Name _____   School _____   Date _____

Velocity: A Bat's Eye View of Velocity

PURPOSE

There are a number of useful ways of modeling (representing) motion. Graphing position, velocity, and acceleration vs. time is a good choice since the rise and fall and shape of a graph are analogous to the changes in these quantities. In this activity we'll create position and velocity graphs of an object with constant velocity. At the end of this activity you should be able to

- Observe a moving object and draw position vs. time (*x-t*) and velocity vs. time (*v*-t) graphs of its motion.
- Look at an *x-t* or *v-t* graph and describe the motion that produced it.
- Look at an *x-t* graph and draw the corresponding *v*-t graph.
- Find displacement, Δ*x* from a *v-t* graph.
- Use the Sketch [Sketch] and Screenshot [📷] tools for creating and saving figures and printing them out for grading.

EQUIPMENT

Virtual Dynamics Track   VPL Grapher   PENCIL ✏️

DISCUSSION

We all know that bats use sound to locate objects in their environment. What about humans? Could we do this too?

Suppose you were a good distance from a wall with no other objects around. If you clapped your hands and listened for the echo off the wall you'd notice that the wait time between clap and echo would vary according to your distance from the wall. Knowing the speed of sound in air (about 330 m/s) and measuring the wait time, you could calculate the distance to the wall.

If you walked toward the wall you'd notice a steady decrease in the wait time due to the decreasing distance the sound has to travel. Likewise, moving away from the wall would steadily increase the wait time. So you can actually determine your distance from the wall and your direction of motion just by observing the echo times and the way in which they change.

The virtual apparatus used in this activity includes a device called an ultrasonic motion sensor. It emits a sound, receives its echo, and with the help of a computer, calculates the distance to the reflecting object. Ours does this about 100 times a second and provides us with a table of position, time data as well as a graph of position vs. time.

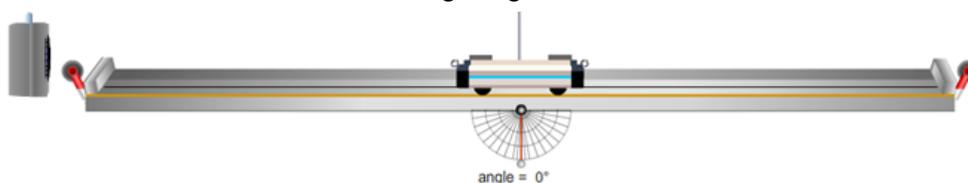We'll bounce our ultrasonic sound waves off a cart moving along a track.

Figure 1 – The Dynamics Track

FAMILIARIZE YOURSELF WITH THE APPARATUS

Let's try graphing. Click on the cart and drag it to the middle of the track. Click on the Sensor to turn it on. It's its own on/off switch. You should see a horizontal red line begin to form about half-way up the *x-t* graph.

Turn off the motion sensor. (You'll always want to turn off the motion sensor when you aren't using it.) Scroll the data table and note the cart's position at mid-track. It should be at about 1.0 m.

Try it again, but this time turn on the motion sensor and then move the cart from side to side. Get the idea? Notice that the graph and data table clear each time you turn on the motion sensor. Do this again, this time making sure that you move the cart all the way in each direction. Use your data table to note the minimum and maximum positions obtainable by the cart.

1. $x_{minimum}$ = _____ m $x_{minimum}$ = _____ m
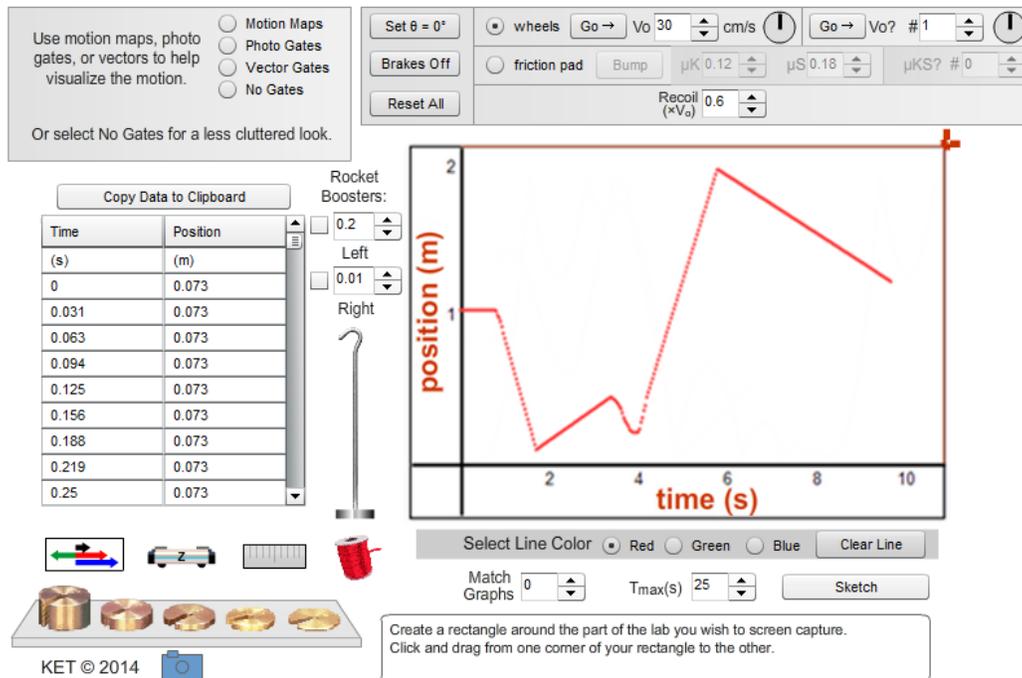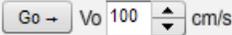
Figure 2 – The Dynamics Track Apparatus

