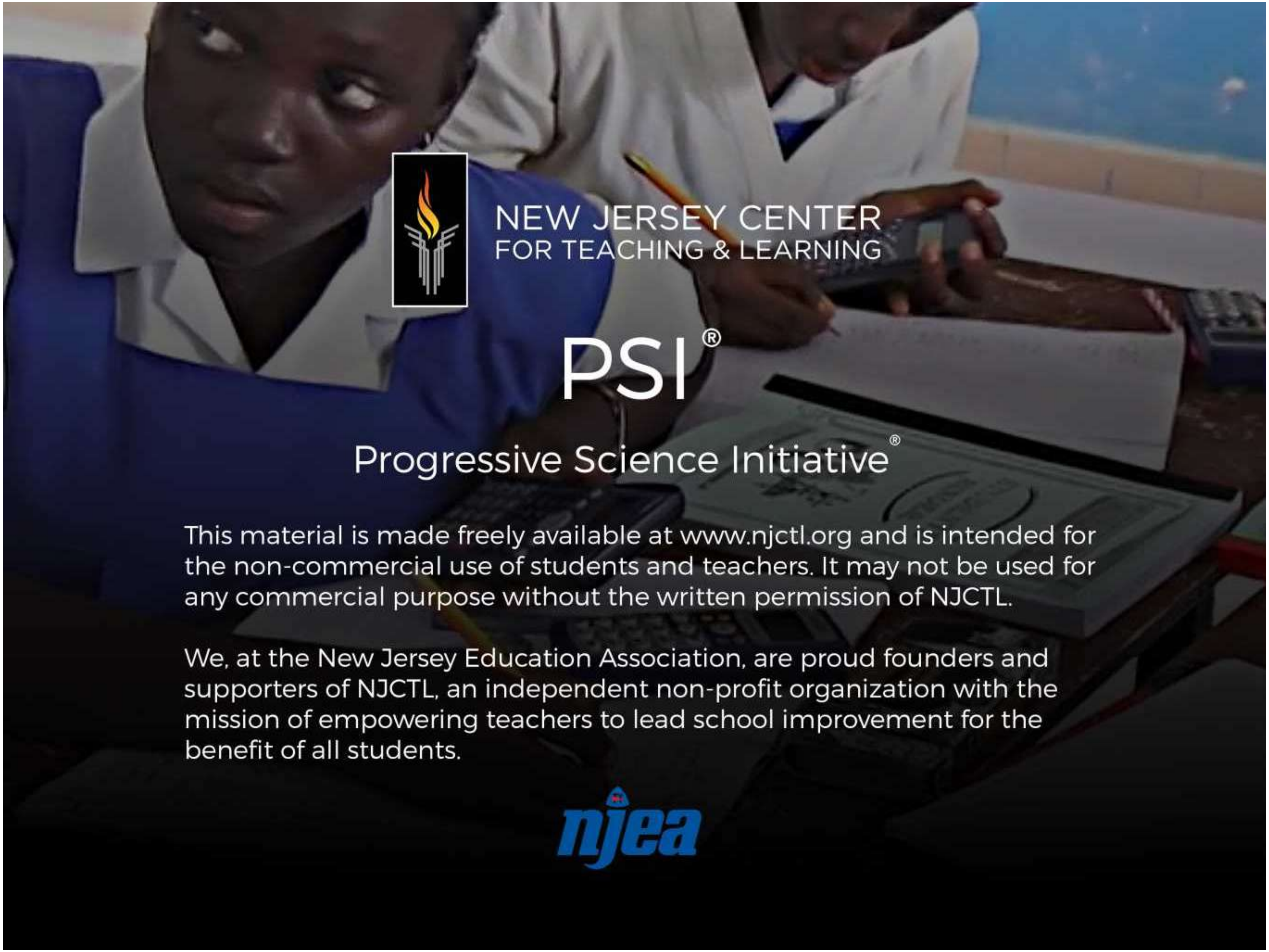

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# Algebra Based Physics

## Kinematics in One Dimension

**2016-09-21**

**www.njctl.org**

# Table of Contents: Kinematics

Click on the topic to go to that section

# Motion in One Dimension

https://www.njctl.org/video/?v=ARE0bLtRFVI

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# Distance

We all know what the distance between two objects is...

*So what is it?*
*What is distance?*
*What is length?*

*ALSO - you can't use the words "distance" or "length" in your* definition; that would be cheating.

# Distance

As you can see from your efforts, it is impossible to define distance.

Distance is a fundamental part of nature. It is so fundamental that it's impossible to define. Everyone knows what distance is, but no one can really say what it is.

However, distances can be compared.

# Distance

We can compare the distance between two objects to the distance between two other objects.

For convenience, we create standard distances so that we can easily make comparisons... and tell someone else about them.

We will be using the meter as our unit for measuring distance. It's just that it's been accepted as a universal standard, so everyone knows what it is.

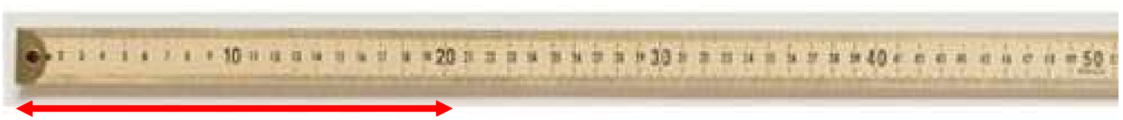
This doesn't define distance, but it allows us to work with it.

# Distance

We'll be using meter as our standard for measuring distance.

The symbol for distance is "d".

And the unit for the meter is "m"




d = 0.2 m

# Time

Similarly, everyone knows what time is...

But try defining it; what is time?

Remember you can't use the word "time"
or an equivalent to the word "time", in your definition.

# Time

Like distance, time is a fundamental aspect of nature.

It is so fundamental that it's impossible to define. Everyone knows what time is, but no one can really say what it is...

However, like distances, times can be compared.

# Time

We can say that in the time it took to run around the track, the second hand of my watch went around once...so my run took 60 seconds. When we compare the time between two events to the time between two other events, we are <u>measuring</u> time.

This doesn't define time, but it allows us to work with it.

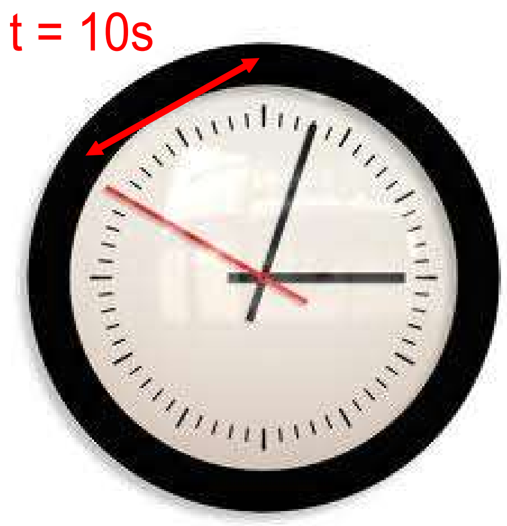
# Time

We will be using the second as our standard for measuring time.

The symbol for time is "t"

The unit for a second is "s".

click here for a "minute physics" on measuring time and distance




Demo

# Speed

Speed is defined as the distance traveled divided by the time it took to travel that distance.

$$speed = \frac{distance}{time}$$

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

Speed is not a fundamental aspect of nature,
it is the ratio of two things that are.

# Speed

The units of speed can be seen by substituting the units for distance and time into the equation

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

$$\frac{meters}{seconds}$$

$$\frac{m}{s}$$

*We read this unit as "meters per second"*

1 A car travels at a constant speed of 10m/s. This means the car:

A increases its speed by 10m every second.

B decreases its speed by 10m every second.

C moves with an acceleration of 10 meters every second

D moves 10 meters every second.

Answer

https://www.njctl.org/video/?v=7E8c3jVbN2w

2 A rabbit runs a distance of 60 meters in 20 s; what is the speed of the rabbit?

Answer

https://www.njctl.org/video/?v=XrtRbPudROU

3 An airplane on a runway can cover 500 m in 10 s; what is the airplane's average speed?


Answer

https://www.njctl.org/video/?v=OJNi1GsWnuI

4 A car travels at a speed of 40 m/s for 4.0 s; what is the distance traveled by the car?


Answer

https://www.njctl.org/video/?v=CWvo93CQnNI

5 You travel at a speed of 20m/s for 6.0s; what distance have you moved?


Answer

https://www.njctl.org/video/?v=mPMcjq1CNxA

6 You travel at a constant speed of 20 m/s; how much time does it take you to travel a distance of 120m?

Answer

https://www.njctl.org/video/?v=_8JNZyQXze4

7 You travel at a constant speed of 30m/s; how much time does it take you to travel a distance of 150m?

Answer

https://www.njctl.org/video/?v=k7od93faZ3E

# Average Speed

Demo

https://www.njctl.org/video/?v=Ry-IJYdAYhk

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# Average Speed

The speed we have been calculating is a constant speed over a short period of time.  Another name for this is instantaneous speed.

If a trip has multiple parts, each part must be treated separately.  In this case, we can calculate the average speed for a total trip.

Determine the average speed by finding the *total* distance you traveled and dividing that by the *total* time it took you to travel that distance.

# Distance and Time Intervals

In physics we use subscripts in order to avoid any confusion with different distances and time intervals.

For example: if an object makes a multiple trip that has three parts we present them as $d_1$, $d_2$, $d_3$ and the corresponding time intervals $t_1$, $t_2$, $t_3$.

# Average Speed & Non-Uniform Motion

The following pattern of steps will help us to find the average speed:

Find the total distance $d_{total} = d_1 + d_2 + d_3$

Find the total time $t_{total} = t_1 + t_2 + t_3$

Use the average speed formula $s_{avg} = \frac{d_{total}}{t_{total}}$

# Average Speed - Example 1

You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?

*To keep things clear, we can use a table (graphic organizer) to keep track of the information...*

# Example 1 - Step 1

Write the given information in the table below:

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | | | |
| II | | | |
| III | | | |
| Total /Avg. | | | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

# Example 1 - Step 1

Write the given information in the table below:

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | | | |
| II | | | |
| III | | | |
| Total /Avg. | | | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

# Example 1 - Step 1

Write the given information in the table below:

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 2500 | 420 | |
| II | | | |
| III | | | |
| Total /Avg. | | | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

# Example 1 - Step 2

Next, use the given information to find the *total* distance and *total* time

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 2500 | 420 | |
| II | 0 | 600 | |
| III | 3500 | 540 | |
| Total /Avg. | | | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

$d_{total} = d_1 + d_2 + d_3$

# Example 1 - Step 2

Next, use the given information to find the *total* distance and *total* time

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 2500 | 420 | |
| II | 0 | 600 | |
| III | 3500 | 540 | |
| Total /Avg. | **6000** | | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

$t_{total} = t_1 + t_2 + t_3$

# Example 1 - Step 3

Next use total distance and time to find average speed.

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 2500 | 420 | |
| II | 0 | 600 | |
| III | 3500 | 540 | |
| Total /Avg. | **6000** | **1560** | |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

$$s_{avg} = \frac{d_{total}}{t_{total}}$$

# Example 1 - Solution

Next use total distance and time to find average speed.

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 2500 | 420 | |
| II | 0 | 600 | |
| III | 3500 | 540 | |
| Total /Avg. | 6000 | 1560 | **3.85** |

*You ride your bike home from school by way of your friend's house. It takes you 7 minutes (420 s) to travel the 2500 m to his house. You spend 10 minutes (600 s) there, before traveling 3500 m to your house in 9 minutes (540 s). What was your average speed for this trip?*

$$s_{avg} = \frac{d_{total}}{t_{total}} = \frac{6000\ \text{m}}{1560\ \text{s}} =$$

# Example 2

Fill in the Table and Determine Average Speed

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | | | |
| II | | | |
| III | | | |
| Total /Avg. | | | |

*You run a distance of 210 m at a speed of 7 m/s. You then jog a distance of 800 m in a time of 235 s. Finally, you run for 25 s at a speed of 6 m/s. What was the average speed of your total run?*

# Example 2 - Reflection

| Segment | Distance | Time | Speed |
|---|---|---|---|
| | (m) | (s) | (m/s) |
| I | 210 | 30 | 7 |
| II | 800 | 235 | 3 |
| III | 150 | 25 | 6 |
| Total /Avg. | 1160 | 290 | 4 |

What happens when you take the 'average' (arithmetic mean) of the speed for each leg of the trip? Is it the same as the average speed?

*Why do you think this happens?*

# Position and Reference Frames

https://www.njctl.org/video/?v=5mPK2E2GkzA

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# Position and Reference Frames

Speed, distance and time didn't require us to define where we started and where we ended up. They just measure how far we traveled and how long it took to travel that far.

However, much of physics is about knowing where something is and how its position changes with time.

*To define position we have to use a reference frame.*

# Position and Reference Frames

A reference frame lets us define where an object is located, relative to other objects.

For instance, we can use a map to compare the location of different cities, or a globe to compare the location of different continents.

However, not every reference frame is appropriate for every problem.

# Reference Frame Activity

Send a volunteer out of the classroom to wait for further instructions.

Place an object somewhere in your classroom. Write specific directions for someone to be able to locate the object

Write them in a way that allows you to hand them to someone who can then follow them to the object.

*Remember: you can't tell them the name of something your object is near, just how they have to move to get to it.  For instance 'walk to the SmartBoard' is not a specific direction.*

Test your directions out on your classmate, (who is hopefully still in the hallway!)

# Reference Frame Activity - Reflection

In your groups, make a list of the things you needed to include in your directions in order to successfully locate the object in the room.

As a class, discuss your findings.

# Results - Reference Frames

You probably found that you needed:

A starting point *(an origin)*

*A set of directions (for instance left-right, forward-backward, up-down)*

*A unit of measure (to dictate how far to go in each direction)*

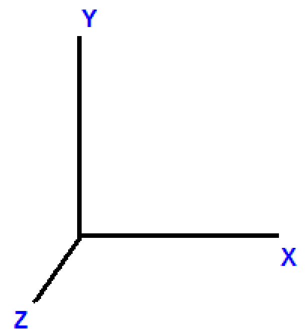
# Results - Reference Frames

In this course, we'll usually:

Define the origin as a location labeled "zero"

Create three perpendicular axes : x, y and z for direction

Use the meter as our unit of measure



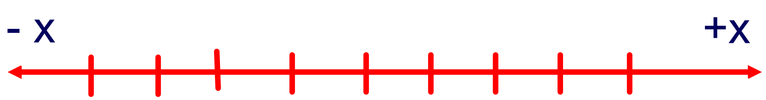
# The Axis

In this course, we will be solving problems in one-dimension.

