Unit 1: Kinematics and Dynamics

Physical Quantities

Physical quantities are any quantities which can be completely described by measuring them. For example, the amount of time to read this sentence is a physical quantity. Physical quantities are classified into 2 types: **scalar quantities** and **vector quantities**.

Kinematics

A branch of physics which deals with the motion of objects without any regard for the causes of this motion.

Dynamics

A branch of physics which deals specifically with the causes of motion of objects.

Scalar Quantities

A scalar quantity is a physical quantity which can be completely described by a number and a correct and applicable unit. Scalar quantities only have a magnitude (size). Examples would include:

mass 5 kg   distance 100 km   volume 34 cm^3 others??

A common scalar quantity is distance.

Vector Quantities

Vector quantities are physical quantities that need more than just magnitude (size). They are quantities which can be completely described using a number, an applicable unit, and a direction. Vectors must have magnitude and direction. Examples include:

displacement 10 km [N 45 E]   velocity 27 m/s [W]

Common vector quantities include velocity, displacement, position.

NOTE -- the direction for a vector can also simply be up, down, right, left, forwards backwards, around the base pads, etc.

Pull

<u>Distance</u>

Distance is the length of line segment or path travelled as an object moves from one location to another. Distance is a scalar quantity because it only needs a magnitude to describe it completely. The symbol for distance is:

Δd (delta d)

The Greek letter delta, Δd, means "change in distance". The most common unit for distance is the meter, m, however, many other units still apply. Consider Sue, who leaves her house and travels a distance (not necessarily in a straight line) of 10 km. We say:

$\Delta d = 10$ km

<u>Position</u>

<u>Position is the location of an object relative to a reference point. Position is a vector quantity</u> because in addition to magnitude, a direction is also necessary to completely describe this physical quantity. The symbol for position is:

$\overrightarrow{\Delta d}$

The unit is the meter with a direction [ ]. Let's consider Sue again. The shortest distance between Sue's house and walmart is 8 km east. The position of walmart is:

$\overrightarrow{\Delta d} = 8$ km [E] of Sue's house

<u>Displacement</u>

Displacement is the change in position of an object. Displacement is a vector quantity because it also needs a direction in addition to a magnitude to completely describe it. It represents the length and direction of the line segment from an initial postion to a final position. The symbol for displacement is:

$\overrightarrow{\Delta d}$

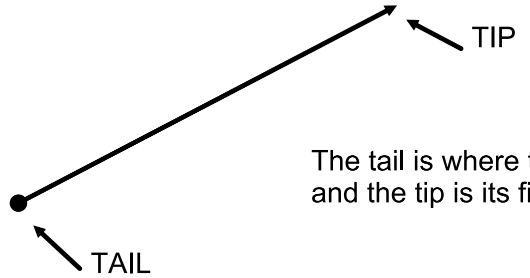
Its unit is the meter, with an applicable direction. It does not need a reference point. Consider Sue again. Her displacement is simply:

$\overrightarrow{\Delta d} = 8$ km [E]

Pull

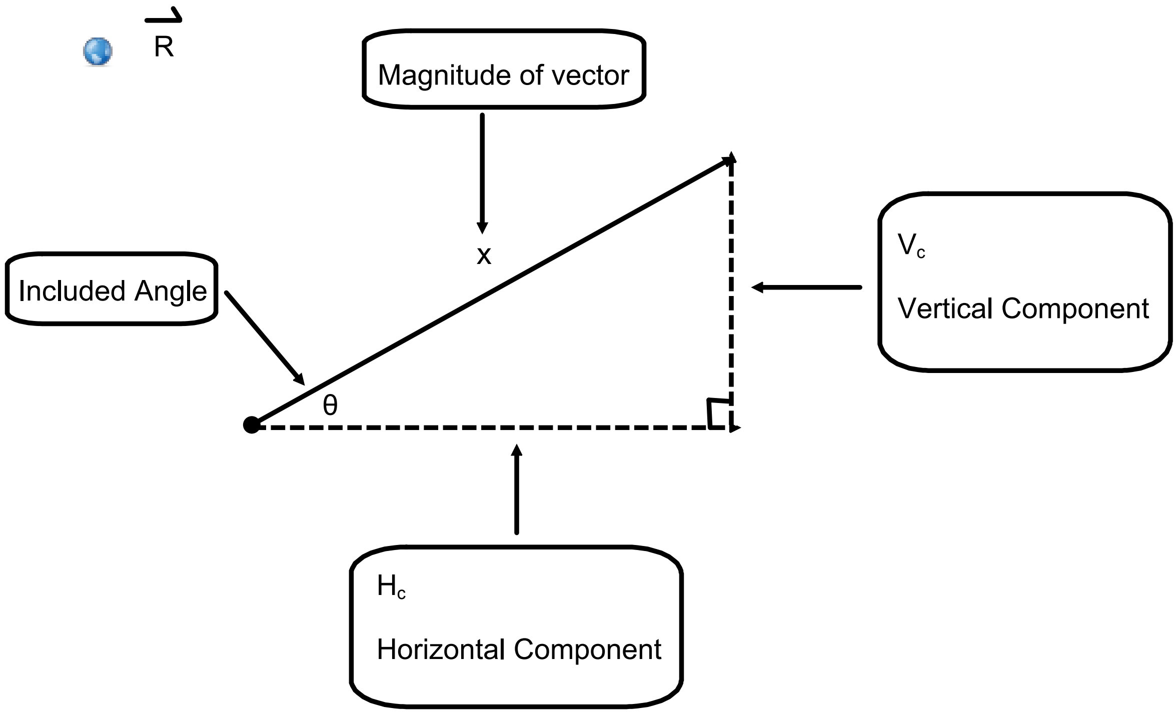
Representing/Drawing Vector Quantities

Every vector has 2 parts, a TAIL and a TIP.



The tail is where the vector originates (origin) and the tip is its final position (terminating point)

In addition to a tip and tail, every vector has **2 components.** Consider vector R below:

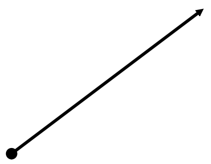


$$\boxed{V_c = x \sin\theta}$$

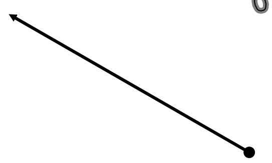
$$\boxed{H_c = x \cos\theta}$$

$$\boxed{x = \sqrt{(V_c)^2 + (H_c)^2}}$$

For the following vectors, draw and calculate the lengths and directions of the vertical and horizontal components.



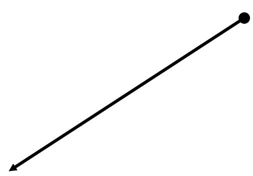
$\vec{P}$ = 100km [N45°E]



8cm [W30° N]

30 km [E]

4mm [W]



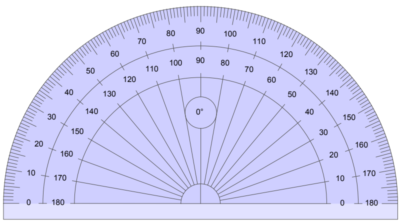
8.3 LY [S60°W]
(LY = light years)

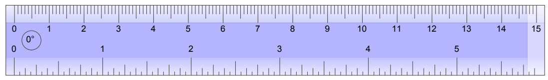
Using Scale Factors to Draw Vectors to Scale

