SPH3U: Velocity Time Graphs

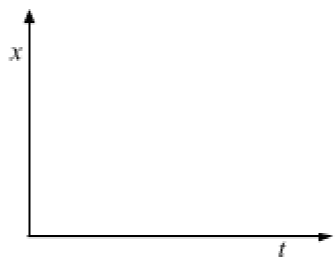
We can represent velocity graphically like we did with position. But be careful: each graph has different rules for its interpretation. We will continue to use **away** from the sensor as the positive direction, and **towards** the sensor as the negative direction.

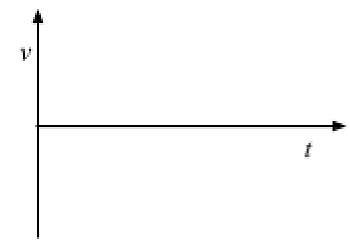
A. Let's Try to Think This Through...

1. Predict. The motion of a student is described by the following events:

1. starts far from the sensor 2. walks slowly towards sensor 3. stops 4. walks quickly away from sensor.

Sketch what you think the position-time and velocity-time graphs will look like, and label the events



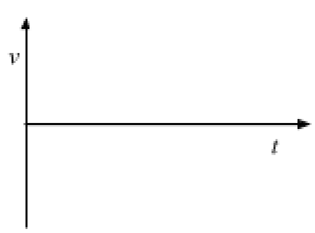


2. Observe. Watch the motion of the student, and the creation of the above graphs, as they execute the events above..

3. Reflect. Identify and explain any significant differences between your predicted graphs and the real ones.

B. Let's Break It Into Pieces…

4. Observe as one of your classmates generates a velocity time graph for the following situations. Assume steady speeds, and ignore the bumps and jiggles in the line (we're human after all!).

Walks quickly away	Walks slowly away	Walks quickly towards	Walks slowly towards
			

5. Interpret. How can we tell from a velocity time graph if the person is:

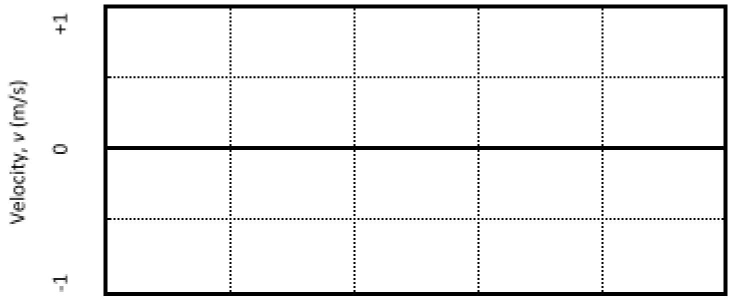
a) moving quickly b) moving slowly c) moving in the positive direction d) moving in the negative direction

6. Observe. Someone will walk slowly towards the sensor - once starting from 5 m, once starting from 3 m. What effect does this change in starting position have on the velocity-time graphs? Explain.

C: Applying our understanding

A person moves in front of a sensor. There are four events: (1) The person starts to walk slowly in the + direction, (2) at 6 seconds the person stops, (3) at 9 seconds the person walks in the negative direction twice as fast as before, (4) at 12 seconds the person stops.

7. Draw your prediction for the shape of the velocity-time graph for the motion described above. Label the events.



Velocity is a vector quantity since it has a magnitude (number) and direction. All vectors can be represented as arrows. In the case of velocity, the arrow does not show the initial and final positions of the object. Instead it shows the object's speed and direction.

SPH3U: Motion Variables

Complete the following table.

Motion Variables	Symbol	Unit	Scalar/ Vector	Description / Example
Distance				
Position				
Displacement				
Time interval				
Speed				
Velocity				
Average velocity				
Acceleration				

SPH3U: Defining Velocity

To help us describe motion carefully we have been measuring positions at different moments in time. Now we will put this together and come up with an important new physics idea.

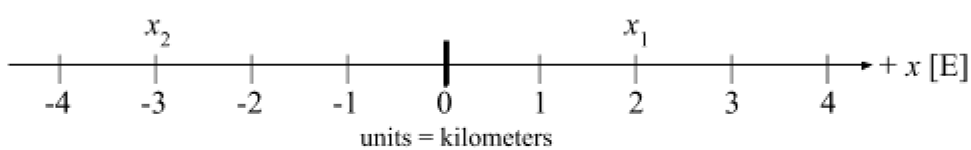
A: Events

When we do physics (that is, study the world around us) we try to keep track of things when interesting events happen. For example when a starting gun is fired, or an athlete crosses a finish line. These are two examples of **events**.

An *event* is something that happens at a certain place and at a certain time. We can locate an event by describing *where* and *when* that event happens. At our level of physics, we will use one quantity, the position (x) to describe where something happens and one quantity time (t) to describe when. Often, there is more than one event that we are interested in so we label the position and time values with a subscript number (x_2 or t_3).

B: Changes in Position - Displacement

Our trusty friend Emmy is using a smartphone app that records the events during her trip to school. Event 1 is at 8:23 when she leaves her home and event 2 is at 8:47 when she arrives at school. We can track her motion along a straight line that we will call the x-axis, we can note the positions of the two events with the symbols $\vec{x}_1$ for the initial position and $\vec{x}_2$ for the final position.



1. **Interpret.** What is the position of x_1 and x_2 relative to the origin? Write your answer two ways: mathematically, using a sign convention, and in words describing the direction.

   math: $\vec{x}_1 = 2\ km$ $\qquad\qquad$ $\vec{x}_2 =$

   words: $\vec{x}_1 =$ 2 km <u>East</u> of the origin $\qquad\qquad$ $\vec{x}_2 =$

2. **Reason and Interpret.** What direction did Emmy move in? Use the sign convention and words to describe the direction. How far is the final position from the starting position? Use a ruler and draw an arrow (just above the axis) from the position x_1 to x_2 to represent this change.

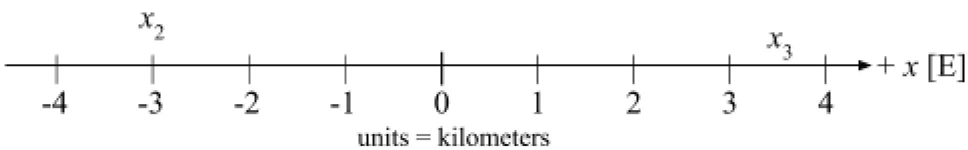
The change in position of an object is called its *displacement* ($\Delta\vec{x}$) and is found by subtracting the initial position from the final position: $\Delta x = x_f – x_i$. The Greek letter Δ("delta") means "change in" and always describes a final value minus an initial value. The displacement can be represented graphically by an arrow, called the *displacement vector*, pointing from the initial to the final position. Any quantity in physics that includes a direction is a *vector*.

3. **Reason.** Is position a vector quantity? Explain. (Hint: to describe Emmy's position, do we need to mention a direction?)

4. **Calculate and Interpret.** Calculate the displacement for Emmy's trip. What is the interpretation of the number part of the result of your calculation? What is the interpretation of the sign of the result?

   $\Delta\vec{x} =$

5. **Calculate and Represent.** Emmy continues her trip. Calculate the displacement for the following example. Draw a displacement vector that represents the change in position.



C: Changes in Position and Time

In a previous investigation, we have compared the position of the physics buggy with the amount of time taken. These two quantities can create an important ratio.

When the velocity is constant (constant speed and direction), the *velocity* of an object is the ratio of the displacement between a pair of events and the time interval. In equal intervals of time, the object is displaced by equal amounts.

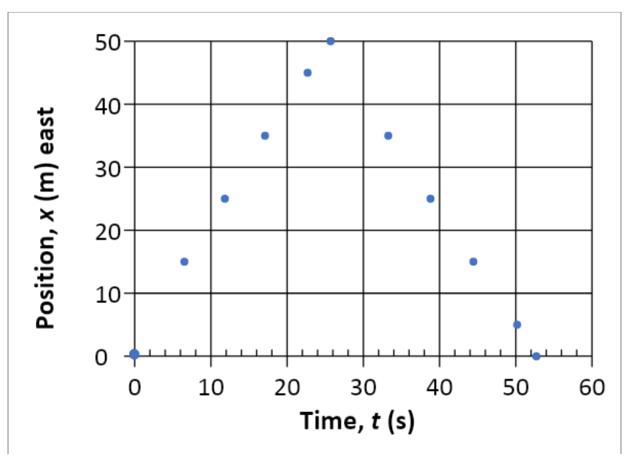
1. **Reason.** Write an algebraic equation for the velocity in terms of $\vec{v}$ $\vec{x}$, $\Delta\vec{x}$, t and Δt. (Note: some of these quantities may not be necessary.)