Typically, we use the x-axis for that direction.

*+x will usually be to the right*

*-x would then be to the left*




*We could define it the opposite way, but unless specified* otherwise, this is what we'll assume. We also can think about compass directions in terms of positive and negative. For example, North would be positive and South negative.

The symbol for position is "x".

8 All of the following are examples of positive direction except:

A to the right

B north

C west

D up

Answer

https://www.njctl.org/video/?v=JnzoLC8tbAE

9 All of the following are examples of negative direction except:

A to the right

B south

C west

D down

Answer

https://www.njctl.org/video/?v=Wm-YzMopcY8

# Displacement

https://www.njctl.org/video/?v=yXc9uj-Qolc

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# Displacement

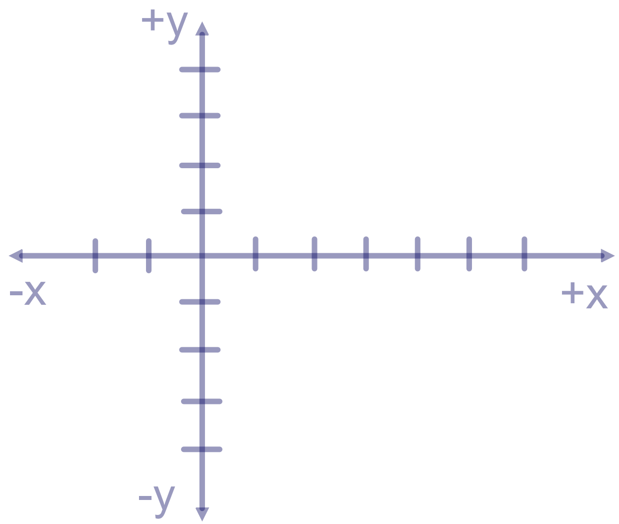
Now that we understand how to define position, we can talk about a change in position; a displacement.

The symbol for "change" is the Greek letter "delta" "Δ".

So "Δx" means the change in x or the change in position

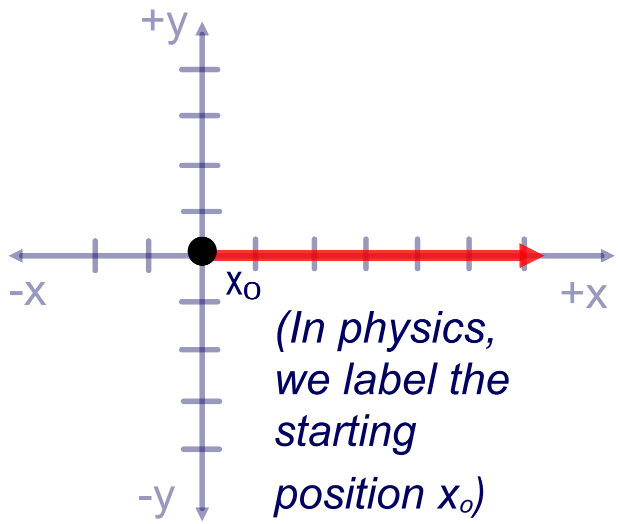
# Displacement

Displacement describes how far you are from where you started, regardless of how you got there.



# Displacement

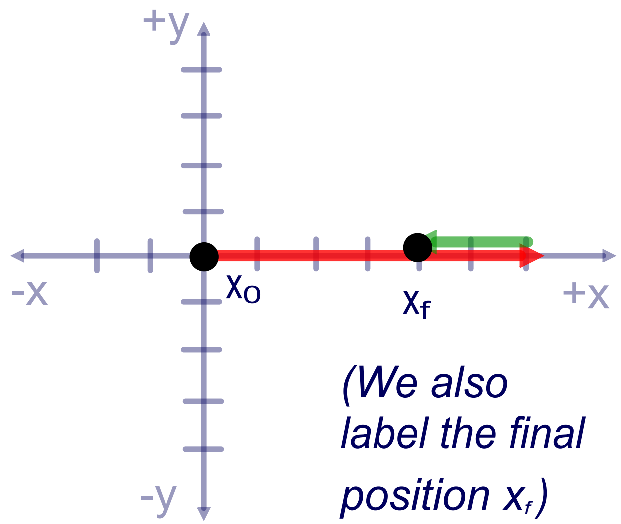
For instance, if you drive 60 miles from Pennsylvania to New Jersey...




*(In physics, we label the starting position $x_o$)*

# Displacement

and then 20 miles back toward Pennsylvania.




*(We also label the final position $x_f$)*

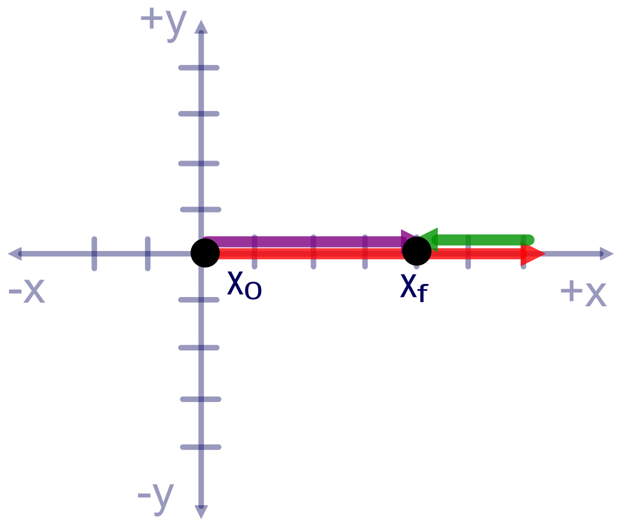
# Displacement

You have traveled:

a distance of 80 miles, and

a displacement of 40 miles,

since that is how far you are from where you started

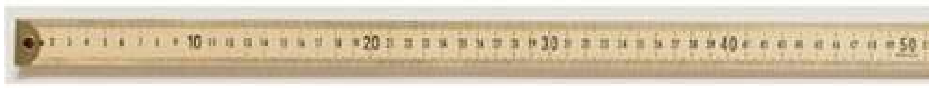



we can calculate displacement with the following formula:

$$\Delta x = X_f - X_o$$

# Displacement

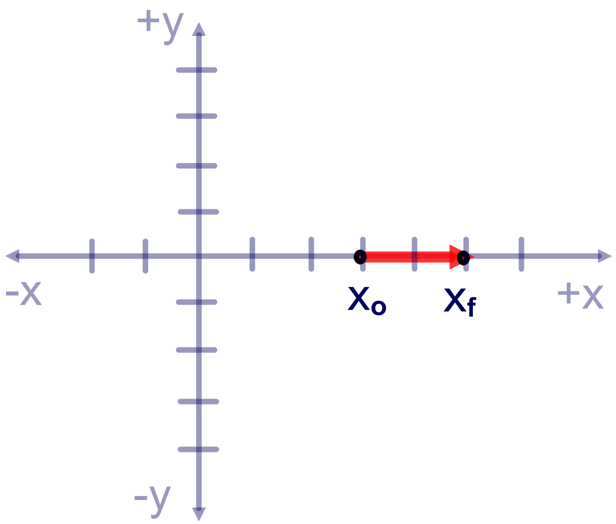
Measurements of distance can only be positive values (magnitudes) since it is impossible to travel a negative distance.



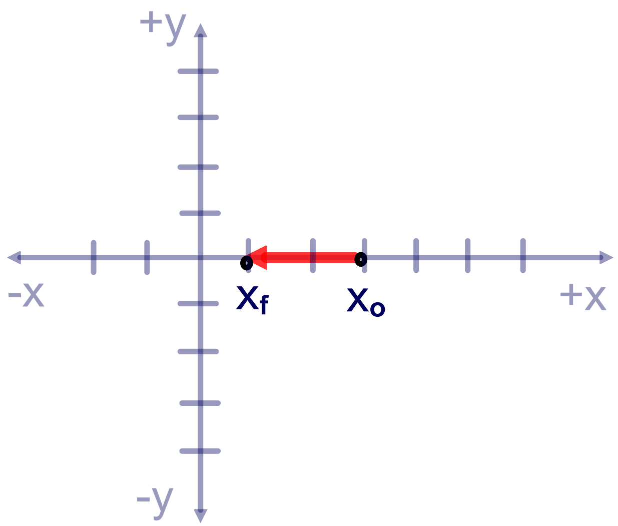
*Imagine trying to measure a negative length with a meter stick...*

# Displacement

However, displacement can be positive or negative since you can end up to the right or left of where you started.




Displacement is positive.




Displacement is negative.

# Vectors and Scalars

Scalar - a quantity that has only a magnitude (number or value)

Vector - a quantity that has both a magnitude *and a direction*

Which of the following are vectors?  Scalars?

| Quantity | Vector | Scalar |
|---|---|---|
| Time | | |
| Distance | | |
| Displacement | | |
| Speed | | |

10 How far your ending point is from your starting point is known as:

A distance

B displacement

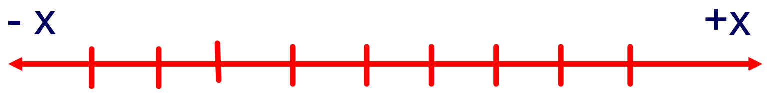
C a positive integer

D a negative integer

Answer

https://www.njctl.org/video/?v=vxIWZ9_rQFo

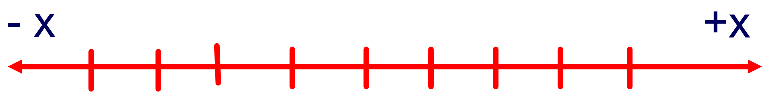
11 A car travels 60m to the right and then 30m to the left.  What distance has the car traveled?




Answer

https://www.njctl.org/video/?v=HxpHVhVbGF4

12 You travel 60m to the right and then 30m to the left. What is the magnitude (and direction) of your displacement?




Answer

https://www.njctl.org/video/?v=DOIpNF9Rdz0

13 Starting from the origin, a car travels 4km east and then 7 km west. What is the total distance traveled?

A 3 km

B -3 km

C 7 km

D 11 km

Answer

https://www.njctl.org/video/?v=vl2i9fvhOVE

14 Starting from the origin, a car travels 4km east and then 7 km west.  What is the net displacement from the original point?

A 3 km west

B 3 km east

C 7 km west

D 11 km east

Answer

https://www.njctl.org/video/?v=iYNfUacg-9A

15 You run around a 400m track. At the end of your run, what is the distance that you traveled?

Answer

https://www.njctl.org/video/?v=Zh-BoXNwIDo

16 You run around a 400m track. At the end of your run, what is your displacement?


Answer

https://www.njctl.org/video/?v=GtCTnmgkkXQ

# Average Velocity

Lab

https://njctl.org/video/?v=js6ZL6kBcsw

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# Average Velocity

Speed is defined as the ratio of distance and time

$$\text{Average speed} = \frac{\text{distance traveled}}{\text{time elapsed}} \qquad s = \frac{d}{t}$$

Similarly, velocity is defined as the ratio of displacement and time

$$\text{Average velocity} = \frac{\text{displacement}}{\text{time elapsed}} \qquad \overline{v} = \frac{\Delta x}{\Delta t}$$

# Average Velocity

Speeds are always positive, since speed is the ratio of distance and time; both of which are always positive.

$$\text{Average speed} = \frac{\text{distance traveled}}{\text{time elapsed}} \qquad s = \frac{d}{t}$$

But velocity can be *positive or negative*, since velocity is the ratio of displacement and time; and displacement can be negative or positive.

$$\text{Average velocity} = \frac{\text{displacement}}{\text{time elapsed}} \qquad \overline{v} = \frac{\Delta x}{\Delta t}$$

*Usually, right is positive and left is negative.*

17 Which of the following is a vector quantity?

A time

B velocity

C distance

D speed

Answer

https://www.njctl.org/video/?v=ZL8OmtS4m8E

18 Average velocity is defined as change in ______ over a period of ______.

A distance, time

B distance, space

C position, time

D position, space

Answer

https://www.njctl.org/video/?v=eIAG7H40utw

19 You travel 60 meters to the right in 20 s; what is your average velocity?

Answer

https://www.njctl.org/video/?v=IMTx61aMxPo

20 An elephant travels 60 meters to the left in 20 s; what is the average velocity?

Answer

https://www.njctl.org/video/?v=0UbmRkIJWwU

21 You travel 60 meters to the left in 20 s and then you travel 60 meters to the right in 30 s; what is your average velocity?

Answer

https://www.njctl.org/video/?v=NQ0nOZFCKZI

22 You travel 60 meters to the left in 20 s and then you travel 60 meters to the right in 30 s; what is your average <u>speed</u>?

Answer

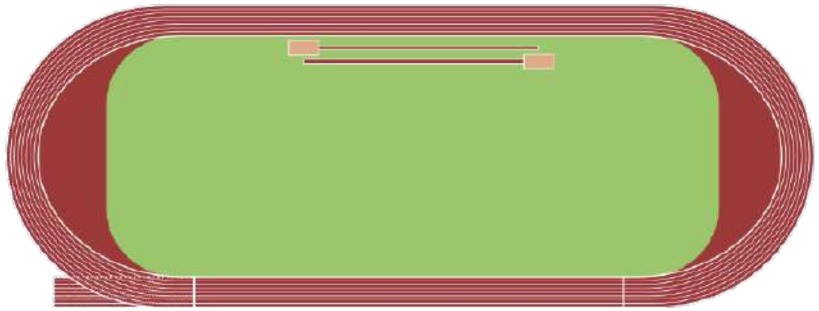
https://www.njctl.org/video/?v=i_iJgYVaRh8

23 You run completely around a 400 m track in 80s. What was your average speed?

Answer

https://www.njctl.org/video/?v=doZMr5s0mgo

24 You run completely around a 400 m track in 80s. What was your average velocity?



Answer

https://www.njctl.org/video/?v=YxRzc-Tg7mA

25 You travel 160 meters in 60 s; what is your average speed?

Answer

https://www.njctl.org/video/?v=5gN0etcCHTI

# Instantaneous Velocity

https://www.njctl.org/video/?v=3VtT9A5parI

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# Instantaneous Velocity

Sometimes the average velocity is all we need to know about an object's motion.