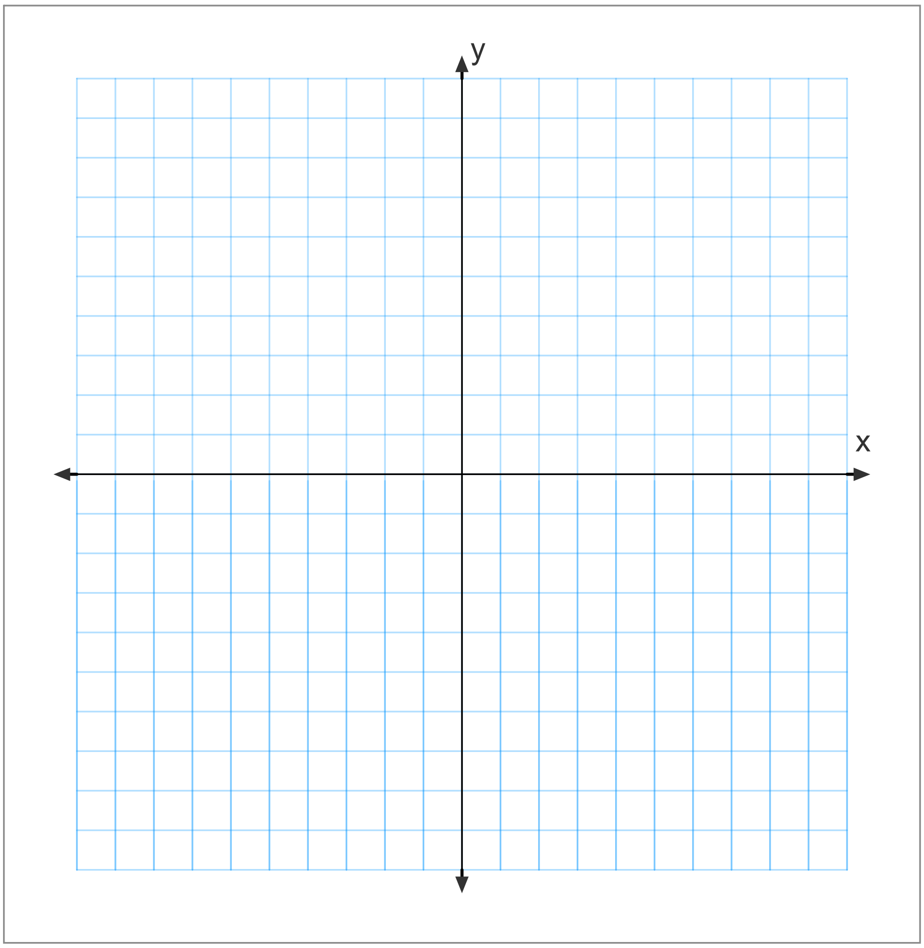
Consider the vector below:

$\vec{A}$ = 500 km [N 30 E]

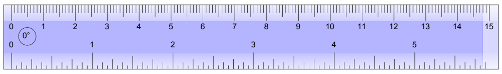
How can we actually draw a vector 500 km long? We'll need to scale it down to fit our axis.
What might be an appropriate scale factor? There are several we could use.

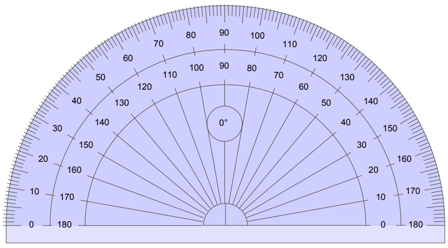


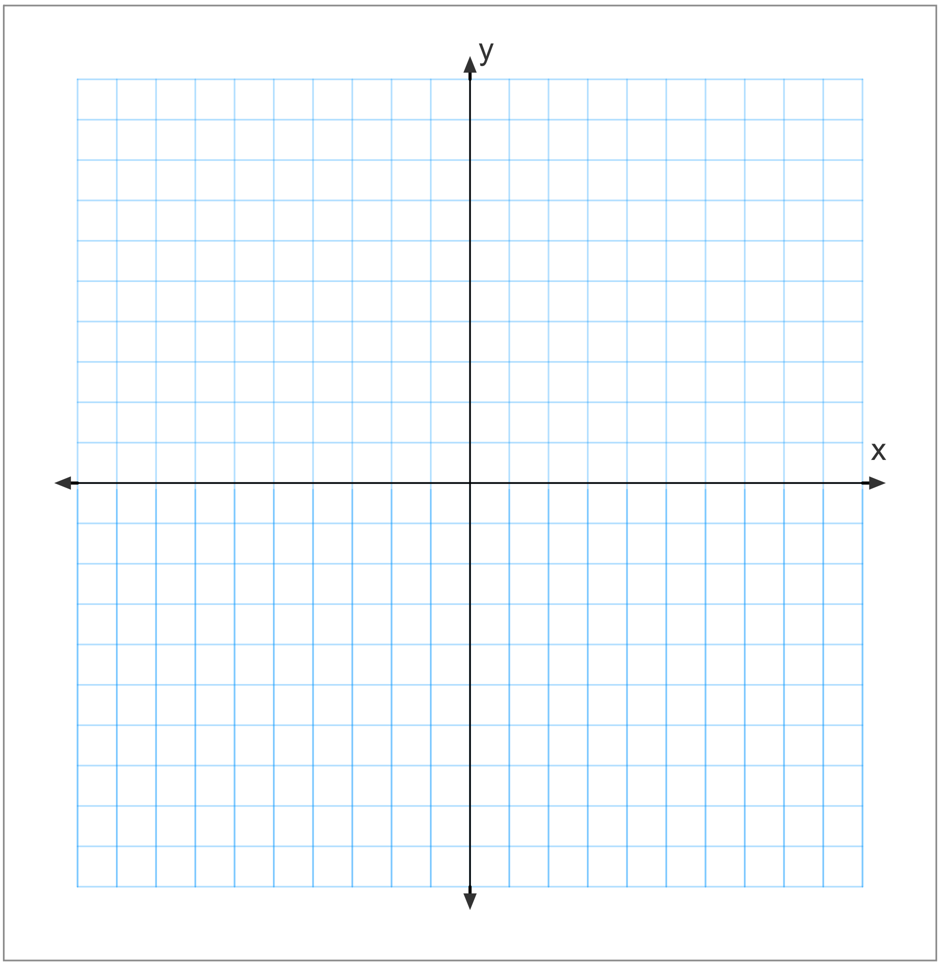




F = 3800 mm [S 70 W]







Pull

Adding Scalar Quantities

To add scalar quantities, we simply use integer rules keeping in mind the units must agree. For instance:

3 hrs + 7.5 hrs + 180 min
= 3 + 7.5 + 3
=13.5 hrs

OR

180 min + 450 min + 180 min
=810 min

Adding Vector Quantities

Adding vector quantities is more involved as they contain directions. There are 2 types of vectors we can add/subtract. They are:

-Collinear Vectors
-Non-Collinear Vectors

Adding Collinear Vectors

Collinear vectors are 2 or more vectors which lie in the same 2-D plane. For example, 3 west vectors, or 2 north vectors, or 5 [W 10 S] vectors, or 2 east and 3 west vectors. When the directions are collinear, it's just a matter of again using integer rules, keeping in mind adding "like" and unlike" signs. For example:

4 m [E] + 5 m [E]
= 9 m [E]

8 m/s [S 60 W] + 15 m/s [S 60 W]
= 23 m/s [S 60 W]

3 N [S] + 5 N [N] + 10 N [N] + 20 N [S] (note N is symbol for Newton's)
= 3 + (-5) + (-10) + 20
=8 m [E]

OR

(-3) + 5 + 10 + (-20)
= -8 m [W]

Adding Non-Collinear Vectors

Non-collinear vectors are two or more vectors which do not lie on the same 2-D plane. For example, a 10 km [W] vector and a 8.5 km [S] vector are non-collinear. To add non-collinear vectors, there are several methods including:

1. SOHCAHTOA and Pythagorean Theorem (only if right triangles exist)
2. Law of Sines and/or Law of Cosines (if non right triangles exist)
3. Vector Resolution
4. Graphically using scale diagrams

$\sin\theta = \text{opp/hyp}$ $\cos\theta = \text{adj/hyp}$ $\tan\theta = \text{opp/adj}$

$a^2 + b^2 = c^2$ $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$ $\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$

$a^2 = b^2 + c^2 - 2bc\cos A$
$b^2 = a^2 + c^2 - 2ac\cos B$
$c^2 = a^2 + b^2 - 2ab\cos C$

$x_R = \sqrt{\Sigma (V_c)^2 + \Sigma (H_c)^2}$ $\theta_R = \tan^{-1}\left[\frac{\Sigma V_c}{\Sigma H_c}\right]$

NOTE The sum of two or more vectors can be named several ways

- sum
- resultant
- resultant displacement
- resultant velocity
- resultant force
- others

Consider the following vector addition examples:

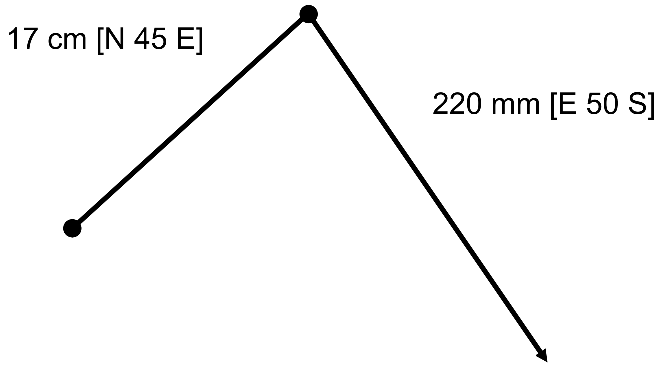
1. Dolly walks 800 m [W] from her home to Home Hardware, then 500 m to Walmart. What is Dolly's final position from home, if Walmart is
    a. due west of HH
    b. due east of HH

2. Randy left his cabin to look for gold. He walked 8 km [S], then 12 km [E], and finally 3 km [N]. Calculate Randy's resultant displacement. Use SOHCAHTOA and Pyth if necessary

3. Mr. Prosser decides to go for a bike ride. He travels 4 km [N 40 W], then 5 km [S], followed by 10 km [E 30 S]. What is his resultant?

