

POSITION, VELOCITY AND ACCELERATION

More and more, science is done using computers to make measurements and to process and understand data. Most of the modern diagnostic medicine is done in a way not too different from the type of equipment and experiment that we will see in today's lab. The basic plan is that we have a special sensor or measuring device that takes data and sends it to a computer to be processed graphically, quickly, and accurately. Almost always there is device called an interface that goes between the sensor and the computer. The graphs recorded in this lab using a computer, interface and a sensor are representation of different motions and are important that you learn how to interpret them. The physical interpretation of any graphs is important to wide career range in medicine, science, and industry.

Learning how to take data in this way includes:

- Learning how to use the “Data Studio” software that processes the data.
- Learning how to connect the computer, the interface, and the sensor.
- Learning some techniques to acquire the specific physical event you want to study.
- Learn how to fit experimental data to simple curves (straight line or parabola).

Enjoy!

This lab uses PASCO equipment and “Data Studio” software in order to introduce the concepts of position, velocity and acceleration, and investigate the relationships among these physical quantities.

Equipment (Figure 1)

- 1) **Motion sensor**, which is nothing more than a loud speaker, able to send out and receive *ultrasounds* (sounds with a very high pitch that cannot be heard by humans, although bats, dogs, dolphins and whales are some examples of animals very sensitive to ultrasounds). The ultrasound beam bounces off a target and returns to the motion sensor. The time it takes for an ultrasound beam to reach the target object and return is used to gauge the distance to the object. The motion sensor is the origin from which the distances are measured and the direction from the detector to the object is, by convention, positive.
- 2) **The 750 PASCO interface** allows different sensors to communicate with a computer. The interface also needs a power source and a USB cable in order to connect to a computer.
- 3) **Computer running the “Data Studio” software** that controls the interface and allows users to record data received from sensors. For example, the software tells the interface when to start/stop sending the ultrasonic package, receives and interprets the electric signal generated by the motion sensor, measures the round-trip time between the moment the original ultrasound package was sent and the moment the echo was received, converts round-trip time into a distance by multiplying it with the speed of ultrasounds in air, records the time the ultrasound signal was sent and the distance to the target into a data table, plots the distance versus time, determines the speed of the target or its acceleration, etc.

Note: Since the motion sensors can capture ultrasounds from every source, including from your colleagues' motion sensors it is recommended that you leave enough space between different teams in order to avoid spurious results. In extreme circumstances (small classroom space), only one experiment will be performed and the graphs of position versus time, etc. will be projected upon a screen.

1a. Simple position versus time graphs

Objective

Investigate the relationship between the graph of the position versus time and the motion it represents.

General procedure for setting up an experiment

Hardware

1. Connect the power source to the PASCO interface and turn the interface on.
2. Connect the USB cable from the interface to the computer and turn the computer on.
3. Plug in the motion sensor in the two leftmost positions: jack #1 for yellow cable and jack #2 for black cable, according to Fig. 1. The interface and the software should automatically detect that the motion sensor was connected.

Software

- 1) Open “Data Studio” software (on Windows machines click on Start icon and browse through the programs listed until you find “Data Studio”, then click on its icon).
- 2) Click on “Create new experiment” icon to start your lab experiment. At this time you should see three separate panels:
 - a) “Experimental setup” containing a picture of the interface.
 - b) “Data” window that will collect your experimental data (to the left of the “Experimental setup” window).
 - c) “Displays” panel that will allow you to visualize the experimental data.
- 3) In order to tell the interface what kind of sensor is attached, click on the “Add Sensors and Instruments” button shown in “Experimental setup” panel, select the appropriate sensor (in this case the motion detector sensor) from the list provided, and drag-and-drop it over the picture of the interface (it will automatically connect to the correct ports).

Data acquisition and visualization

- 1) Before clicking the “Start” button to record data, select how the experimental data will be displayed. For this purpose, drag the data icon called “Position” from “Data” window and releases it on top of the appropriate display method from the “Displays” panel. For example, you could drop data collected under the “Position” icon on top of “Table” and, as a result, “Data Studio” will display the table of position and time. The table could be then export and plot using software or plotted on graph paper. However, “Data Studio” can plot the graph for you if you drop the data collected on top of the “Graph” icon under the “Displays” menu.
- 2) You are now ready to record data by clicking on the “Start” button. You can check to see if the sensor is connected and working by waving your hand in front of it. If the motion sensor works, an oscillatory graph should appear on your computer screen and you should hear a clicking noise.