For example:
A race along a straight line is really a competition to see whose average velocity is the greatest.

The prize goes to the competitor who can cover the displacement in the shortest time interval.


But the average velocity of a moving object can't tell us how fast the object moves at any given point during the interval Δt.

# Instantaneous Velocity

Average velocity is defined as change in position over time. This tells us the 'average' velocity for a given length or *span* of time.


If we want to know the speed or velocity of an object at a *specific point in time* (with this radar gun for example), we want to know the instantaneous velocity...

Watch what happens when we look for the instantaneous velocity by reducing the amount of time we take to measure displacement.

# Instantaneous Velocity

| Displacement | Time | Velocity |
|---|---|---|
| 100m | 10 s | |

In an experiment, an object travels at a constant velocity. Find the magnitude of the velocity using the data above.

# Instantaneous Velocity

| Displacement | Time | Velocity |
|---|---|---|
| 100m | 10 s | 10 m/s |
| 10 m | 1 s | |

What happens if we measure the distance traveled in the same experiment for only one second?

What is the velocity?

# Instantaneous Velocity

| Displacement | Time | Velocity |
|---|---|---|
| 100m | 10 s | 10 m/s |
| 10 m | 1 s | 10 m/s |
| 0.001m | 0.0001 s | |

What happens if we measure the distance traveled in the same experiment for a really small time interval?

What is the velocity?

# Instantaneous Velocity

| Displacement | Time | Velocity |
|---|---|---|
| 100 m | 10 s | 10 m/s |
| 10 m | 1 s | 10 m/s |
| 1.0 m | 0.10 s | 10 m/s |
| 0.10 m | 0.010 s | 10 m/s |
| 0.010 m | 0.0010 s | 10 m/s |
| 0.0010 m | 0.00010 s | 10 m/s |
| 0.00010 m | 0.000010 s | 10 m/s |

Since we need time to measure velocity, we can't know the exact velocity "at" a particular time... but if we imagine a really small value of time and the distance traveled, we can estimate the instantaneous velocity.

# Instantaneous Velocity

To describe the motion in greater detail, we need to define the velocity at any specific instant of time or specific point along the path. Such a velocity is called instantaneous velocity.

Note that the word *instant* has somewhat different meaning in physics than in everyday language. Instant is not necessarily something that is finished quickly. We may use the phrase "It lasted just an instant" to refer to something that lasted for a very short time interval.



# Instantaneous Velocity

In physics an instant has no duration at all;
it refers to a single value of time.

One of the most common examples we can use to understand instantaneous velocity is driving a car and taking a quick look on the speedometer.

At this point, we see the instantaneous value of the velocity.

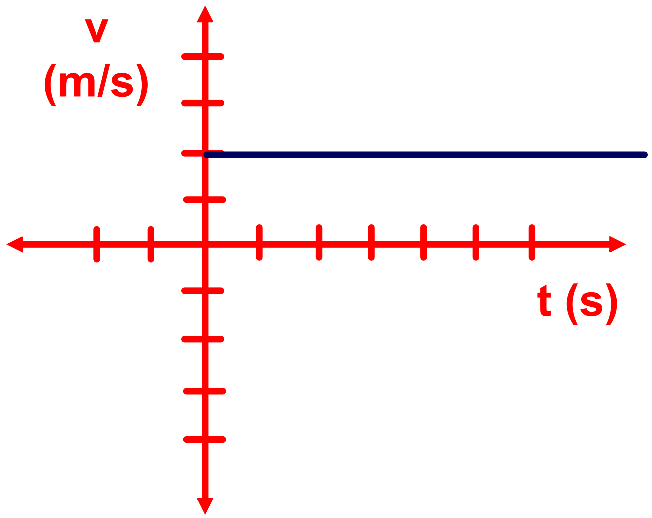
# Instantaneous Velocity

The instantaneous velocity is the same as the magnitude of the average velocity as the time interval becomes very very short.

$$v = \frac{\Delta x}{\Delta t} \quad \text{as } \Delta t \longrightarrow 0$$

# Velocity Graphing Activity

The graph below shows velocity versus time.

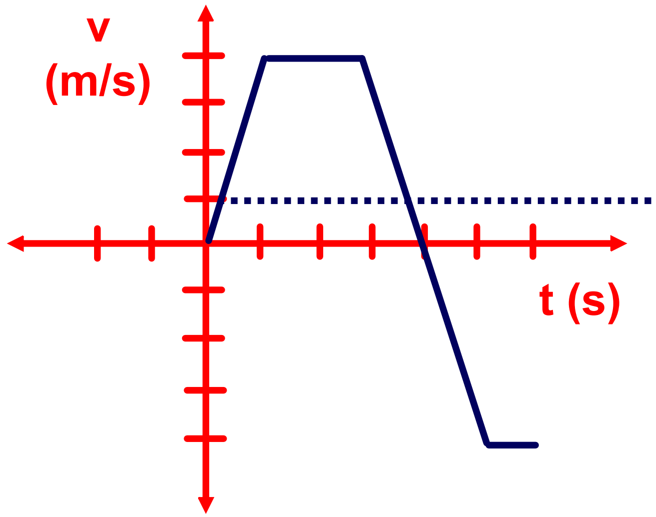



How do you know the velocity is constant?

Answer

# Velocity Graphing Activity

The graph below shows velocity versus time.

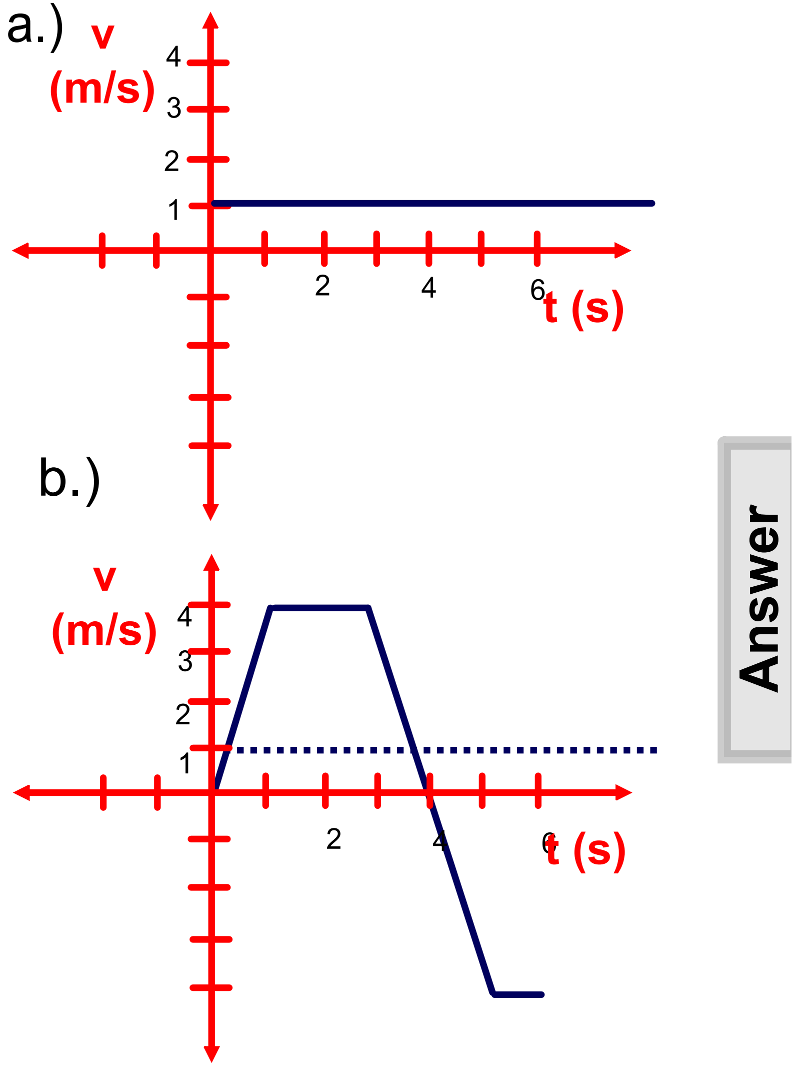



When is the velocity increasing? Decreasing? Constant?

Discuss.

# Velocity Graphing Activity

Use the graph to determine the Average Velocity of (a)



# Velocity Graphing Activity

Use the graph to determine the Average Velocity of (b)

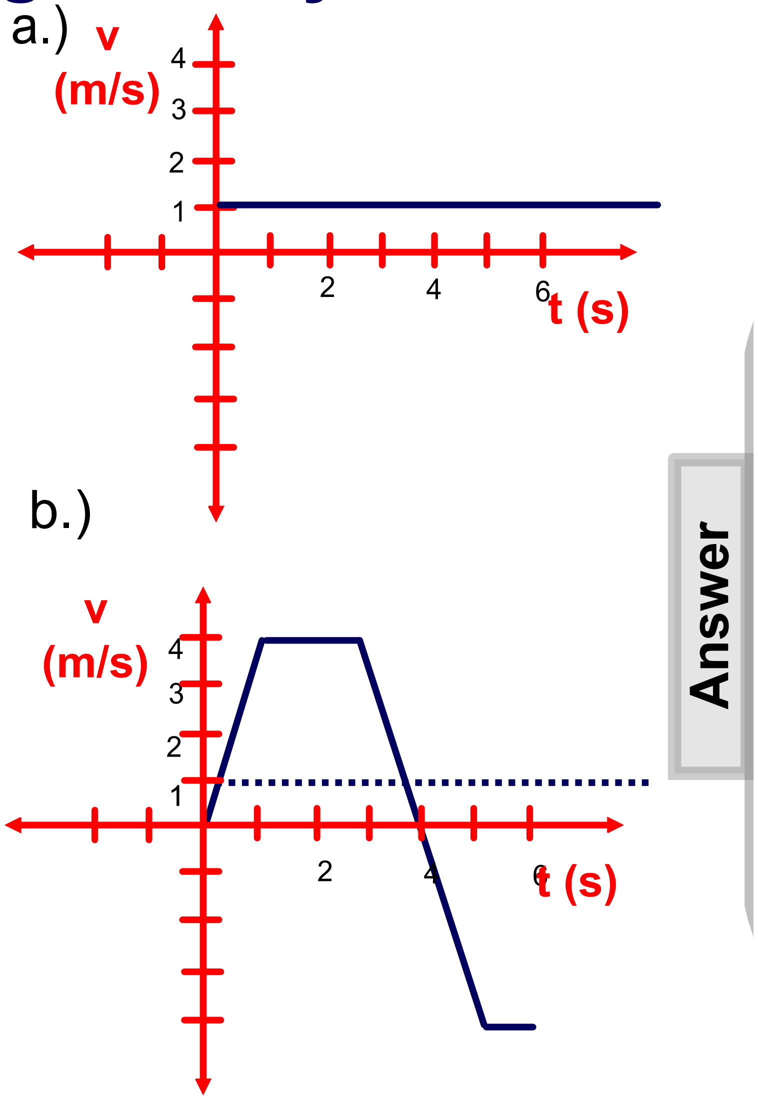
from 0s to 1s

from 1s to 3s

from 3s to 4s

from 4s to 5s

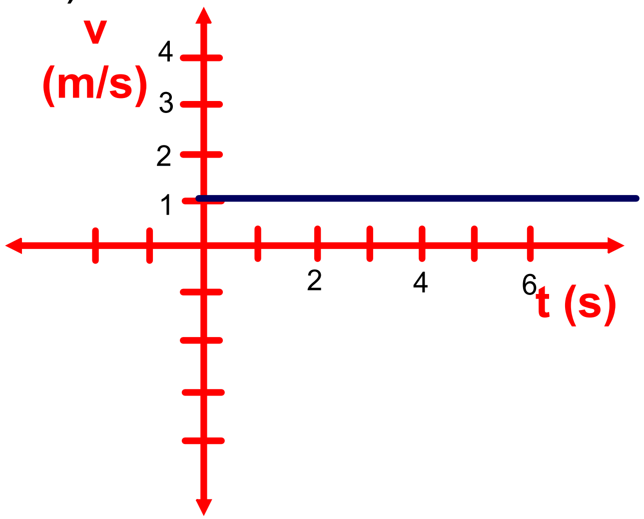
from 3s to 5s



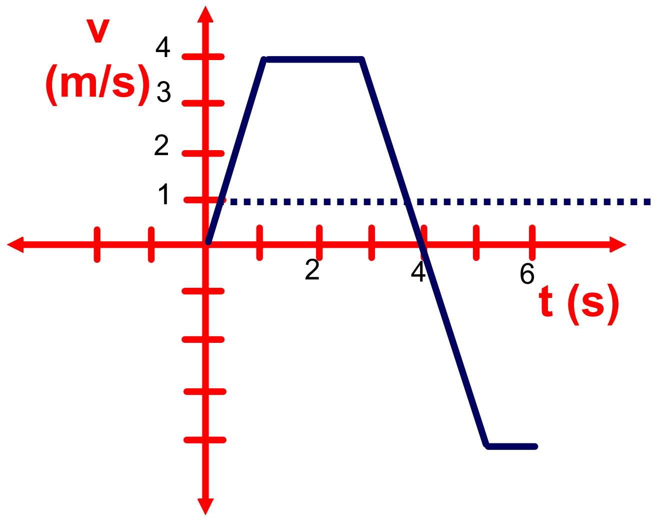
# Velocity Graphing Activity

Use the graph to determine the Instantaneous Velocity of (a) at 2 seconds

a.)



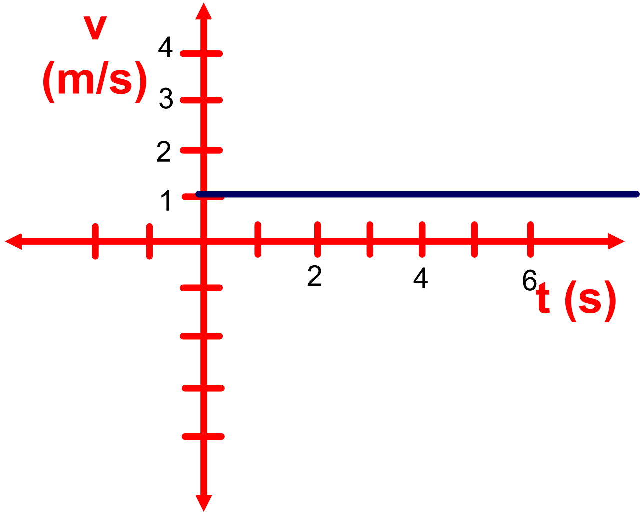

b.)




