Physics – Motion

Why do we care about motion?

- Motion is the study of how objects move without regard to the forces that make them move.
- It is one of the first units you would study if you took Physics in grade 11, community college or university
- The concepts you will learn allow you to figure out your average speed on a trip and the time it would take to make a journey
- The concepts are expanded on in further years and could be used to determine where a rocket will land, how long it would take for a space probe to get to Mars or how fast a car was going before it was in an accident if you know the length of the skid marks
- What careers would use this?
  - Physicist (obviously)
  - Engineer (engineers use physics, chemistry, math and sometimes biology to design buildings, machines, devices, etc so that they are safe and don't waste material)
  - Police officers with their radar guns or if they do accident reconstruction
  - Nascar
  - Drag Racing
  - Pilots, Airports
  - Trucking dispatchers for planning shipments
  - Everyday people when they are planning trips

Displacement vs. Distance

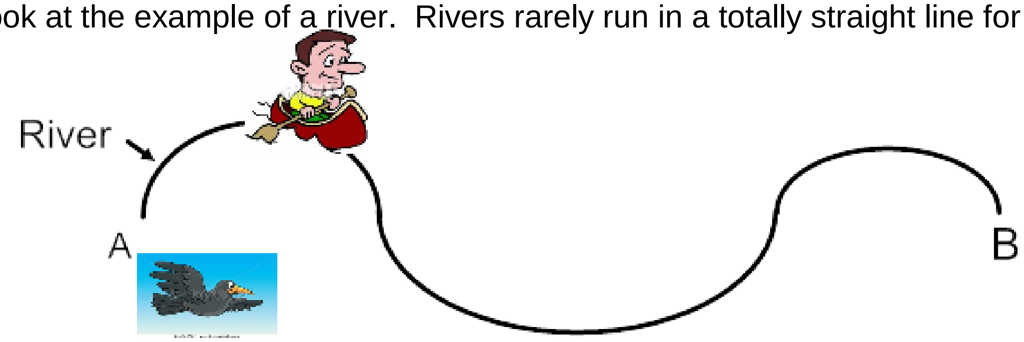
Quite often these two terms are used as if they are the same thing. In reality they are the same for some situations but not for others. Let's look at what they are and why they are sometimes are the same and sometimes they are different.

Displacement - how far a person or object is from where they started in a straight line
- have you ever heard the term "as the crow flies"? This old saying means that a crow would fly directly from one point to another in a straight line
- it also includes direction. Which could be left, right, up, down, east, west, or an angle depending on the question

Distance - how far a person or object travels in total regardless of the number of turns
- does not have a direction

The best way to visualize this is with examples.

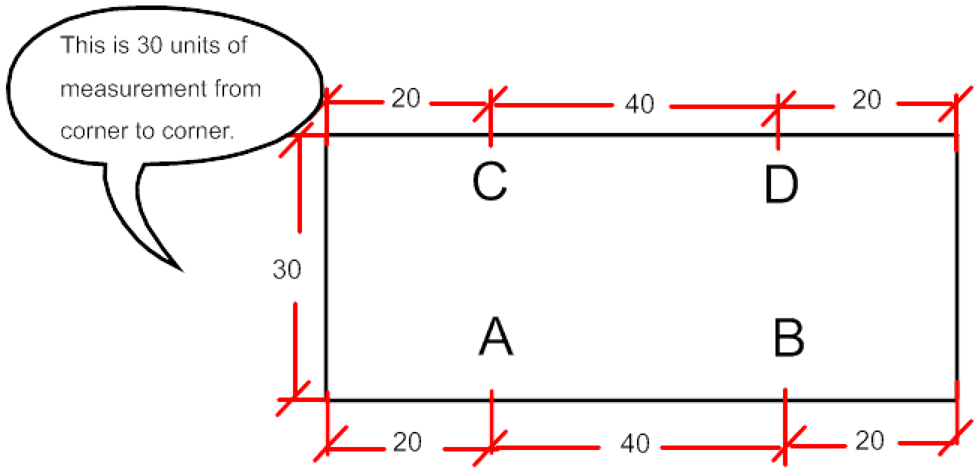
Let's look at the example of a river. Rivers rarely run in a totally straight line for very long.



If you wanted to paddle from Point A to Point B you would travel the total distance of the river.

- How far you travel is the distance.
- The crow could fly directly from Point A to B in a straight line. This is the displacement from Point A to Point B

So now we have an idea what the difference is, let's expand the conversation. Can they ever be the same? Explain.



How do you read the diagram above? Each section is a measurement. So from A to B starting at A the measurement is 40 units. We say units because we don't know what it is measured in. We will discuss that at a later time.