4. Using vector resolution, determine the resultant vector for the three vectors that follow:
    40 km [W 50 S], 80 km [N 25 E], and 35 km [E 65 S]

5. Using LOS or LOC, determine the resultant vector for the following diagram:



Pull

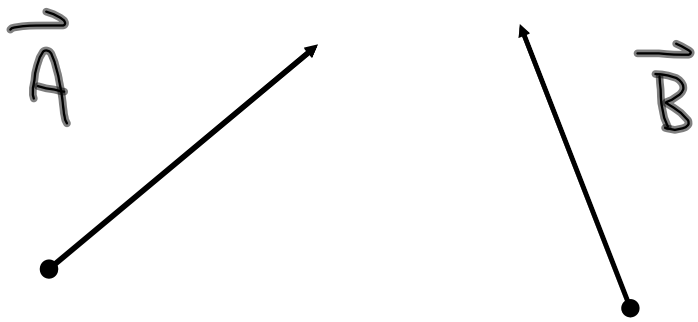
Pull

Pull

Subtracting Vectors

Consider the two vectors, $\vec{A}$ and $\vec{B}$ below

Infinite Cloner!



What's $\vec{A} + \vec{B}$

What's $\vec{A} - \vec{B}$

Period and Frequency Refresher

Recall from Physics 20, the concepts of Period and Frequency. They were quantities that dealt with **periodic motion**. Motion that repeated itself on a regular interval.

Frequency

Frequency is a scalar quantity measured in Hertz, Hz. It is defined as the number of complete cycles/back and forth motions/to and fro motions/vibrations of an object in a given amount of time.

Frequency = # of vibrations/elapsed time

$= N/\Delta t$

Period

Period is a scalar quantity measured in a unit of time (often sceonds). It is defined as the elapsed time it takes an object to complete one full cycle/back and forth motion/to and fro motion/vibration.

Period = elapsed time/# of vibrations

$T = \Delta t/N$

NOTE: Recall that period and Frequency re reciprocals of each other. In other words:

$T = 1/$ and $= 1/T$

Pull

Example

1. The pendulum on a grandfather clock makes 10 complete to and fro motions in 12 sec. Calculate the period and frequency of the pendulum.

Speed and Velocity

Speed

Speed is defined as the distance travelled per unit of time. It is a scalar quantity. Simply stated, speed is "how fast something is moving". The symbol for speed is "v" and two very common units are meter per second, m/s, and kilometer per hour, km/h.

$$\text{Speed} = \frac{\text{total distance travelled}}{\text{elapsed time}}$$

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

Average Speed

Average speed is defined as the total distance travelled during various "legs" of a trip divided by the total time (sum of time per "leg"). It has the same formula as for regular speed. Its symbol is v_{AV}.

$$\boxed{v_{AV} = \frac{\overline{\Delta d}}{\Delta t}}$$

Instantaneous Speed

Instantaneous speed is defined as speed at an exact instant in time. It requires the use of a calculus topic to calculate it accurately. We will look at the idea of instantaneous velocity in a later topic without the use of calculus!

Velocity

Velocity is generically defined as speed in an applicable direction. In other words, it is how fast an object is moving in a particular direction. It needs both magnitude and direction. Velocity is a vector quantity. The symbol for velocity is $\vec{v}$. It's true definition is the change in displacement of an object divided by the elapsed time.

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

$$\boxed{\vec{v} = \frac{\Delta \vec{d}}{\Delta t}}$$

RECALL m/s -----> km/hr multiply by 3.6 km/hr -------> m/s divide by 3.6

Average Velocity

Average velocity is much the same as ordinary velocity, however it generally involves more than one vector quantity.

$$\boxed{\vec{v}_{AV} = \frac{\Delta \vec{d}}{\Delta t}}$$

Instantaneous Velocity

Instantaneous velocity is the velocity (speed and direction) of an object at a particular instant in time. To calculate it accurately (mathematically speaking), we need calculus, however there are a couple of other methods.

1. Slope of tangent lines (graphing method, not very accurate)
2. Half-time intervals (very accurate, but time consuming)

Examples

1. Ron left home and jogged 3 km [S] in 30 minutes, 4 km [W] in 30 minutes, and finally 5 km [S] in one hour. Calculate:

   a. Ron's average speed
   b. Ron's average velocity

2. Mr. P hikes 6 km [E] in 2 hrs, then 8 km [N] in 4 hrs. Calculate:

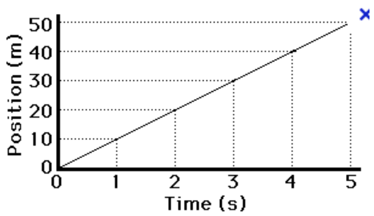
   a. his average speed
   b. his average velocity
   c. had Mr. P returned back home in 7 hours, what would his average velocity be?

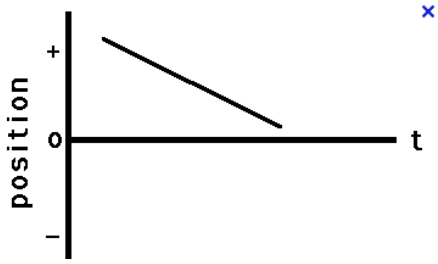
3. During a marathon, one portion included a 20 km run. Zeus was an athlete in the marathon and ran at a an average speed of 3.85 m/s for the first 10 km, but was only able to run at an average speed of 3.15 m/s on the last 10 km. What was Zeus' average speed for the entire 20 km marathon?