Answer

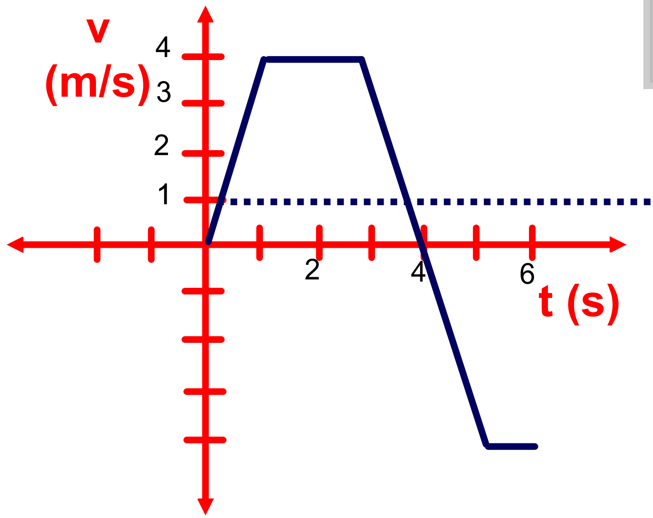
# Velocity Graphing Activity

a.)




Use the graph to determine the Instantaneous Velocity of (b) at 2 seconds

b.)

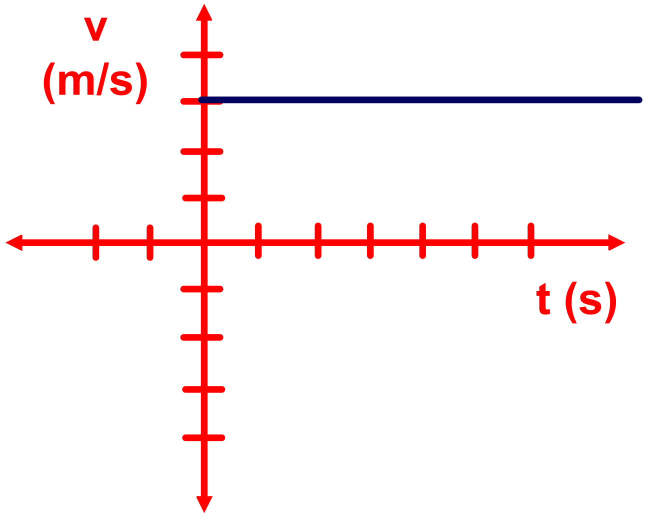



Answer

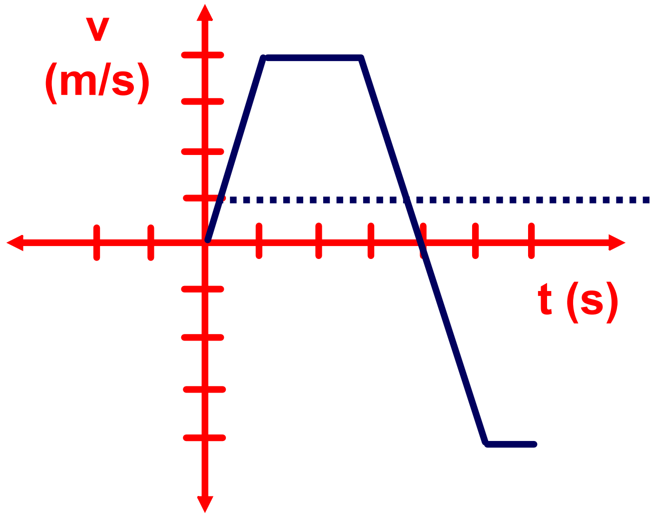
# Instantaneous Velocity

These graphs show (a) constant velocity and (b) varying velocity.

(a) When the velocity of a moving object is a constant the instantaneous velocity is the same as the average.




(b) When the velocity of a moving object changes its instantaneous velocity is different from the average velocity.



# Acceleration

Demo

https://www.njctl.org/video/?v=jGbVA3e9Op4

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# Acceleration

Acceleration is the rate of change of velocity.

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

$$a = \frac{v - v_o}{t}$$

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

# Acceleration

$$a = \frac{v - v_o}{t}$$

Acceleration is a vector, although in one-dimensional motion we only need the sign.

Since only constant acceleration will be considered in this course, there is no need to differentiate between average and instantaneous acceleration.

# Units for Acceleration

Units for acceleration

You can derive the units by substituting the correct units into the right hand side of these equations.

$$a = \frac{\Delta v}{\Delta t} \longrightarrow \frac{m/s}{s} = m/s^2$$

26 Acceleration is the rate of change of __________ .

A displacement

B distance

C speed

D velocity

Answer

https://www.njctl.org/video/?v=4tmNAmswOd0

27 The unit for velocity is:

A m

B m/s

C $m/s^2$

D $ft/s^2$

Answer

https://www.njctl.org/video/?v=D-h5qV2Plys

28 The metric unit for acceleration is:

A m

B m/s

C $m/s^2$

D $ft/s^2$

Answer

https://www.njctl.org/video/?v=EMkc2W5u6vw

29 A horse gallops with a constant acceleration of $3 m/s^2$. Which statement below is true?

A The horse's velocity doesn't change.

B The horse moves 3m every second.

C The horse's velocity increases 3m every second.

D The horse's velocity increases 3m/s every second.

Answer

https://www.njctl.org/video/?v=CbtjHuAk-Ew

# Solving Problems

After you read the problem carefully:

1. Draw a diagram (include coordinate axes).

2. List the given information.

3. Identify the unknown (what is the question asking?)

4. Choose a formula (or formulas to combine)

5. Rearrange the equations to isolate the unknown variable.

6. Substitute the values and solve!

7. Check your work. (You can do the same operations to the units to check your work ... try it!)

https://www.njctl.org/video/?v=mAeQP2Q00As

30 Your velocity changes from 60 m/s to the right to 100 m/s to the right in 20 s; what is your average acceleration?

Answer

https://www.njctl.org/video/?v=7HM0imp3Q_Y

31 Your velocity changes from 60 m/s to the right to 20 m/s to the right in 20 s; what is your average acceleration?

Answer

https://www.njctl.org/video/?v=Dm5nPrPW_v4

32 Your velocity changes from 50 m/s to the left to 10 m/s to the right in 15 s; what is your average acceleration?

Answer

https://www.njctl.org/video/?v=qG-r5XclzaY

33 Your velocity changes from 90 m/s to the right to 20 m/s to the right in 5.0 s; what is your average acceleration?

Answer

# Kinematics Equation 1

https://www.njctl.org/video/?v=69S2wEpXyAU

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# Motion at Constant Acceleration

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

but since "Δ" means change

$\Delta v = v - v_o$ and

$\Delta t = t - t_o$

$$a = \frac{v - v_o}{t}$$

if we always let $t_o = 0$, $\Delta t = t$

$$at = v - v_o$$

$$v - v_o = at$$

Solving for "v"

$$\boxed{\mathbf{v = v_o + at}}$$

This equation tells us how an object's velocity changes as a function of time.

34 Starting from rest, you accelerate at 4.0 m/$s^2$ for 6.0s. What is your final velocity?

Answer

https://www.njctl.org/video/?v=my2wda8jQn0

35 Starting from rest, you accelerate at 8.0 $m/s^2$ for 9.0s. What is your final velocity?

Answer

https://www.njctl.org/video/?v=iyPkgH3fJ-0

36 You have an initial velocity of 5.0 m/s. You then experience an acceleration of -1.5 $m/s^2$ for 4.0s; what is your final velocity?

Answer

https://www.njctl.org/video/?v=X_jWqMS3myk

37 You have an initial velocity of -3.0 m/s. You then experience an acceleration of 2.5 $m/s^2$ for 9.0s; what is your final velocity?

Answer

https://www.njctl.org/video/?v=DREeRklptKI

38 How much time does it take to accelerate from an initial velocity of 20m/s to a final velocity of 100m/s if your acceleration is 1.5 $m/s^2$ ?

Answer

https://www.njctl.org/video/?v=J4FZ8vf_RSw

39 How much time does it take to come to rest if your initial velocity is 5.0 m/s and your acceleration is $-2.0\ m/s^2$?

Answer

https://www.njctl.org/video/?v=1EQ_eMYq9pQ

40 An object accelerates at a rate of 3 $m/s^2$ for 6 s until it reaches a velocity of 20 m/s. What was its initial velocity?

Answer

https://www.njctl.org/video/?v=cQ58qrtCejU

41 An object accelerates at a rate of 1.5 m/$s^2$ for 4 s until it reaches a velocity of 10 m/s. What was its initial velocity?

Answer

https://www.njctl.org/video/?v=-q-YF4pzxBM

# Graphing Motion at Constant Acceleration

In physics there is another approach in addition to algebraic which is called graphical analysis. The formula $v = v_0 + at$ can be interpreted by the graph. We just need to recall our memory from math classes where we already saw a similar formula $y = mx + b$.

From these two formulas we can make some analogies:

$v$     $y$ *(dependent variable of x),*

$v_0$     $b$ *(intersection with vertical axis),*

$t$     $x$ *(independent variable),*

$a$     $m$ *( slope of the graph- the ratio between rise and run Δy/Δx).*

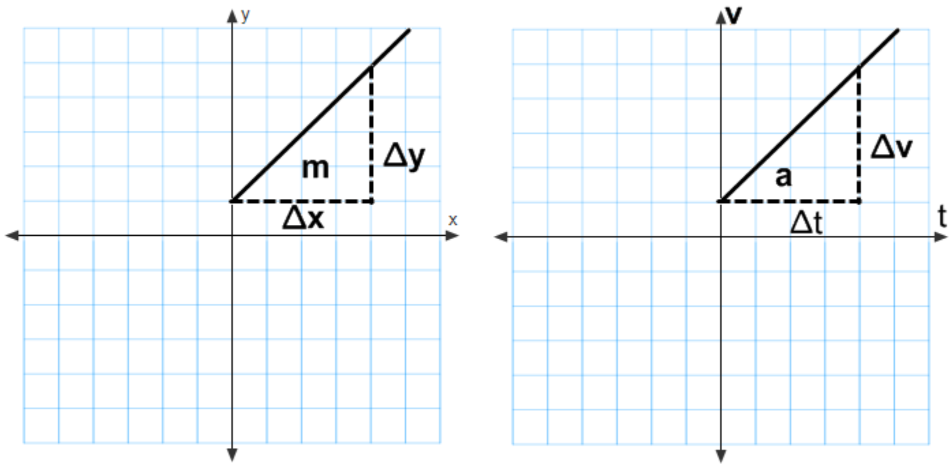
https://www.njctl.org/video/?v=j9W0rZTZ09M

# Motion at Constant Acceleration

Below we can find the geometric explanation to the acceleration $a = \Delta v / \Delta t$.

If slope is equal to: $m = \Delta y / \Delta x$

Then consider a graph with velocity on the y-axis and time on the x-axis. What is the slope for the graph on the right?

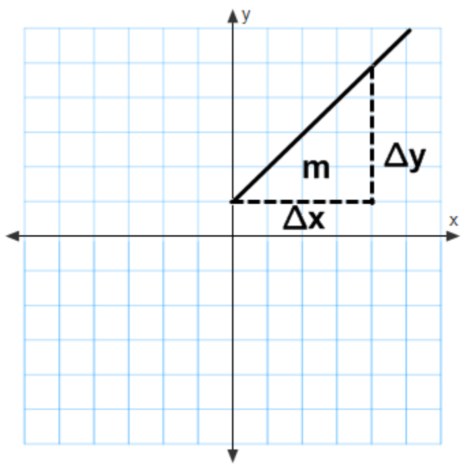


# Motion at Constant Acceleration

The graph on the right has a slope of Δv/Δt, which is equal to acceleration.  Therefore, the slope of a velocity vs. time graph is equal to acceleration.

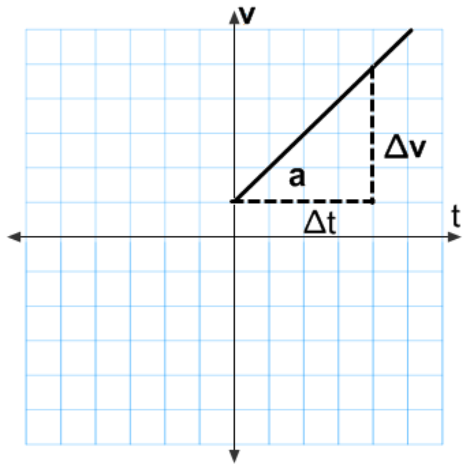
(slope)

$m = \Delta y/\Delta x$

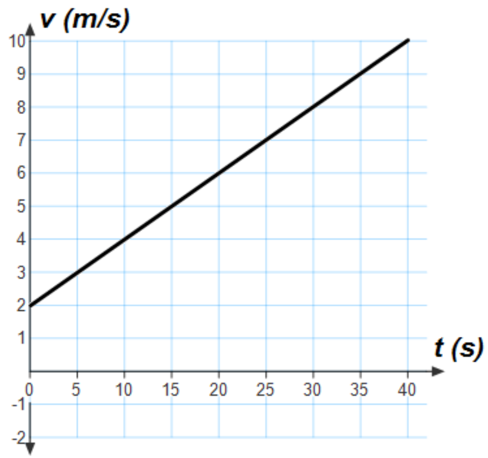



(slope of velocity vs. time)

$a = \Delta v/\Delta t$



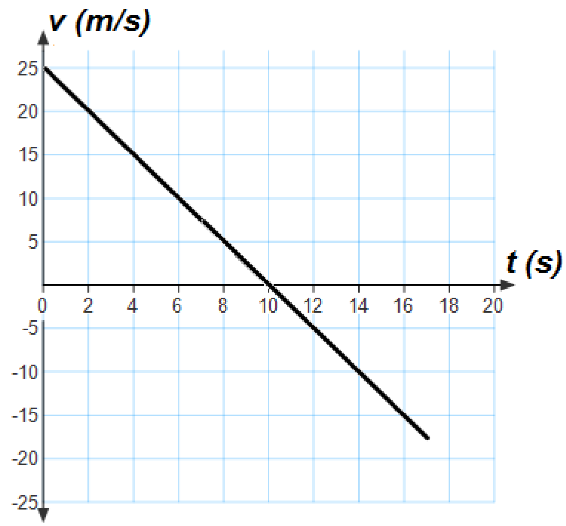
42 The velocity as a function of time is presented by the graph. What is the acceleration?