2. **Calculate.** Consider the example with Emmy between events 1 and 2. What was her displacement? What was the interval of time? Now find her velocity. Provide an interpretation for the result (don't forget the sign!).

In physics, there is an important distinction between *velocity* and *speed*. Velocity includes a direction while speed does not. There is also a similar distinction between *displacement* and *distance*. Displacement includes a direction while distance does not.

D: Velocity and Speed

Your last challenge is to find the velocity of Penny from her position-time graph. The positive direction is east. Event 1 is the start of the race, event 2 is when she turns around, and event 3 is when she touches the wall to finish.



1. **Calculate.** What is Penny's displacement during each half of the race? Use the appropriate symbols!

2. **Calculate.** Find her velocity during each half of her race.

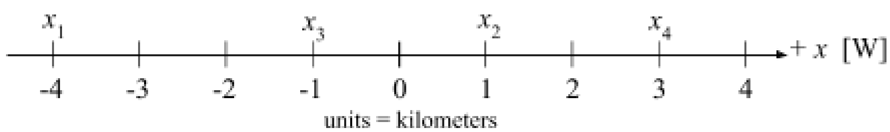
3. **Calculate.** Find her speed during each half of the race.

SPH3U Homework: Defining Velocity Name:

A: Where's My Phone?

Albert walks along Glebe Ave. on his way to school. Four important events take place. The +*x* direction is west.

Event 1: At 8:15 Albert leaves his home.
Event 2: At 8:28 Albert realizes he has dropped his phone somewhere along the way. He immediately turns around.
Event 3: At 8:37 Albert finds his phone on the ground with its screen cracked (no insurance).
Event 4: At 8:41 Albert arrives at school.



1. **Represent**. Draw a vector arrow to represent displacement for each interval of Albert's trip and label them $\Delta\vec{x}_{12}$, $\Delta\vec{x}_{23}$, $\Delta\vec{x}_{34}$

2. **Calculate.** Complete the chart below to describe the details of his motion in each interval of his trip.

Interval	1-2	2-3	3-4
Displacement expression	$\Delta\vec{x}_{12} = \vec{x}_2 - \vec{x}_1$		
Displacement result			
Interpret direction			
Time interval expression	$\Delta t_{12} = t_2 - t_1$		
Time interval result			
Velocity			

3. **Reason.** Why do you think the size of his velocity is so different in each interval of his trip? Explain.

4. **Explain.** Why is the sign of the velocity different in each interval of his trip?

5. **Calculate.** What is his displacement for the **entire trip**? (Hint: which events are the initial and final events for his whole trip?)

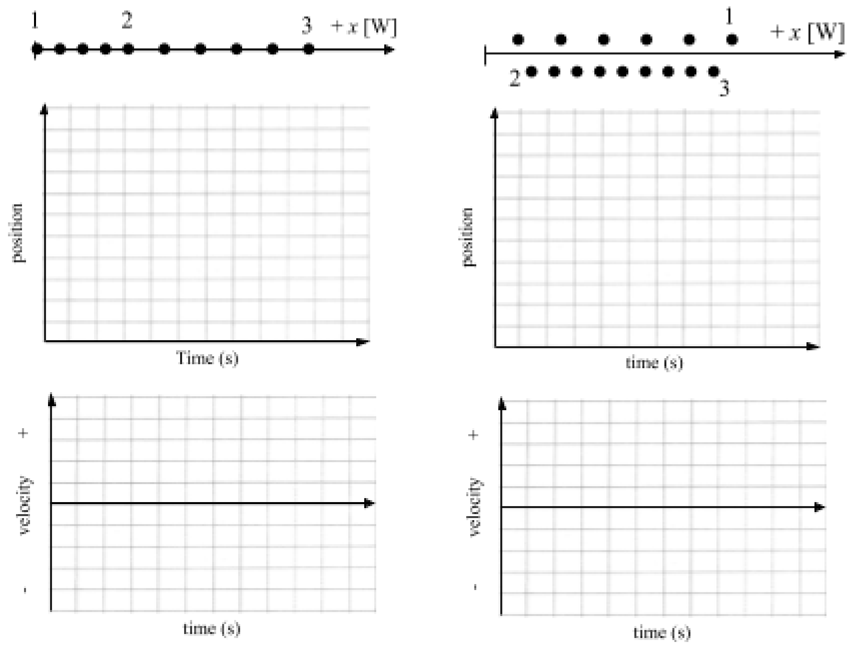
6. **Interpret**. Explain in words what the result of your previous calculation **means**.

1. Two motion diagrams track the movement of a student walking in a straight line.

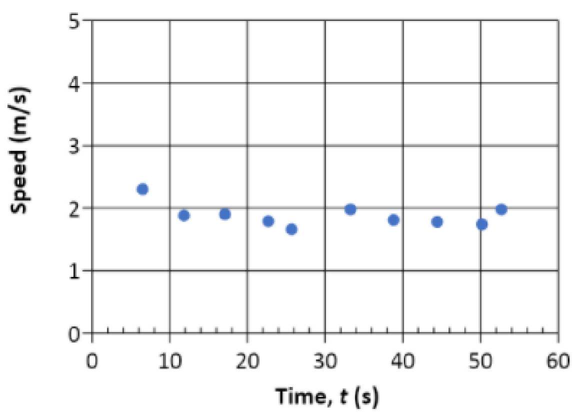
   (a) **Represent.** Sketch a position-time graph for each motion diagram. The scale along the position axis is not important. Use one grid line = 1 second for the time axis.

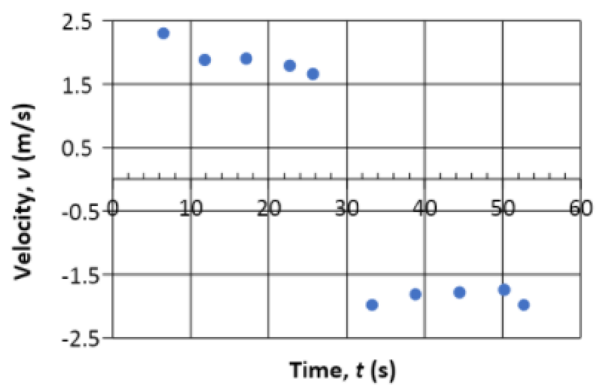
   (b) **Represent.** Sketch a velocity-time graph for each motion diagram. The scale along the velocity axis is not important.

   (c) **Interpret.** Label each section of each representation as "fast" or "slow". Is each set consistent?