Example M.1 - Determine the displacement and distance between each set of Points, in the direction stated.

Points	Direction	Displacement	Distance
A to B	CW*		
A to B	CCW*		
A to A	CW		
A to C	CCW		
B to A	CW		
B to A	CCW		
A to D	CW		

*CW - means clockwise - the same direction a clock rotates

*CCW - means counter clockwise - the opposite direction of a clock

Measurement

Now that we have talked a bit about displacement and distance let's move on.

What are some of the units we can measure displacement or distance with?

What are some of the tools we use to measure displacement or distance?

Activity 1: Displacement vs. Distance

Calculating Displacement

Now that we have discussed how to find distance and displacement by measuring how do you find the displacement if you are given points?
In order to find the displacement you need to have the starting and end points

$d = x - x_o$	d = displacement x = final position x_o = initial position

Example M.2 Brendan walked from Walmart to his home. If home was 300 away, what is the a)Distance? b)Displacement?

Example M.3 Nathan was at his friend's house which is 2km west of town. He lives 4km east of town. a) Calculate his displacement from his friend's house when a) he stops in town b) when he gets home. c) calculate the distance travelled.

Example M.4 Stella is walking on the park trails. She starts at the 14km marker. She walks west and takes a break at the 5km marker. a) What is her displacement b) What is her distance?

Example M.5 Jessica lives in a small town 35km east of Kansas City. She goes on a trip that gives her a displacement of -250km. Where does she end up relative to Kansas City?

Speed or Velocity?

Both measure how fast an object is going.

Speed - is a measurement of the distance an object has travelled divided by the time it was travelling, without regard for direction.

Velocity - is a measurement of the displacement of an object divided by the time it was travelling. It must indicate direction.

*Time - is the duration between two events and is usually measured in seconds, minutes or hours allow we usually don't do calculations in physics in minutes.

One of the most important skills necessary to be successful in Physics is algebra, which is the solving of equations to determine the value of unknown variable.

Example M.6: Solve the following equations for then unknown variable.

1. $y = mx + b$
$m = 2$
$x = 4$
$b = -3$

2. $y = mx + b$
$m = 2$
$x = -5$
$b = -3$

3. $y = mx + b$
$y = 14$
$x = 4$
$b = -6$

4. $y = mx + b$
$y = 14$
$x = 1/2$
$b = -6$

5. $v = v_o + at$
$v_o = 20$
$a = -3$
$t = 4$

6. $v = v_o + at$
$v_o = 20$
$v = 2$
$t = 4$

7. $v = v_o + at$
$v_o = 100$
$t = 20$
$v = 8$

8. $v = v_o + at$
$v = 100$
$t = 20$
$a = 3$

So how do you calculate velocity and speed? Well, generally in physics we are concerned with velocity because often direction is important and as we said distance doesn't include direction. We will go into more detail later about this.

Velocity is defined as displacement divided by time. So it would look like this:

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

The problem with this is that we are going to need to expand on this equation later so we need to write it in a different form so that it works with other equations later.

So	$v = \frac{x - x_0}{t}$	we replaced d with $x - x_o$
then	$vt = x - x_o$	we multiplied both sides by t
	$x_0 + vt = x$	add x_o to both sides
finally	$x = x_o + \bar{v}t$	-switch sides, because all equations start with one variable -also, because we will be using different types of velocities we need to be specific. We us the ¯ to signify that this average velocity.

$x = x_o + \bar{v}t$	x = final position x_o = initial position v = average velocity t = time interval

Note : $\bar{v}$ is used as **average velocity but can also be used as **constant** velocity if the object stays at a constant rate such as a car on cruise control.

Example M.7 Aaron sets out from his house for a bike ride. He slows down and speeds up along the way as you would expect on a bicycle but averages a velocity 8m/s east for the trip. If he bikes for 1800 seconds where does he end up. Note: if no initial position is stated you can assume it is zero (0).

Example M.8 Sally usually rides her bicycle to school on sunny days. She lives 2000m to the east of school. On a good day without a lot of traffic she can get to school in about 700 seconds. Determine her average velocity.

Example M.9 Henry and Francis are having a race. Henry is a bit slower but gets a head start. Francis will start at 0m and he gives Henry a 20m head start. They will both race to the 100m finish line. If Henry can run an average of 4m/s and Francis can average 6m/s determine how long it takes a) Henry to get to the finish line b) how long it will take Francis to get to the finish line. c) How much of a head start should Henry get if they are to arrive at the same time?

