Changing Velocity: An Introduction to Linear Acceleration

(completion time: approx. 2 h) (7/5/06)

Introduction

In addition to position and velocity, "acceleration" is often used to describe the motion of an object. In physics, "velocity" is understood to mean more than just the speed of an object. Velocity has direction as well as speed. (i.e. It is a "vector" quantity.) Since acceleration is defined as the time rate of change of the velocity, any change in either the direction or the speed (i.e. magnitude) of the velocity results in acceleration, which is also a vector. For linear (i.e. straight-line) motion, direction does not change, and the only change in velocity is the change in speed. When such motion is represented on a velocity vs. time graph, the slope of the line represents the total rate of change of velocity, and, therefore, the linear acceleration. In this lab we will be exploring linear acceleration and its relationship to changes in the velocity and the position.

Equipment

· motion sensor · Science Workshop interface · wood block
· cart (low friction) · Computer with DataStudio Software* · metal track with stop
· ruler

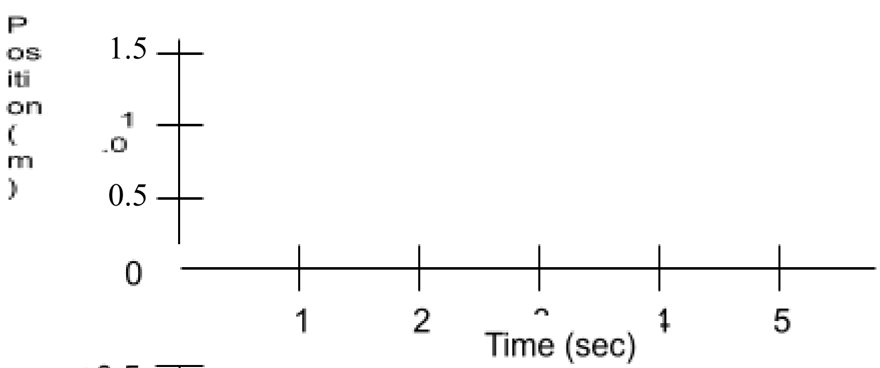
** The DataStudio Starter Manual is online at: www.pasco.com.*

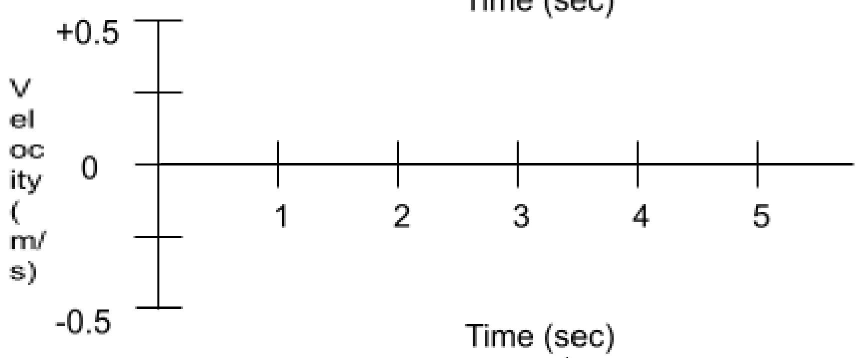
Procedure

Part I

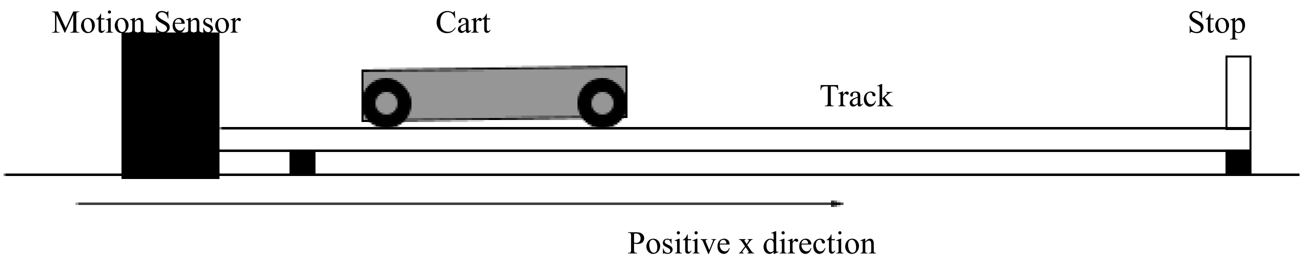
Activity 1: Motion of a Cart at a Constant Velocity