2. The two graphs below show data from Penny Oleksiak's 100-m gold-medal race.





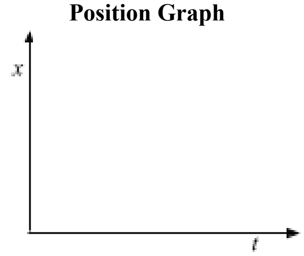
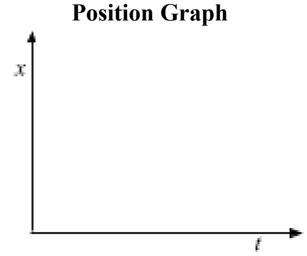
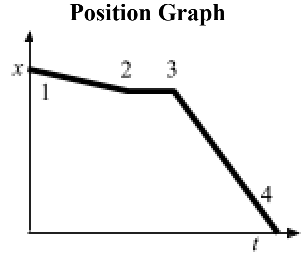
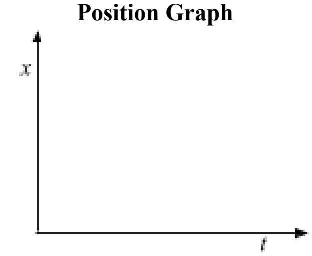
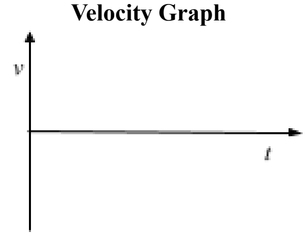
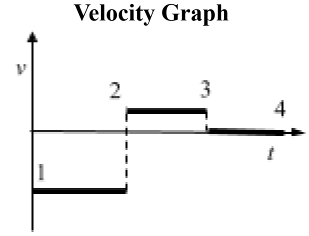
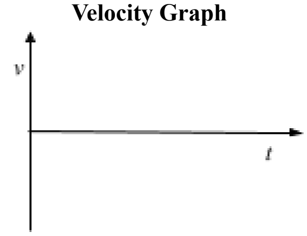
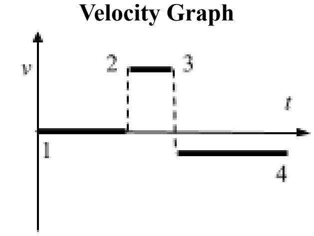
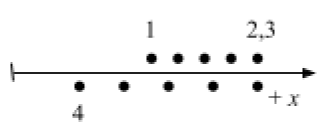
   (a) **Read.** What is Penny's speed at 22 s? What is her velocity at 22 s?

   (b) **Read.** What is Penny's speed at 33 s? What is her velocity at 33 s?

   (c) **Interpret.** Is Penny's speed constant? What about her velocity? What is your evidence?

Homework: Representations of Motion

Each column in the chart below shows five representations of one motion. The small numbers represent the events. Remember that the motion diagram is a dot pattern. If the object remains at rest, the two events will be located at the same point. If it changes direction, shift the dots just above or below the axis. See the example below. Remember that in the motion diagrams the origin is marked by a small vertical line. The positive *x*-direction is east.

Situation 1	**Situation 2**	**Situation 3**	**Situation 4**
Description 1-2: 2-3: 3-4:	**Description**	**Description**	**Description** 1-2: It starts at the origin and remains at rest for a while. 2-3: It move quickly in the positive direction (east) with a constant velocity 3-4: It moves slowly in the negative direction (west) with a constant velocity.
Position Graph 	**Position Graph** 	**Position Graph** 	**Position Graph** 
Velocity Graph 	**Velocity Graph** 	**Velocity Graph** 	**Velocity Graph** 
Motion Diagram 	**Motion Diagram** 	**Motion Diagram** 	**Motion Diagram** 
Velocity Vectors (velocity during each interval) 1-2: 2-3: 3-4:	**Velocity Vectors** (velocity during each interval) 1-2: 2-3: 3-4:	**Velocity Vectors** (velocity during each interval) 1-2: 2-3: 3-4:	**Velocity Vectors** (velocity during each interval) 1-2: 2-3: 3-4:

SPH3U: Problem Solving

A: Problem Solving Example

We can build a deep understanding of physics by describing and representing a problem in many different ways. An example will be be shown to the following question:
A runner passes two markers on a track, one of which is 60.0 m from her starting point, the other 80.0 m. If she is running at 9.7 m/s [East] along the track, how long did it take for her to cover this distance?

A: Pictorial Representation

Sketch, coordinate system, label givens using symbols, conversions, describe events

B: Word Representation

Describe motion (no numbers), assumptions

C: Physics Representation

Motion diagram, motion graphs, velocity vectors, events

D: Mathematical Representation

Number and describe steps, complete equations, substitutions with units, final statement with units, direction and significant digits

1. **Explain.** Is the athlete in this problem running in the positive or negative direction? In how many ways is this shown in the solution?

2. **Explain.** In the word description, it is assumed that the runner travels at constant velocity. Find all the examples in the solution that show the runner travelling at constant velocity.

Problem Solving Practice

1. Usain Bolt ran the 200. m sprint at the 2012 Olympics in London in 19.32 s. Assuming he was moving with a constant velocity, what is his speed in m/s during the race? What about in km/h? (10.4 m/s or 37.3 km/h)

A: Pictorial Representation

Sketch, coordinate system, label givens using symbols, conversions, describe events

B: Word Representation

Describe motion (no numbers), assumptions

C: Physics Representation

Motion diagram, motion graphs, velocity vectors, events

D: Mathematical Representation

Number and describe steps, complete equations, substitutions with units, final statement with units, direction and significant digits

Problem Solving Practice

2. In February 2013, a meteorite streaked through the sky over Russia. A fragment broke off and fell downwards towards Earth with a speed of 12 000. km/h. The fragment was first spotted just as it entered our atmosphere at a position of 127 km above Earth. What was its position above Earth 10.0 seconds later? (93.7 km)

A: Pictorial Representation

Sketch, coordinate system, label givens using symbols, conversions, describe events

B: Word Representation

Describe motion (no numbers), assumptions

C: Physics Representation

Motion diagram, motion graphs, velocity vectors, events

D: Mathematical Representation

Number and describe steps, complete equations, substitutions with units, final statement with units, direction and significant digits

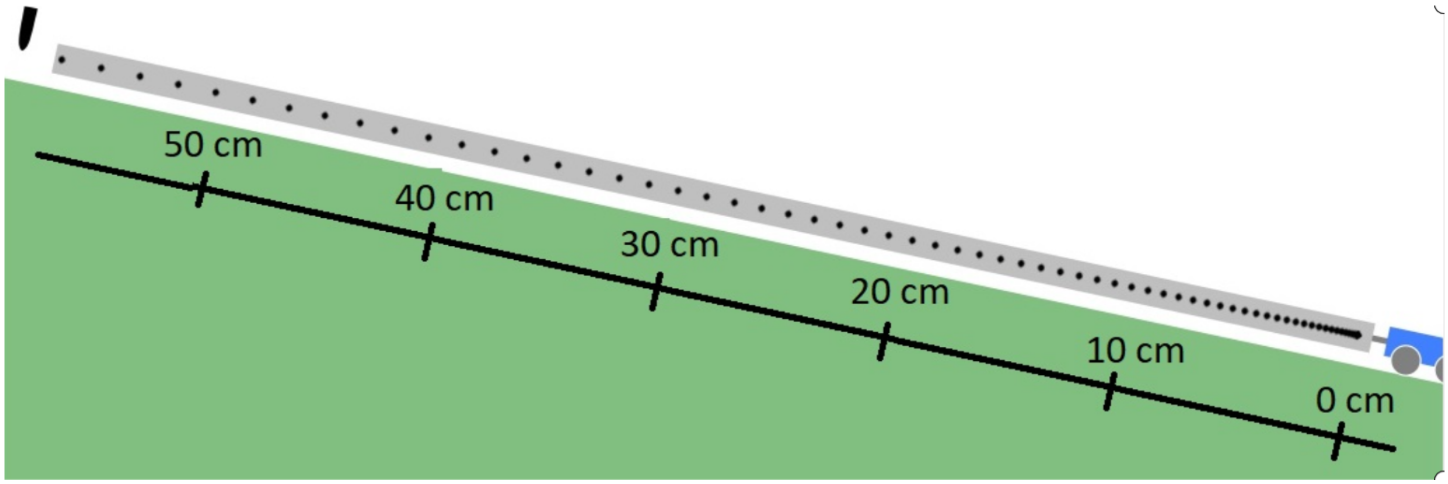
SPH3U: Changing Velocity

A: Motion with Changing Velocity

Your teacher will show you a demonstration of a cart rolling down an inclined plane, pulling a tickertape through a tickertape timer.

1. **Find a Pattern.** From the **first dot** on the tickertape below, draw lines that divide the dot pattern into intervals of six *spaces* as shown here. Do this for 10 intervals. 

2. **Reason.** The timer is constructed so that it hits the tape 60 times every second. How much time does each six-space interval take? Explain your reasoning.