Motion and Units

As we have discussed algebra is an important component of Physics. Another important component is the ability to convert units. Some units you have worked with for years and you know from habit such as 100cm = 1m (Think meter stick). Another might be 12 inches in 1 foot. This is a conversion we know even though it isn't something that is specifically taught in school.

The problem with what we are doing is that we have to make sure the units of measurement work together. For example if you have a velocity in km/h and a time in minutes they won't work together so we have to make them match.

Usually we want to go with meters, seconds and meters/second. There are different reasons but the most important one is that later when we discuss acceleration it is always in m/s^2. Sometimes we can work in km and hours depending on the situation.

So how do we convert units? We will use the table below to convert measurements of time, velocity and displacement but the principle can be extended to any form of unit conversion as long as you know the conversion ratio. We can use the principle to convert displacement, volume, weight, fuel economy, data storage, etc. If it is something that can be measured we can convert it. Any scientist, technician, engineer or tradesman can convert a variety of units in their head!

The method we are going to be using is called the factor label method. We will use the table provided but various versions of the table are available in textbooks and online. Follow the example below to see how it is done.

So how do we convert units? Some things we just know. Like 2m equals 200cm but when you can't remember you need a method. Here is one method that is commonly used. It is called the factor label method. It can be used to convert anything as long as you know the equivalent ratio.

Example : Follow the example below to convert 0.5km to m.

Step 1 : make a table or chart like the one below

Step 2 : Put the value you are starting with in the top left corner

0.5km	

Step 3: In this method of converting we multiply all values on the top together and divide by all the values on the bottom. This includes all the numerical values and the units. By doing this we will end up with the same units on the top and bottom and be able to eliminate the units we started with.

In this example since we have km on the top to start we need to put km on the bottom in the next set of spaces to eliminate the km.

0.5km	
	km

Step 4 : Since we want to convert to m it will go on the top. We need to look in the table to see what the relationship is between **km** and **m**. In our table the relationship is 1km=1000m. We can also write this as a ratio of 1km/1000m or 1000m/1km. (Some tables may have them reversed as 1m=0.001km.)

The ratio then goes in our table with the same numerical value assigned to each unit as we found them in the table.

0.5km	1000m
	1 **km**

Note that in the table the ratio is still the same as it was in the table. We just need to figure out where to put the units we want to get rid of and then put the numbers in as stated in the table. It isn't always a 1 on the top or bottom, that is decided by the units.

Step 5: Do the math and solve for the answer. (Remember we multiply the top and divide by the bottom.)

$$\begin{array}{c|c} 0.5\text{km} & 1000\text{m} \\ \hline & 1\ \mathbf{km} \end{array}$$

$$= 0.5\text{km} \times 1000\text{m} \div 1\text{km}$$
$$= \frac{500\cancel{\text{km}} \times \text{m}}{\cancel{\text{km}}}$$
$$= 500\ \text{m}$$

So 0.5km equals 500m. Which makes sense since 1km = 1000m

Name	Prefix Unit	Equivalent amount of base unit
kilometer	1km	1000m
hectometer	1hm	100m
dekameter	1dam	10m
meter	1m	1m
decimeter	1dm	0.1m
centimeter	1cm	0.01m
millimeter	1mm	0.001m
micrometer or micron	1μm	0.000001m

1 day	24 hours
1 hour	3600 seconds
1 min	60 seconds

Example M.10 Convert the following.

a) Convert 12km to m
b) Convert 3.4hm to m
c) Convert 4.6 dam to m
d) Convert 2.2 cm to m
e) Convert 0.89mm to m

f) Convert 5.65 m to mm
g) Convert 0.12m to dm
h) Convert 5642 m to km

i) Convert 3 hours to min
j) Convert 86400 seconds to hours

What happens when you can't convert because it isn't a direct ratio from the table? Or it is already a ratio like km/h?
It is the same process but an extra step.

Look at the following examples.
Let's convert 12 500 cm to km

12500 ~~cm~~	0.01 ~~m~~	1 km
	1 ~~cm~~	1000~~m~~

= 12500 x 0.01 ÷ 1000
= 0.125 km

we need to do the extra step because we can only convert to m or from m with this table.

If we are converting a rate we again use the same principle but we fill both of the first pair of spaces. 1km/h means 1 km÷ 1 h.

Let's convert 36km/h to m/s

36 km	1000m	1 hr
1 hr	1 km	3600 sec

= 36 x 1000 ÷ 3600

= 10 m/s

Before we practice let's do one more

Let's convert 20 m/s to km/h

20 m	1 km	3600 sec
1 sec	1000 m	1 hr

= 20 x 3600 ÷ 1000

= 72 m/s

Example M.11 Convert the following

a) 25 m/s to km/h

b) 108 km/h to m/s

c) 2400 cm/min to m/s

Changing velocities

So far we have talked about average velocity. Remember that we can use the same equation if it is constant velocity.