Predict how the position and velocity graphs would look if the cart were to move away from the motion sensor slowly, at a constant velocity, starting at the 0.1 m mark. Sketch and label your predictions on the graph below, using ***dashed lines.***





Set the switch on your motion sensor to the narrow-beam (short range) position. Place your motion sensor next to one end of the track and place your cart on the track. Make sure the track is level by seeing if the cart tends to roll more easily in one direction than the other. You may need to adjust the leveling foot on the bottom of the stop at the end of the track. When the track is level, place the cart near the sensor as shown below:



Now, test your predictions. Select the "Position" and "Velocity" graph options. Push the cart, then quickly remove your hand, and click the Start button on the monitor. (Be sure that the cart is not too close to the motion sensor and that your hand is not between the cart and motion sensor when you click on the Start button.) If necessary, try again, until you get a reasonably constant velocity motion along nearly the full length of the track. Copy these results onto your graph on the previous page, using ***solid lines***, then, answer the following questions:

1. Did your position-time and velocity-time graphs agree with your predictions? If not, discuss why with your lab partners and explain here:
2. What characterizes constant-velocity motion on a position-time graph?

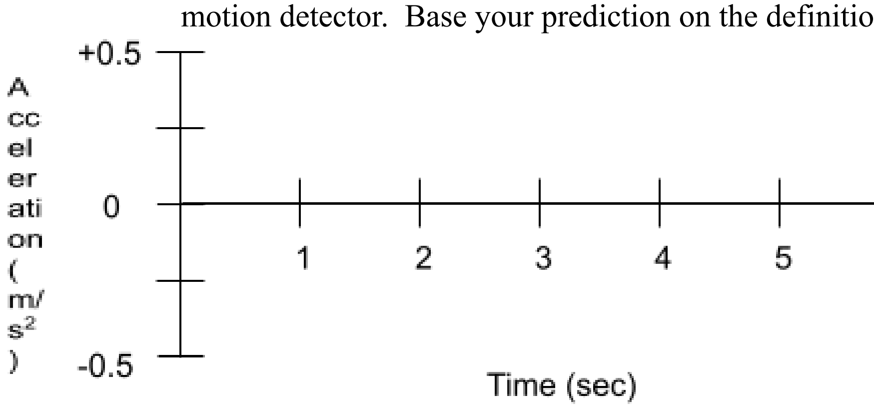
3. What characterizes constant-velocity motion on a velocity-time graph?

4. What do these observations tell you about constant velocity?

5. Using precise, carefully chosen language, explain what "constant velocity" means.

Activity 2: Acceleration of a Cart Moving at a Constant Velocity

Using a ***dashed line*** on the graph below, sketch your prediction for the acceleration of the cart you just observed moving at constant velocity away from the motion detector. Base your prediction on the definition of acceleration.



In addition to the position-time and velocity-time graphs, display the acceleration-time graph for the previously obtained constant-velocity data. Using a ***solid line***, draw and label the displayed acceleration graph on the same axes (preceding page) on which you made your prediction.

To calculate the average acceleration of the cart during some time interval, you must measure its velocity at the beginning and end of the time interval, subtract the initial velocity from the final velocity, and divide this difference (keeping the sign and units!) by the duration of the time interval (which is always positive). Using this method, calculate the average acceleration for at least three different time intervals. To obtain numerical data for velocity, click on Table (on the left of your screen) while viewing the velocity graph. Use only data from the part of the table that corresponds to the nearly constant-velocity motion. (Alternatively, velocity and time data may be estimated visually from your velocity-time graph.) Plot these data points on the preceding acceleration-time graph at the midpoint of each corresponding time interval ***using X's***.

