**Graphing Motion: Match the Graph**

**Background**

Velocity is defined as a change in position per time. If an object is not moving, then the velocity is zero. However, if the object is moving, then it has a non-zero velocity. If we remember that the “delta” symbol, Δ, means “change” then we write the velocity as



In fact, the velocity is actually defined as the derivative, or



Even if you don’t know calculus, the most important to realize is that the *derivative* relates to the *slope*. That means that if you look at a position versus time graph, the velocity is the slope of that graph at any point. If the graph has a constant slope like the one shown in Figure A, it means that the velocity is constant. If it has a changing slope, like the example in Figure B, it means that the velocity is changing.

|  |  |
| --- | --- |
|  |  |
| Figure A: Constant Velocity | Figure B: Changing Velocity |

Similarly, acceleration is defined as a change in velocity per time. If the velocity is not changing, then the acceleration is zero. However, if the object has a changing velocity, then it has a non-zero acceleration.



And just like the velocity is really a derivative, so is the acceleration.



And again, it means that if you look at a velocity versus time graph, the acceleration is the slope of that graph at any point. If the graph has a constant slope, it means that the acceleration is constant. If it has a changing slope, it means that the acceleration is changing.

**Goal:** To use what you’ve learned about the shapes of position, velocity, and acceleration versus time graphs and kinesthetically create the motion that makes certain graphs.

**Creating the Graphs**

Our goal for today is to explore what graphs of motion really mean. You’ll be doing kinesthetic activities that require you to move in a pattern that re-creates the graph – which should help you associate the graph with what the motion really looks like.

To create the graphs, you will need a motion sensor and an individual-sized white board (to serve as the object that the sensor detects).

* First, set up a new Capstone Experiment. To do this, open the PASCO Capstone program from the Desktop. When you open the program, it will prompt you to create a new experiment. For this lab, we want to create a graph, so you can choose the “*Table & Graph"* option.
* Next, add the Motion Sensor to the program. Do this by clicking the “*Hardware Setup*” icon at the top of the left vertical tool bar. When you open this tool, you should see an image of the 850 Interface that is on your table. Plug your motion sensor into the interface first. Then, go back to the image of the interface in the Capstone program and click on the part of the image that matches where you plugged the sensor in. This should pull up a list of possible sensors - choose “*Motion Sensor II”* from that list. You should now see an image of the sensor attached to the interface in the Capstone program.
  + *Note: this process of creating an experiment and adding sensors is one that we will do repeatedly in Physics lab. Make sure you learn how to do it, and feel free to go back and practice these steps a few times.*
* Now that the sensor is attached, you can choose what variables you want on your graph. Do this by clicking on the “Select Measurement” button on each axis of the graph. From there, you will see a list of physical quantities that the sensor is able to measure for you. For each of the nine graphs below, adjust the variables on the axes appropriately.

For each graph below, move your body in a pattern that allows you to create a graph with the same shape. To begin collecting data, hit the “Record” button at the bottom of the screen. Then, simply hit “Stop” when you are finished. When you’ve figured out how to match the graph, explain the motion that made it possible. If you don’t like the data you recorded, you can delete it using the “Delete Last Run” button at the bottom of the screen. *Note: it is more important to get the correct shape than to worry about the exact values of time or distance/velocity.*

|  |  |  |  |
| --- | --- | --- | --- |
| **Graph** | **Description of Motion** | **Graph** | **Description of Motion** |
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You learned in the *Graphing Motion: Match the Graph* lab that position, velocity and acceleration are interconnected, can be graphed, and represent real physical motions. In this activity, you’ll practice interpreting both position vs. time and velocity vs. time graphs.

**Position vs. Time Graphs**

Answer the questions about the graphs shown

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **A** |  | **B** |  | **C** |  | **D** |  |
| **E** |  | **F** |  | **G** |  | **H** |  |

Which graph(s) show  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show positive velocity? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show negative velocity? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show increasing velocity? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Remember -6 < 2.

