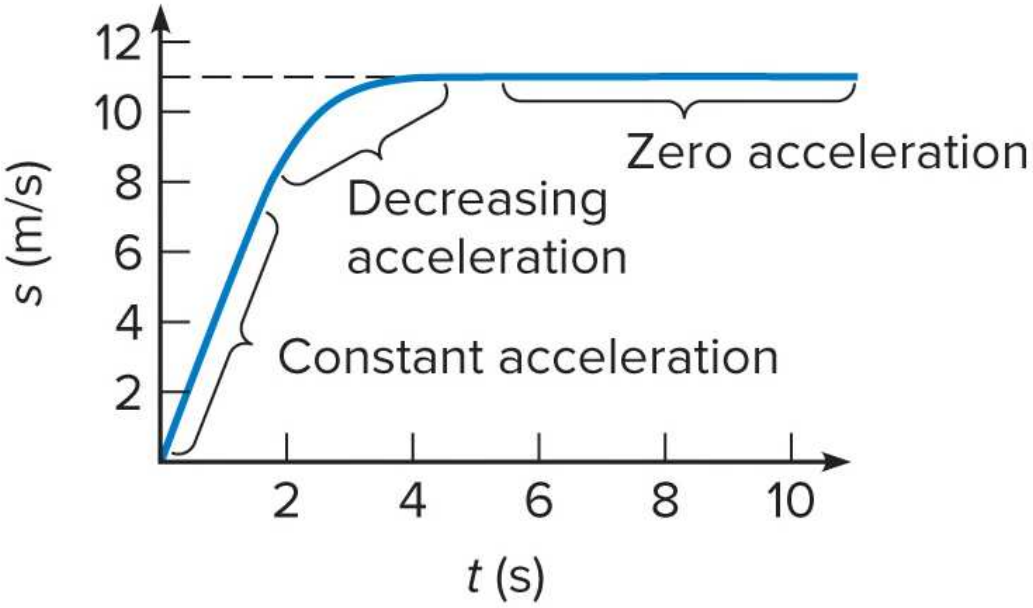
How does the acceleration change for a sprinter?

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.

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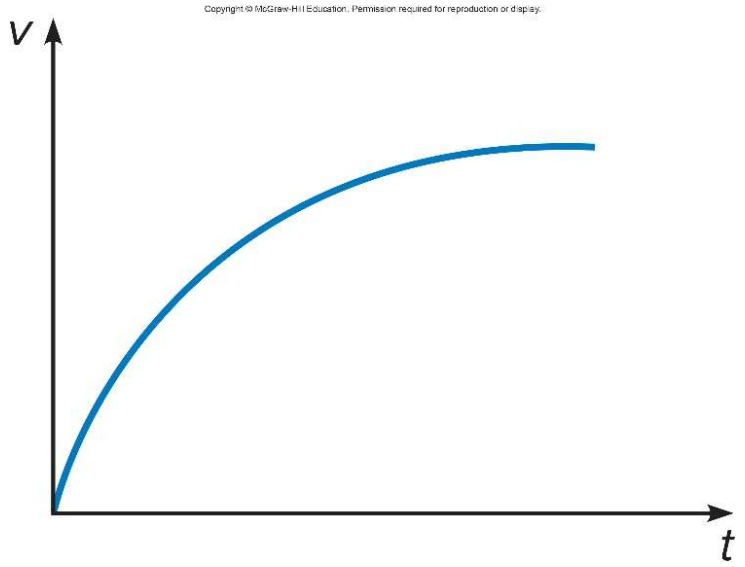
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The velocity graph of an object is shown. Is the acceleration of the object constant?

a) Yes.

b) No.

c) It is impossible to determine from this graph.



b) No, the acceleration is NOT constant. 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.

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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.

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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 speeding up at a constant rate would have a constant acceleration.

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The velocity graph for uniform acceleration is a straight line with a constant slope. The slope of the velocity graph is equal to the acceleration.