However, in Physics we are often interested in knowing the velocity at the beginning of a time interval and at the end of the time interval. We will use these values at a later point to calculate acceleration but right now we are going to use them to calculate average velocity and it turn displacement.

First thing we need to discuss is the variables. We will use the following:

v_o - this is pronounced V not. It is used to signify the ***initial velocity*** in a situation. It can be measured in the regular units for velocity (km/h, m/s or other less common versions)
- think of the subscript 0 (little 0) as representing the beginning when time is starting or equal to 0!

v - this is simply v and signifies the ***final velocity***.

How do you know which is which. This is where the importance of English comes in. Usually the initial velocity is in past tense and the final is in present of future tense. See the scenarios below for examples

v_o (initial velocity)	v (final velocity)
was travelling at...	ended up travelling...
initally...	finally.
is moving at...	speeds up/ slows down to...
at rest...	accelerates to...
was moving at....	comes to complete stop.

When trying to figure out problems in Physics or anything for that matter read the question and use your knowledge about English and Math to break it into parts and then choose a direction or equation.

So how do we use this new found information?

The average velocity is the average of your final and initial velocities. See the formula and examples below.

Average velocity with Final and Initial Velocity

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

v = average velocity

v = final velocity

v_o = initial velocity

Note : the units do not really matter as long as they match.
In other words they must all be km/h or m/s

Example M:12 Courtney is sitting at a red light in her red corvette. The light turns green and she instantaneously guns the engine of her car. If Courtney is soon traveling at a velocity of 90 km/h in a northern direction (in a 50 km/h speed zone) what is her average velocity?

Example M.13 : Sally and Huckle are walking through Busytown attempting to find clues to their newest mystery. They are walking at 2m/s east. They think they see a clue ahead and start running. By the time they are done running they have reached a velocity of 6m/s east. a) If it takes them 5 seconds to reach the 6m/s determine their average velocity. b) Calculate their displacement during this time interval.

Example M.14 : Patrick and Jeremy are driving in Sussex at 54 km/h towards Apohaqui. Once they reach the highway they speed up to a velocity of 110 km/h. a) What is their average velocity? b) What was their displacement within this time period if it took 8 seconds to reach 108km/h?

Example M.15 Kurt is travelling down the highway when he has to come to a complete stop for highway construction. His average velocity while slowing down was 54km/h north. How fast was he travelling initially?

Example M.16: Lucy is travelling north on the highway when she notices a large plume of smoke over the next hill. At the moment she sees the smoke she also notices she is next to the 167km marker on the side of the road. Being a defensive driver she decides to slow down. She comes to a stop at the 168km marker. It took her 1 minute to get between the 2 markers. How fast was she going at the moment she started to slow down. This one is a bit tricky. Break it into parts.

Acceleration

Acceleration is the change in velocity over a specific time interval. As you will remember velocity has a measurement and a direction. Generally when we talk of acceleration we are talking of a change in measurement/magnitude but in some instances we would have a constant rate but a change in direction. We won't be doing those type of question this semester though.

You will also see acceleration defined as the rate of change of velocity. The term rate means how fast something is changing over time. In the concept of acceleration this means how fast the velocity is changing.

Let's consider two scenarios. In each scenario the object is initially at rest and accelerates to 20m/s. In the first scenario this process takes 5 seconds and in the second it takes 10 seconds. Using your experience you would say that the velocity increased at a greater rate in the first scenario in order to achieve the final speed in less time.

If we were to write this in terms of variables it would look like:

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

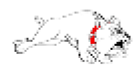
Rearranged it is expressed in its most common form below

$v = v_o + at$	v = final velocity (m/s) v_o = initial velocity (m/s) t = time (seconds) a = acceleration (m/s^2)***

***Note: we ALWAYS express acceleration in m/s^2, ∴all other measurements must be in the appropriate units.

Also, you should be aware that acceleration is rarely constant but for our purposes we will assume that it is constant during the time intervals in question.

Example M.17 Nolan is riding his bicycle at a velocity of 3m/s when he sees a dog running toward him. He starts to pedal faster and accelerates at $1.5m/s^2$ for 3 seconds. What is his final velocity?



Example M.18 Benny is rolling in his garage built coaster car at a velocity of 4m/s when his wheel falls off. If he slows down with an acceleration of $0.75m/s^2$ determine his velocity after 5 seconds.