Learn how to do the following.

1. Display the ruler above the track. Note how it can be dragged up and down.

2. Turn the brake on and off using the Brakes On/Brakes Off toggle button.

3. Use the V_o (initial velocity) tool and Go→ button to launch the cart at a known positive or negative velocity.

4. Change the color of the lines drawn on the graph. Do you have to clear a line before overwriting it?

5. Change the time scale of the graph using the $T_{max}(s)$ tool. Reset to normal, $T_{max} = 10$ seconds.

6. Change the way the cart recoils when it hits the track ends. Reset to the normal setting of Recoil = .2.

Creating graphs and sketches to print out for grading using the "Screenshot" **and "Sketch Graph" tools.**

In this lab you'll be asked to print out screenshots (captured images) for grading. Sometimes these will be screenshots of a graph or some part of the apparatus. Sometimes you'll be asked to create a sketch on screen, create a screenshot of your sketch, and then save it, print it out, and attach it to this document in the space provided. See your Lab Manual for details on the use of the "Screenshot" and "Sketch" tools provided in many of the virtual labs.

When you create a screenshot you'll first save it locally to your hard drive, a thumb drive, or similar. The filename to use will be provided in the lab document like the one you're reading now. For example, a little later in this lab you'll be asked to "take a screenshot of the graph produced by the apparatus, save it locally as 'Vel_IB1a.png', print it out, and attach it in the spaced provided below."

Using Grapher – Graphs, best fit lines, slopes, areas, saving data

The Dynamics Track data table contains position vs. time data. You'll be using this with our Grapher tool. Let's try it. Move your cart to the left end of the track. Adjust T_{max} to 25 seconds. For the following, don't stop until you've gone over and back twice as directed. If you run out of room try again.

Turn on the motion sensor. Drag the cart to the right quickly, then back fairly slowly. Continue by doing the reverse – dragging to the right slowly, then returning to the left quickly. Turn off the motion sensor.

Congratulations, you've made a capital M. (See Figure 3.) If not, give it another try.

Hopefully the graph's shape already means something to you but let's go a bit further. Click the "Copy Data to Clipboard" button. Your data is now in your computer's clipboard. You could paste it into a number of software programs such as Excel. We'll use our Grapher Tool because it lets us manipulate the data in ways that are useful in physics.

Open Grapher. Click in the box below "Click in the box below and hit Ctrl+V to paste data." Type Ctrl+V. That is, hold down the Control key and type "v". By convention the independent variable, time, appears in the *x*-column in the data table. The dependent variable, position, appears in the *y*-column. You'll see what the other columns are for soon.

You'll see an "M" just like the one in the Dynamics Track graph. To adjust the scale of the two axes, click the "Man" button, short for manual scaling. Try 20, 0, 2, and 0. Click Submit, then Close.

Edit the axis labels to "Position (m)" on the ordinate and "Time (s)" on the abscissa. (To save room, we don't include titles in the graphs.) Let's also shrink the graph a bit by clicking the check boxes beside the "2" next to the Graphs button. You can see that we can add a third graph but won't need to in this lab.

Let's see what we can learn from our graph and data. Your M-graph should have four slanting segments. We want to find the slopes of the two segments <u>inside the M</u>.

- In Grapher click at a point somewhere in the graph a bit to the right of the time when the first of the two inside segments begins. (See the left edge of the shaded area in the figure at about 5.3 seconds.)