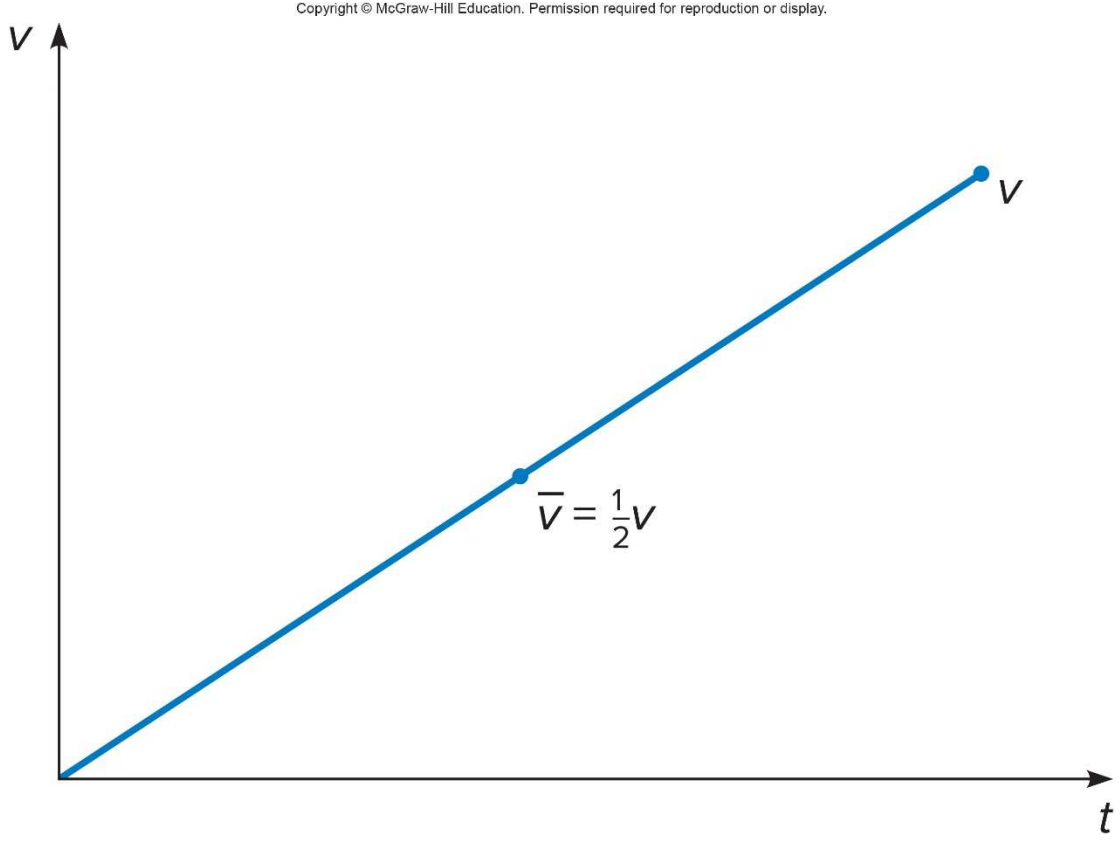
For this example, the car starts out with zero initial velocity.

The velocity then increases at a steady rate.