Example M.19 Callie is travelling on the highway when she sees a police car. She automatically puts her brakes on and has an acceleration of $-5m/s^2$. If she gets her car slowed down to 25m/s north how fast was she previously travelling if she slowed down for 2.0 seconds?

Example M.20 Walter is racing his 1989 Mustang drag car. It is quite fast and requires a parachute to help get it stopped safely. Walter typically pulls the 'chute when he is

going 250km/h. If the parachute provides about -12m/s^2 of acceleration determine how long it would take to reduce his velocity to 100km/h.

Acceleration situations without final velocity

Sometimes we want to determine the displacement of an object and we don't know the final velocity. In all the situations so far we have either had the average velocity or we had the initial and final velocity and could determine the displacement. We can still do that but long ago Physicists determined a formula that is a combination of the previous formulas. We will also look at this equation again when we look at graphing.

$x = x_o + v_o t + \frac{1}{2}at^2$	x = final position (m) x_o = initial position (m) v_o = initial velocity (m/s) a = acceleration (m/s^2) t = time (s)

Example M.21 Danielle is moving at 1.5m/s east when she accelerates at 0.5m/s^2 east for 8 seconds. a) How far did she travel during this time? b) How fast was she travelling at the end of this period?

Example M.22 Chris is running a 50m race. If he starts from rest and it take him 8 seconds determine his average acceleration. Assume he is heading north.

Example M.23 Martha is travelling east when she puts her brakes on. Her acceleration is $-4.2 m/s^2$. If she slows for 5 seconds and travels 0.20km east how fast was she going initially?

Acceleration Due to Gravity

In all examples up to this point we have dealt with objects moving on the ground. We need to look at objects that are thrown in the air or are falling. Objects that are falling or going up in the air without a power source (like rockets or planes) have an acceleration that is created by the pull of the Earth's gravity. This acceleration is assumed to be constant near the Earth's surface and is equal to $-9.8 m/s^2$.

$a = g = -9.8 m/s^2$	*a is also called g because it is due to gravity

Example M.24 A kangaroo can jump quite high due to its strong legs. A kangaroo is observed and determined to jump to a maximum height of 2.5m. If it is in the air for 0.70s and experiences an acceleration of $-9.8 m/s^2$ determine the initial velocity of the kangaroo.

Example M.25 A group of grade 10 students are trying to test this acceleration of gravity concept. They go on the roof of their school (they don't have a balcony so don't ask if we can go on the roof) and do repeated tests. They find an average time to hit the ground of 1.23 seconds. If gravity is equal to what they assumed, how tall is the roof of the school?

Example M.26 A rocket is shot straight up from ground level with an initial velocity of 180km/h. a) When will it land? b) What is the maximum height the rocket reached. You can neglect any resistance from the air.

Graphing

Why is it important?

Who uses graphs?

What are important parts of graphs?

Review of Variables and Terms in Graphing

Independent Variable - the variable that changes over the course of the experiment in order to compare results. Often it is time as time moves on independently of anything else. However, it could be a multitude of other measurable items as shown in the graphs that we looked at.

Dependent Variable - the variable that changes as a result of the changes in the independent variable. It ***depends*** on the independent variable. It is the variable that you are usually interested in.

Title - Always at the top and tells the user what the graph is about. Without the title the graph is often useless.

Graphing using a table of values

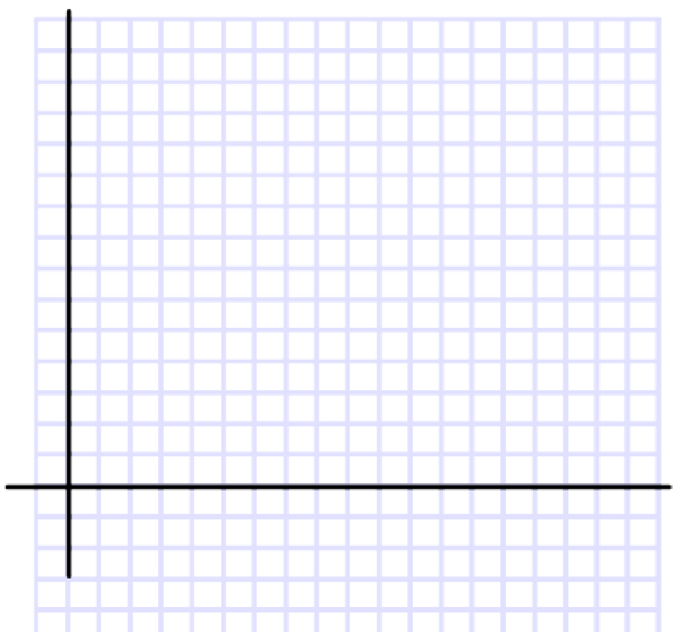
- the first column is your independent variable and the second column is the dependent variable