Note: Also review the step-by-step procedure detailed during “Measurements” lab for more in-depth information accompanied by pictures.

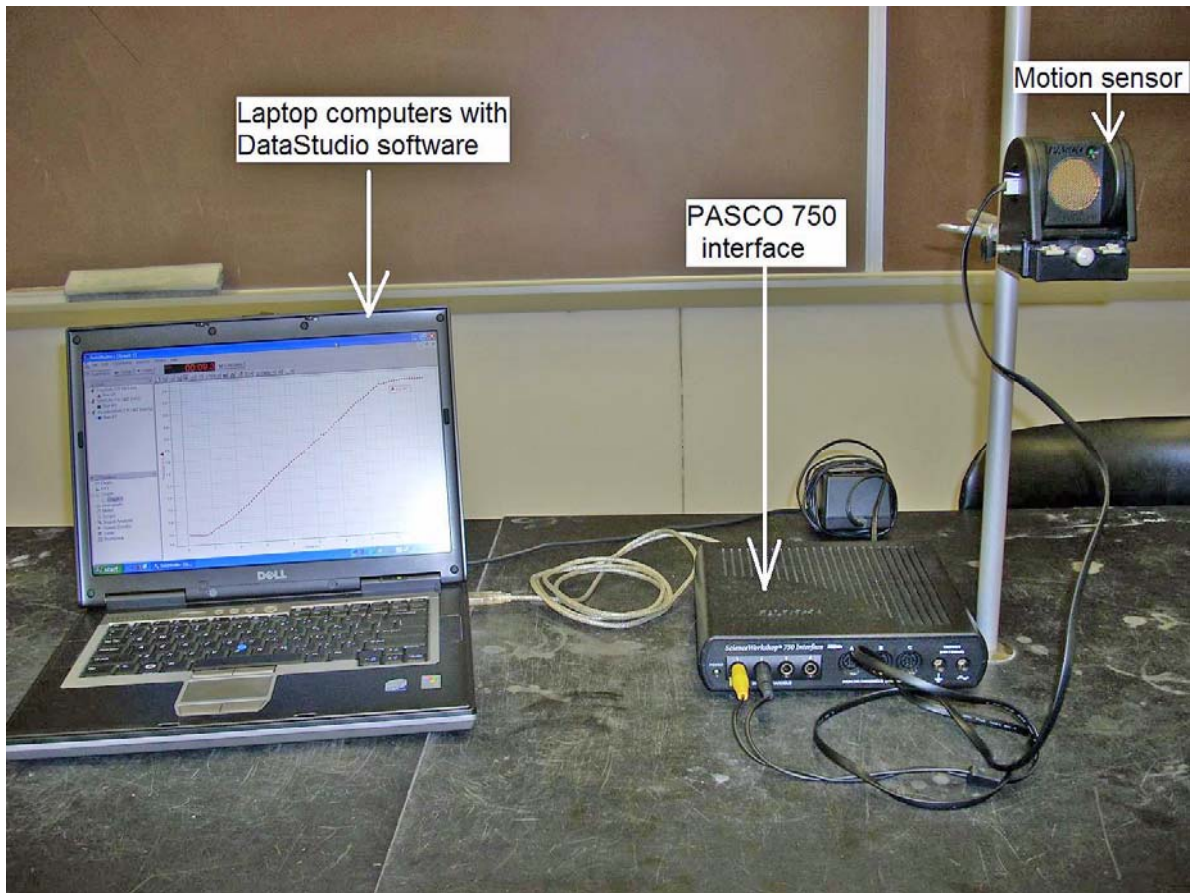


Figure 1. Experimental setup contains a laptop computer with DataStudio software for data acquisition, a PASCO 750 interface connected to computer via an USB cable, and a motion sensor connected to interface.

Position versus time recordings

In this part of the experiment, we are going to use this equipment to make a graph of you walking away from and towards the motion sensor.

- 1) This experiment will require two people. One person should take care of data collection (click on the “Start/Stop” button). The second person is the moving “target” and should walk slowly and steadily *away* from the motion sensor at a constant speed. Make sure that the small switch on top of the motion sensor is set on the long-range scale (read instruction on the back of the motion sensor). The person, who walks should start at about $\frac{1}{2}$ m from the motion sensor, and should be careful not to swing his/her, arms (pretty much walking like a robot).
- 2) Sketch the position versus time graph in the corresponding box of Fig. 2A and repeat the experiment if necessary. Show the appropriate values for position and velocity on your graph.