Answer

https://www.njctl.org/video/?v=ZKzgAnarr40

43 The velocity as a function of time is presented by the graph. Find the acceleration.



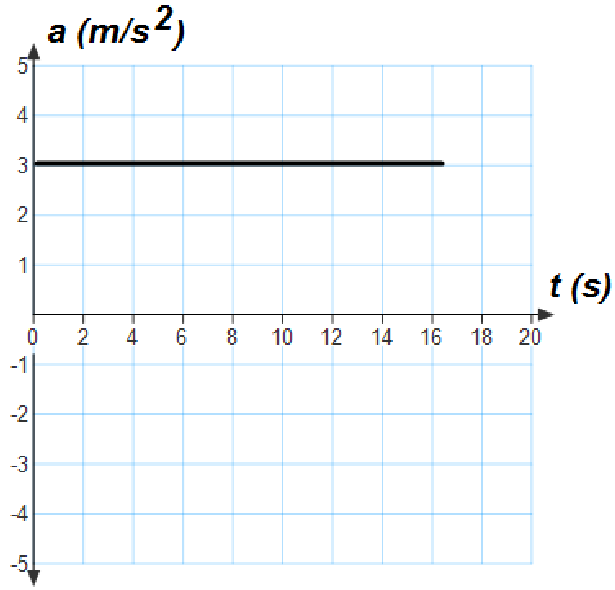

Answer

https://www.njctl.org/video/?v=owkR-TAxlgs

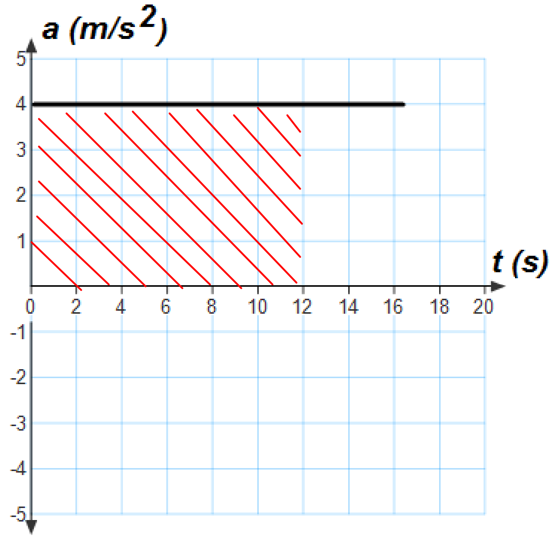
# Motion at Constant Acceleration

The acceleration graph as a function of time can be used to find the velocity of a moving object. When the acceleration is constant the velocity is changing by the same amount each second. This can be shown on the graph as a straight horizontal line.

In order to find the change in velocity for a certain limit of time we need to calculate the area under the acceleration line that is limited by the time interval.



# Motion at Constant Acceleration

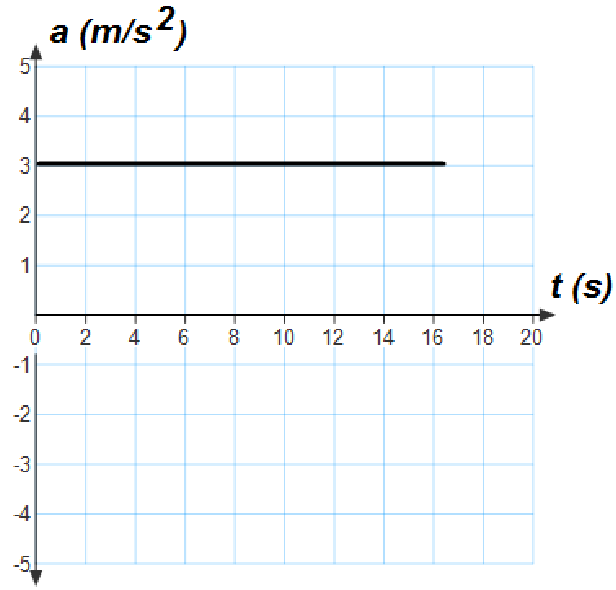



The change in velocity during first 12 seconds is equivalent to the shadowed area

$\left(4\frac{m}{s^2} \times 12s = 48\frac{m}{s}\right).$

The change in velocity during first 12 seconds is 48 m/s.

44 The following graph shows acceleration as a function of time of a moving object. What is the change in velocity during first 10 seconds?




Answer

https://www.njctl.org/video/?v=D3bQyx0ygFM

# Free Fall:
# Acceleration Due to Gravity

Demo

https://www.njctl.org/video/?v=rB95M_Rgmq8

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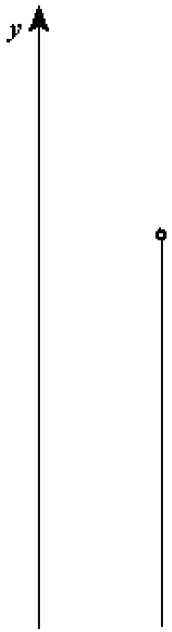
# Free Fall




All unsupported objects fall towards Earth with the same acceleration. We call this acceleration the "acceleration due to gravity" and it is denoted by g.

$$g = 9.8\ m/s^2$$

Keep in mind, ALL objects accelerate towards the earth at the same rate.

g is a constant!

Click here to watch Galileo's famous experiment performed on the moon

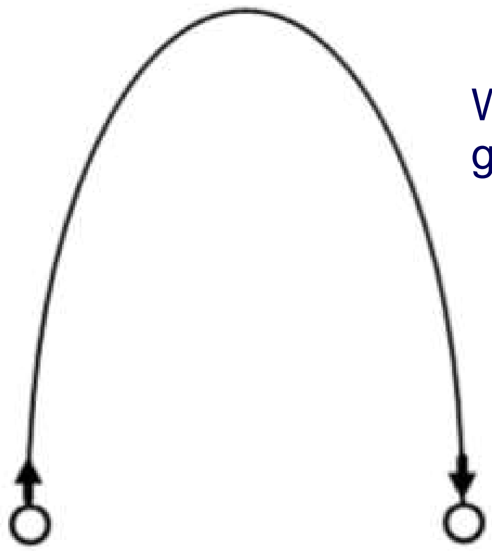
free fall demo sheet

# Free Fall

What happens at the top?

What happens when it goes down?

What happens when it goes up?



An object is thrown upward with initial velocity, $v_o$

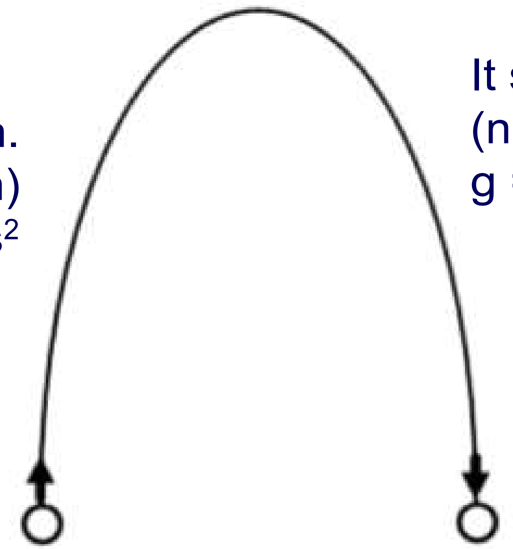
(Click on question for answer.)

What happens when it lands?

# Free Fall Answers

It stops momentarily.
$v = 0$
$g = -9.8\ m/s^2$

It slows down.
(negative acceleration)
$g = -9.8\ m/s^2$

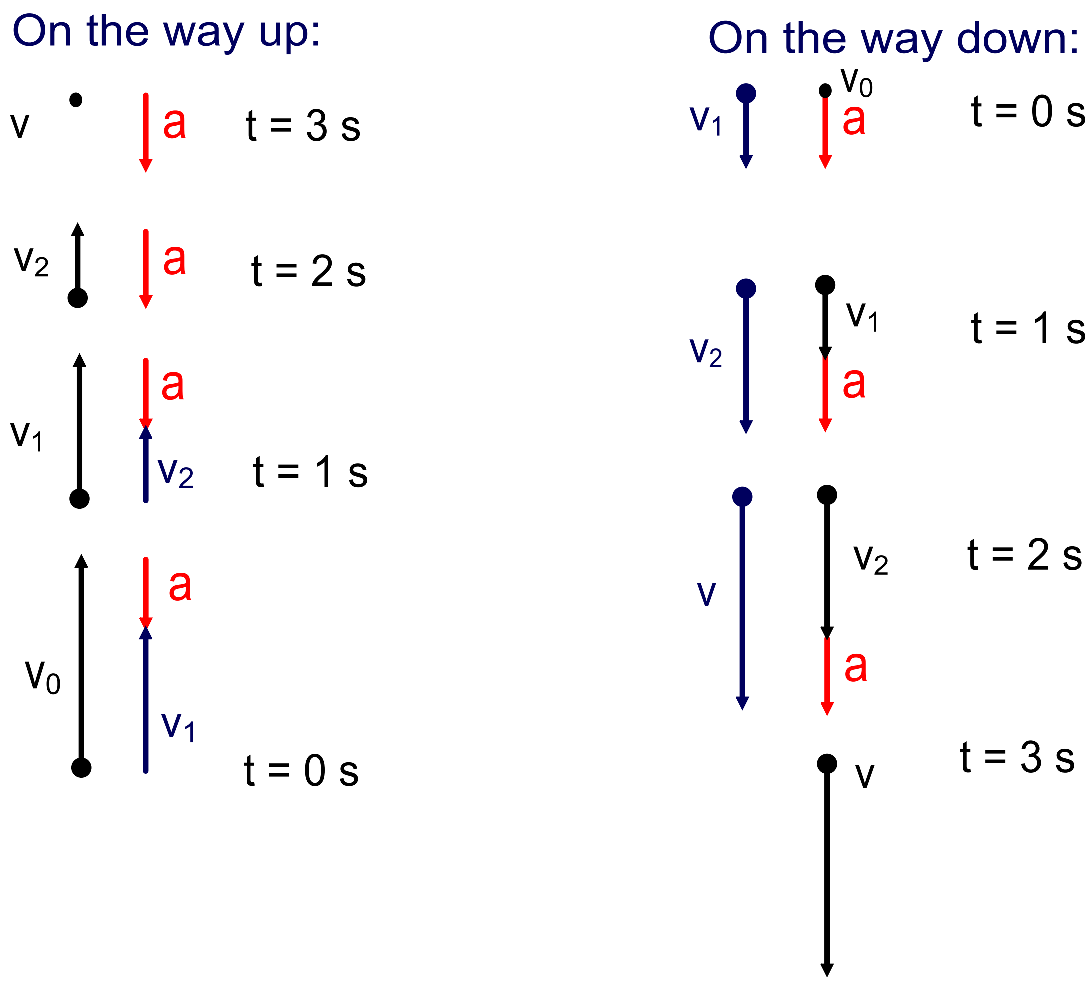


It speeds up.
(negative acceleration)
$g = -9.8\ m/s^2$

An object is thrown upward with initial velocity, $v_o$

It returns with its original velocity.

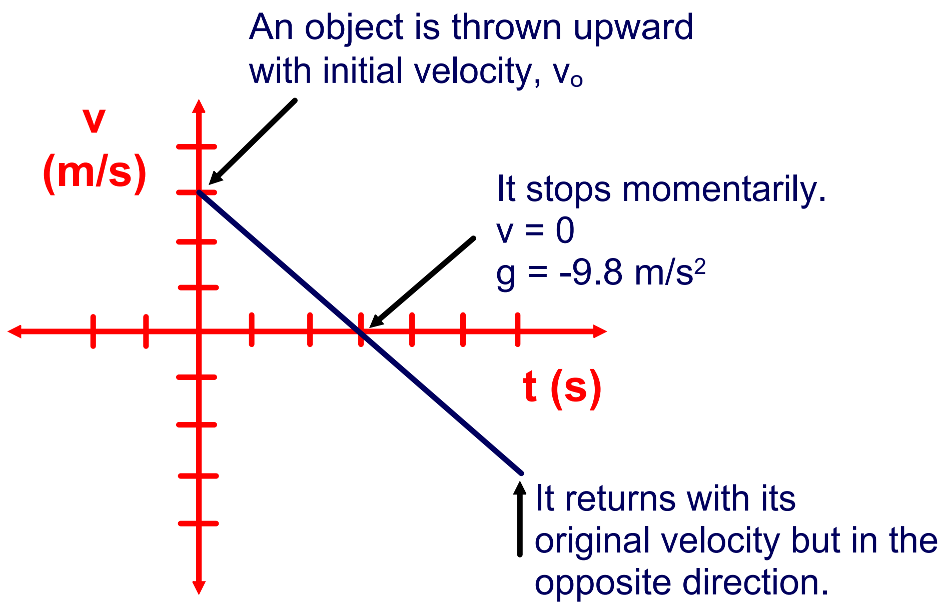
# Free Fall



On the way up:
v
a
t = 3 s
v2
a
t = 2 s
a
v1
v2
t = 1 s
a
v0
v1
t = 0 s
On the way down:
v1
v0
a
t = 0 s
v1
v2
a
t = 1 s
v
v2
a
t = 2 s
v
t = 3 s

# Free Fall

For any object thrown straight up into the air, this is what the velocity vs. time graph looks like.



45 A ball is dropped from rest and falls (do not consider air resistance). Which is true about its motion?

A acceleration is constant

B speed is constant

C speed is decreasing

D acceleration is decreasing

Answer

https://www.njctl.org/video/?v=lqrx6I6fFPo

46 An acorn falls from an oak tree. You note that it takes 2.5 seconds to hit the ground. How fast was it going when it hit the ground?