Example M.27

x	y
0	0
1	4
2	8
3	12
4	16

Graphing with an equation

Example M.28
Create a table of values for the following equation
x = 4 + 2t
*Just like any equation the variable
by itself is the dependent variable



Graphing in Physics

Example M.29

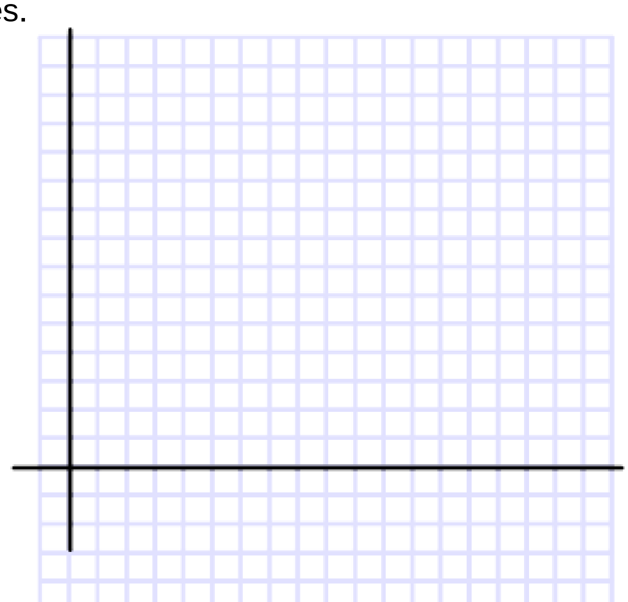
Create a table of values for the following equation

$x = x_0 + vt$

*Just like any equation the variable
by itself is the dependent variable
so in this situation we are looking for
final position each second

Create a table of values.

Let's use 0 for x_0



Slope - is the measure of how steep a line is

- it will tell us how quickly the dependent variable changes in relation to the independent variable.
- in Physics the units of y divided by x will help determine what the slope represents

How do we find slope?

You will remember it as rise over run or as a formula

$$m = \frac{\Delta y}{\Delta x}$$

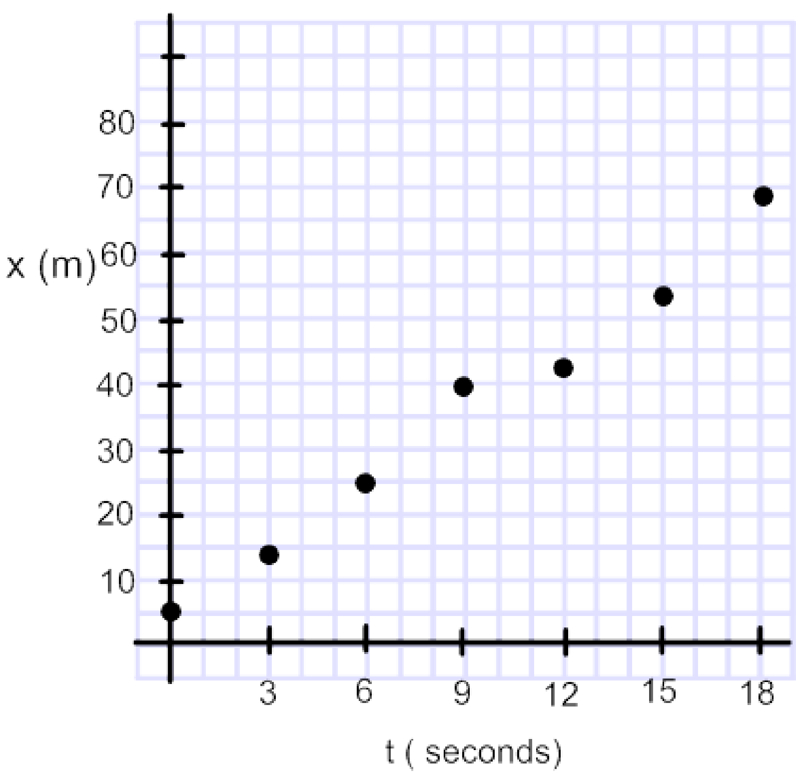
or if using any two points on a line

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

Example M.30 Determine the slope of the graph in example M.29.