- Drag to the right. A gray box will appear. Continue dragging until you're near the end of that segment and then release. (At about 12 seconds in the figure.) The vertical position of the mouse pointer is unimportant when you're dragging horizontally.

- By doing this you have also selected the data associated with this section of the graph. We can then use some other Grapher tools to analysis this data. Let's try it.
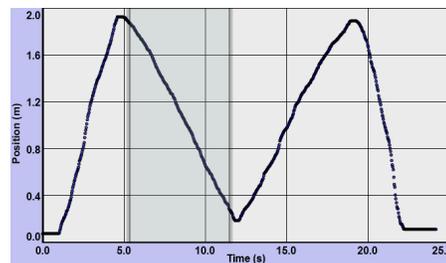

Figure 3 – The "M"

Linear fit y = mx + b	Linear fit y = mx + b
m (Slope) = -0.271	m (Slope) = 0.265
b (Y-intercept) = 3.396	b (Y-intercept) = -3.025

Figures 3a, 3b – Linear Fit Data

With the data still selected click the Linear Fit check box. Data will now appear in the Linear Fit data box. Grapher has drawn the **line of best fit** for that part of your graph in pink. The values for the M-graph shown in Figure 3 are displayed in Figure 3a.

Now repeat for the next segment to the right, the rising segment inside the "M." You now have a second line of best fit. Its data will appear in the text box as shown in Figure 3b. The two slopes, -0.271 m/s and 0.0265 m/s. **These slopes are the average velocities, Δ*x*/Δ*t*, for these two segments.** They are calculated using a mathematical technique called *linear regression*.

A word of caution. You many have seen slopes appear that are way off. Right now I'm seeing -0.060 for example. What gives? Without clicking, move you mouse pointer up and down, crossing back and forth between graphs 1 and 2. A line of best fit is drawn for each graph. But the data displayed is for the highlighted graph, the one you have your pointer over.

PROCEDURE

Let's use these tools to learn to think about motion graphically. In this lab we'll observe how the position and velocity of an object are reflected in the shape of its position or velocity vs. time graph, and conversely how the shape of these graphs describe the motion of an object. In the next lab we'll investigate acceleration.

I. Position

IA. Motion away from the motion sensor.

Set T_{max} to 10 seconds. Set the Recoil to 0. Turn off the cart brake. (You'll want it off for all the steps that follow.) **You'll use the motion sensor throughout this lab. You'll turn it on just before you start a trial and then turn it off afterwards.**

OK, let's collect some data and plot a graph.

1a. Position the cart at the left end of the track. Start it moving at a slow speed to the right using "V_o" and "Go→." Use 20 cm/s for V_o.
Careful with units! The V_o selector is in cm/s but our graphs will be plotted in m/s.
And remember you'll always want the motion sensor running during each trial.

| Go → | Vo | 20 | ▲▼ | cm/s |

**Is the entire graph significant? If not, what parts are?**

There will often be extraneous segments on your graphs that should be ignored. This step of the lab is called "Motion away from the motion sensor." And you're told to use a speed of 20 cm/s. You should be able to tell which part of the graph represents this slow constant speed away from the sensor. In this case you should have a straight line that rises at an angle of less than 45°. (If not, try again.) The extra parts of the graph are not significant and should be omitted from your sketches.

Sketch the graph in the space provided in Graph IA1a. **(Never mind. It's already done for you this time, along with IA1b and Q2, Q3, and Q4! The non-scratched-out parts are the "significant" parts referred to above.)**
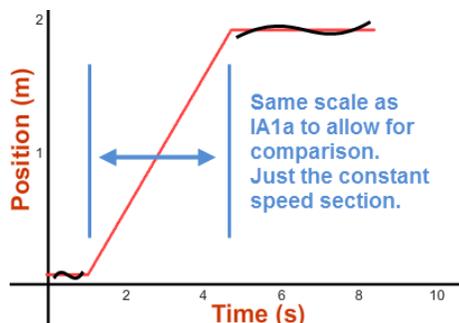
1b. Repeat with another trial at a faster speed of 50 cm/s. The sketch (Graph IA1b) is again pre-drawn for you.

You should see now why we're using the same scale for each graph. Otherwise we couldn't make comparisons between related graphs.