$$a = \frac{\Delta v}{t} \Rightarrow \Delta v = at$$

$$v = v_0 + at$$

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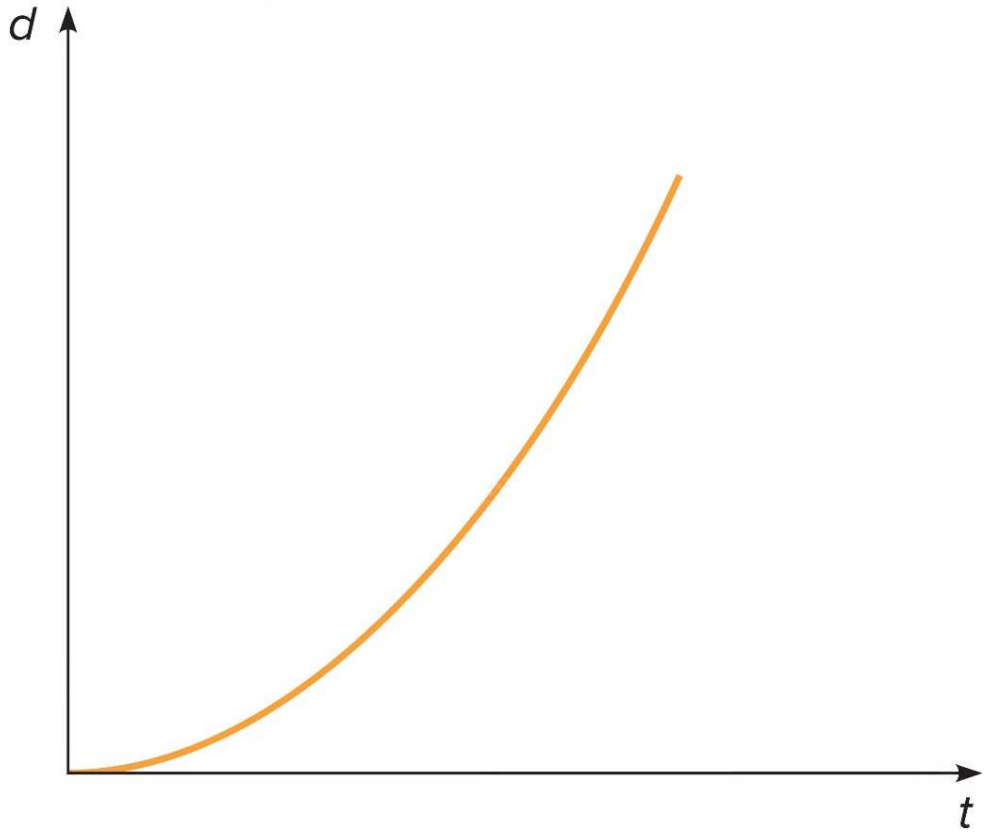
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The distance graph for uniform acceleration has a constantly increasing slope, due to a constantly increasing velocity. The distance covered grows more and more rapidly with time.

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.

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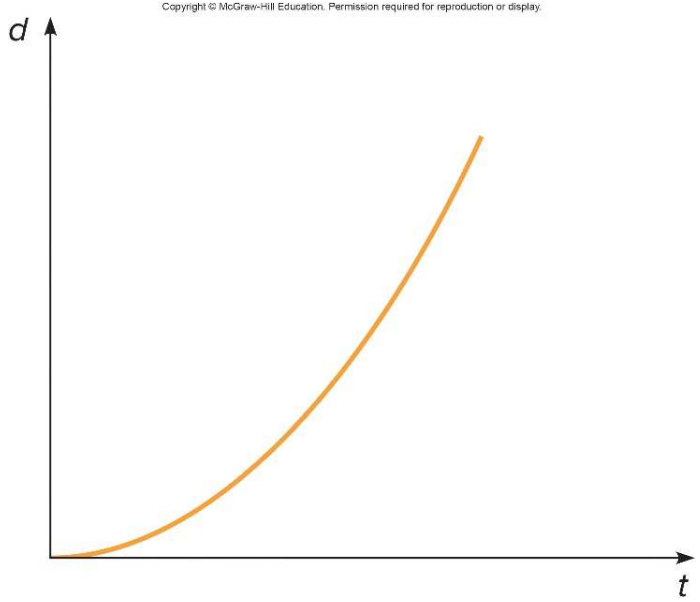
The distance traveled is equal to the area under the velocity graph, for example, the triangular area under the blue curve below.

If the car starts out with zero initial velocity, the final velocity is *at* and the average velocity is 1/2*(at)*.