Answer

https://www.njctl.org/video/?v=ZjGTOtqx7Fk

47 A rock falls off a cliff and hits the ground 5 seconds later. What velocity did it hit the ground with?

Answer

https://www.njctl.org/video/?v=qSo50sEyALQ

48 A ball is thrown down off a bridge with a velocity of 5 m/s. What is its velocity 2 seconds later?

Answer

https://www.njctl.org/video/?v=_ush_fkVoyk

49 An arrow is fired into the air and it reaches its highest point 3 seconds later. What was its velocity when it was fired?

Answer

https://www.njctl.org/video/?v=6CXXQIqCZro

50 A rocket is fired straight up from the ground. It returns to the ground 10 seconds later. What was its launch speed?

Answer

https://www.njctl.org/video/?v=tJybBb09Uos

# Motion at Constant Acceleration

If velocity is changing at a constant rate, the average velocity is just the average of the initial and final velocities.

$$\bar{v} = \frac{v + v_o}{2}$$

And we learned earlier that

$$\bar{v} = \frac{\Delta x}{t}$$

$$\frac{\Delta x}{t} = \frac{v + v_o}{2}$$

Some problems can be solved most easily by using these two equations together.

$$\Delta x = \frac{(v + v_o)}{2} t$$

https://www.njctl.org/video/?v=mQ8GOB-nL3c

51 Starting from rest you accelerate to 20 m/s in 4.0s. What is your average velocity?

Answer

https://www.njctl.org/video/?v=RbtF1rQASGw

52 Starting with a velocity of 12 m/s you accelerate to 48 m/s in 6.0s. What is your average velocity?

Answer

https://www.njctl.org/video/?v=DnHDGc5cAh0

53 Starting with a velocity of 12 m/s you accelerate to 48 m/s in 6.0s. Using your previous answer, how far did you travel in that 6.0s?

*Previous Answer*
*average velocity = 30 m/s*

Answer

https://www.njctl.org/video/?v=RU2c0x7AAiM

# Kinematics Equation 2

Demo

Lab

https://www.njctl.org/video/?v=ZPaD7pUZxrM

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# Motion at Constant Acceleration

$\bar{v} = \frac{\Delta x}{t}$

$\bar{v} = \frac{v + v_o}{2}$

$v = v_o + at$

$\Delta x = \bar{v}\,t$

$x - x_o = \frac{1}{2}(v + v_o)t$

$x - x_o = \frac{1}{2}vt + \frac{1}{2}v_ot$

$x = x_o + \frac{1}{2}v_ot + \frac{1}{2}vt$

$x = x_o + \frac{1}{2}v_ot + \frac{1}{2}(v_o + at)t$

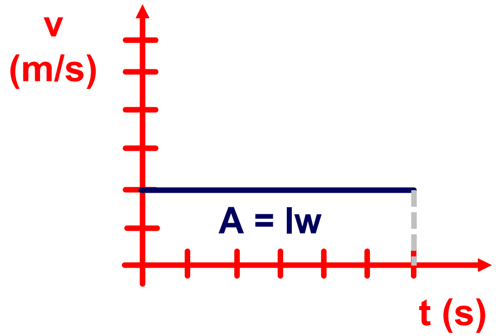
$x = x_o + \frac{1}{2}v_ot + \frac{1}{2}v_ot + \frac{1}{2}at^2$

$$\boxed{x = x_o + v_ot + \frac{1}{2}at^2}$$

We can combine these three equations to derive an equation which will directly tell us the position of an object as a function of time.

# Motion at Constant Acceleration

*Graphical Approach*



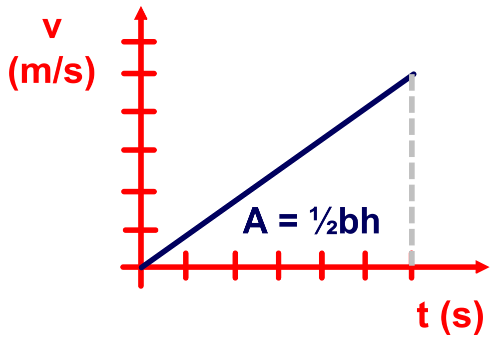

If the area under the graph is length x width (A = lw), then:

$A = v_0t$ Since we know that $v = \frac{\Delta x}{t}$, then area is really $\Delta x$.

$A = \Delta x = v_0t$

# Motion at Constant Acceleration

*Graphical Approach*




If the area under this graph is ½ base x height, then:

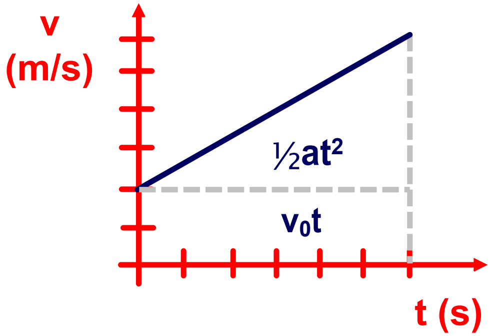
$A = \frac{1}{2}t\Delta v$ Since we know that $a = \frac{\Delta v}{t}$,

$\Delta v = at$.

$A = \Delta x = \frac{1}{2}t(at) = \frac{1}{2}at^2$

# Motion at Constant Acceleration

*Graphical Approach*




Therefore, the area under a velocity vs. time graph is displacement. It can be calculated by combining the previous two results.

$$A = \Delta x = v_0t + \frac{1}{2}at^2$$

$$x - x_0 = v_0t + \frac{1}{2}at^2$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

54 An airplane starts from rest and accelerates at a constant rate of 3.0 m/$s^2$ for 30.0 s before leaving the ground. How far did it move along the runway?

Answer

https://www.njctl.org/video/?v=OhB6n5VNJpA

55 A Volkswagen Beetle moves at an initial velocity of 12 m/s. It coasts up a hill with a constant acceleration of $-1.6\ m/s^2$. How far has it traveled after 6.0 seconds?

Answer

https://www.njctl.org/video/?v=Iv8l_-RG_fY

56 A motorcycle starts out from a stop sign and accelerates at a constant rate of 20 m/$s^2$. How long will it take the motorcycle to go 300 meters?

Answer

https://www.njctl.org/video/?v=Uh87-Cgt6ak

57 A train pulling out of Grand Central Station accelerates from rest at a constant rate. It covers 800 meters in 20 seconds. What is its rate of acceleration?

Answer

https://www.njctl.org/video/?v=A2YjfXJW1pA

58 A car has an initial velocity of 45 m/s. It accelerates for 4.8 seconds. In this time, the car covers 264 meters. What is its rate of acceleration?

Answer

https://www.njctl.org/video/?v=Kcw5NEHp2zg

59 A Greyhound bus traveling at a constant velocity starts to accelerate at a constant 2.0 $m/s^2$. If the bus travels 500 meters in 20 seconds, what was its initial velocity?

Answer

https://www.njctl.org/video/?v=MQxR6xG-AiM

# Kinematics Equation 3

Demo

Lab

https://www.njctl.org/video/?v=Uk8LcZ1WIxg

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# Motion at Constant Acceleration

We can also combine these equations so as to eliminate *t*:

$$v^2 = v_o^2 + 2a(x - x_o)$$

60 A car accelerates from rest to 30m/s while traveling a distance of 20m; what was its acceleration?

Answer

https://www.njctl.org/video/?v=RNQxw3-mQCU

61 You accelerate, from rest, at $10 m/s^2$ for a distance of 100m; what is your final velocity?

Answer

https://www.njctl.org/video/?v=kZBFio3GHFY

62 You accelerate from 20m/s to 60m/s while traveling a distance of 200m; what was your acceleration?

Answer

https://www.njctl.org/video/?v=z2Y9RQqk_l0

63 Beginning with a velocity of 25m/s, you accelerate at a rate of $2.0 m/s^2$. During that acceleration you travel 200m; what is your final velocity?

Answer

https://www.njctl.org/video/?v=x7iGi9eGtn0

64 A dropped ball falls -8.0m; what is its final velocity?

Answer

https://www.njctl.org/video/?v=v7dJTLjftrE

65 A ball with an initial velocity of 25m/s is subject to an acceleration of $-9.8\ m/s^2$ ; how high does it go before coming to a momentary stop?

Answer

https://www.njctl.org/video/?v=ReTH6IKoUYs

# Motion at Constant Acceleration

We now have all the equations we need to solve constant-acceleration problems.

$$v = v_o + at$$

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

$$v^2 = v_o^2 + 2a(x - x_o)$$

https://www.njctl.org/video/?v=S4VkyTF8uBg

# Mixed Kinematics Problems

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66 An arrow is projected by a bow vertically up with a velocity of 40 m/s, and reaches a target in 3 s. How high is the target located?

Answer

https://www.njctl.org/video/?v=OVCqcjGQEwY

67 An object accelerates from rest, with a constant acceleration of 8.4 $m/s^2$, what will its velocity be after 11s?

Answer

https://www.njctl.org/video/?v=D7wd9ctbXkM

68 An object accelerates from rest to a velocity of 34 m/s over a distance of 70 m. What was its acceleration?

Answer

https://www.njctl.org/video/?v=bmQkTIhu5u4

# Graphing

https://www.njctl.org/video/?v=unLHH0wj01k

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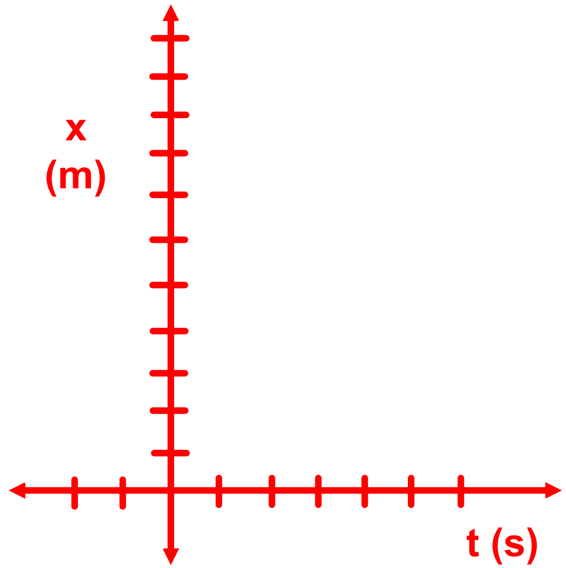
# Position vs Time Graphs

An object's position at any point in time can be graphed.

These graphs show position but also can be used to find an object's velocity.

Position is the dependent variable (y-axis), and time is the independent variable (x-axis).



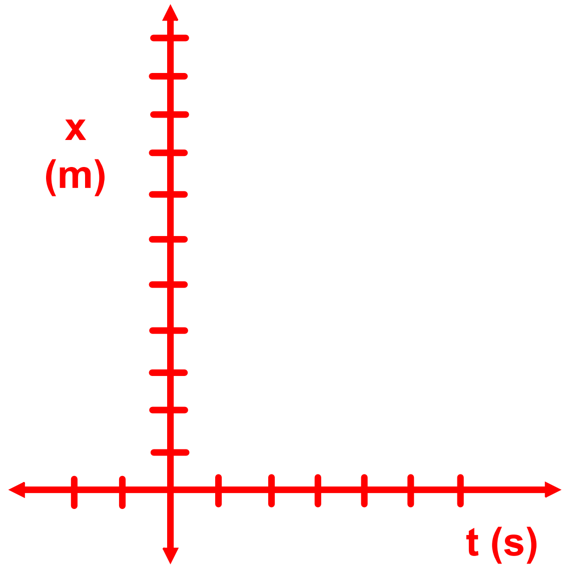
# Creating a Position vs. Time Graph

1. Draw a cartesian coordinate system by drawing a vertical and horizontal axis.

2. Label the vertical axis as position (x), and the horizontal axis as time (t).

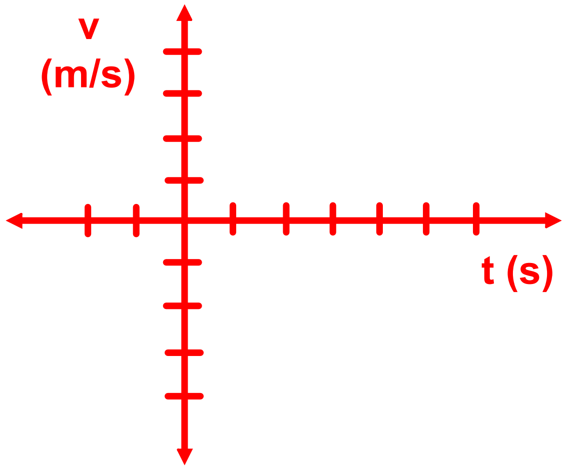
3.  Add units next to each axis label, showing position measured in meters, and time measured in seconds

4. Add points to the graph requires both the position and time it happened.



# Velocity vs. Time Graphs

Similarly, the same approach can be used to create a velocity vs. time graph.




A velocity versus time graph differs by having the velocity on the vertical axis.

A velocity versus time graph shows describes an objects velocity, it's displacement, and acceleration.

Starting at the position, $x_0$ = 4 m, you travel at a constant velocity of +2 m/s for 6s.