IA1a. Cart moves slowly away from the motion sensor
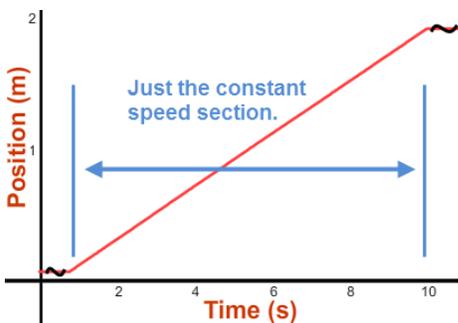
IA1b. Cart moves quickly away from the motion sensor

2. What is similar about the 2 graphs? NOT THE MOTIONS, the shapes of the graphs. Remember to just look at the significant, constant velocity part of the graphs. (The answers are given below to make it clear what you're looking for.)

They are both straight lines.   Free answer just to get you started!

3. What is different about the 2 graphs?

Graph IA1b has a steeper slope.   Free answer!

4. What does the **slope** of a position-time graph indicate about the motion of the cart?

Velocity (both speed and direction)   Last free answer! You're on your own now.

Some might say that questions like "what's similar?" are a bit vague. But there are properties of **graphs** like their curvature, slope including +/- sign, steepness or levelness, minimum, maximum, etc., that we use to describe them. Likewise there are terms describing **motion** such as speed, at rest, speeding up, etc. The key here is that the shape of the graph is analogous to the motion. These corresponding descriptions of graphs and motion are what this lab is about.

From here on you'll be producing you own graphs. When you're instructed to "draw" or "sketch" a graph you should hand draw it on the graph grid provided. In your hand-drawn sketches omit the parts of the graphs that occurred before and after the actual motion of interest as described in the graph captions. And be sure to use the correct time interval. You may leave in the extraneous part of the graphs in your image printouts. (We don't have a way of editing them at this time.)

Your analysis – answers to questions, etc. – should deal only with the significant parts of the graphs.

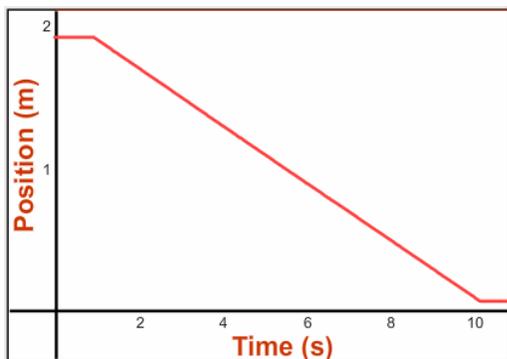### IB. Motion toward the motion sensor

We'll now repeat part IA, but this time the cart will start at the right end and move to the left. (Use a negative V_o.)

1a. Launch the cart at -20 cm/s.

Take a screenshot of the graph produced by the apparatus, save it locally as "Vel_IB1a.png", print it out, and attach it in the spaced provided below.

1b. Repeat with another trial at -50 cm/s. Save your screenshot as "Vel_IB1b.png", print it out, and attach it below.

IB1a. Cart moves slowly toward the motion sensor

IB1b. Cart moves quickly toward the motion sensor
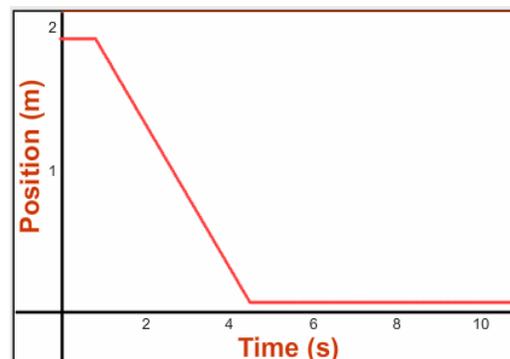
2. What is similar about the 2 graphs? (IB1a and IB1b.)

_____

3. What is different about the 2 graphs?

_____

4. Look at the graphs in part IA and the corresponding graphs in part IB. What attribute of a position-time graph indicates the direction of motion? Explain how this works for motion in each direction.

_____

_____

_____

Creating Prediction Graphs for printing

In the objectives of this lab it was stated that one goal was to learn to look at a graph and describe the motion that it represents. That's why we say that a graph can be used as model of a motion. Similarly you need to be able to do the reverse – look at a motion and sketch a graph that describes that motion. You can then check your prediction using the graph produced by the Dynamics Track. It doesn't matter so much if your prediction is correct or incorrect. What's important is that you have a clearly reasoned prediction that you can check against the experimental result. That's where the learning happens.

For example, suppose you said "ok, the cart starts out sitting still for two seconds, so nothing should appear on the graph during that time." When you look at the graph that's created on screen you'd see that there was a horizontal line during that time and it's located a height on the graph corresponding to the position of the cart when it was sitting still. That information tells you how to correct your original thinking. Without that original thinking, there may be no lesson learned.