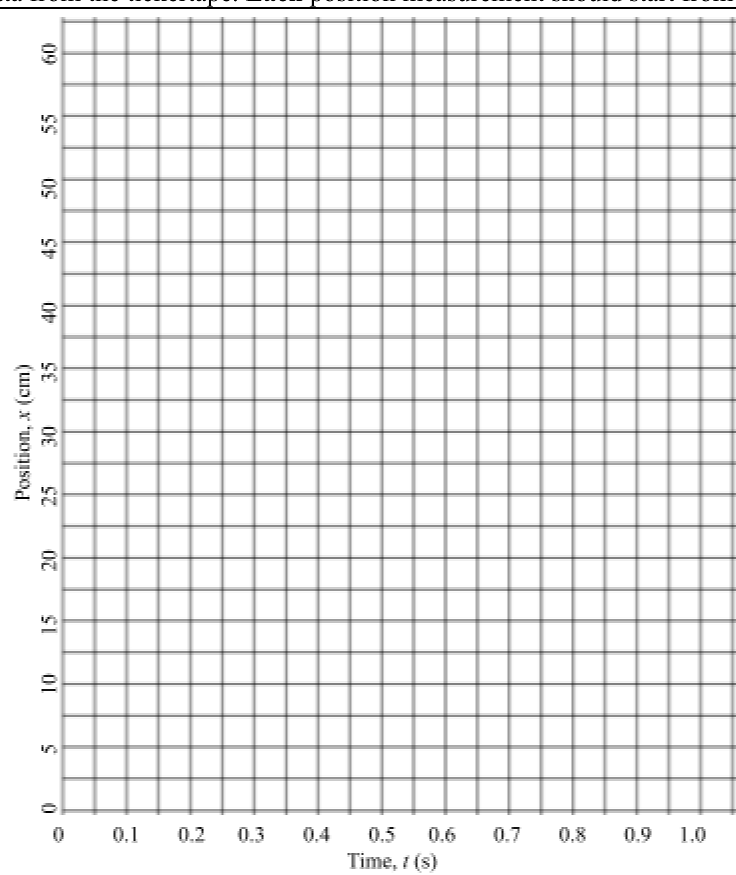


3. **Measure.** Collect a set of position/time data from the tickertape. **Each** position measurement should start from the first mark: "0".

Time, t (s)	Position, x (cm)
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	

4. **Find a Pattern.** Plot the data in a graph of position vs. time. What general shape do the data make?

5. **Represent**. Draw a smooth curve through the data points. You do not have to actually connect the dots.



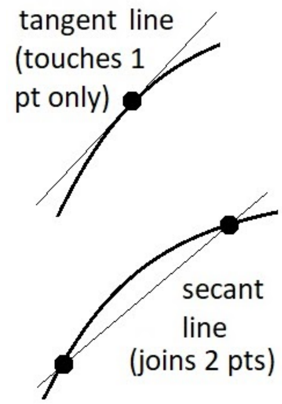
6. **Explain.** During the time interval from 0 to 1.0 seconds, how can you tell if the velocity is changing:

a) from the ticker tape?

b) from the table of values?

c) from the position-time graph?

7. **Draw & Calculate**. Draw a secant line on your graph connecting the position at 0.2 s with the position at 0.5 s, and then determine the slope of that line.



8. **Interpret.** What does the slope of this secant line represent in this case?

The slope of the secant line on a curving position-time graph gives the object's *average velocity* over that time interval

9. **Draw & Calculate**. Draw a tangent line on your graph at 0.8 s. Determine the slope of that line.

10. **Interpret.** What does the slope of this tangent line represent in this case?

The slope of the tangent to a curving position-time graph give the object's *instantaneous velocity*

11. **Reason.** Is it possible for the average velocity over a given interval to be the same as the instantaneous velocity at some specific time during that interval? Consider a diagram to help explain.	12. **Reason.** A student claims that during any time interval there must be an instantaneous velocity that is the same as the average velocity over that interval. Do you agree? Consider diagrams to help explain.

SPH3U: The Idea of Acceleration

A: The Idea of Acceleration

Interpretations are powerful tools for making calculations. Please answer the following questions by **thinking and explaining** your reasoning to your group, rather than by plugging into equations. Consider the situation described below:

A car was traveling with a constant velocity 20 km/h. The driver presses the gas pedal and the car begins to speed up at a steady rate. The driver notices that it takes 3 seconds to speed up from 20 km/h to 50 km/h.

1. **Reason.** How fast is the car going 2 seconds after starting to speed up? Explain.

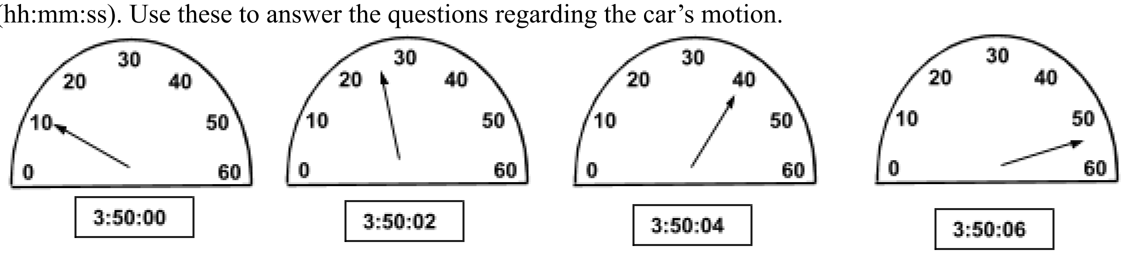
2. **Reason.** How much time does it take to go from 20 km/h to 80 km/h? Explain.

3. **Interpret.** A student who is studying this motion subtracts 50 – 20, obtaining 30. How would you interpret the number 30? What are its units?

4. **Interpret.** Next, the student divides 30 by 3 to get 10. How would you interpret the number 10? (Warning: don't use the word *acceleration*, instead explain what the 10 describes a change in. What are the units?)

B: Watch Your Speed!

Shown below are a series of images of a speedometer in a car showing speeds in km/h. Along with each is a clock showing the time (hh:mm:ss). Use these to answer the questions regarding the car's motion.



1. **Reason.** What type of velocity (or speed) is shown on a speedometer – average or instantaneous? Explain.

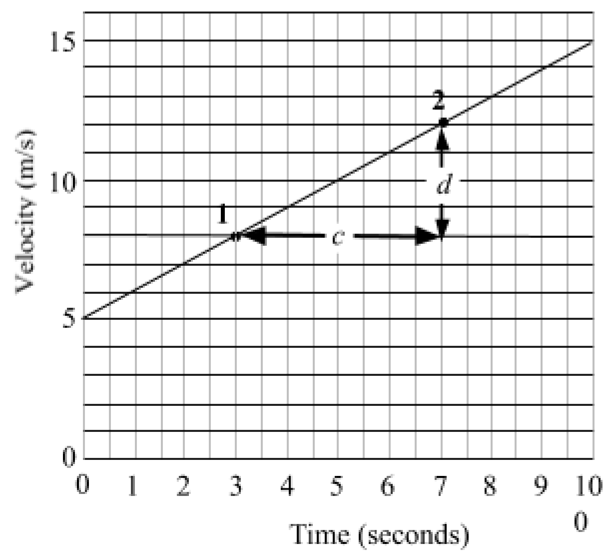
2. **Explain.** Is the car speeding up or slowing down? Is the change in speed steady?

3. **Explain and Calculate.** Explain how you could find the acceleration of the car. Calculate this value and write the units as (km/h)/s.

4. **Interpret.** Marie exclaims, "In our previous result, why are there two different time units: hours and seconds? This is strange!" Explain to the student the significance of the hours unit and the seconds unit. The brackets provide a hint.

C: Interpreting Velocity Graphs

To the right is the velocity versus time graph for a particular object. Two moments, 1 and 2, are indicated on the graph.



1. **Interpret.** What does the graph tell us about the object at moments 1 and 2?

2. **Interpret.** Give an interpretation of the interval labelled c. What symbol should be used to represent this?

3. **Interpret.** Give an interpretation of the interval labelled d. What symbol should be used to represent this?

4. **Interpret.** Give an interpretation of the ratio d/c. How is this related to our discussion in part A?

5. **Calculate.** Calculate the ratio d/c including units. Write the units in a similar way to question B#3.