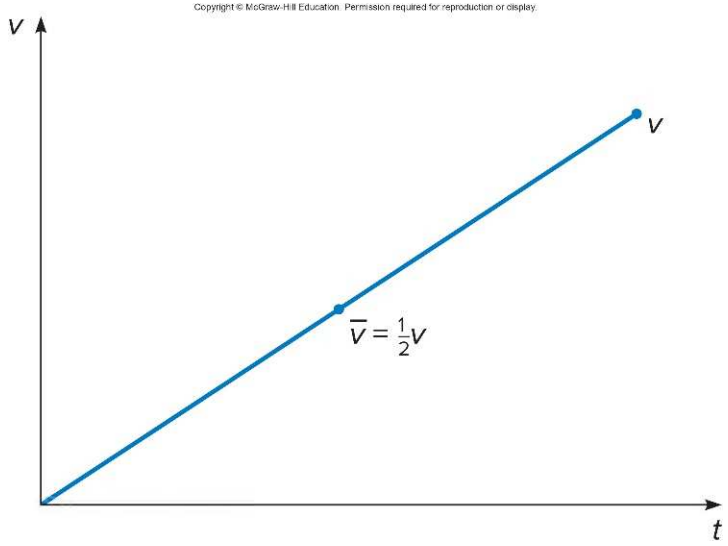
$$\bar{v} = \frac{1}{2}v = \frac{1}{2}at$$

$$d = \bar{v}t = \frac{1}{2}at^2$$

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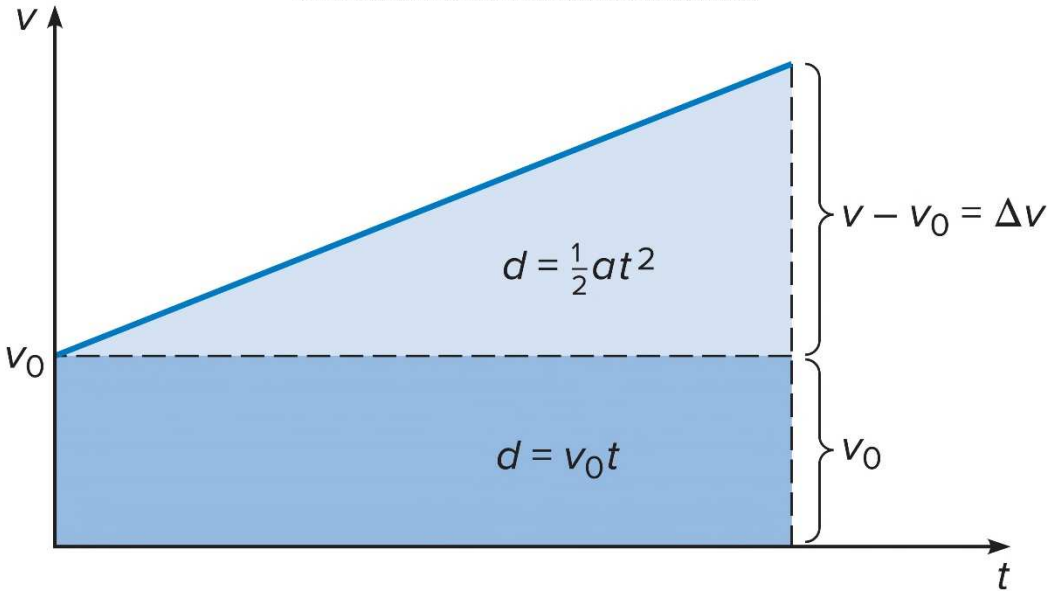


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For a non-zero initial velocity, the total distance covered is the area of the triangle plus the rectangle as shown below.

The first term is the area of the rectangle, representing the distance the object would travel if it moved with constant velocity v_0 for a time t.

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$$d = v_0 t + \frac{1}{2} a t^2$$

The second term is the area of the triangle, representing the additional distance traveled due to the acceleration.

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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