Your drawing should be accurate. Be sure to draw horizontal and vertical scales and copy the correct value for each point on the graph. Do not blindly trust your graphs that are shown on your computer screen. Make sure you understand the meaning of each graphs and you should discuss these graphs with your team members before you copy it in your report.

- 3) Repeat the above two steps with the student moving steadily *away* at a moderately fast pace and at a constant speed. Record your graph in the corresponding box of Fig. 2B.
Note: You have two options at this time:
 - i. Record the new data on the same graph, which we recommend for this experiment. For this purpose, drag the second set of recorded data on top of the previous graph.
 - ii. Record the new data on different graphs by dragging the data on top of the “Graph” option. This action will clear the previous plot.
- 4) Perform two more experiments with the student starting 3-4 m away from the motion detector. In one experiment, move *slowly towards* the motion sensor at a constant speed. In the second experiment, move *faster towards* the motion sensor at a constant speed.
- 5) Draw the two new graphs of position versus time in the appropriate panels of Fig. 2C and D.

Note: For Fig. 2, carefully copy from the computer screen each of the four graphs you obtained. They do not have to be perfect, but they should be qualitatively correct. It is also very important to copy the units from the “Data Studio” graphs.

Questions

1. Describe the difference between fast and slow motion based on recorded position versus time graphs (Fig. 2).

2. Describe the difference between positions versus time graphs representing motion towards/away from the motion sensor.

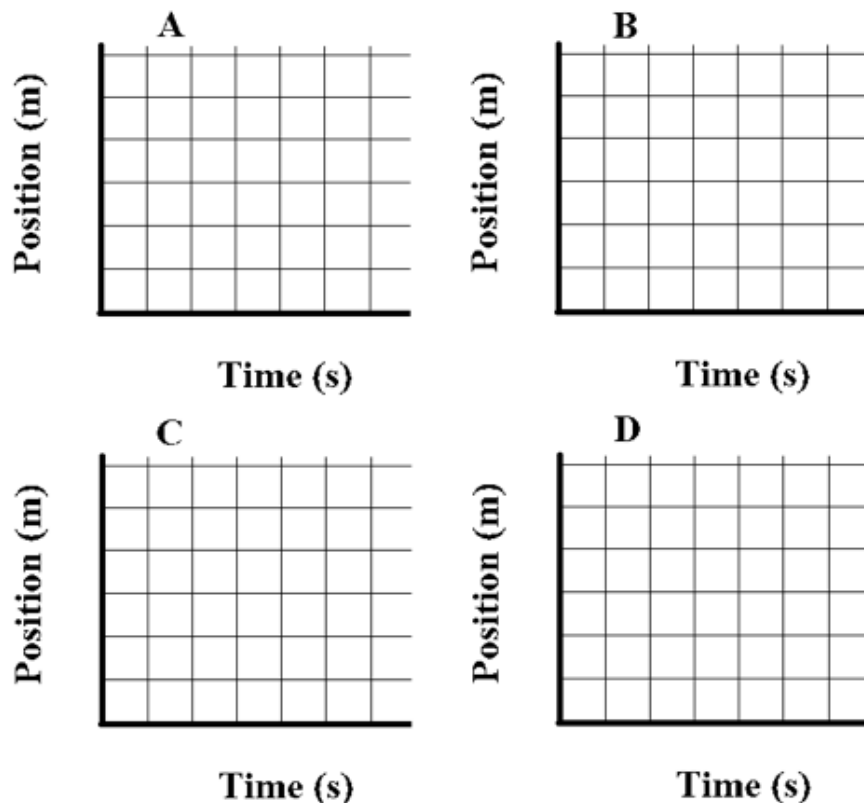


Figure 2. Sketches of position versus time graphs. (A) Walking *slowly* away from the motion sensor. (B) Walking *fast* away from the motion sensor. (C) Walking *slowly towards* the motion sensor. (D) Walking *fast towards* the motion sensor.

1b. More complicated motion

Here is the following scenario: a student *walks slowly away* from the motion sensor for about three seconds, *stands stills* for about three seconds, and then *walks towards* the motion sensor about twice as fast as before.