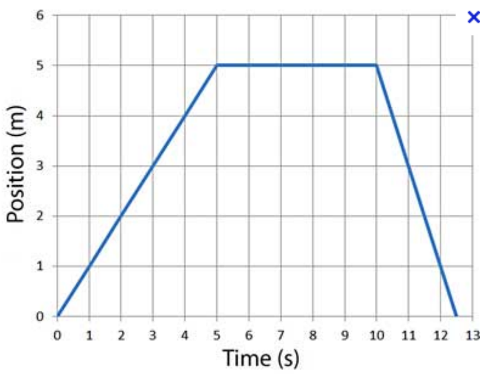
Pull

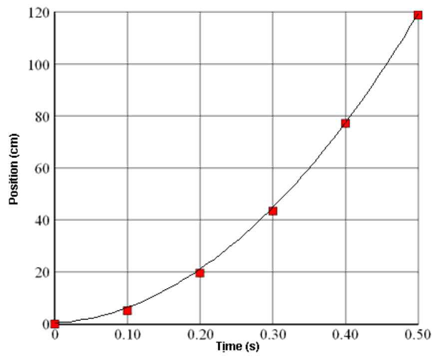
Pull

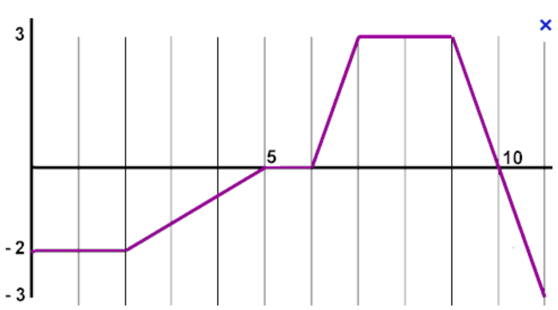
Position - Time Graphs

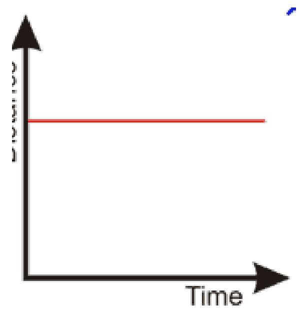




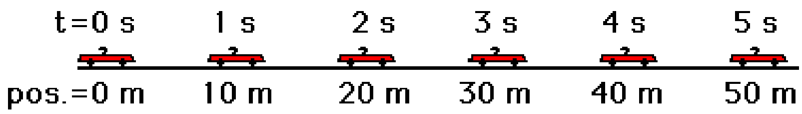




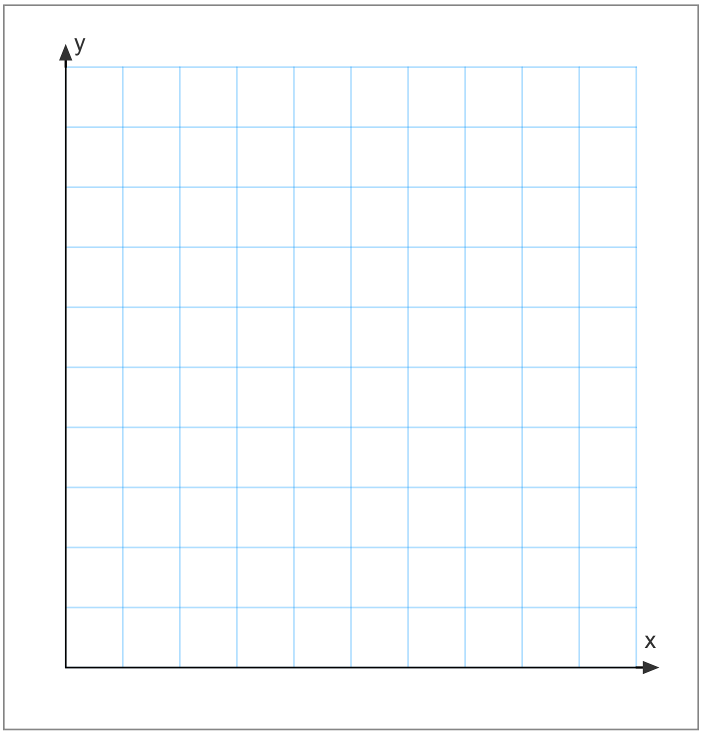




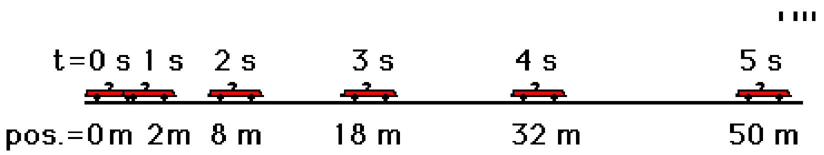
To begin, consider a car moving with a **constant, rightward (+) velocity** - say of +10 m/s.



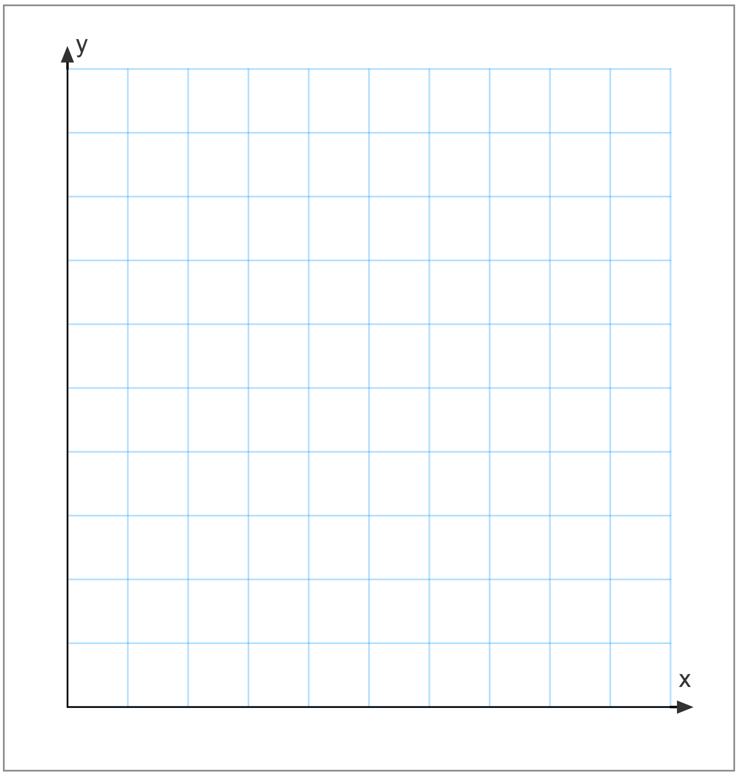
Δt	$\overrightarrow{\Delta d}$

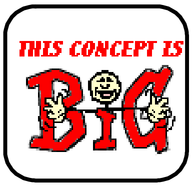


Now consider a car moving with a **rightward (+), changing velocity** -
that is, a car that is moving rightward but speeding up or *accelerating*.

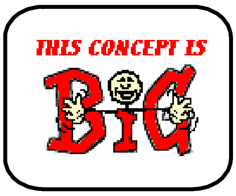


Δt	$\overrightarrow{\Delta d}$



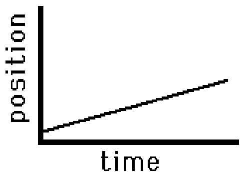


The Importance of Slope

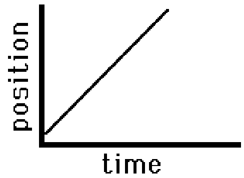


The shapes of the position versus time graphs for these two basic types of motion - constant velocity motion and accelerated motion (i.e., changing velocity) - reveal an important principle. The principle is that the slope of the line on a position-time graph reveals useful information about the velocity of the object. It is often said, "As the slope goes, so goes the velocity." Whatever characteristics the velocity has, the slope will exhibit the same (and vice versa). If the velocity is constant, then the slope is constant (i.e., a straight line). If the velocity is changing, then the slope is changing (i.e., a curved line). If the velocity is positive, then the slope is positive (i.e., moving upwards and to the right). This very principle can be extended to any motion conceivable.

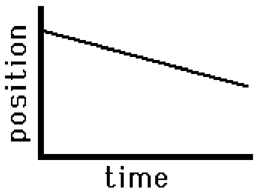
Slow, Rightward(+)
Constant Velocity



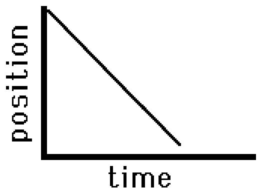
Fast, Rightward(+)
Constant Velocity



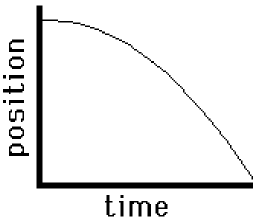
Slow, Leftward(-)
Constant Velocity



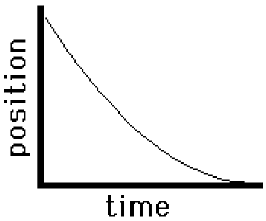
Fast, Leftward(-)
Constant Velocity

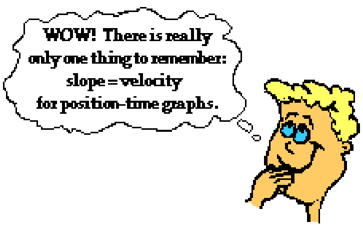


Negative (-) Velocity
Slow to Fast



Leftward (-) Velocity
Fast to Slow

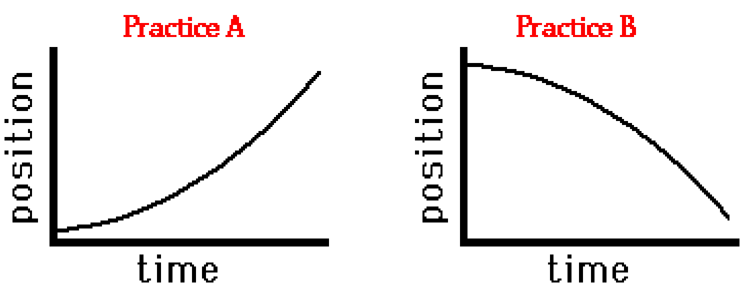




Pull

Check Your Understanding

Use the principle of slope to describe the motion of the objects depicted by the two plots below. In your description, be sure to include such information as the direction of the velocity vector (i.e., positive or negative), whether there is a constant velocity or an acceleration, and whether the object is moving slow, fast, from slow to fast or from fast to slow. Be complete in your description.