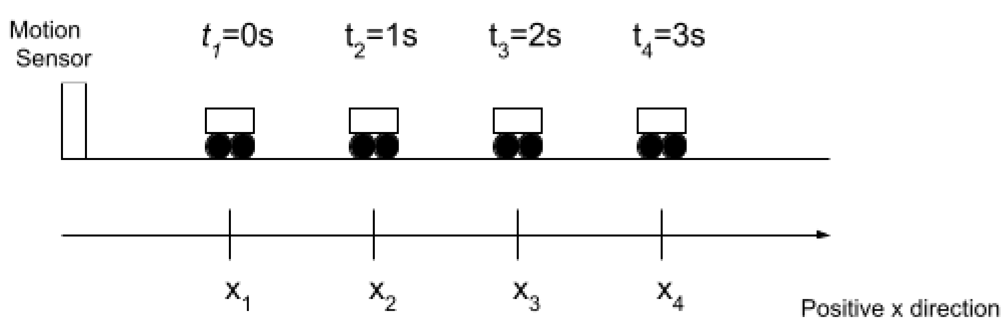
Now, answer the following questions:

1. Does your acceleration-time graph (solid line) agree with your prediction (dashed line)?

2. Does your acceleration-time graph agree reasonably well with your calculated acceleration values?
If not, explain why there are differences.

3. What value must the acceleration be for an object moving with a truly constant velocity?
How do you know?

The idealized motion diagram below shows successive positions of a cart at equal time intervals. The positions are also equally spaced. At each indicated time, use a ruler to draw a vector (i.e. arrow) above the cart that might represent the velocity of the cart as it moves away from the motion sensor. Assume the cart is already moving at time t_1.



To find the average acceleration vector during a time interval, you must find the vector representing the ***change in velocity*** and divide this vector by the time interval. By definition, the vector representing the change in velocity is the vector that would have to be added to the initial velocity to result in the final velocity. In the following space, *state the magnitude of the change-in-velocity vector between times t_3 and t_4, and explain how you determined that value (use drawings if helpful):*

Now, answer the following:

1. From this change-in-velocity vector (above), what value would you calculate for the acceleration?
   Explain.

2. Is this value in agreement with the acceleration graph obtained previously? Try to explain any differences.

CHECKPOINT: DISCUSS YOUR RESULTS FOR PART I WITH YOUR PARTNERS AND CHECK WITH YOUR INSTRUCTOR BEFORE PROCEDING.

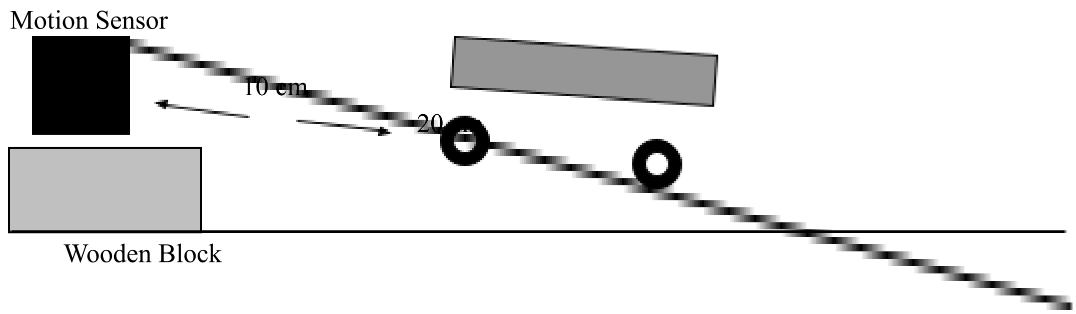
Part II

In this portion of the lab, you will be asked to predict and observe the shapes of position-time, velocity-time and acceleration-time graphs for a cart moving down a smooth ramp with increasing velocity. You will be able to see how these three representations of the motion are related to each other when the cart is speeding up.