6. **Explain.** Use your knowledge of fractions to explain how the units of (m/s)/s are simplified.

SPH3U: Calculating Acceleration

A: Defining Acceleration

The expression $\Delta\vec{v}/\Delta t$ represents the *change* in velocity occurring in each unit of time and is called *acceleration* $\vec{a}$:

$$\vec{a} = \frac{\overrightarrow{\Delta v}}{\Delta t} = \frac{\overrightarrow{v_f} - \overrightarrow{v_i}}{\Delta t}$$

Note in the equation above, we wrote v_f and v_i for the final and initial velocities during some interval of time. If your time interval is defined by events 2 and 3, then v_3 is the final velocity and v_2 is the initial velocity.

B: Problem Solving

1. **Hit the Gas!** You are driving along the 401 and want to pass a large truck. You floor the gas pedal and begin to speed up. You start at 102 km/h, accelerate at a steady rate of 2.90 (km/h)/s (obviously not a sports car). What is your velocity after 5.30 seconds when you finally pass the truck?

A: Pictorial Representation
Sketch, coordinate system, label givens using symbols, describe events

C: Physics Representation
Motion diagram, motion graphs, velocity vectors, events

B: Word Representation
Describe motion (no numbers), explain why, assumptions

D: Mathematical Representation
Number and describe steps, complete equations, algebraically isolate, substitutions with units, final statement

2. **The Rocket** A rocket is travelling upwards. A second engine begins to fire causing it to speed up at a rate of 21.0 m/s^2. After 4.30 seconds it reaches a velocity of 115 m/s and the engine turns off. What was the velocity of the rocket when the second engine began to fire?

To describe motion in the vertical direction, use the symbol y for the *vertical* position. All other symbols remain the same. In physics, the symbol x will only be used for *horizontal* position. The sketch for the situation should show the vertical motion and the coordinate system should show which vertical direction is the $+y$-direction. The motion diagram and the velocity vectors should point vertically.

A: Pictorial Representation

Sketch, coordinate system, label givens & unknowns using symbols, conversions, describe events

C: Physics Representation

Motion diagram, motion graphs, velocity vectors, events

B: Word Representation

Describe motion (no numbers), explain why, assumptions

D: Mathematical Representation

Number and describe steps, complete equations, algebraically isolate, substitutions with units, final statement

Calculating Acceleration Homework *(from Irwin Physics 11 p67)* ***NOTE**: NEED TO DO THESE ON A SEPARATE PIECE OF PAPER. INCLUDE PICTORIAL, PHYSICS, WORD AND MATHEMATICAL REPRESENTATIONS*

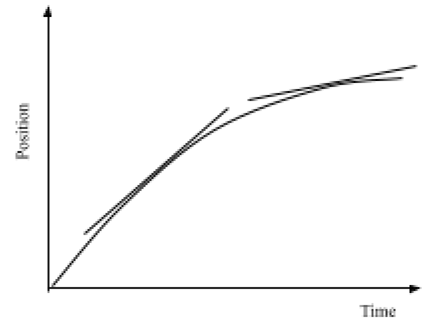
47. A pitcher can throw a baseball at 100 km/h. If the ball starts from rest and accelerates over 1.5 s, what is the acceleration of the ball? ANS: *19 m/s^2 [fwd]*	**48.** A car moving at 10.0 m/s north ends up moving 10.0 m/s south after a period of 12 s. What is its acceleration? ANS: *48. 1.7 m/s^2 [S]*	**52.** What is an object's final velocity if it accelerates at -2.0 m/s^2 for 2.3 s from a velocity of 50.0 km/h? ANS: *52. 9.3 m/s [fwd]*

SPH3U: Speeding Up or Slowing Down?

There is one mystery concerning acceleration remaining to be solved. Our definition of acceleration, $\Delta v/\Delta t$, allows the result to be either positive or negative, but what does that mean? Today we will get to the bottom of this.

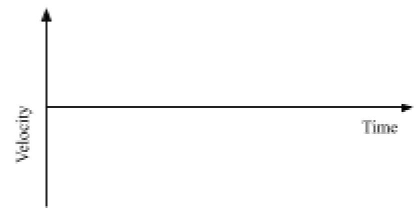
A: Acceleration in Graphs

Suppose the motion of a student is shown in the position-time graph to the right.



1. **Interpret.** Describe the motion of the student shown in the diagram.

2. **Interpret.** What does the slope of a tangent to a position-time graph represent?



3. **Reason.** What is happening to the slope of the tangent in the position-time graph as we move from left to right along the curve? What does this tell us about the velocity?

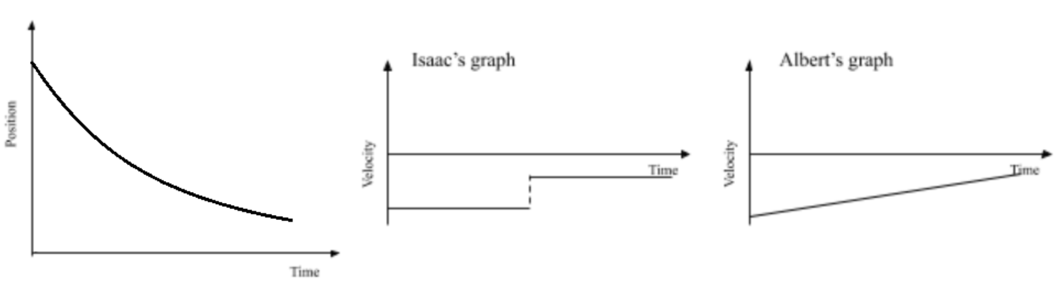
4. **Predict.** What will the velocity-time graph look like? Draw a line or curve on the velocity time graph to the right..

5. **Interpret.** Is the cart speeding up or slowing down? Use the two tangents to the graph to help explain.

To help interpret position graphs, we will use the *tangent trick*. Use a ruler or pencil as the tangent line to a position graph. Interpret the slope of the tangent. Then move the tangent to a new spot along the graph and interpret. Decide if the object is speeding up or slowing down. This trick can also be used to decide how to sketch a position graph.

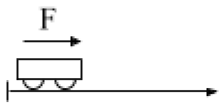
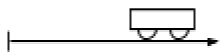
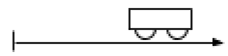
6. **Reason.** Is the change in velocity positive or negative? What does this tell us about the acceleration?

7. **Reason.** Isaac and Albert draw a velocity graph to match the position graph on the left. Which velocity graph do you think best matches the position graph? Explain.



B: The Sign of the Acceleration

1. **Observe, Predict and Interpret.** Your teacher will lead you through four different situations using the CBR.

	1	**2**	**3**	**4**
Description	The object starts from rest near the detector. The object is pulled away from the detector.	The object starts from rest far from the detector. The object is pulled **towards** the detector.	The object is moving away from the detector. The object is pulled **towards** the detector.	The object is moving towards the detector. The object is pulled **away** from the detector.
Sketch with Force				
Position graph				
Velocity graph				
Acceleration graph				
Slowing down or speeding up?				
Sign of Velocity				
Sign of Acceleration				

Acceleration is a **vector** quantity, so the sign indicates a direction. This is **not** the direction of the object's motion!

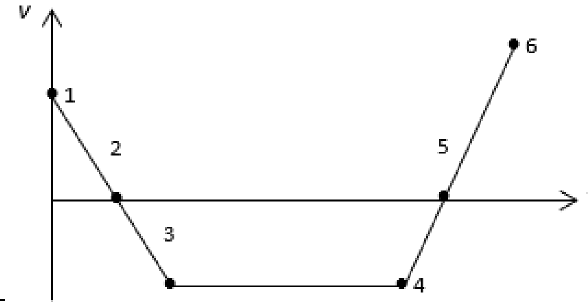
2. **Reason.** Emmy says, "We can see from these results that when the acceleration is positive, the object always speeds up." Do you agree with Emmy? Explain.

3. **Reason.** What conditions for the acceleration and velocity must be true for an object to be speeding up? To be slowing down?

4. **Reason.** Which quantity in our chart above does the sign of the acceleration **always** match?