See Answer to A

See Answer to B

Calculating Velocity, $\vec{v}$, on a P-T Graph

On a P-T, velocity, $\vec{v}$, can be found by calculating slope. However, a brief review on slope may be helpful.

$$\text{Slope} = \frac{\text{rise}}{\text{run}}$$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

Since $\vec{v} = m$, we can say:

$$\vec{v} = \frac{y_2 - y_1}{x_2 - x_1}$$

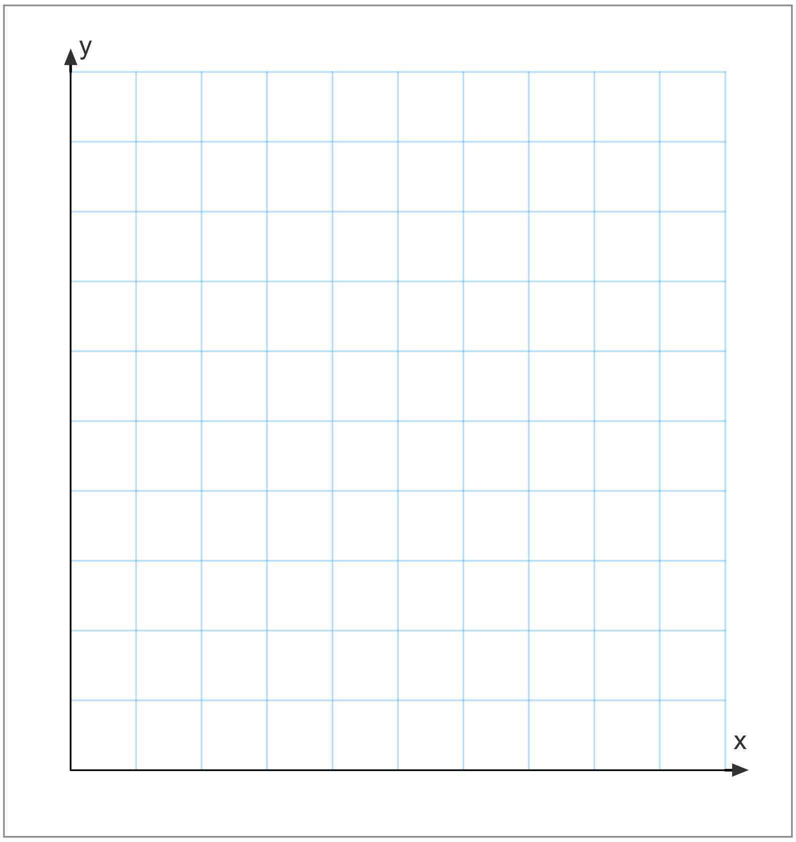
But, since P-T graphs rarely deal in a "x" and "y" axis, we should think of velocity this way:

$$\boxed{\vec{v} = \frac{\Delta\vec{d}_2 - \Delta\vec{d}_1}{\Delta t_2 - \Delta t_1}}$$

$$\boxed{\vec{v} = \frac{\Delta\vec{d}}{\Delta t}}$$

Consider the following scenario of a vehicle in motion travelling east at a constant velocity.

Δt hr	$\overrightarrow{\Delta d}$ km[E]
0	0
0.25	20
0.50	40
1	80
1.50	120
2	160
3	240

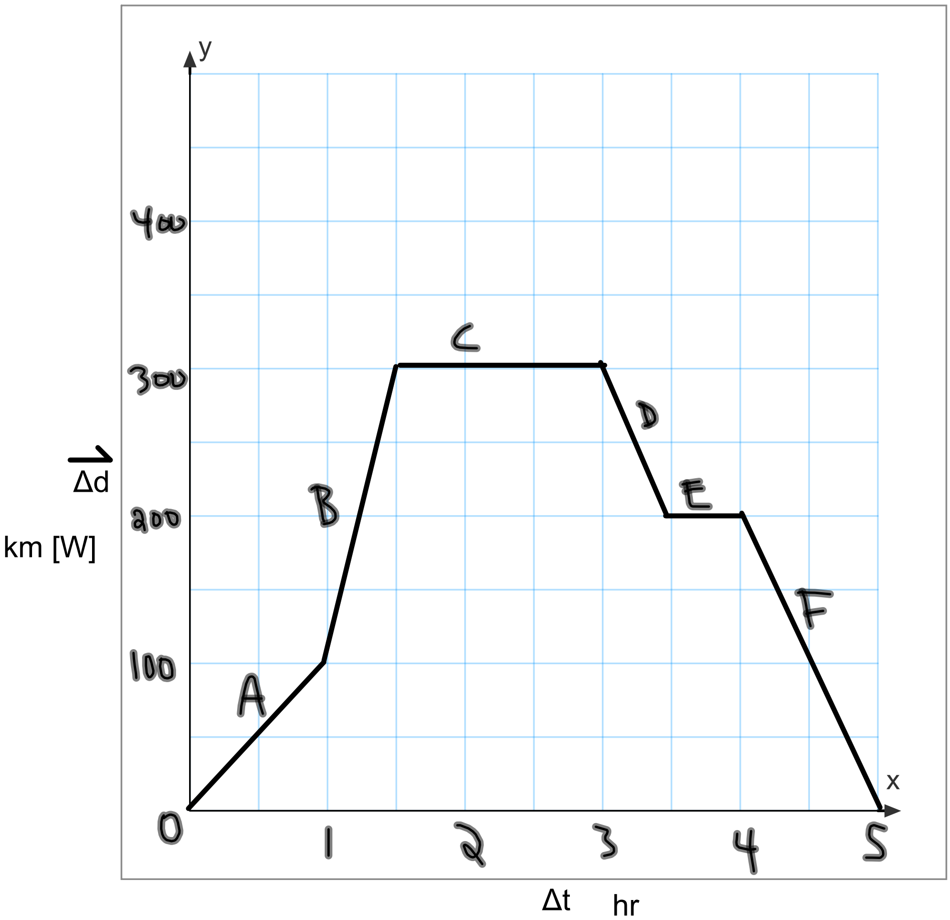


Calculate the velocity of the vehicle between 0 hrs and 0.50 hrs.
Calculate the velocity of the vehicle between 1 hr and 3 hrs?
What do you notice?

Pull

P-T Graphs for a Round Trip

Consider the following P-T graph for an object travelling with a constant velocity during a round trip.



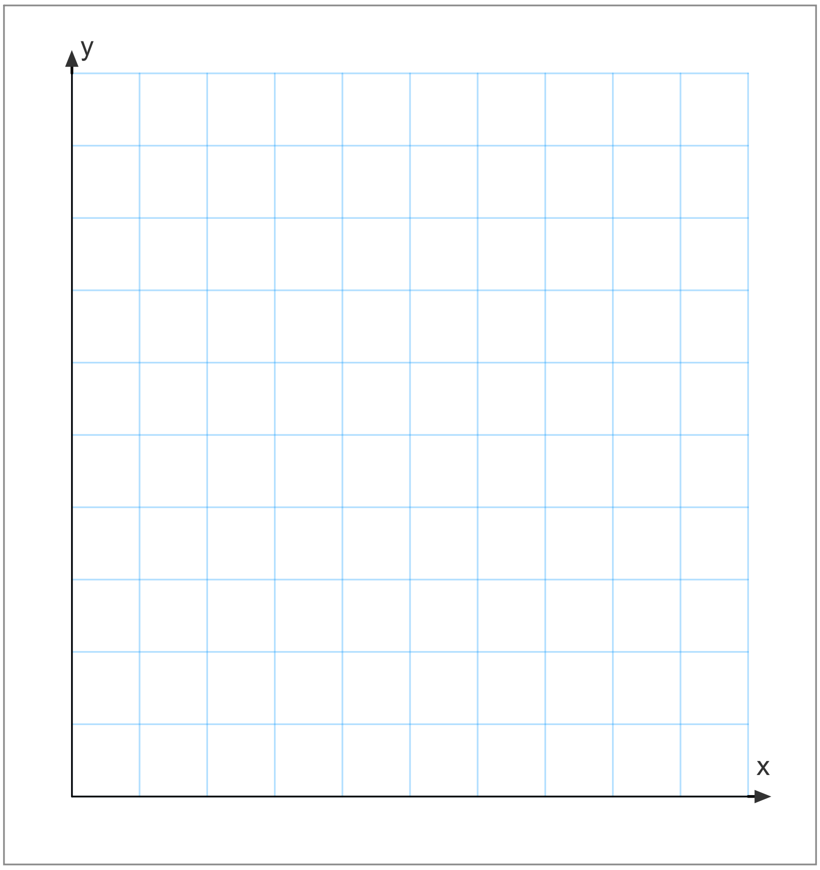
Calculate the $\vec{v}$ for each interval.
Calculate the $\vec{v}_{AV}$ for intervals A and B, A and C, C and E, D and F
Calculate $\vec{v}_{AV}$ for the interval A and F

Pull

P-T Graphs for Non-Uniform Motion (Changing Velocities)