After you make your sketches in your lab document you may be asked to use the Sketch Graph tool to create an on-screen sketch. You'll be asked to do this so that you can then take a Screenshot of the sketch to print out. We'll try that in a moment.
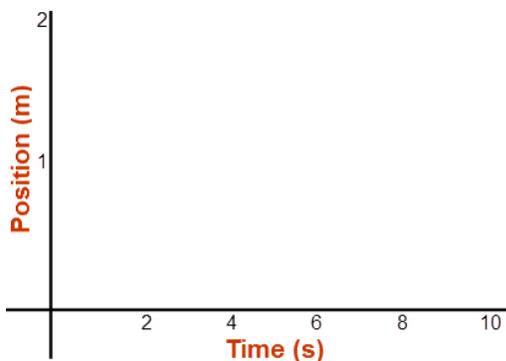
IC. Making Prediction Graphs

Please step away from the cart… The label of the next graph is **… Prediction…** You can't make a prediction graph *after* seeing the graph generated by the apparatus. Instead you'll do everything **except start the sensor** and then create a prediction of what the graph of the observed motion would look like. So follow instructions a-c **without using the sensor**. Then use the numbered instructions that follow to create your graph sketch on the grid provided (IC1a).

   a.   Set the Recoil to .3. Set V_o to 50 cm/s. Place the cart at the left end of the track.

   b.   (Do not use the sensor here until #6.) Let the cart sit still for two seconds.

   c.   Launch the cart. (Go→) Let it continue until the ten seconds run out. Stop the sensor.

These instructions should help you think about how to draw a graph based on a motion you're observing.

1.   Instruction (b) said to let the cart sit still at the left end for 2 seconds. What would that look like on an *x-t* graph?

   As you discovered earlier, when the cart is at the left bumper, its position, *x* is about .075 m. Just below .1 m.

   So it's at about .1 m at $t = 0$. And it's still there at $t = 2$ s.

   Draw a point on graph IC1a at ($t = 0$ s, $x = .1$ m)

   Repeat for (2 s, .1 m)

   What would go between those two points? Lots of points = one line. Draw a line between the two points.

2.   Instruction (c) says "Launch the cart."

   How long should it take the cart to reach the right end of the track? It travels about 2 m at 50 cm/s. That's 4 seconds.

   So it's at a bit less than 2 m (1.925 m) at 6 sec. Draw a point at about (6 s, 2 m)

3.   What goes between the points at 2 and 6 seconds? From IA you know what a constant positive velocity looks like on a graph, so add that.

4.   It's going to bounce back off the right end and then travel until the ten seconds run out. Its speed will be slower because of the .3 recoil. You know what a negative velocity looks like from 1B. Go ahead and add that to your graph. Just guess at the slope.

IC1a. **Prediction**: Still, Away quickly, bounce back slowly, stop	IC1b. **Observation**: Still, Away quickly, bounce back slowly, stop

5.   Now that you've hand drawn your sketch you need to draw it on the lab screen to print out. You should be able to recreate your sketch using the Sketch tool discussed earlier.

   •   Click "Sketch" in the Dynamics Track. Whoa! Big change. You have an extra, editable graph now.

- Drag the black box on the right downward to move the *x*-axis to a position near the bottom of the graph.
- Edit the axis labels and number ranges to match the built in position-time graph below it. Then use the first two sketching tools – the dot ⬚ and the line ⬚ to reproduce your prediction graph.
- Use the Screenshot tool to capture the onscreen sketch and save it locally as "Vel_IC1a.png", print it out, and attach it in the space provided.

6. It would be nice to do a real trial now and compare. Fortunately when you "Exit Graph" you don't lose your drawing. Click the Exit Graph button and set up the initial conditions. Follow instructions a – c; this time using the sensor.

7. Click Sketch Graph again and voila! Both graphs appear together. How'd you do?

8. Sketch your actual observed graph in Graph IC1b.

9. Use the techniques you followed above using Sketch Graph to create and save "Vel_IC1b.png". Don't start from scratch. It should just be a minor edit of what you did for Vel_IC1a.png. Print out your figure and attach it above.

10. Use "Copy Data to Clipboard," and create a position vs. time graph with it in Grapher.

11. What about the motion does a horizontal segment on a position, time graph indicate?

_____

12. What does the Recoil of .3 mean? Be specific. You'll need to analyze the data to find the velocities (slopes) like you did with the M-graph.

_____

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ID. Interpreting a Graph

Let's see how much skill you've developed in relating the motion of an object and its *x-t* graph.