1. Before you do the actual experiment, try to figure in advance what is going to happen. To do that uses a dashed line to draw your prediction in the graph below.

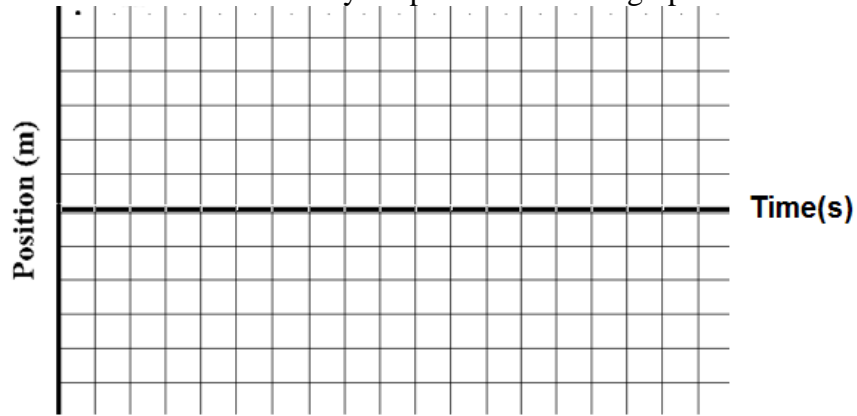


Figure 3. A complex motion of a target moving slowly away, standing still and moving fast toward the motion sensor. The dashed line represents the prediction and the continuous line is the actual recording.

2. Test your prediction by performing the motion described earlier. Collect your data and repeat the motion if necessary. Draw your graph in Fig. 3 using a continuous line and label the two curves “predicted” and “observed”.
3. Are the predicted and observed graphs essentially the same? Explain any major differences that have occurred such as-different slopes, different signs.

2a. Velocity versus time graph

Objective

Investigate the relationship between the graph of velocity versus time and the motion it represents.

In the previous sections, we represented the motion using a position versus time graph. An equivalent way of representing the motion is with a graph that describe how fast/slow, and in what direction an object moves, *i.e.*, a velocity versus time graph. Velocity is defined as the rate of change of position with respect to time. This quantity takes into account the speed (how fast) and also the direction of motion (away or towards the motion sensor).

Specific procedural steps for velocity versus time recordings

Data acquisition and visualization

1. Delete all previously collected data either by clearing each data record or closing all open experiments and starting a new one (review the “Software” and “Data acquisition and visualization” sections of the “General procedure for setting up an experiment” in section 1a).
2. From the “Data” panel drag the “Position” icon and release it on top of the “Graph” icon inside the “Displays” panel.
3. From the “Data” panel drag the “Velocity” icon and release it on top of the “Graph” icon inside the “Displays” panel. At this time, you should have two different empty panels: one for position versus time and the other for velocity versus time.
4. Repeat the four walking patterns that you performed in section 1a (walk slowly away, fast away, slowly towards, and fast towards the motion sensor) and collect your data. To adjust the scales such that the plots fill the entire panel you can change the horizontal/vertical scales by clicking on the numbers shown along the corresponding direction. Copy the graphs of position versus time and velocity versus time from your computer’s screen in the corresponding panels of Fig. 4.

Data analysis

For each of the four experiments do the following:

- 1) Select a region showing a clear linear ramp in the position versus time graph by holding the left button of the mouse and moving the cursor over the desired data range.
- 2) Click on “Fit” button shown on the top menu and select “Linear fit”. Among other information provided by a linear fit, the slope of the selected ramp of position versus time graph will give the *average velocity* over the time interval you selected.
- 3) On the corresponding velocity versus time graph, select the same time range and click on the Σ (“Statistics”) icon. Check only the mean and standard deviation from the drop-down menu. You should immediately see the *mean velocity* and its standard deviation for the time range you selected.
- 4) Compare the slope obtained from the position versus time graph (step 2 above) against the mean velocity from velocity versus time graph (step 3 above). Record the data below with units. How do they compare in each of the four cases shown in Fig. 4?