So far, we have only dealt with P-T graphs for uniform motion (constant velocity). These graphs always consisted if straight lines. What happens to the shape of a P-T graph when the velocity of an object is non-uniform (changing)? When velocity is changing, this implies acceleration (speeding up or slowing down, or changing directions, or any combination of the preceding). Consider the following scenario: A small cart is at the top of a ramp. It is released at the very top and accelerates on the way down. At the bottom of the ramp, the cart comes to an instantaneous stop, strikes a spring, and is propelled back up the ramp decelerating (negative acceleration) on the trip back up. The TOV for this action is below:

Δt sec	$\vec{\Delta d}$ m [down]
0	0
0.2	0.1
0.4	0.4
0.6	0.75
0.8	1.3
1.0	0.75
1.2	0.4
1.4	0.1
1.5	0

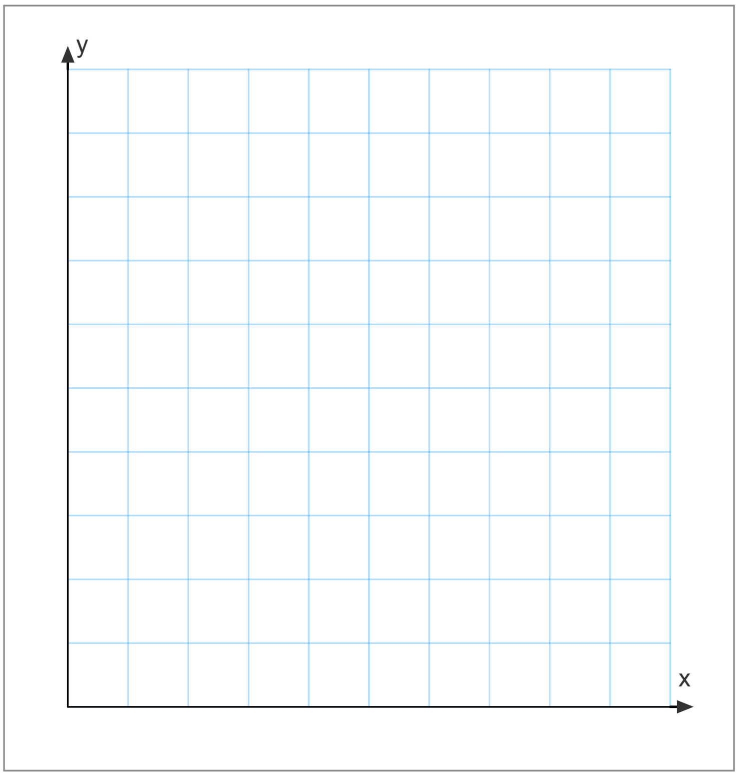


Calculate:

What is $\vec{v}_{AV}$ down the ramp?
What is $\vec{v}_{AV}$ up the ramp?
What is the instantaneous velocity at 0.4 seconds?

Consider the following P-T Graph:

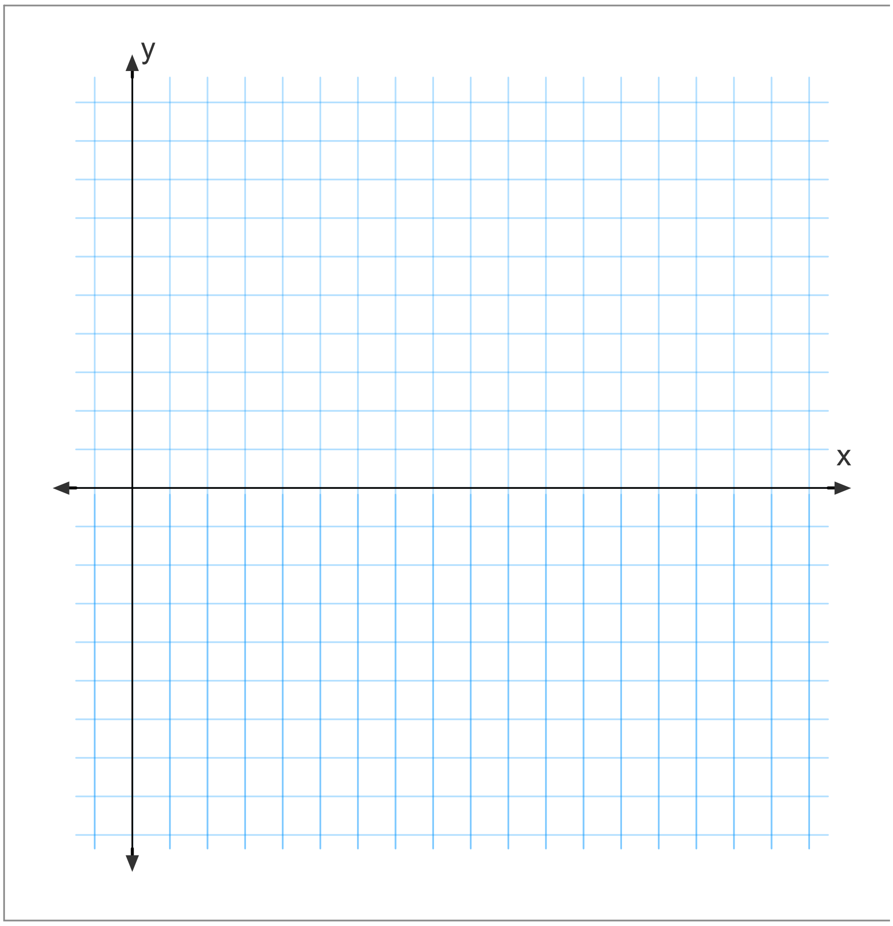
Δt sec	$\overrightarrow{\Delta d}$ m [E]
0	0
4	1.5
8	4
12	10
14	6
17	2
20	0



Calculate:
$\vec{v}_{AV}$ between A and C
instantaneous velocity at C
$\vec{v}_{AV}$ between C and E
instantaneous velocity at D
$\vec{v}_{AV}$ between A and G

Consider the following $\vec{\Delta d}$-T graph below:

Δt sec	$\vec{\Delta d}$ m [N]
0	1.5
2.5	1
5	0
7.5	-1.5
10	0.5
13.5	1
17	2



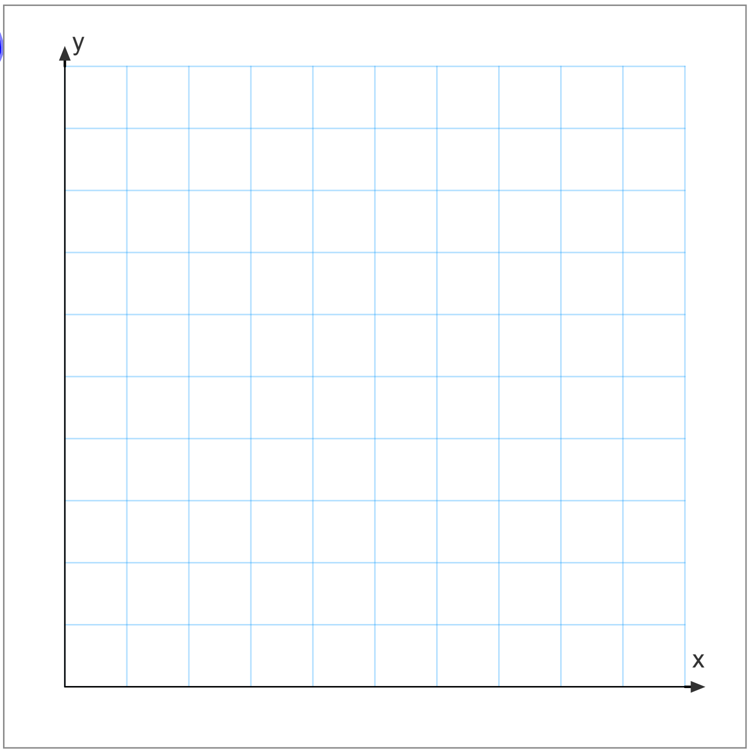
Calculate:

$\vec{v}_{AV}$ for the first 2.5 seconds
$\vec{v}_{AV}$ for the interval 2.5 sec to 7.5 seconds
instantaneous velocity at 2.5 seconds
time at which the instantaneous velocity is 0
$\vec{v}_{AV}$ for the interval 0 seconds to 17 seconds
Why is calculating instantaneous velocity so difficult?