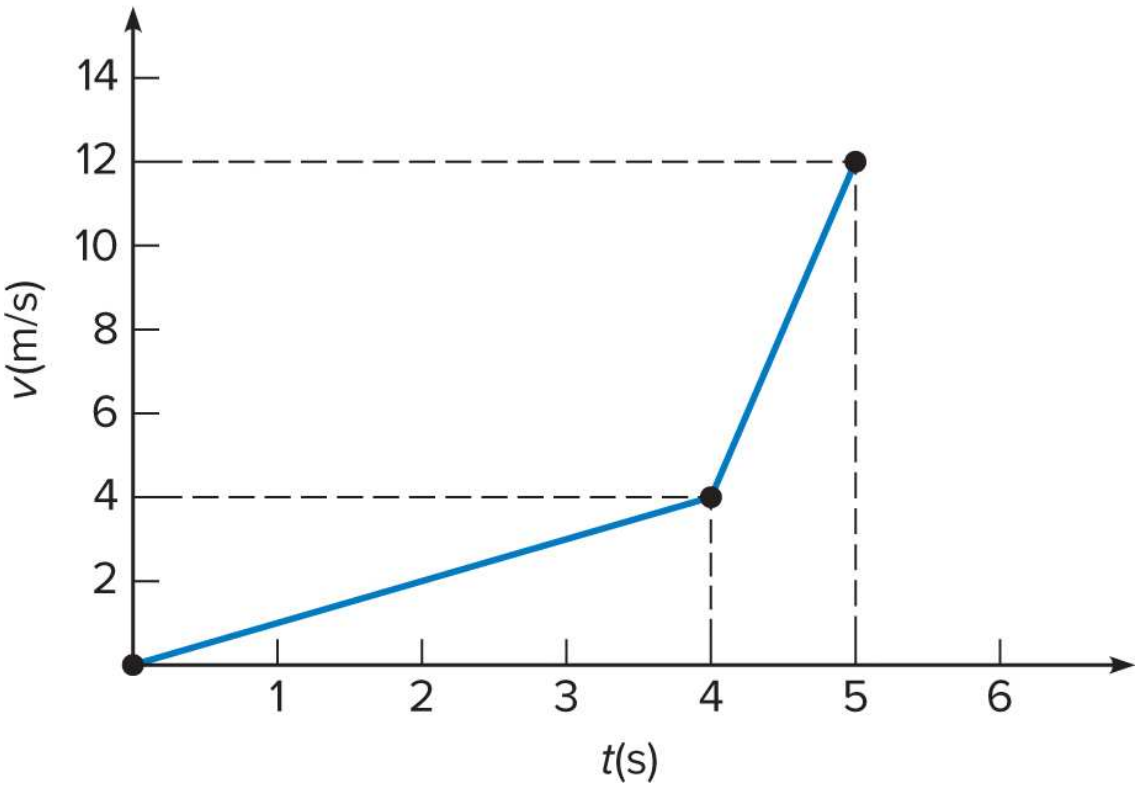
b) 3 m/s^2

c) 2 m/s^2

d) 1.5 m/s^2

e) 1 m/s^2

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e) 4 m/s ÷ 4 sec = 1 m/s^2

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The velocity of a car increases with time as shown. What is the average acceleration between 4 s and 5 s?