Always compare the magnitudes of the velocities, the speeds, using the terms *faster* or *slower*. Describe the motion of accelerating objects as *speeding up* or *slowing down* and state whether it is moving in the positive of negative direction. **Never** use the d-word, *deceleration.* Note that we will always assume the acceleration is uniform (constant).

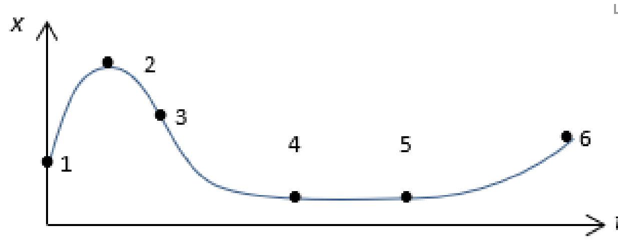
HW: Speeding Up and Slowing Down



1. Interpret and Explain. A person walks back and forth in front of a motion detector producing the velocity graph shown to the right. Six events have been labelled on the graph. The chart below lists different examples of motion. Find the appropriate interval(s) of time in the graph that correspond to that type of motion and provide evidence from the graph supporting your choice.

Type of Motion	Interval(s)	Evidence
positive acceleration		
negative acceleration and a positive velocity		
acceleration of zero		
speeding up		
slowing down		
at rest (means not moving for a period of time)		
change of acceleration	Moments:	

2. **Interpret and Explain**. A person walks back and forth in front of a motion detector and produces the position graph shown to the right. The chart below lists different examples of motion. Find the appropriate interval(s) of time or events in the graph that correspond to that type of motion and provide evidence from the graph supporting your choice.



Type of Motion	Interval(s)	Evidence
zero velocity		
speeding up		
slowing down		
turning around		

SPH3U Area and Displacement

A graph is more than just a line or a curve. We will discover a very handy new property of graphs which has been right under our noses (and graphs) all this time!

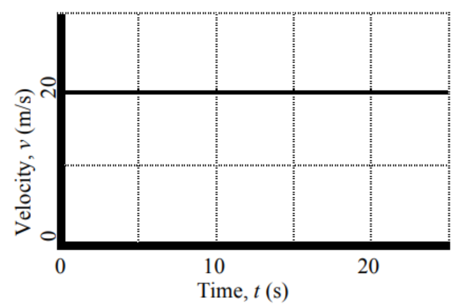
A: Looking Under the Graph

A car drives south along a straight road at 20 m/s. After 5 s the car passes a streetlight and at 20 s the car passes a bus stop.

1. **Calculate** the displacement of the car between the streetlight and the bus stop using the formula $\vec{v} = \Delta\vec{x}/\Delta t$

2. **Sketch.** Now we will think about this calculation in a new way. Draw and shade a rectangle on the graph that fills in the area between the line of the graph and the time axis, for the time interval of 5 to 20 seconds.

3. **Interpret.** Calculate the area of the rectangle. Note that the length and width have a meaning in physics, so the final result is not a physical area. Use the proper physics units that correspond to the height and the width of the rectangle. What physics quantity does the final result represent?

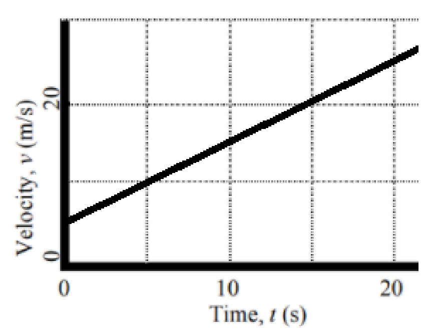


Area under a velocity graph. The *area* under a velocity-time graph for an interval of motion gives the *displacement* during that interval. Both velocity and displacement are vector quantities and can be positive or negative depending on their directions. According to our usual sign convention, areas above the time axis are positive and areas below the time axis are negative.

B: What if Velocity is not Constant?

Consider the velocity time graph shown in the diagram.
Suppose we want to know how far the car travelled between t_1 = 5.0 s and t_2 = 15.0 s.
Shade in the area representing the distance travelled over this interval.

Calculate the area of your shaded region. Remember to include units.



Extend. Find an expression for the area under the graph using some or all of the variables t_1, t_2, Δt, $\vec{v}_1$, $\vec{v}_2$

SPH3U: The BIG Five

Last class we found three equations to help describe motion with constant acceleration. A bit more work along those lines would allow us to find two more equations which give us a complete set of equations for the five kinematic quantities.

A: The BIG Five – Revealed!

Here are the BIG five equations for uniformly accelerated motion.

The **BIG** Five	$\vec{v}_1$	$\vec{v}_2$	$\Delta\vec{x}$	$\vec{a}$	Δt
$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$					
$\Delta\vec{x} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$					
$\Delta\vec{x} = \vec{v}_2\Delta t - \frac{1}{2}\vec{a}(\Delta t)^2$					
$\Delta\vec{x} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$					
$\vec{v}_2^{\,2} = \vec{v}_1^{\,2} + 2\vec{a}\Delta\vec{x}$					

1. **Describe.** Define carefully each of the kinematic quantities in the chart below.

$\vec{v}_1$	
$\vec{v}_2$	
$\Delta\vec{x}$	
$\vec{a}$	
Δt	

2. **Reason.** What condition must hold true (we mentioned these in the previous investigation) in order to use the big 5 kinematic equations?

B: As Easy as 3-4-5

Solving a problem involving uniformly accelerated motion is as easy as 3-4-5. As soon as you know **three** quantities, you can always find a **fourth** using a BIG **five**! Write your solutions carefully using our solution process.

Problem 1

A traffic light turns green and an anxious student floors the gas pedal, causing the car to accelerate at 3.4 m/s^2 for a total of 10.0 seconds. We wonder: How far did the car travel in that time and what's the big rush anyways?

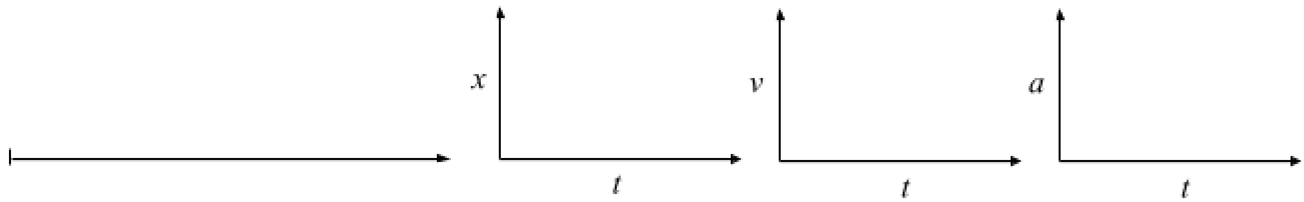
A: Pictorial Representation

Sketch, coordinate system, label givens with symbols, conversions, describe events

Emmy says, "I am given only two numbers, the acceleration and time. I need three to solve the problem. I'm stuck!" Explain how to help Emmy.

C: Physics Representation

Motion diagram, motion graphs, velocity vectors, events



D: Mathematical Representation

Describe steps, complete equations, algebraically isolate, substitutions with units, final statement

Big Five Homework *(from Irwin Physics 11 p67)*

35. A sneeze causes you to momentarily shut your eyes. If this process takes 0.50 s and you are moving at 30.0 km/h, how far will you travel in that time?

37. How far would a car move in 4.80 s if its velocity changed from 14.0 m/s to 16.0 m/s?

43. What was the initial velocity of an object that moved 120 m in 5.60 s, reaching a final velocity of 15.0 m/s in that time? Was the object speeding up or slowing down?

44. If Donovan Bailey reaches a top speed from rest of 10.2 m/s in 2.5 s, what is his acceleration?

45. If a sprinter accelerates at 2.2 m/s^2 for 2.5 s starting from rest, what is her final velocity?

46. If it takes 0.080 s for an air bag to stop a person, what is the acceleration of a person moving 13.0 m/s and coming to a complete stop in that time?

56. A car traveling at 40. km/h accelerates at 2.3 m/s^2 for 2.7 s. How far has it traveled in that time? What is its final velocity?

58. If 100 m sprinters accelerate from rest for 3.5 s at 2.8 m/s^2, how far have they run to this point? How long will it take them to complete the 100 m sprint, assuming they maintain their speed the rest of the way?