1. Describe the motions that would produce the graphs shown below. Be sure to discuss relative speeds (how fast or slow relative to one another) and directions (right or left.) For example, your answer might (incorrectly) read – "starts out fast to the right, stops, continues faster to the right, stops, reverses direction and goes to the left at the same speed as in the first segment." (Note that brevity is OK here.)
You should have a statement for each of the five line segments on each graph.

If you'd like some confirmation of your answers, try the lab's "Match Graphs" tool with graphs 7 and 8. When you select that tool, the graph appears and the little red ball will rise and fall on the position axis as you drag the cart from side to side. Just pick a graph, drag the cart until it's at the position where your graph starts and then turn on the sensor. Then drag the cart to try to keep the line tracing the pre-drawn graph. It's hilarious. Using $T_{max} = 25$ is a good idea. It's very challenging, but if you do it perfectly you might win a fabulous plush toy. Probably not though.
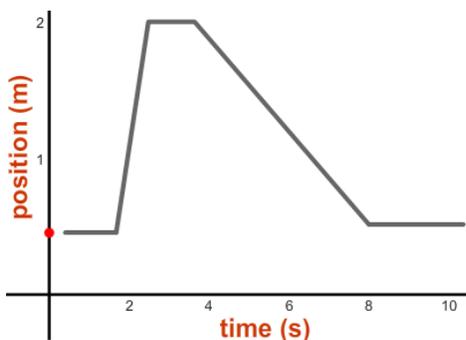
1a. _____

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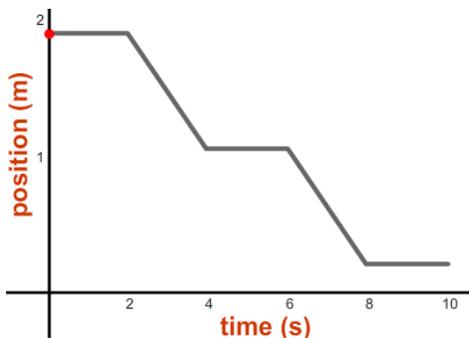
1b. _____

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_____

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_____

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II. VELOCITY

We've seen that our *x-t* graph is an analog, a model, of the motion itself. But, there's more. The graph contains the data necessary to create the corresponding velocity vs. time graph. We'll explore that now.

IIA. Motion away from and then toward the motion sensor:

Looking back at part IA we see that the cart moved slowly (IA1a), and then quickly (IA1b), away from the motion sensor. In part IB they did the same but toward the sensor. We'll now create velocity-time graphs for these motions.

1. Set Recoil to 0. Recreate your first position-time graph by launching the cart with an initial velocity of 20 cm/s. Be sure to start quickly enough so that there is a horizontal section on both ends of the graph. One way to do that is to use the delay clock. ⏱ Try it. It works like the Go→ button except there's a 5 second delay before launch. If you click this button and wait until the clock is at about 11 o'clock and then turn on the sensor you'll have what you need.

2. Using the Sketch Graph tool, create a velocity vs. time graph that looks like Graph IIA below. The dots are inserted to help you read the velocity scale. They're located at approximately at ±.6, ±.3, and 0. Be sure to include them. You'll use the Sketch tool and this *v-t* graph for the rest of this section.

3. Look at your just-created *x-t* graph to see the time when the cart started moving. You know that the velocity is .2 m/s at this time. Put a dot on the *v-t* graph representing the velocity at the time when the cart starts moving. That would be at (your start time, .2 m/s.) Add another dot for the last time when the cart is moving at .2 m/s just before it hits the bumper.

4. What about the velocity between these two times? If the velocity is constant, then you'd have a succession of dots between your initial and final dots. A.k.a., a line. Add a horizontal line to indicate the cart's motion at a constant .2 m/s.

   We'll find the velocity line for 50 cm/s a different way.

   - With the dynamics track, launch the cart at 50 cm/s from the left end just as you did previously with 20 cm/s.
   - Copy Data to Clipboard.
   - Paste the data into Grapher as before using the Ctrl+V technique.
   - Check the box for Graph #2 to display it.
     Click the Manual scale button on the top graph. Adjust its graph scales to 8, 0, 2.0, and 0. Submit and Close.
     Click the Manual scale button on the bottom graph. Adjust its graph scales to 8, 0, .6, and -.6. Submit and Close.
     Label the axes appropriately for velocity vs. time, including units.