(A) slope of position vs. time graph: _____ average velocity: _____

(B) slope of position vs. time graph: _____ average velocity: _____

(C) slope of position vs. time graph: _____ average velocity: _____

(D) slope of position vs. time graph: _____ average velocity: _____

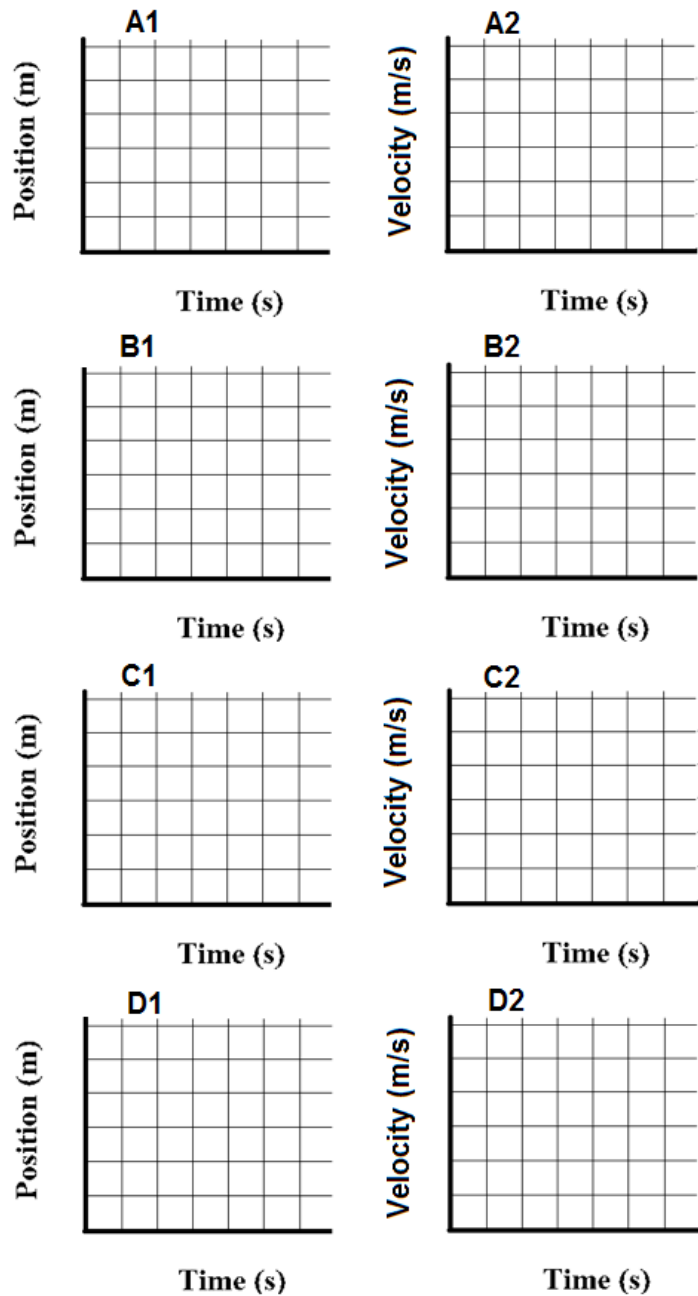


Figure 4. Sketches of the position and velocity versus time graphs. Carefully copy each graph that you obtained. They do not have to be perfect, but they should be qualitatively correct. It is also very important to copy the units from “Data Studio” graphs. (A) Walking slowly away from the motion sensor. (B) Walking quickly away from the motion sensor. (C) Walking slowly towards the motion sensor. (D) Walking fast towards the motion sensor.

Questions

1. What is the difference between velocity graphs representing slow motion and fast motion in the same direction?

2. How is the velocity versus time graphs different for the motion away and towards the motion sensor?

2b. Even more complicated motion

Here is the following scenario: a student starts about 3-4 m away from the motion sensor and walks slowly toward it for about three seconds, stands still for about three seconds, and then walks towards the motion sensor about twice as fast as before for another three seconds.

1. Using a dashed line draw your prediction in the graph below.

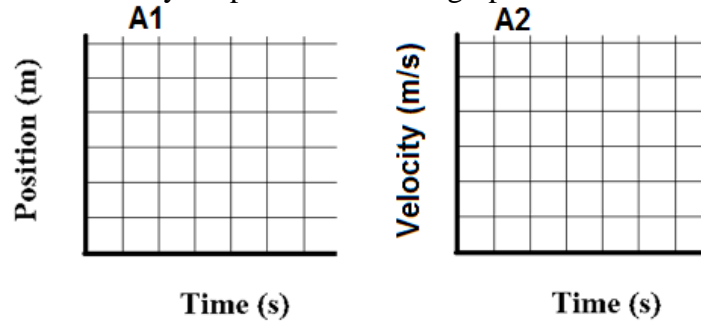


Figure 5. A complex motion of a “target” moving slowly away, standing still and moving fast towards the motion sensor. The dashed line represents the prediction and the continuous line is the actual recording.