Which graph(s) show decreasing velocity? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Velocity vs. Time Graphs**

Answer the questions about the graphs shown

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **A** |  | **B** |  | **C** |  | **D** |  |
| **E** |  | **F** |  | **G** |  | **H** |  |

Which graph(s) show  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show positive acceleration? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show negative acceleration? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show increasing acceleration? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Which graph(s) show decreasing acceleration \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Catch the Speeder[[1]](#footnote-1)\***

**Background**

Consider this: you are a highway patrol person, parked along the road. A speeder passes you while moving at a constant velocity. You immediately pursue the speeder, accelerating at a constant rate. When and where do you catch the speeder?!

In fact, most objects in motion around us are at times accelerating and at other times traveling at a constant velocity. But what if you had to choose between the two? Which would you choose to run a faster race: constant velocity or constant acceleration?

This lab will build on the information you learned in the *Match the Graph* activity to help you apply motion graphs to real world situations.

**Goal:** To compare the difference between constant velocity and constant acceleration, using position-time graphs. Also, to determine where two moving objects will “catch” each other.

* Think about this: what does it mean to “catch” something? What physical parameters (time, position, velocity, acceleration, etc.) must be the same for this to happen?

**Speeder and Patrol Car - Data Collection and Analysis**

For this experiment, set up a PASCO track and use a motion sensor to collect data. The speeder is traveling at a constant speed, so it will be represented by a constant velocity cart. The patrol car is accelerating, so it will be represented by a PAScar that has a fan attached.

* Start by setting up the Capstone program. Make sure that the 850 Interface is connected. Plug the motion sensor into the Interface and also add it to the Capstone program. Attach the motion sensor to the track by sliding it on to the open end. Add a graph of position versus time and also a graph of velocity versus time. You can add graphs to the display by clicking on the *Graph* icon on the right and dragging it into your display area.
* Place the back of the motorized car (the speeder) at the 10cm mark on the track. ***Adjust the speed of the cart to a medium setting***. Click the record button to start collecting data, then start the car.
* Now, place the back of the fan cart (the patrol car) at the 30cm mark on the track. Start the fan and hold the cart still. Click the record button to start collecting data, hold the cart until the data lines cross and release the cart.

Note: as you hopefully realized above, the patrol car catches the speeder when they meet *in the same place* and *at the same time.* So, if we want to see the catch, the lines for the speeder and the patrol car must intersect on the position versus time graph. If your lines do not intersect, clear the data in the Capstone program, adjust the speed of the motorized cart, and run the experiment again. If you cannot see both data sets, click the “Select Visible Data” button on the tool bar above each graph (the icon is a multicolored triangle). Select the data sets from this menu that you want to appear on the graph - you must do this for each graph separately.

* Sketch the position vs. time graph and velocity vs. time graphs for both the motorized car (speeder) and the fan cart (patrol car).
* Explain the shape of each of these four lines. What does that tell you about the motion of each?
* Use the smart tools (such as the delta tool) to determine the time it takes for the patrol car to catch the speeder. Then, determine how far the patrol car travelled before catching the speeder.
* What is the velocity of the speeder? Explain your answer as well as how you determined it from the graphs.
* What is the acceleration of the speeder? Explain your answer as well as how you determined it from the graphs.
* What is the velocity of the patrol car at the time of the catch? Explain your answer as well as how you determined it from the graphs.
* What is the acceleration of the patrol car? Explain your answer as well as how you determined it from the graphs.

**Summary Questions**

* Compare the intersection of the lines on the position-time and velocity-time graphs. Is the time associated with these intersections the same? Explain.
* At the instant the patrol car catches the speeder, which variables are the same for both cars?
* When the patrol car catches the speeder, which has the greater velocity? Explain why your answer makes sense.

**Catch the Speeder**

**Follow Up Questions**

There are four ways to describe motion: words, tables of data, graphs of data, and motion diagrams

In the lab, you looked at position vs. time and velocity vs. time graphs, mimicked the motion to create a similar graph, and then described this motion with words. You also saw a table of this data created by the Capstone program.