a) 16 m/s^2

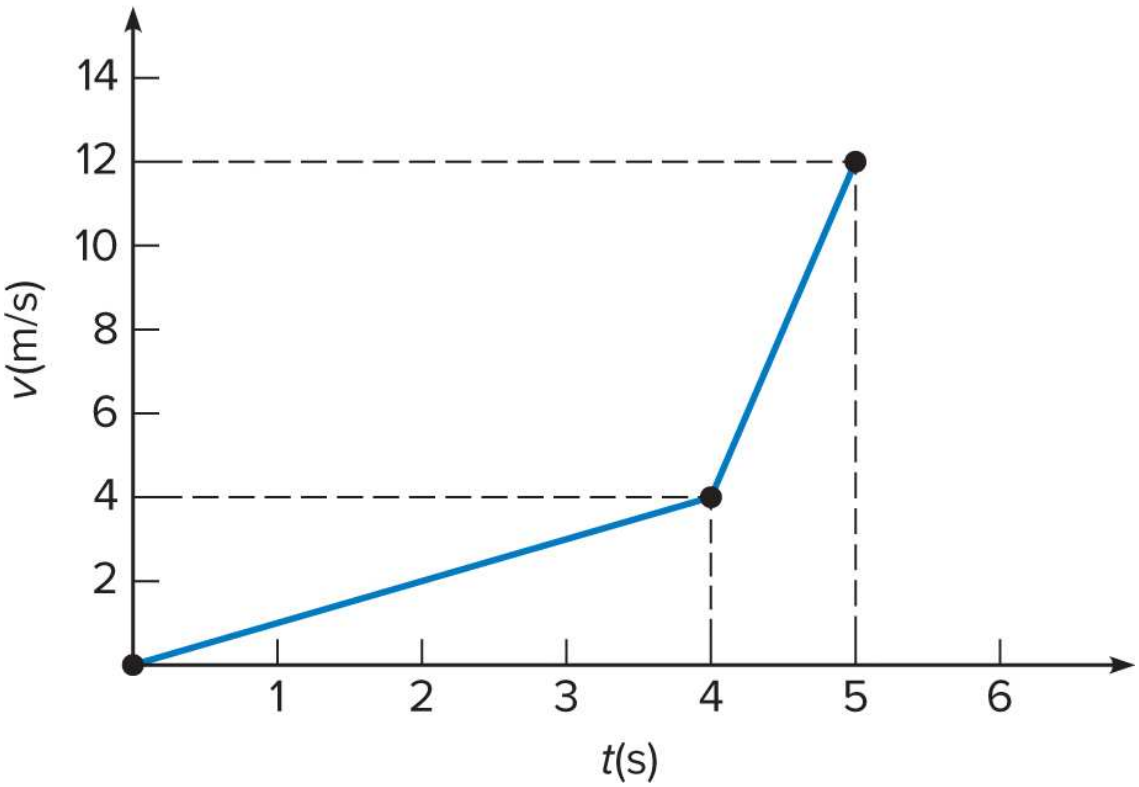
b) 12 m/s^2

c) 8 m/s^2

d) 4 m/s^2

e) 2 m/s^2

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c) (12 – 4) m/s ÷ (5 – 4) sec = 8 m/s^2

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The velocity of a car increases with time as shown. What is the average acceleration between 0 s and 5 s?