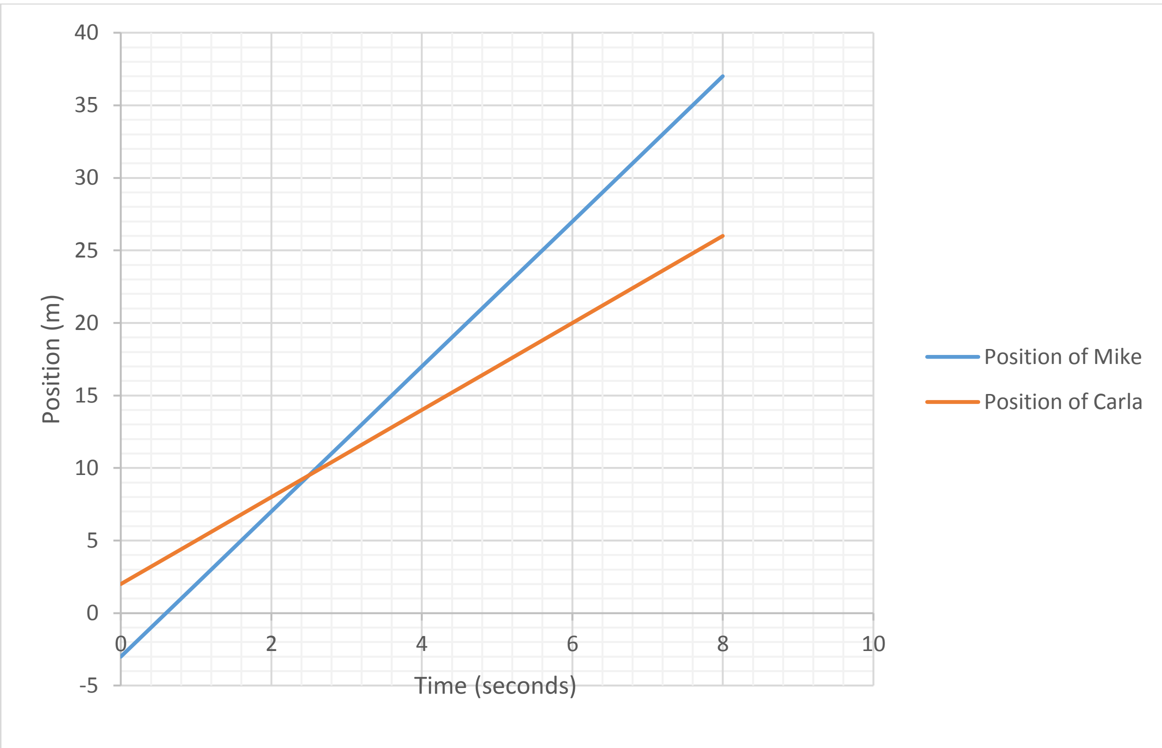
Line of Best Fit

- we won't be using this much but you should be aware of what it is
- it is a line that is will have close to the same number of data points below and above it.
- See the graph below
- Excel will draw the line for you and give you the equation
- we use it when we want a slope but a line can't be drawn through the data perfectly

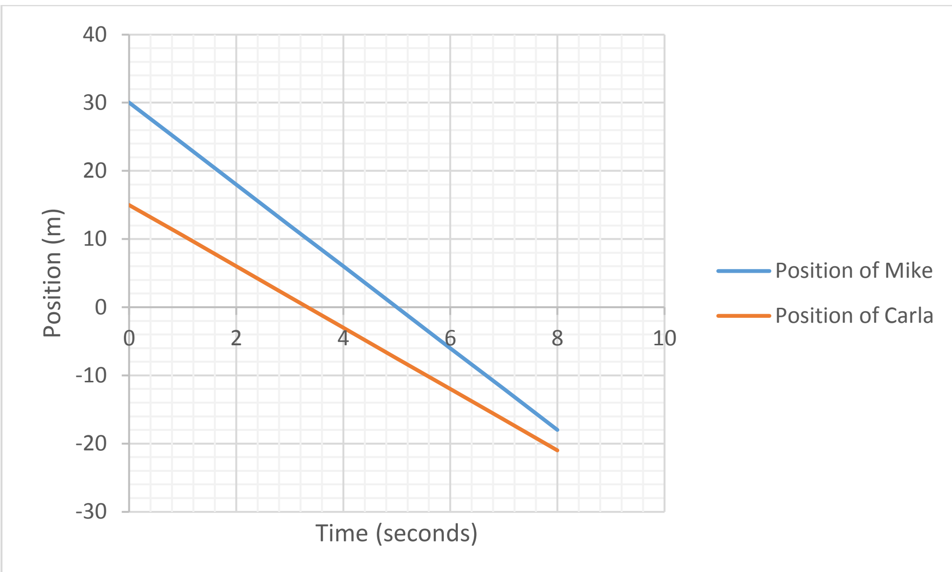


Example M.31 Determine the slope of the line of best fit for the graph above

Example M.32 - a)Determine the velocity of Mike and Carla in the graph below.
b) When would Mike pass Carla? c) Determine an equation to represent their position at any time.