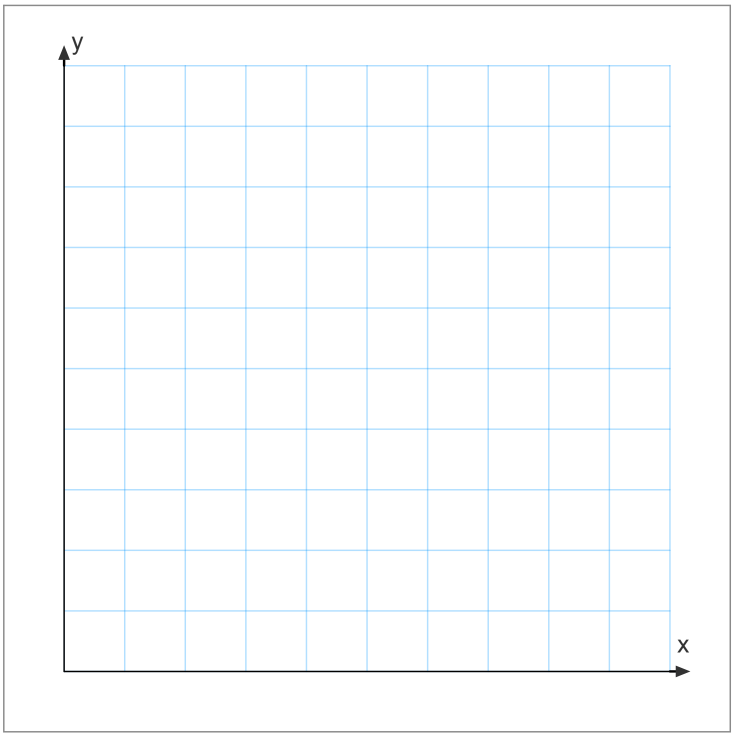
Velocity-Time, V-T Graphs

Consider the following P-T data for a lion running at a constant velocity.

Δt (sec)	$\Delta \vec{d}$ (m [E])
0	0
1	15
2	30
3	45
4	60
5	75
6	90

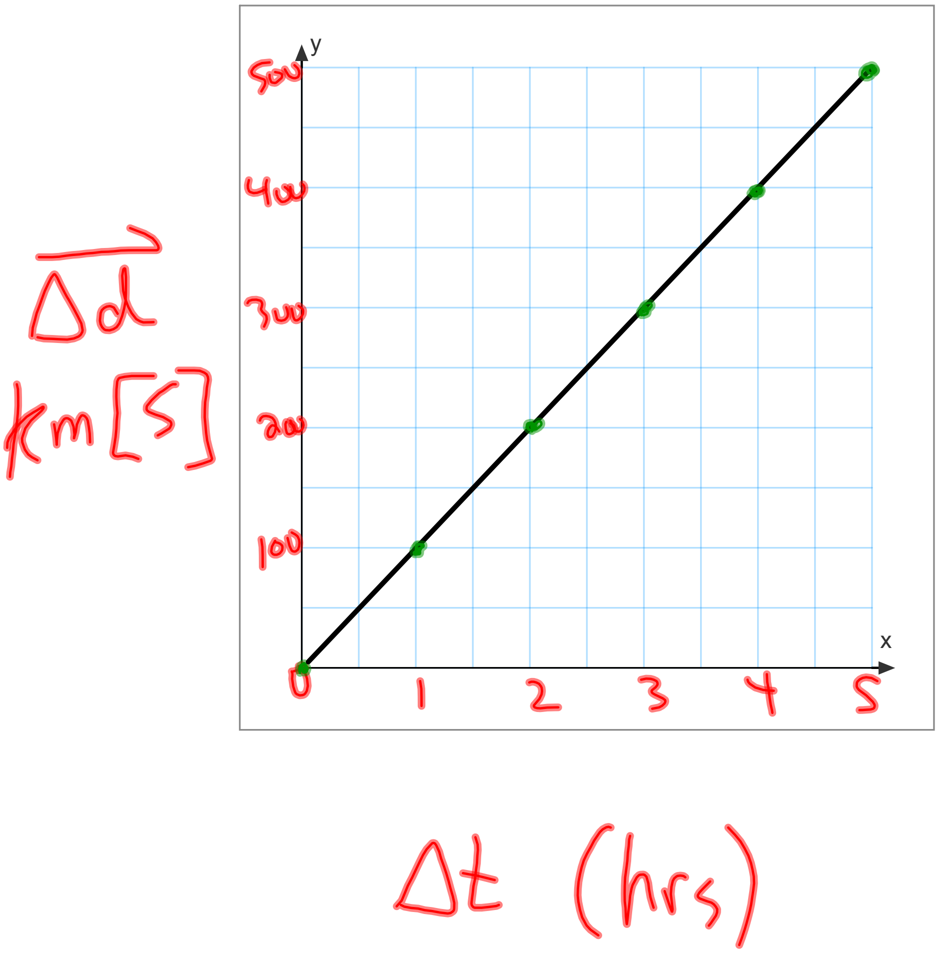


What would a V-T graph look like for this data?



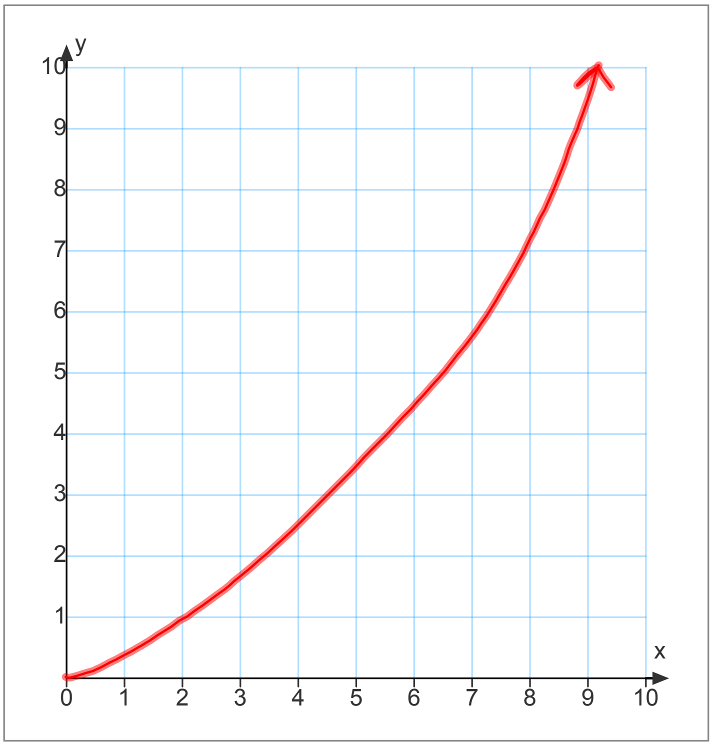
What does a V-T graph tell us?

Consider the following P-T graph for constant velocity.



What would the corresponding velocity-time, V-T graph look like?

Consider the following P-T graph:



What would the corrsponding V-T graph look like for this? It has non-uniform motion.

Practice

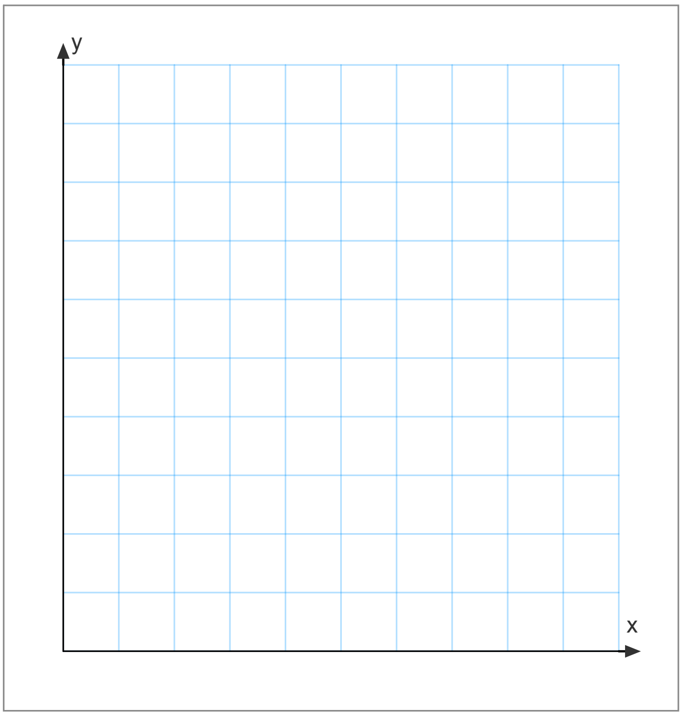
V-T Graphs for Constant Acceleration (Non-Uniform Motion)

Recall a P-T graph for constant velocity (uniform motion) yields a positive or negative slope graph with a zero slope V-T graph. The zero slope V-T graph indicates zero acceleration. Let's find out what a V-T graph would look like for for an object whose velocity is changes (non-uniform motion). Consider the following P-T data:

Δt (sec)	$\vec{\Delta d}$ m [Dn]
0	0
1	2
2	8
3	18
4	32
5	50
6	72

This data represents a hawk diving with a constant velocity.