a) 12 m/s^2

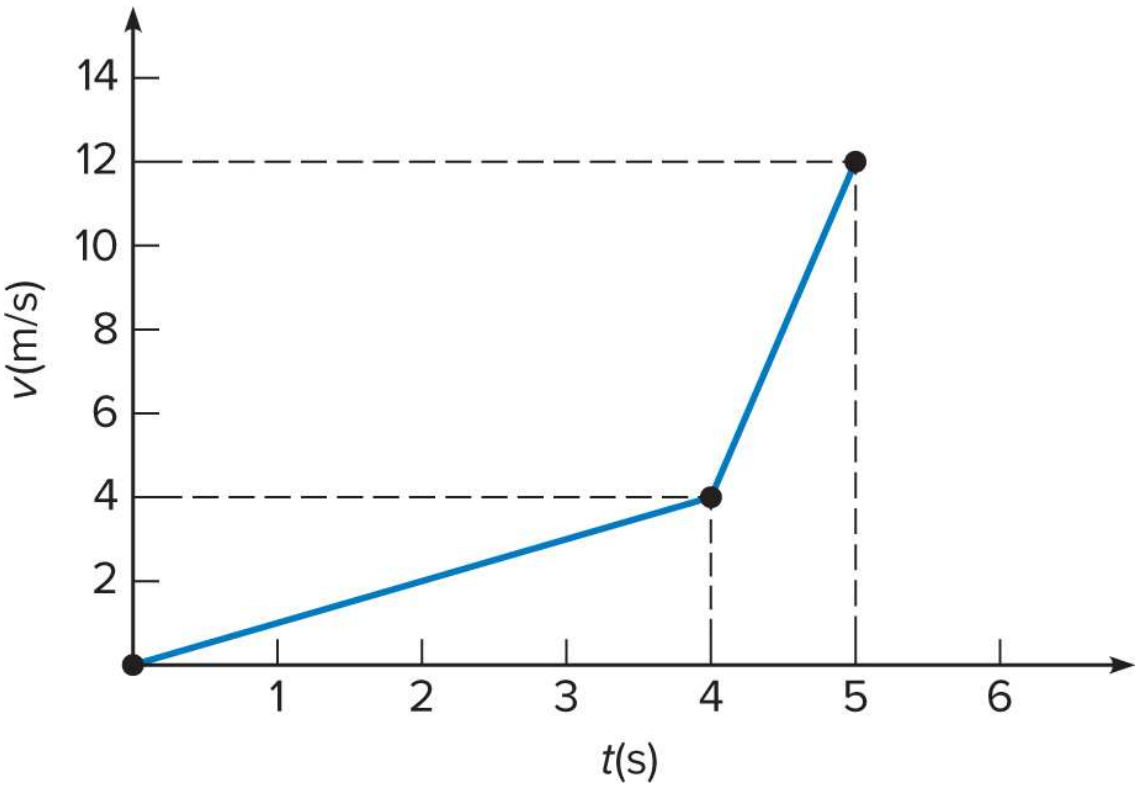
b) 6 m/s^2

c) 2.4 m/s^2

d) 1.2 m/s^2

e) 1 m/s^2

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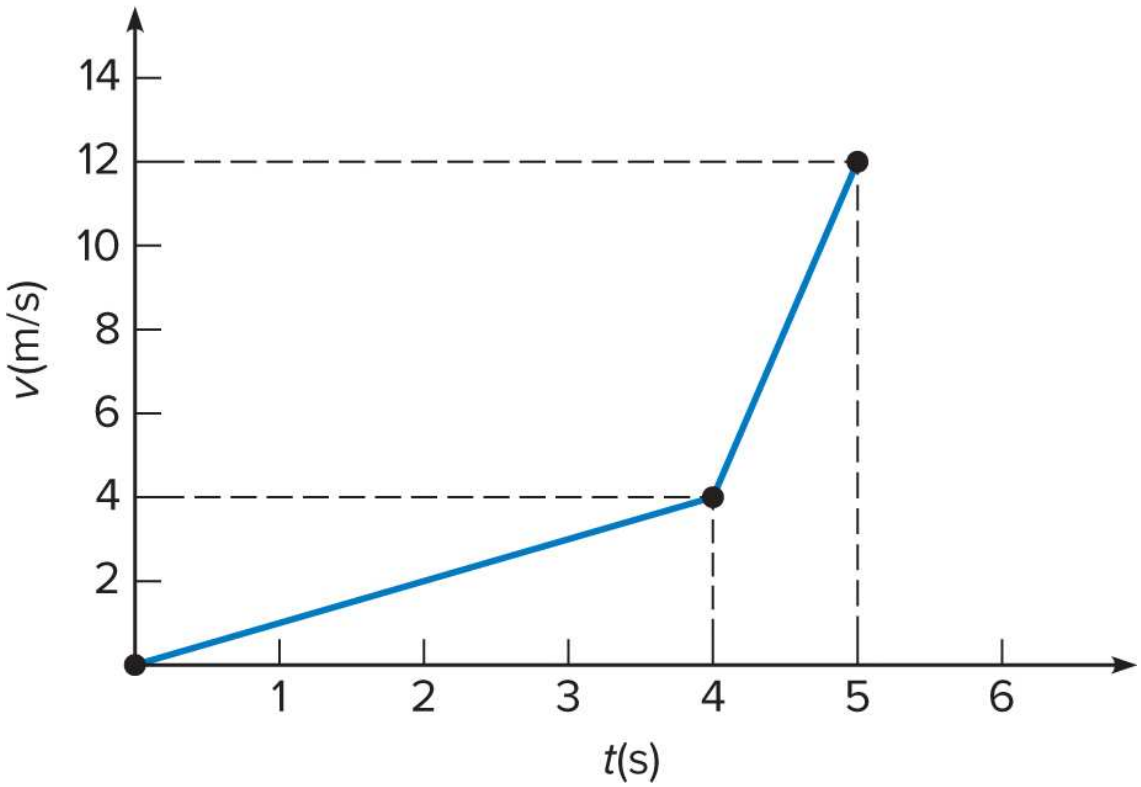
c) 12 m/s ÷ 5 sec = 2.4 m/s^2

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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 5 sec different from the average acceleration from 0 to 5 sec?

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