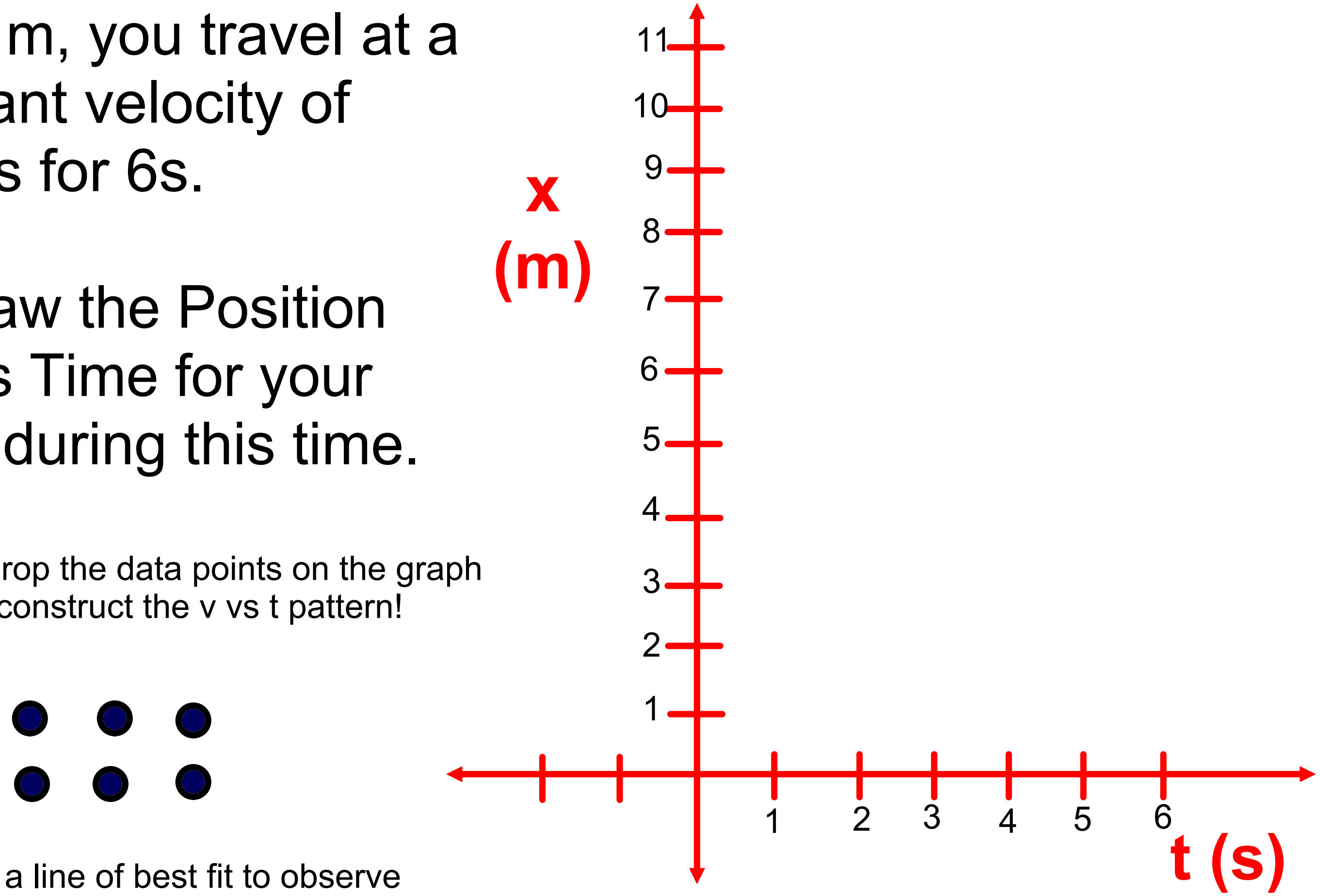
a. Determine your position at the times of 0s; 2s; 5s; and 6s.

Answer

Starting at the position, $x_0$ = 4 m, you travel at a constant velocity of +1 m/s for 6s.

b. Draw the Position versus Time for your travel during this time.

Drag and drop the data points on the graph in order to construct the v vs t pattern!



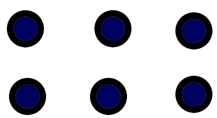

Draw a line of best fit to observe the pattern.

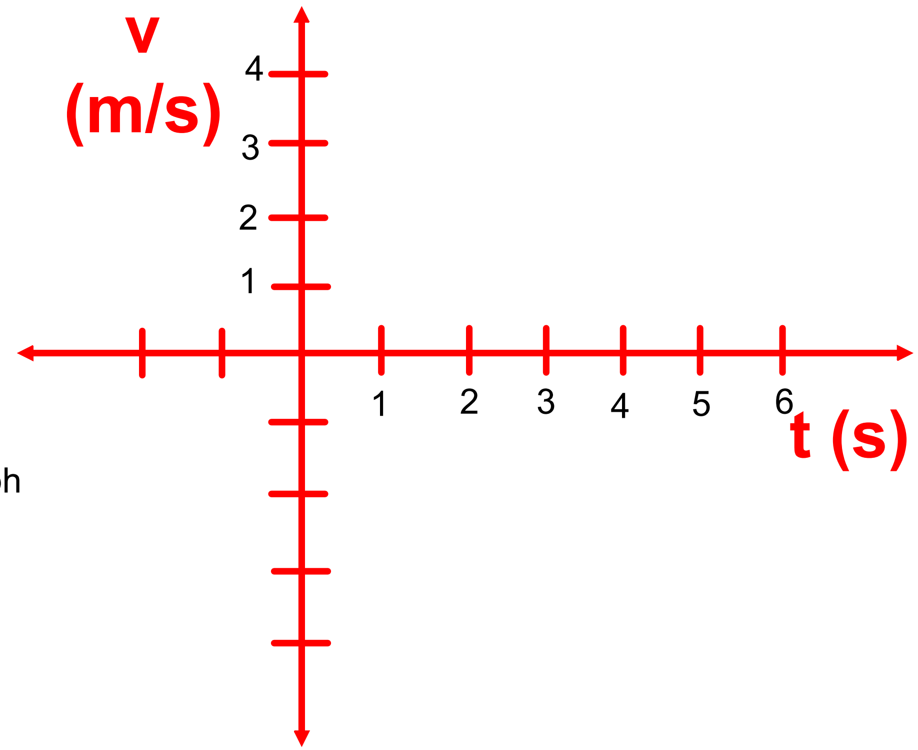
Answer

Starting at the position, $x_0$ = 4 m, you travel at a constant velocity of +2 m/s for 6s.

c. Draw the Velocity versus Time graph for your trip.

Drag and drop the data points on the graph in order to construct the v vs t pattern!





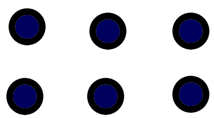

Draw a line of best fit to observe the pattern.

Answer

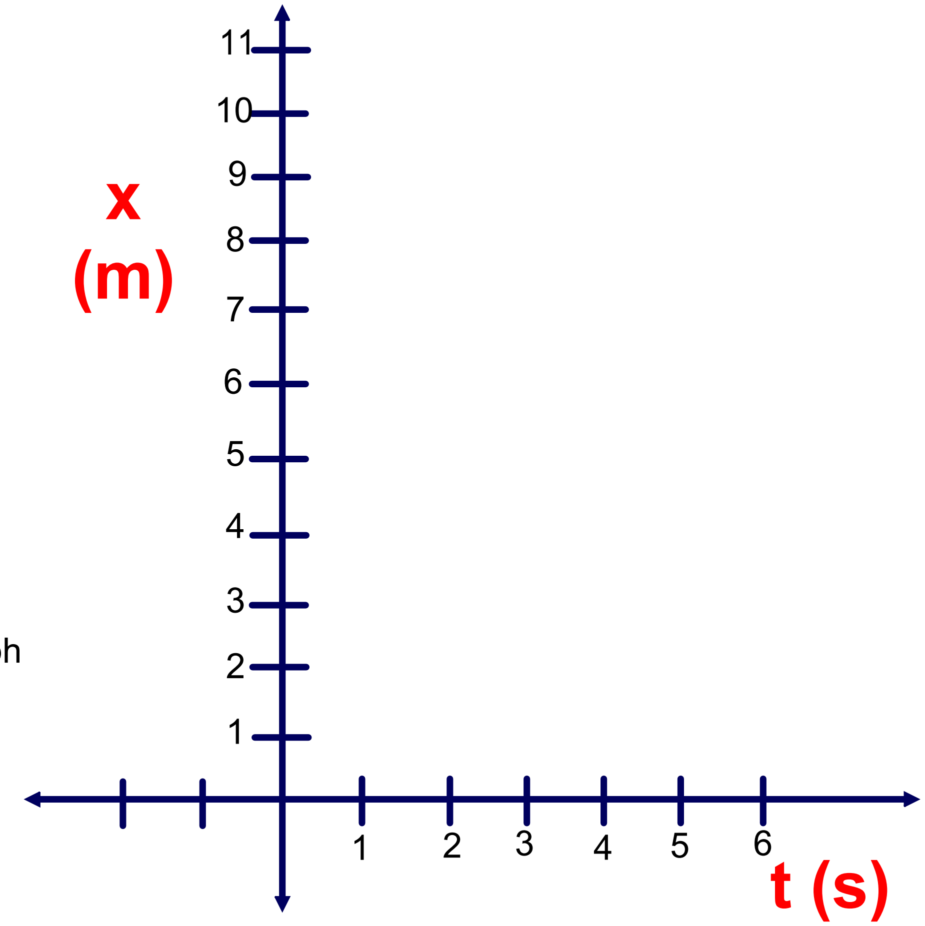
Starting at the position, $x_0$ = 10 m, you travel at a constant velocity of -1m/s for 6s.

d. Draw the Position versus Time for your travel during this time.

Drag and drop the data points on the graph in order to construct the v vs t pattern!



Draw a line of best fit to observe the pattern.



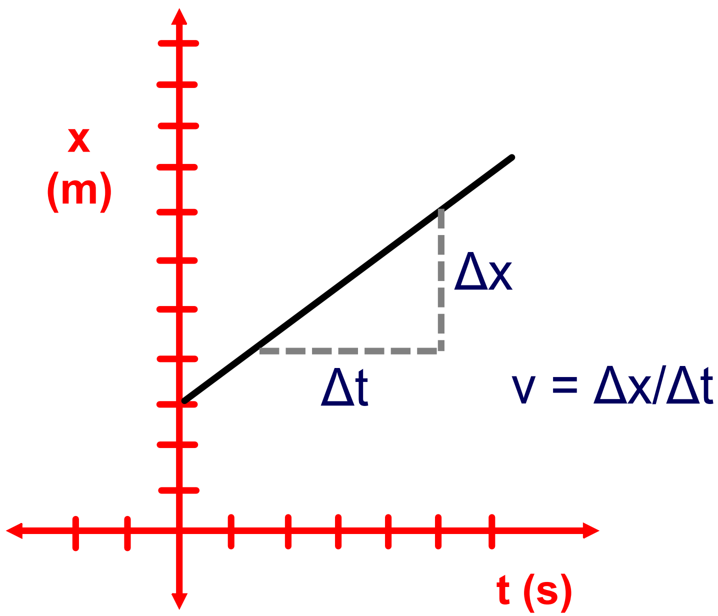

Answer

# Analyzing Position vs Time Graphs

Recall earlier in this unit that slope was used to describe motion.

The slope in a position vs. time graph is $\Delta x/\Delta t$, which is equal to velocity.

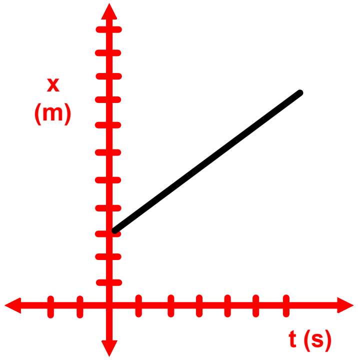
Therefore, slope is equal to velocity on a position vs. time graph.



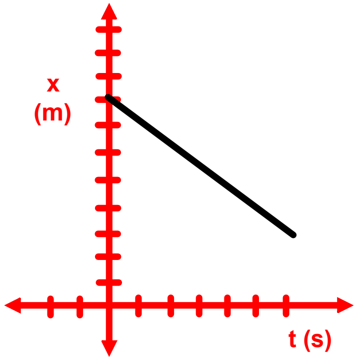
# Analyzing Position vs Time Graphs

A positive slope is a positive velocity, a negative slope is a negative velocity, and a slope of zero means zero velocity.

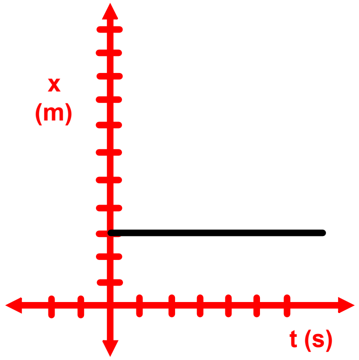
positive slope
$v > 0$




negative slope
$v < 0$



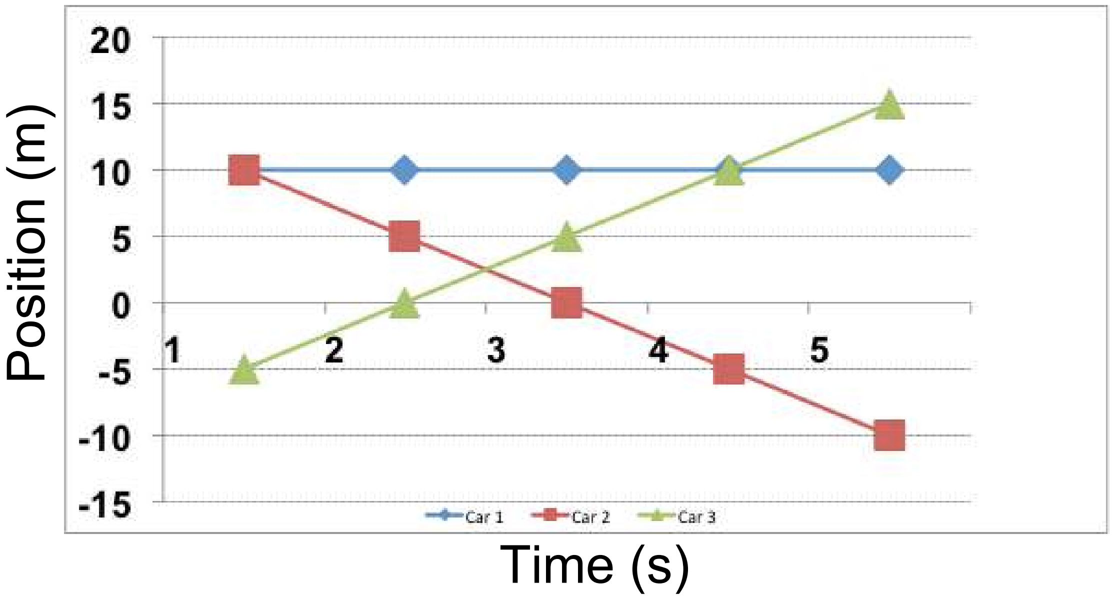

zero slope
$v = 0$




A positive velocity means moving in the positive direction, a negative velocity means moving in the negative direction, and zero velocity means not moving at all.

The position versus time graph, below, describes the motion of three different cars moving along the x-axis.