Activity 1: Speeding Up

Predict how the position-time, velocity-time, and acceleration-time graphs would look if the cart were to roll away from the sensor down a gently inclined ramp (as shown below) with increasing speed, starting from rest, 0.1 m from the sensor. Sketch and label your predictions on the graph on the next page, using ***dashed lines.***

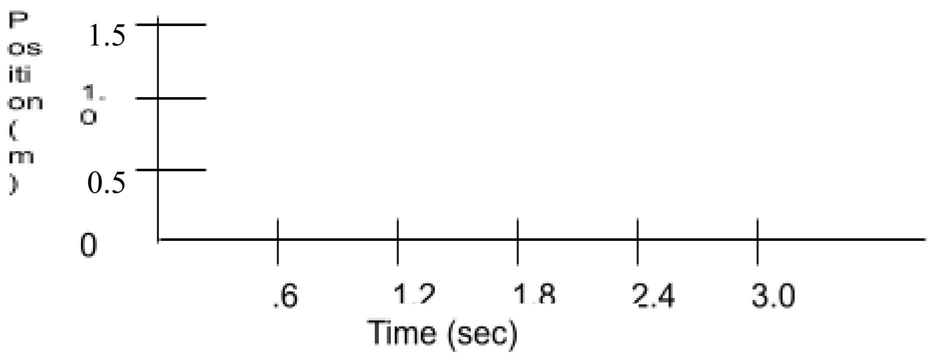
Tilt the track by placing a wood block under one end, then place the motion sensor on the block by the elevated end. Set the cart on the track approximately 0.1 m (10 cm) in front of the motion sensor as shown below. *Be sure that the track is stable.*

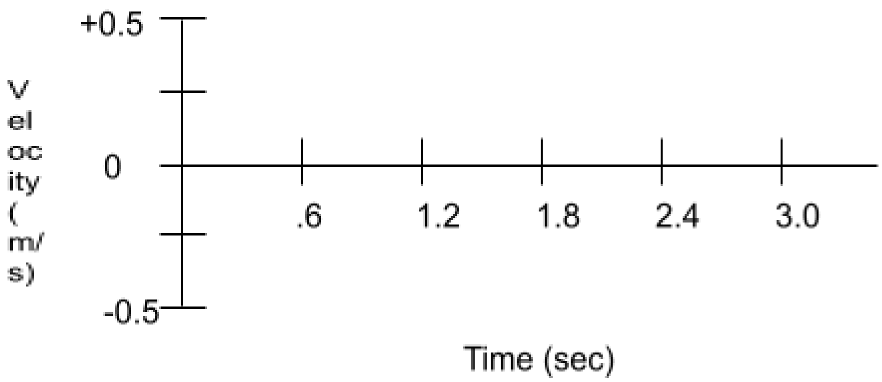


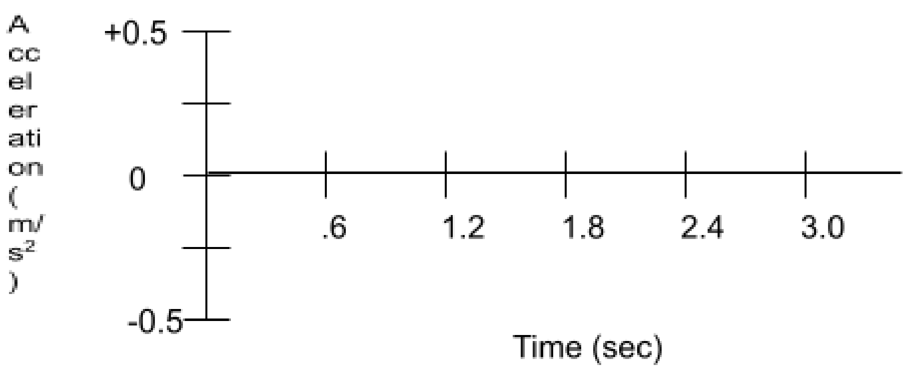
1. Make sure that the sensor is oriented such that it detects the cart and measures its position (i.e. distance from the sensor) all the way to the end of the track.

2. Hold the cart on the track, 0.1 m from the sensor. Start graphing data. When you hear the clicks of the motion sensor, release the cart from rest. *Stop taking data and stop the cart just before it goes off of the end of the track.*

3. Repeat, if necessary, until you get a nice set of graphs. You should display position-time, velocity-time, and acceleration-time graphs. Copy your results onto the following graphs using ***solid lines***.







Questions:

1. How does your position graph differ (qualitatively) from the position graph for the steady (i.e. approximately constant-velocity) motion that you observed in Part I?

2. Why is the sign of the velocity on your graph positive?
(i.e. What does it tell you about the motion?)

3. What feature of your velocity graph signifies that the cart was *speeding up?*

4. During the time that the cart is speeding up, is the acceleration positive or negative?

5. How does speeding up while moving away from the detector result in this sign for the acceleration? (Remember that acceleration is the rate of change of velocity.)