Example M.33 - a) Determine Mike and Carla's velocities. b) Determine an equation to represent their position at any time. c) When will they meet?



Putting it together - Interpreting Graphs

Based on what we have learned already, look at the following graphs and state:

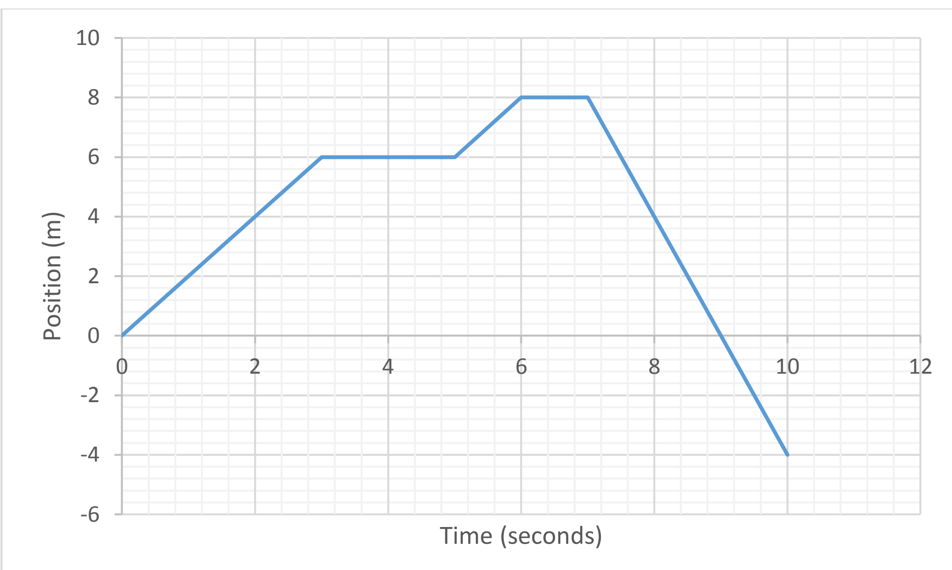
a) what is happening over each time interval (each time interval would have a different slope) as in moving east, west or not at all

b) what is the velocity in each time interval

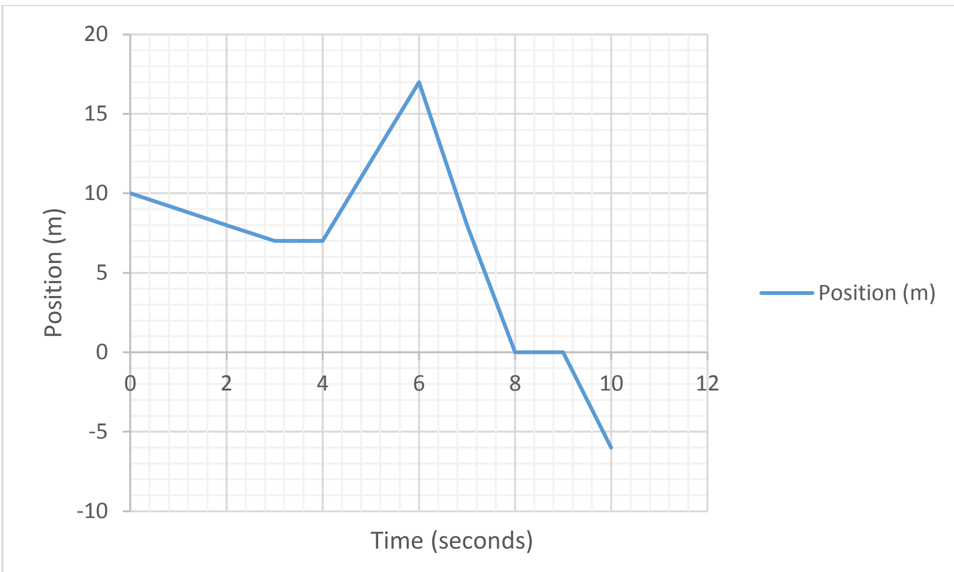
c) average velocity for the entire time period

Spreadsheet of graphs

Example M.34



Example M.35



Example M.36 – State your velocity in km/h