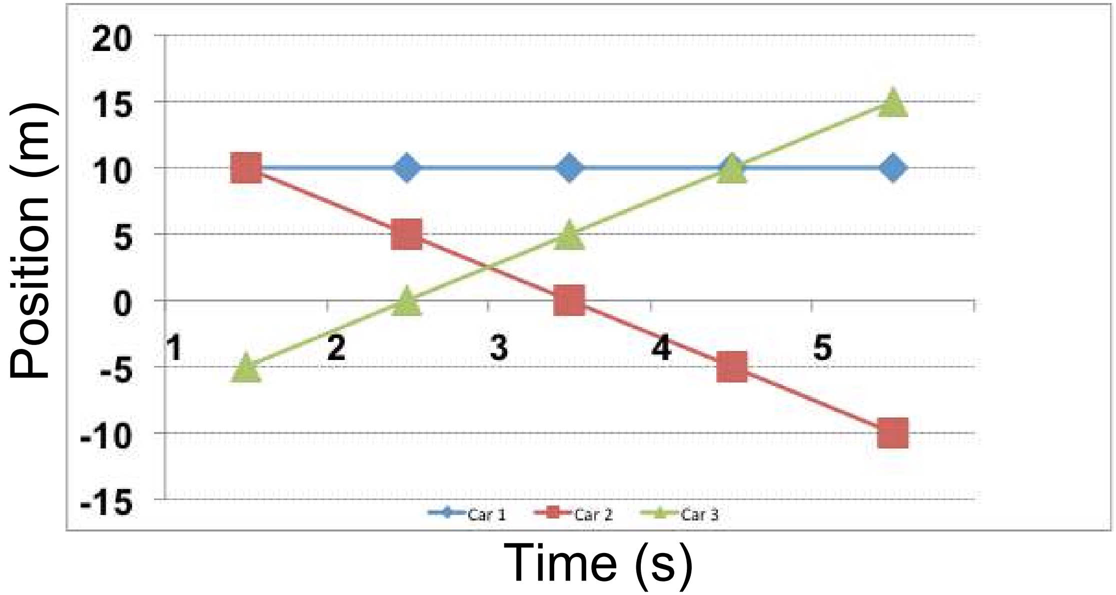
a. Describe, in words, the velocity of each of the cars. Make sure you discuss each car's speed and direction.




Answer

The position versus time graph, below, describes the motion of three different cars moving along the x-axis.

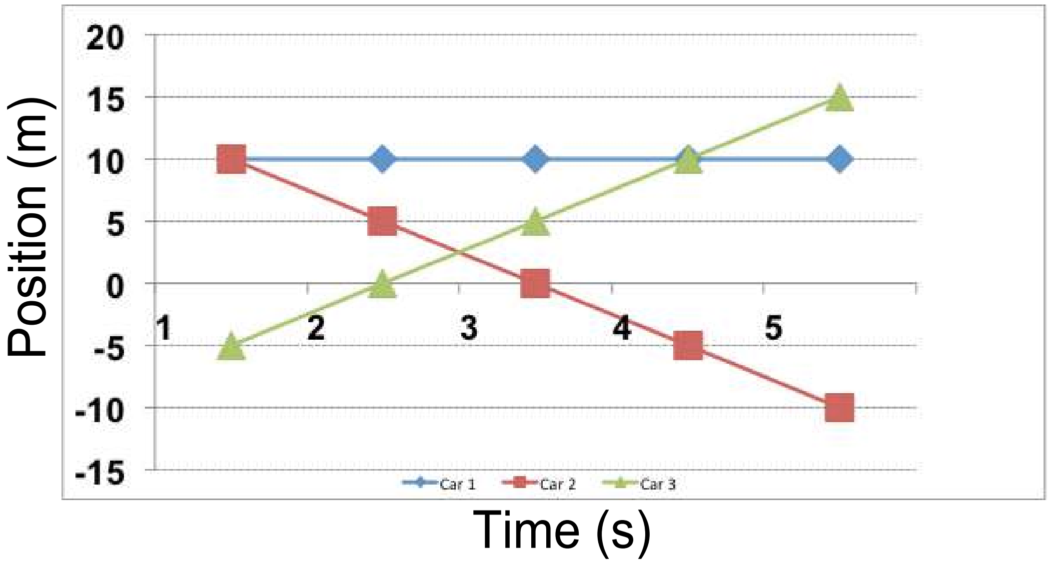
b. Calculate the velocity of each of the cars.

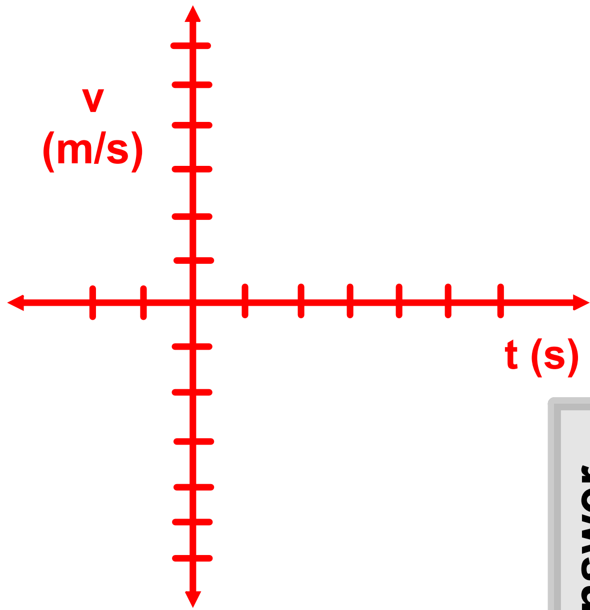



Answer

https://www.njctl.org/video/?v=0z2PvzGoFGo

c. Draw, on one set of axes, the Velocity versus Time graph for each of the three cars.

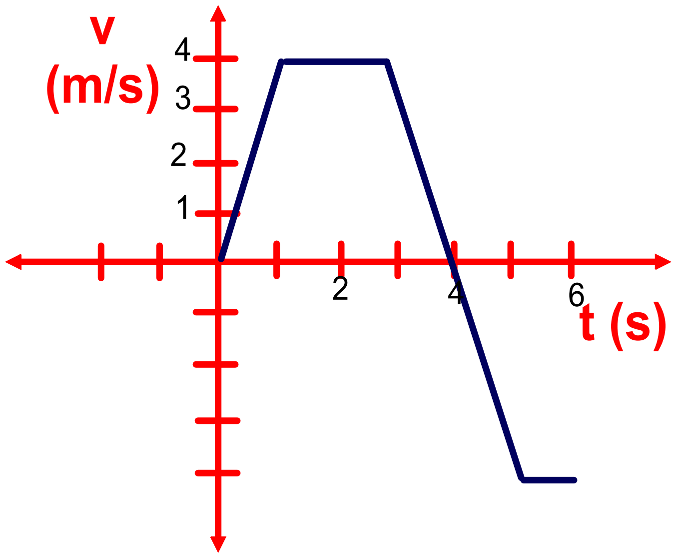



Answer

The velocity vs time graph, below, describes the motion of an object moving along the x-axis.

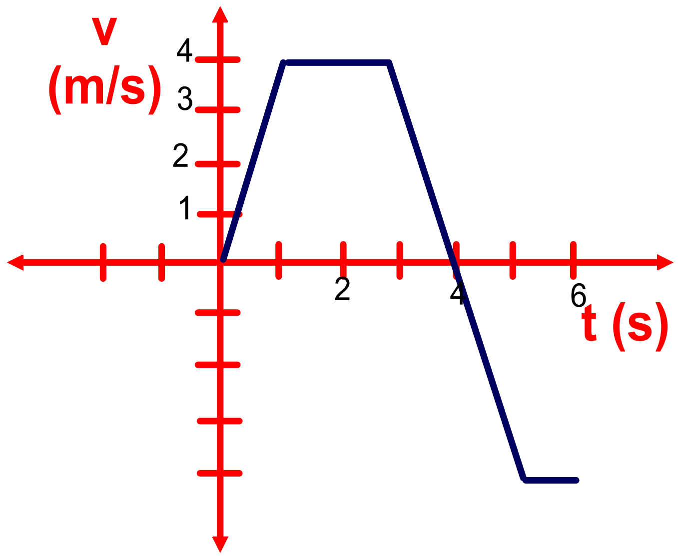
69 When is velocity zero?




Answer

https://www.njctl.org/video/?v=W3YyvDwwBbc

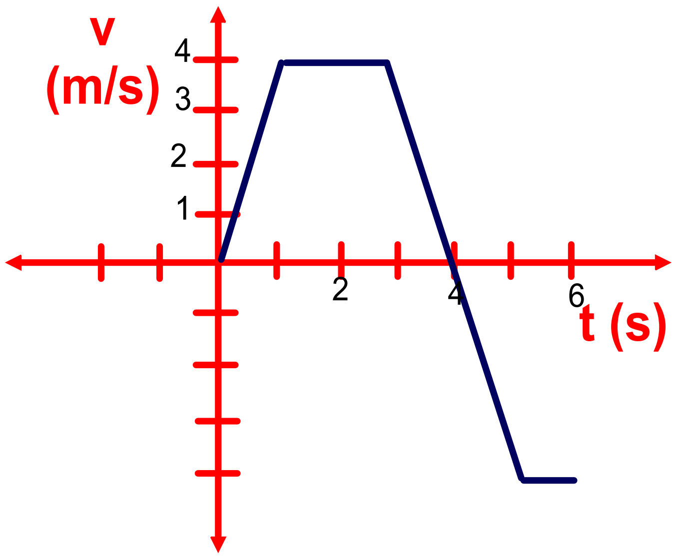
The velocity vs time graph, below, describes the motion of an object moving along the x-axis.




Answer

Describe in words what is happening to the speed during the following intervals.
a) 0s to 1s  b) 1s to 3s c) 3s to 4 sec
d) 4s to 5s  e) 5s to 6s

70 The velocity vs time graph, below, describes the motion of an object moving along the x-axis.

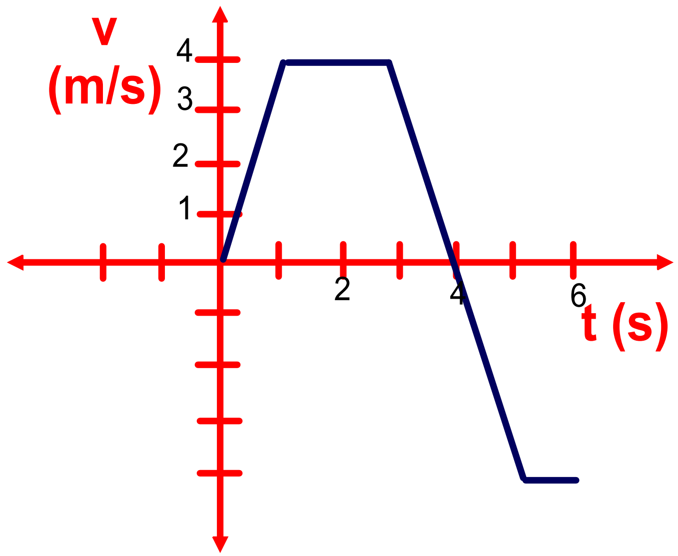



Determine the average speed during the following intervals.

a) 0s to 1s b) 1s to 3s c) 3s to 4 sec
d) 4s to 5s e) 5s to 6s f) 3s to 5s

https://www.njctl.org/video/?v=Lqhl24yBB0E

The velocity vs time graph, below, describes the motion of an object moving along the x-axis.




$V_{avg} = (V_f + V_i)/2$

a) 0s to 1s $V_{avg}$ = +2m/s

b) 1s to 3s $V_{avg}$ = +4m/s

c) 3s to 4s $V_{avg}$ = +2m/s

d) 4s to 5s $V_{avg}$ = -2m/s

e) 5s to 6s $V_{avg}$ = -4m/s

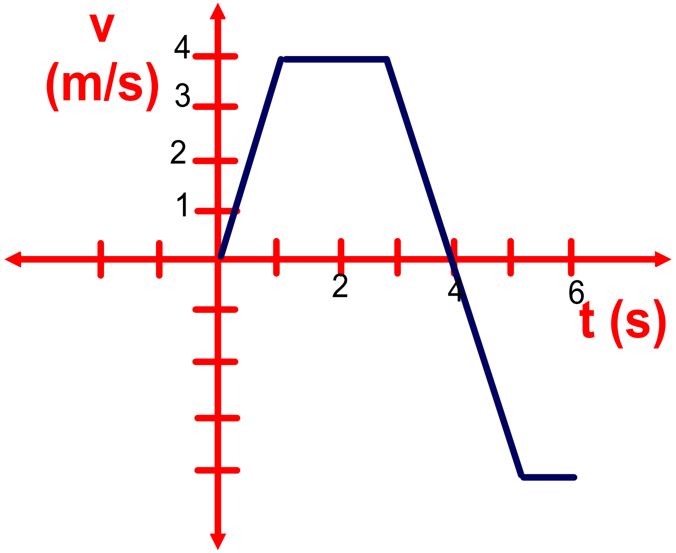
f) 3s to 5s $V_{avg}$ = 0m/s

Answer

Determine the displacement during the following intervals.
a) 0s to 1s b) 1s to 3s c) 3s to 4 sec
d) 4s to 5s e) 5s to 6s

https://www.njctl.org/video/?v=oQ_FqdWsOfQ

The velocity vs time graph, below, describes the motion of an object moving along the x-axis.




71 Determine the net displacement during the first four seconds of travel.

https://www.njctl.org/video/?v=eZAznYcQQ7s

Answer

# Summary

- Kinematics is the description of how objects move with respect to a defined reference frame.

- Displacement is the change in position of an object.

- Average speed is the distance traveled divided by the time it took; average velocity is the displacement divided by the time.

https://www.njctl.org/video/?v=iyQH4q1hbUU

# Summary (continued)

- Instantaneous velocity is the limit as the time becomes infinitesimally short.
- Average acceleration is the change in velocity divided by the time.
- Instantaneous acceleration is the limit as the time interval becomes infinitesimally small.

# Summary (continued)

- There are four equations of motion for constant acceleration, each requires a different set of quantities.

$$v = v_o + at$$

$$x = x_o + v_o t + \tfrac{1}{2}at^2$$

$$v^2 = v_o^2 + 2a(x - x_o)$$

$$\overline{v} = \frac{v + v_o}{2}$$