   Both of these graphs hold the value of the cart's velocity. Here's how to find it. We could use any time interval but let's use an approximately 2-second interval to examine each graph. Perhaps from 2 to 4 seconds, or 2.5 to 4.5 seconds. Just pick one. I'll use 2 to 4 seconds in my example.

   a) In the *x-t* graph, click anywhere along the vertical graph grid line at 2 seconds. Drag to the right until you reach the 4 second line and release the mouse button. Click the linear fit check box. This will produce a straight line and populate the data box.

    b) Do the same thing for the v- t graph except this time click the "Stats" checkbox. This will populate the Stats data box. Roll over (put your pointer in) the top graph and check the slope of that graph in the Linear Fit data box. Then roll over the bottom graph and note the mean value of that graph in the Stats box. They should both say approximately .50. The slope of the *x-t* graph, $\Delta x/\Delta t$, is ~.50, the average velocity. The average *value* of the *v-t* graph, ~.50, is the average for what is plotted for our 2-second interval on that graph, also the velocity.

5. The **slope** of the position-time graph, including its sign, and the **mean value** of the velocity-time graph, (the height of the line), including its sign are both measures of

_____

6. Note that the line on the *v-t* graph in Grapher is just what you need to add to Graph IIA that you're building with Sketch Graph. Be sure to draw this line for the same time interval as the one in the Grapher graph. This should be more than 2 seconds. A bit less than 4 seconds.

Now for the trip back to the left.

7. Repeat the necessary steps above to create the third graph line using -20 cm/s. Use the slope of the position-time graph.

8. Repeat the necessary steps above to create the fourth graph line using -50 cm/s. Use the mean value of the velocity-time graph.

9. Take a Screenshot of the four line graph, save it as "Vel_IIA.png", print it out, and attach it below.

  IIA. **Observations:** Slow away, fast away; slow toward, fast toward

10. What is similar about the 4 graphs? (Not the motions, the graphs.)

_____

_____

11. What is different about the graphs for 20 cm/s and 50 cm/s (other than their lengths)?

_____

_____

12. What about the motion does a horizontal segment on a velocity-time graph indicate?

_____

13. What about the motion does the height of a horizontal straight-line *v-t* graph indicate? _____

14. How is the direction of motion indicated by a velocity-time graph?

_____

_____

IIB. There and back again: From velocity to displacement

So we've found that we can determine the velocity of the cart from the slope of the position-time graph or the height of the velocity-time graph. Let's see what the velocity-time graph can tell us about the displacement, Δx. We'll use a motion similar to what we used in part IC.

1. Set V_o to 80 cm/s, set the Recoil to .5, and move the cart to the left end.

    Using the delay clock to help you start the timer right before you launch the cart, run a few trials. We want the cart to reach the right bumper before $t = 4$ s. It should then bounce back and reach the left bumper well before the ten second clock expires. We're only interested in this trip over and back. See Figure 4. (The x and y-axis numbering may not be the same. That's OK.)

2. Once you have a good run, Copy Data to Clipboard and use Ctrl-V to create an x-t graph with Grapher. You should have something shaped like Figure 4a, but it might be shifted to the right or left.

3. If Graph #2, the v-t graph, is not displayed, click its check box to display it. Adjust your graph scales to (10, 0, 2, 0) for the x-t graph and (10, 0, 1, -1) for the v-t graph. Label the axes, including units. We now want to use the velocity-time graph can tell us about the displacement, Δx.

The Examine tool: If you turn on "Examine" and move your pointer over a point such as the + sign in the x-t graph in Grapher you'll see some numbers appear in the Examine data box. E.g. (1.152, 0.795). These numbers represent the (time, position) at a given point. That is, 1.152 seconds after the sensor started, the cart was at 0.795 m.

4. Three points, 1-3, have been added to the figure. Using the Examine tool just described, find the (t, x) values for each point.

    pt. 1: $t_1 = $ _____ s $x_1 = $ _____ m

    pt. 2: $t_2 = $ _____ s $x_2 = $ _____ m

    pt. 3: $t_3 = $ _____ s $x_3 = $ _____ m
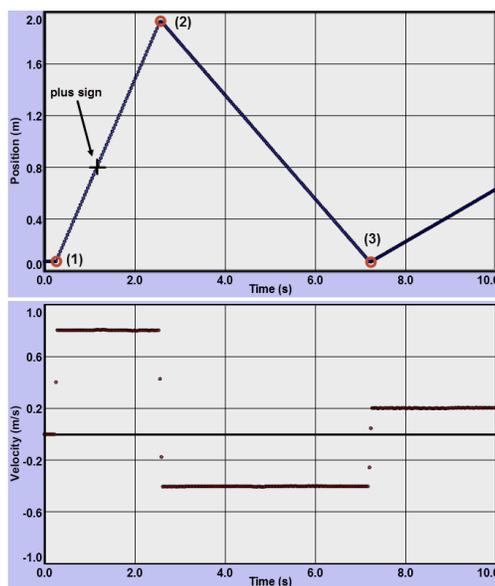
Figures 4a (x-t) and 4b (v-t)

5. Using this data from the x-t graph, calculate the displacement of the cart for the three intervals listed and enter them in the table below. Be sure to include signs. You'll do v-t later.