Now, let's consider the corresponding P-T graph:



What's $\vec{v}_{AV}$ for the hawk?
What's the velocity at each instant in time, that is, the instantaneous velocity?

In order to accurately construct a V-T graph for non-uniform, we really need a precise description of the velocity at each specific time in the interval to see how it's changing. That is we need to know the instantaneous velocity at 1 sec, 2 sec, 3 sec, 4 sec, 5 sec, and 6 seconds. How can we precisely find this data? Drawing tangent lines by hand is less than accurate, and we don't have the calculus knowledge to do it?? Scientists have discovered a very unique method called "Half-Time" intervals. This process is very easy, accurate, and doesn't require higer level mathematics. The slope of a V-T graph will give us acceleration.

Half-Time Intervals

To calculate the instantaneous velocity for a specific instant in time, say 2 seconds, we must locate the half-time interval for 2 seconds. That is, 2 seconds is half way between what two other times?

2 sec (1 sec - 3 sec)
2 sec (0 sec - 4 sec)

How about 3 seconds half time interval(s)

3 sec ( )
3 sec ( )
more?

Let's consider our TOV of P-T data from previously:

0 sec

1 sec

2 sec

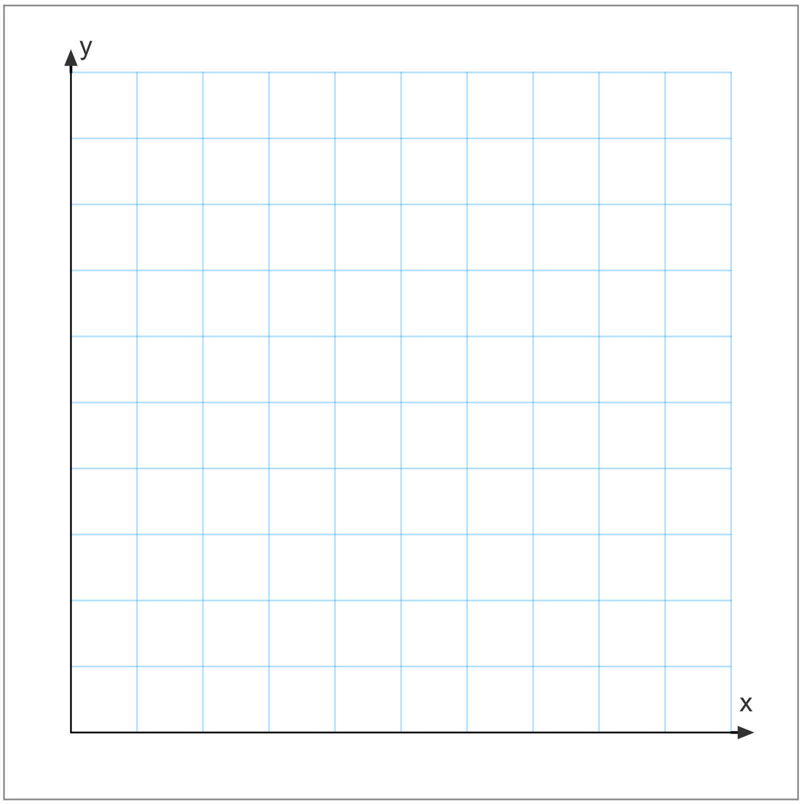
3 sec

4 sec

5 sec

6 sec

Pull



What is the acceleration of the hawk?

What is the displacement of the hawk during the dive?

Pull

Accleration = slope from a V-T graph

Pull

Kinematics Equations/Formulas

Drawing graphs to calculate velocity, displacement, and acceleration is time consuming and prone to graphing errors. There are some kinematics formulas/equations that will find all this info for us.

$$\vec{v}_{AV} = \frac{\vec{v}_1 + \vec{v}_2}{2}$$

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{\Delta d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$$

$$\vec{\Delta d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$(\vec{v}_2)^2 = (\vec{v}_1)^2 + 2\vec{a}\vec{\Delta d}$$

$$\left.\begin{array}{l} * \quad \vec{\Delta d} = \vec{v}_{AV}\Delta t \\ * \quad \vec{\Delta v} = \vec{a}_{AV}\Delta t \end{array}\right\}$$

not used very often

Section 3.3 Equations for Uniformly Accelerated Motion

1. A flying saucer decelerates uniformly from 20 m/s [E] to 50 m/s [W] in 9.0 s. Find the average velocity of the saucer for the 9 second interval.

2. A subway train travelling west at 20 m/s is brought to rest in 10 s. Find the displacement of the subway train while stopping.

3. A Cadillac with an initial velocity of 10 m/s [E] accelerates at 5.0 m/s^2 [E] . How long will it take the Cadillac to acquire a final velocity of 25 m/s [E] ?

4. A golf ball, rolling up a steep hill at 50 m/s, is slowing down with an acceleration of -5.0 m/s^2. Find its displacement after 30 s.

5. A golf ball rolls down a hill with a constant acceleration of 2.0 m/s^2. If the ball starts from rest,
   a) what is the velocity at the end of 4.0 s?
   b) how far did the ball move?

6. An electron is accelerated uniformly from rest to a velocity of 2.0×10^7 m/s.
   a) If the electron travelled .10 m while it was being accelerated, what was its acceleration?
   b) How long did the electron take to attain its final velocity?

7. During a 30 s interval, the velocity of a rocket increased from 200 m/s to 500 m/s . What was the displacement of the rocket during this time interval?

Kinematics Equations HIA

Using Kinematics Equations for Uniform Acceleration

1. An Indy 500 race car's velocity increases from 4 m/s to 36 m/s over a 4 second interval. What is the car's average acceleration?
2. A bus travelling at 30 km/h accelerates at a constant 3.5 m/s^2 for 6.8 seconds. What is the final velocity of the bus in km/h?
3. If a car accelerates from rest at a constant 5.5 m/s^2, how long will be required to reach 28 m/s?
4. A car slows from 22 m/s to 3 m/s with a constant acceleration of -2.1 m/s^2. How long does it require?

5a) If an object has 0 acceleration, does that mean that it's velocity is zero? Give an example.
5b) If an object has a instantaneous velocity of 0 does this mean it's acceleration is 0? Give an example.

6. What is the displacement of a train as it is accelerated uniformly from 11 m/s to 33 m/s in a 2 second interval?
7. A rocket travelling at 88 m/s is accelerated uniformly to a velocity of 132 m/s over a 15 second interval. What is its displacement during this time?
8. A car accelerates at a constant rate from 15 m/s to 25 m/s while it travels 125 m. How long does this motion take?
9. A bike rider accelerates to a constant velocity of 7.5 m/s during 4.5 seconds. The bike's displacement is 19 m. What was the initial velocity of the bike?
10. A car starting from rest accelerates uniformly at 6.1 m/s^2 for 7 seconds. How far does the car move?
11. An air plane must reach a velocity of 71 m/s for take-off. If the runway is 1 km long, what must the constant acceleration be?
12. Starting from rest, a race car moves 110 m in the first 5 seconds of uniform acceleration. What is the car's acceleration?
13. A driver brings a car travelling at 22 m/s to a full stop in 2 seconds.
a) What is the car's acceleration?
b) How far does it travel before stopping?
14. A biker passes a lamp post at the crest of a hill at 4.5 m/s. She accelerates down the hill at a constant rate of 0.4 m/s^2 for 12 seconds. How far does she move down the hill during this time?
15. An air plane accelerates from a velocity of 21 m/s at a constant rate of 3 m/s^2 over 535 m. What is the plane's final velocity?
16. The pilot stops the same plane in 484 m using a constant acceleration of -8 m/s^2. How fast was the plane moving before braking began?
17. A person wearing a shoulder belt(seat belt) can survive a car crash if the acceleration is less that -300 m/s^2. Assuming constant acceleration, how far must the front end of the car collapse if it crashes while going 101 km/h?
18. A car is initially sliding backwards down a hill at -25 km/h. The driver guns the car. By the time the car's velocity is 35 km/hr, it is 3.2 m from its starting point. Assuming the car was uniformly accelerated, find the car's acceleration

Attachments

Speed and Velocity HIA.docx

P-T, V-T Practice.docx

Half-Time HIA

Half Time HIA.pdf