2. Test your prediction by performing the motion described earlier. Collect your data and repeat the motion if necessary. Draw your graph using a continuous line.

3a. Acceleration versus time graph

Objective

Investigate the relationship between the graphs of the position, velocity, and acceleration versus time and the motion they represent, in the particular case of motion with constant acceleration.

In section 2a we represented the motion using position and velocity versus time graphs. We found that the slope of the position versus time graphs accurately represents the average velocity. Acceleration is defined as the rate of change of velocity with respect to time. This quantity takes into account how fast the speed changes and also the direction of motion (away or towards the motion sensor). The cart moved down the inclined track at a constant acceleration (see the experimental setup in Fig. 6). For this experiment, set a small angle for the track (less than 5 degrees).

Necessary materials

In addition to the motion sensor, PASCO interface and a computer, we need one PASCO track with end stoppers and one cart that can roll on the track without friction.

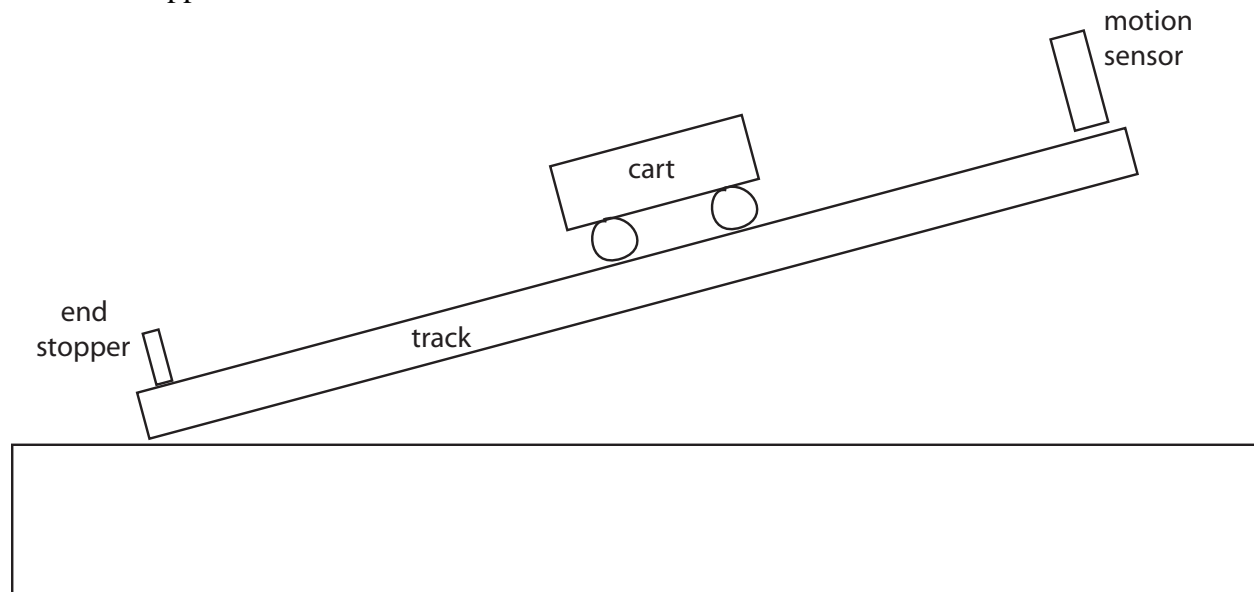


Figure 6. Motion with constant acceleration down the inclined track. The motion sensor records the position of the cart versus time and the software also computes the velocity and the acceleration of the cart.

Specific procedural steps for acceleration versus time recordings

Data acquisition and visualization

- 1) Delete all previously collected data either by clearing each data record or closing all open experiments and starting a new one (review the “Software” and “Data acquisition and visualization” sections of the “General procedure for setting up an experiment” in section 1a).
- 2) From the “Data” panel, drag the “Position”, “Velocity”, and “Acceleration” icon and release them, one by one, on top of the “Graph” icon inside the “Displays” panel.