Another way to describe motion is the motion diagrams - in a motion diagram, locations are plotted on a scaled line (or graph) at equal time increments. In this activity, you will draw two one-dimensional motion diagrams, calculate velocities, and calculate accelerations.

|  |  |
| --- | --- |
| x (m) | t (s) |
| 0.0 | 0.0 |
| 4.0 | 2.0 |
| 8.0 | 4.0 |
| 12.0 | 6.0 |
| 16.0 | 8.0 |
| 20.0 | 10.0 |

**Case #1**

A car is traveling eastward down a street. The table of data shown here lists the car’s position at certain times. The origin is a certain stop sign, and our stopwatch started when the car was at the stop sign. Follow these steps to create a motion diagram for the car.

1. Make an “*x*” on the line shown at each position from the table, and label it with the corresponding time.
2. The change in position can be written as , where  So, for each point, we can calculate a change in position. For the first point, the equation would be , the second would be , and so on. On a motion diagram, this change in position can be represented by an arrow that starts at the initial point and ends at the final point (those are the vectors!). Draw the  vector between each of the points below.
3. Velocity is defined as the change in position divided by the change in time, or  Using the same procedure as above, draw the velocity vectors below the position vectors. So,
4. Acceleration is defined as the change in velocity divided by the change in time, or  So, Using the same procedure as above, draw the acceleration vectors. If it is zero, write “”

0

20

15

10

5

Now, perform the calculations necessary to fill in the white/blank cells in the table below using the same data. (The shaded portions of the table cannot be completed - can you explain why?)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| **0.0** | **0.0** |  |  |  |  |
| **1.0** |  |  |  |  |  |
| **2.0** | **4.0** |  |  |  |  |
| **3.0** |  |  |  |  |  |
| **4.0** | **8.0** |  |  |  |  |
| **5.0** |  |  |  |  |  |
| **6.0** | **12.0** |  |  |  |  |
| **7.0** |  |  |  |  |  |
| **8.0** | **16.0** |  |  |  |  |
| **9.0** |  |  |  |  |  |
| **10.0** | **20.0** |  |  |  |  |

Do the numerical answers that you found in the table above correspond to the lengths of the arrows for change in position, velocity, and acceleration? Explain.

**Case #2**

|  |  |
| --- | --- |
| x (m) | t (s) |
| 0.0 | 0.0 |
| 4.0 | 2.0 |
| 12.0 | 4.0 |
| 24.0 | 6.0 |
| 40.0 | 8.0 |
| 60.0 | 10.0 |

A different car is also traveling eastward down a street, but the table of data for this car is different, as is the scale on the associated motion diagram. Follow the steps in Case #1 to create a motion diagram for this car.

0

20

10

30

40

50

60

Now, perform the calculations necessary to fill in the white/blank cells in the table below using the same data. (The shaded portions of the table cannot be completed - can you explain why?)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| **0.0** | **0.0** |  |  |  |  |
| **1.0** |  |  |  |  |  |
| **2.0** | **4.0** |  |  |  |  |
| **3.0** |  |  |  |  |  |
| **4.0** | **12.0** |  |  |  |  |
| **5.0** |  |  |  |  |  |
| **6.0** | **24.0** |  |  |  |  |
| **7.0** |  |  |  |  |  |
| **8.0** | **40.0** |  |  |  |  |
| **9.0** |  |  |  |  |  |
| **10.0** | **60.0** |  |  |  |  |

Do the numerical answers that you found in the table above correspond to the lengths of the arrows for change in position, velocity, and acceleration? Explain.

Which motion diagram would best represent the speeding car in the *Catch the Speeder* activity? Which motion diagram would best represent the patrol car? Explain your reasoning.

1. \* Adapted from a *ScienceWorkshop500* lab by PASCO, Inc. [↑](#footnote-ref-1)