	Displacement from x-t graph	Displacement from v-t graph
from pt. 1 to pt. 2 by $\Delta x_{1\text{-}2} = x_2 - x_1 =$	_____ m	_____ m
from pt. 2 to pt. 3 by $\Delta x_{2\text{-}3} = x_3 - x_2 =$	_____ m	_____ m
from pt. 1 to pt. 3 by $\Delta x_{1\text{-}3} = x_3 - x_1 =$	_____ m	_____ m

That's all very nice but we were promised that the velocity graph would produce these displacements for us. You should have found the displacement from point 1 to point 2 to be approximately equal to the displacement from point 2 to point 3 but with opposite signs. And you should have found the displacement from point 1 to point 3 to be approximately equal to zero.

This is logical since the distance from bumper to bumper is the same both ways. And the displacement is equal to the distance except the displacement for the trip back is negative to reflect the motion in the negative direction. Likewise the

overall displacement is zero since that's the distance from the starting point to the starting point. It's also the sum of two equal but oppositely directed displacements.

So what is there in the *v-t* graph that tells this same story? Click, without dragging, in the *v-t* graph in Grapher. Then click the Integrate checkbox. The *integral* is another calculus term that "just" means the area under a graph in this case.

The area between the graph and the time axis of each graph is highlighted in blue. We're just interested in the *v-t* graph.

With the Examine tool on, as you move your mouse pointer across the *v-t* graph you'll see each point highlighted with a circle. Click on any point and drag and then release at another. Only that area will now be highlighted in blue. In the integrate data box you'll see a number which is equal to the integral, the area under the graph you've just selected. The units of that measurement are the product of the units of each axis – m/s × s which equals meters. So the area you selected is actually equal to the displacement, Δx, during the time interval you selected.

6. Select an area under a section of the first horizontal line on the *v-t* graph. Note the area, Δx in the integrate data box. Repeat for a section under the second horizontal line. There is something different about the two values that is very significant. What is it and what does this difference represent about each of your chosen displacements?

_____

_____

_____

7. So the total displacement for the first horizontal line should match the value of $x_2 - x_1$ in your data table in #5. Try it. You'll have to make a judgment call about your choice of your first and last points. Using the lone dots between the velocity axis and the horizontal line are a good bet. Record the displacement value from the data box as the first entry under *v-t* graph in #5 above. Both values for $x_2 - x_1$ should be about the same.

Why does the change in height of the *x-t* graph, $x_2 - x_1$, equal the area under the *v-t* graph? For a constant velocity it's pretty easy to see. The height of the *v-t* graph is the velocity. The width of it is $t_2 - t_1 = \Delta t$. So the area is

$$\text{Area under a } v\text{-}t \text{ graph: } \Delta x = v_{avg} \, \Delta t = v_{const.} \, \Delta t$$

As we'll see in an upcoming lab that it even works with a non-constant velocity.

8. Go ahead and fill in the other two blanks in #5.

The second displacement $x_3 - x_2$ is the displacement in the negative directions, thus the negative area.

The third displacement $x_3 - x_1$ is the total displacement for the trip over and back. So it has approximately zero area.

9. One last thing. Look back at the fourth bullet in the Purpose section. Why are we finding, Δx? Why not just x? Suppose our track was actually one meter longer. And suppose we moved our starting point one meter to the right. All our position data would be increased by one meter. The *x-t* graph would be one meter taller and all the lines would move one meter higher on the graph.

But our *v-t* graph would be unaffected since it's based on the slopes which are found from $\Delta x/\Delta t$. And Δx doesn't reflect position, only change in position. A rise from 1 m to 2 m is indistinguishable from 2 m to 3 m. So our velocity graph can just allow us to calculate changes in positions, that is, displacements, not actual positions.

It's the same with our equation $\Delta x = x_f - x_o = v_{avg} \, t$

With v_{avg} and t we can find how far we've been displaced, but without knowing where we started, x_o, we can't find out where we are, x_f.

So to find out our actual position we'd use $x_f = x_o + V_{avg} \, \Delta t$.

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