- 3) Start recording the data and release the cart from rest about $\frac{1}{2}$ m from the motion sensor down the inclined track. Be sure to catch the cart before it hits the end stopper.
- 4) Carefully draw the graphs of position, velocity and acceleration versus time from your computer screen in the corresponding panels of Fig. 7.

Data analysis – the relationship between the rate of change of velocity and acceleration

- 1) Select a region showing a clear linear ramp in velocity versus time graph by holding the left button of the mouse and moving the cursor over the desired data range.
- 2) Click on the “Fit” button shown on the top menu and choose “Linear fit”. Among other information provided by a linear fit, the slope of the selected ramp of velocity versus time graph will give the *average acceleration* over the time interval you selected.
- 3) On the acceleration versus time graph, choose the same time range and click on the Σ (“Statistics”) icon. Check only the mean and standard deviation from the drop-down menu. Record the *mean velocity* and its standard deviation for the time range you selected.
- 4) Compare the slope obtained from velocity versus time graph (step 2 above) against the mean acceleration from acceleration versus time graph (step 3 above). What conclusion can you draw from such a comparison?

Slope of velocity vs. time graph (Fig 7B): _____
 average acceleration (Fig. 7C): _____

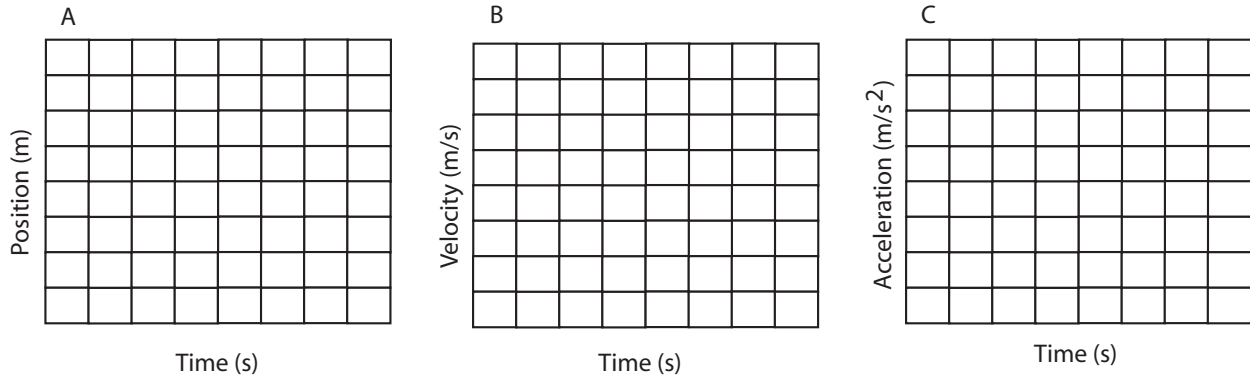


Figure 7. Sketches of position (A), velocity (B), and acceleration (C) versus time. Carefully copy each graph you obtained. They do not have to be perfect, but they should be qualitatively correct. It is also very important to copy the units from “Data Studio” graphs.

Question

Based on the information provided by the velocity and acceleration versus time graphs, predict the time evolution of position:

$$x = \text{_____} + \text{_____} t + \text{_____} *t^2$$

Hint: Select a region of the velocity versus time graph that starts immediately after the cart was released such that the initial velocity (v_i) is almost zero. Estimate the initial position (x_i) of the cart from Fig. 7A and also estimate the mean acceleration (a) for the time interval before the cart hits the end stopper from Fig. 7C. Theoretically, the position should be given by

$$x = x_i + v_i t + \frac{1}{2} a t^2.$$

Data analysis – the relationship between the position, velocity and acceleration graphs

- 5) Select the same time interval from the position versus time graph as before such that the corresponding velocity graph shows a clear linear ramp.
- 6) Click on the “Fit” button shown on the top menu and choose “Quadratic fit”. Record the parameters of the parabola and the goodness of the fit:

$$x = \text{_____} + \text{_____} t + \text{_____} *t^2$$

Finding the acceleration of gravity

Assuming there is no friction between the cart and the track, the acceleration of the cart is $a = g \sin \theta$, where g is the acceleration of gravity and θ is the angle of the inclined (Fig. 6). Use the acceleration measured above and the angle of the inclined to determine the acceleration of gravity, g . Is the estimation close to the accepted value of 9.81 m/s^2 ? What is the percent error?

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