65. A dragster accelerates from rest for a distance of 450 m at 14 m/s^2. A parachute is then used to slow it down to a stop. If the parachute gives the dragster an acceleration of -7.0 m/s^2, how far has the dragster traveled before stopping?

35. 4.2 m 37. 72m [fwd] 43. 28m [fwd] 44. 4.1 m/s2 [fwd] 45. 5.5 m/s [fwd] 46. 160 m/s2 [backward] 53. -19 m/s 56. 38 m 57. 22 m 58. 12s 65. 1350m (rounds to 1400m)

SPH 3U: Kinematics Problem Set Name: ________________

For each question, complete (A) the pictorial representation, (B) the word representation, (C) the physics representations and (D) the mathematical representations.

Horizontal Motion

1) (a) How long does it take a cyclist to accelerate from 12.0 m/s [W] to 18.0 m/s [W] if they can accelerate at 2.1 m/s^2 [W]? (b) How far does the cyclist travel in this time? $\Delta t = 2.9\text{s}$ $\Delta\vec{x} = 43\text{m}$ [W]
2) Find the acceleration, in m/s^2 and the displacement in m of a car that changes its velocity from 54.0km/h [NE] to 72.0km/h [SW] in 25.0s. $\vec{a} = 1.40$ m/s2 [SW] $\Delta\vec{x} = 62.5\text{m}$[SW]

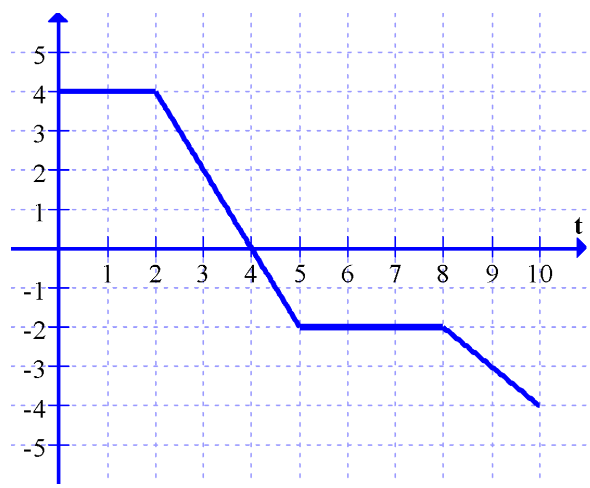
Horizontal motion with 3 or more events

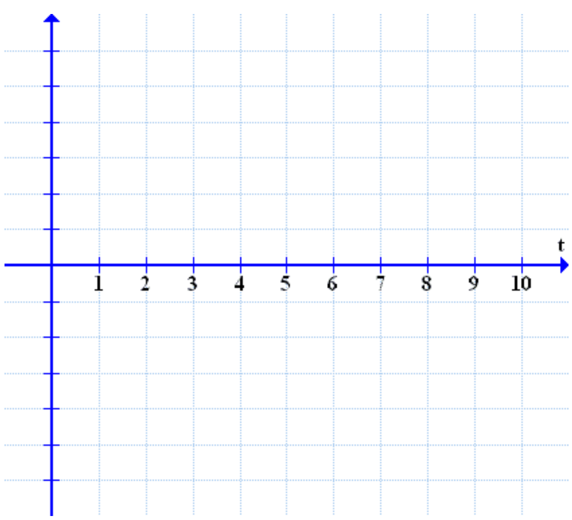
3) On a bicycle, a student starts from rest and accelerates at 2.0 m/s^2 [E] for 3.0 s. They then continue at constant velocity for 5.0 s and then they stop pedaling and come to rest in 8.0m. Find the total displacement of the ride and the average velocity. $\Delta\vec{x}_{14} = 47\text{m}$ $\vec{v}_{avg} = 4.4$ m/s

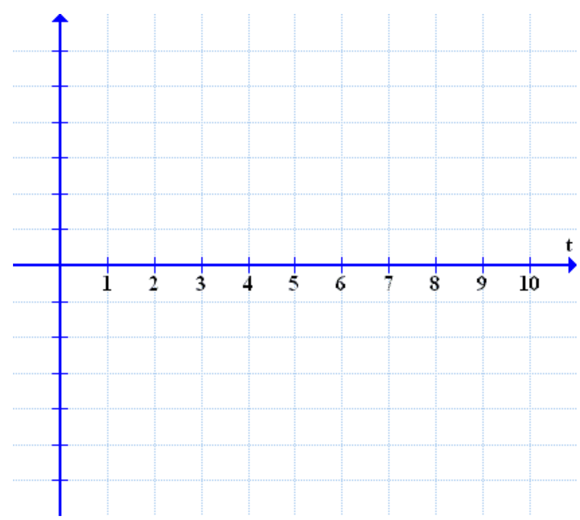
4) A remote-control car initially moving at 1.0 m/s [E] accelerates at 3.0 m/s^2 [E] until it reaches a velocity of 34 m/s [E]. The car then travels an additional 510 m [E]. Find all unknown quantities.
$\Delta t_{13} = 26\text{s}$ $\Delta\vec{x}_{13} = 7.0\text{x}10^2\text{m}$

Graphing

5) The motion of an object is described by the following graph. If the graph represents
   a) a position-time graph, draw the corresponding velocity-time graph
   b) a velocity-time graph, draw the corresponding position-time graph







SPH3U: Vectors in Two-Dimensions

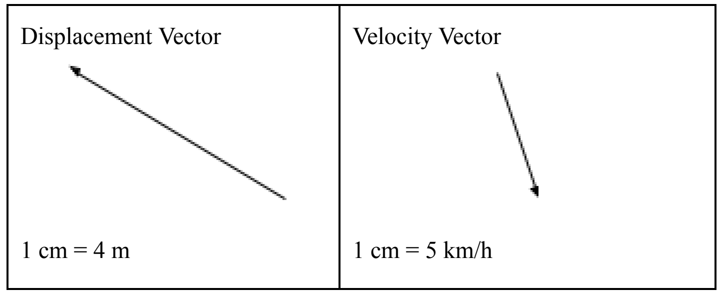
The main model of motion we have developed so far is motion in a straight line. Now consider two-dimensional motion.

A: Representing a Two-Dimensional Vector

We visually represent vectors by drawing an arrow. We have already done this with displacement and velocity vectors.

1. **Interpret.** What does the length of a displacement vector describe?

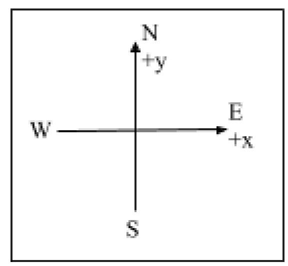
2. **Interpret**. What does the length of a velocity vector describe?



B: Vector Addition aka Treasure Hunt

Suppose you are at a starting location, shown as an **x** below. Someone tells you that you can find a treasure if you walk 400 m [East], then 300 m [North].

Use a ruler to draw the vectors corresponding to those instructions, and mark another **x** where the treasure is buried. You will need to choose an appropriate scale. Remember to put an arrowhead at the end of each vector.



x

In order for you to save some time, you could have instead walked a direct line from your starting point to the buried treasure. Using a dotted line, draw a new vector between your starting point and the treasure (this is called the *resultant vector*)

How to write vectors that aren't going either straight up/down/left/right? Imagine a person travels 3.5 m in a direction north and 60º to the west. We will record this as: $\vec{\Delta d} = 3.5\ m\ [N60^{o}W]$. The symbol $\vec{\Delta d}$ with an arrow signifies a displacement (a change in the position vector). The number part, 3.5 m, is called the magnitude of the vector, and the direction goes in square brackets.

Use a ruler and a protractor to measure the important characteristics of your resultant vector (both magnitude and direction), and record the resultant vector that would bring you directly from your starting point to the treasure.

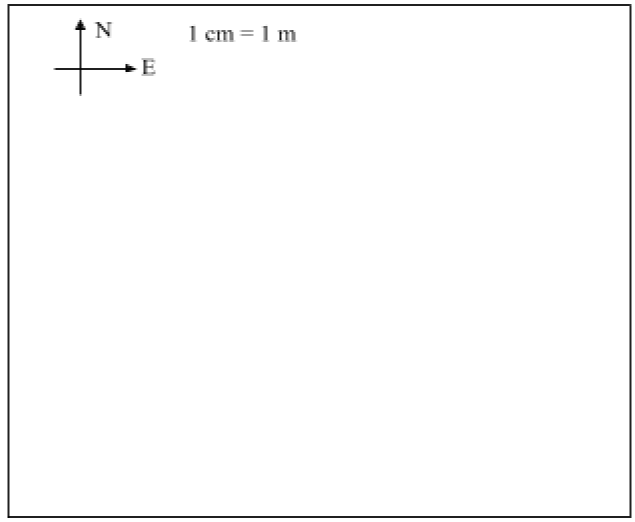
B: Let's Take a Walk

You and a friend take a stroll through a forest. You travel 6 m [E] and then 5 m [S].

1. **Represent.** Draw the two displacement vectors one after the other (tip to tail). *Start your vectors at the centre of the coordinate system.*

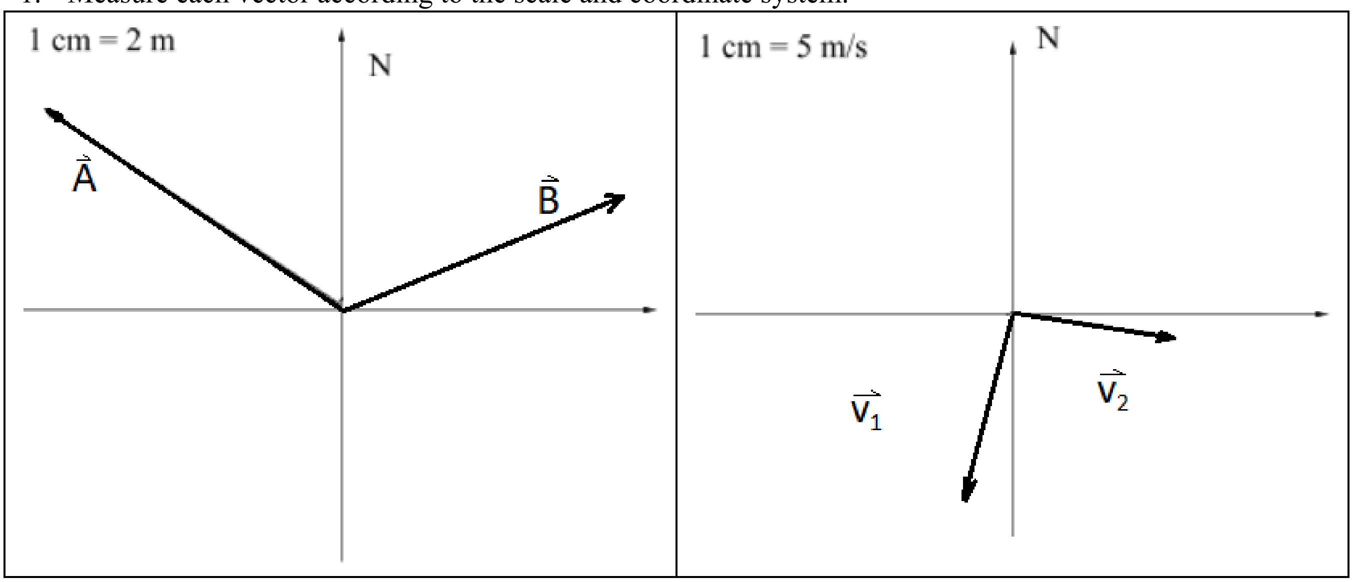
2. **Interpret.** After travelling through the two displacements, how far are you from your starting point? In what direction?

3. **Represent.** Draw a single vector arrow which represents the total displacement for your friend's entire trip. Label the three vectors in your diagram as $\Delta\vec{d}_1$, $\Delta\vec{d}_2$ and $\Delta\vec{d}_T$



SPH3U: Vector Practice

1. Measure each vector according to the scale and coordinate system.



2. Draw each vector to scale on the space above, each starting at the origin of the coordinate system.

$\vec{C}$ =12 m [S 10º E]

$\vec{D}$ =9 m [W 70º S]

$\vec{V}_3$ = 35 m/s [N 15ºW]

$\vec{V}_4$ = 20 m/s [E 40º N]

3. Add the two displacement vectors together tip-to-tail. Find the total distance, displacement average speed and average velocity if the whole trip took 2.0 hours. Use the scale 1 cm = 10 km.

a) 80 km [W] & 60 km [N]

d) 40 km [E] & 30 km [S50ºW]

SPH3U - 2D Projectile Motion Problems

20. A movie scene has a car fall off a cliff. If the car took 5.5 s to reach the ground, how high was the cliff?

21. If the car in Problem 20 had an initial horizontal velocity of 26 m/s, how far from the cliff bottom did the car land?

22. A bullet is shot horizontally from a gun. If the bullet's speed exiting the muzzle is 325 m/s and the height of the gun above the ground is 2.0 m,
a) how long was the bullet in the air?
b) how far did the bullet travel horizontally before it hit the ground?

23. A tennis player serves a tennis ball from a height of 2.5 m. If the ball leaves the racket horizontally at 160 km/h, how far away will the ball land?

24. A pitcher throws a baseball at 140 km/h. If the plate is 28.3 m away, how far does the ball drop if we assume the ball started travelling toward the plate horizontally?

25. Two pennies are sitting on a table 1.2 m high. Both fall off the table at the same time, except one is given a significant push. If the pushed penny is moving at 4.1 m/s horizontally at the time it leaves the table,
a) which penny lands first?
b) how far from the table does the pushed penny land?

27. A plane is flying horizontally with a speed of 90 m/s. If a skydiver jumps out and free falls for 10.6 s, find
a) how far the skydiver falls.
b) how far the skydiver moves horizontally.
c) the final vertical velocity of the skydiver.
d) the final velocity of the skydiver.

28. A plane flying level at 80 m/s releases a package from a height of 1000 m. Find
a) the time it takes for the package to hit the ground.
b) the distance it travelled horizontally.
c) the final velocity of the package.

31. Will a football, kicked at 14.0 m/s vertically and 9.0 m/s horizontally, clear a bar 3.0 m high and 20 m away from the kicker? Solve in two different ways.

32. Will a tennis ball served horizontally at 100 km/h from a height of 2.2 m clear a net 0.9 m high and 10 m away? Solve in two different ways.

33. Emanual Zacchini was shot over three ferris wheels, landing in a net at the same height from which he was shot (described in Fig. 3.19). Given his initial velocity of 27 m/s [R53°U] and range of 69 m, find
a) his maximum height reached.
b) the time spent in air, using two different methods.
c) his final velocity, using logic and computation.

ANSWERS

20. 150 m
21. 140 m
22. a) 0.64 s, **b)** 210 m
23. 32 m
24. 2.60 m
25. a) land at same time
b) 2.0 m
26. (22) 330 m/s [R1.1°D],
(23) 45 m/s [R9.0°D]
(24) 40 m/s [R10°D]
27. a) 550 m, **b)** 950 m, **c)** 100 m/s,
d) 130 m/s [R48°D]
28. a) 14 s **b)** 1100 m
c) 160 m/s [R60°D]
29. a) 1000 m **b)** 1100 m **c)** 230 m
30. 8.5 m
31. yes
32. yes
33. a) 24 m, **b)** 4.3 s,
c) 27 m/s [R53°D]
35. 101.5 km/h, 98.5 km/h
36. a) −35 km/h, **b)** 35 km/h,
c) 135 km/h, **d)** 135 km/h

FORMULAS

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

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

$$\Delta\vec{x} = \vec{v}_1\Delta t + \tfrac{1}{2}\vec{a}(\Delta t)^2$$

$$\Delta\vec{x} = \vec{v}_2\Delta t - \tfrac{1}{2}\vec{a}(\Delta t)^2$$

$$\Delta\vec{x} = \tfrac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{v}_2^{\,2} = \vec{v}_1^{\,2} + 2\vec{a}\Delta\vec{x}$$