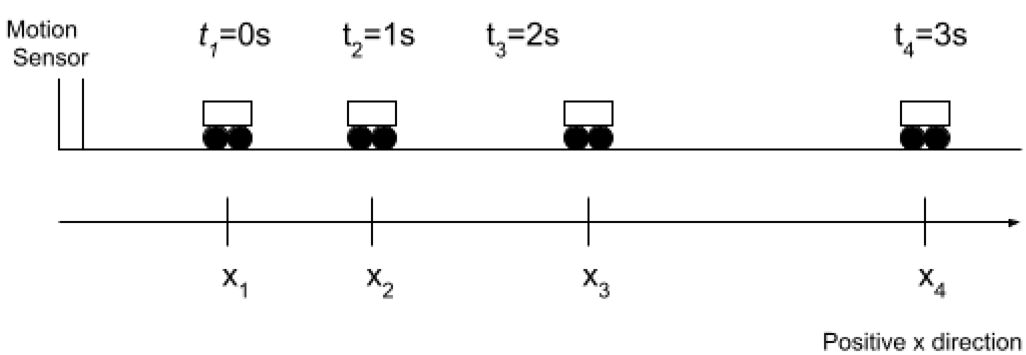
6. How does the velocity vary in time as the cart speeds up?

7. Does it increase at a steady (constant) rate or in some other way?

8. How does the *acceleration* vary in time as the cart speeds up?

9. Is this what you would expect based on the velocity graph?
Explain why or why not.

10. The diagram below shows the position of a cart at equal time intervals as it speeds up while moving away from the motion sensor. Assume that the cart is stationary at t_1. At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time.



11. Show below how you would find the vector representing the change in velocity between the times t_3 = 2s and t_4 = 3s in the diagram above. (Recall the definitions of "acceleration" and "change-in-velocity vector" given in Part 1, and that two vectors are added by adding the tail of one vector to the tip of the other.)

12. Based on the direction of this change-in-velocity vector and the direction of the positive x-axis, what is the sign of the acceleration?

13. Does this agree with your answer to Question 4? (If not, explain.)

Activity 2: Velocity and Acceleration Data for a Cart that is Speeding Up

In this activity, you will examine the motion of a cart on a ramp more quantitatively (i.e. Your analysis and results will consist of numbers with units.). You will determine the cart's acceleration from your velocity-time graph and compare it to the acceleration read from your acceleration-time graph.

Look back at the graphs obtained using DataStudio in Activity 1 (Speeding Up). Display a table of calculated numerical values for acceleration as described in Part I, Activity 2. Select 5 equally spaced values of the acceleration, and record them in the table below. (Alternatively, visually estimate 5 equally space values from the graph.) Use only data obtained after the cart was released and before the cart was stopped.

Acceleration Values (m/s^2)

1	
2	
3	
4	
5	

Average of above acceleration values:_______m/s^2

The average acceleration during a particular time interval is defined as the average rate of change of velocity with respect to time—the change in velocity divided by the change in time. By definition, the rate of change of a quantity graphed with respect to time is also the slope of the curve. Thus, the (average) slope of an object's velocity-time graph is also its (average) acceleration.

Use the velocity graph data table to obtain the velocity and time coordinates at the beginning (Point 1) and end (Point 2) of the "speeding up" portion of your graph, and record them in the following table:

	Velocity (m/s)	Time (sec)
Point 1:		
Point 2:		

Calculate the change in velocity and the corresponding change in time (time interval) between points 1 and 2. Then, divide the change in velocity by the change in time. This is the average acceleration. Record your calculations in the following table:

Change in velocity (m/s)	
Time interval (sec)	
Average acceleration (m/s^2)	

Questions:

1. Is the acceleration positive or negative?
   Should it be? (Explain)

2. Is this what you expected?
   (If not, explain why you expected otherwise, and discuss the matter with your lab partners.)

3. Does the average acceleration you just calculated agree with the average acceleration you found from the acceleration graph?

   Did you expect them to agree?

   How would you account for any differences?

Part III:

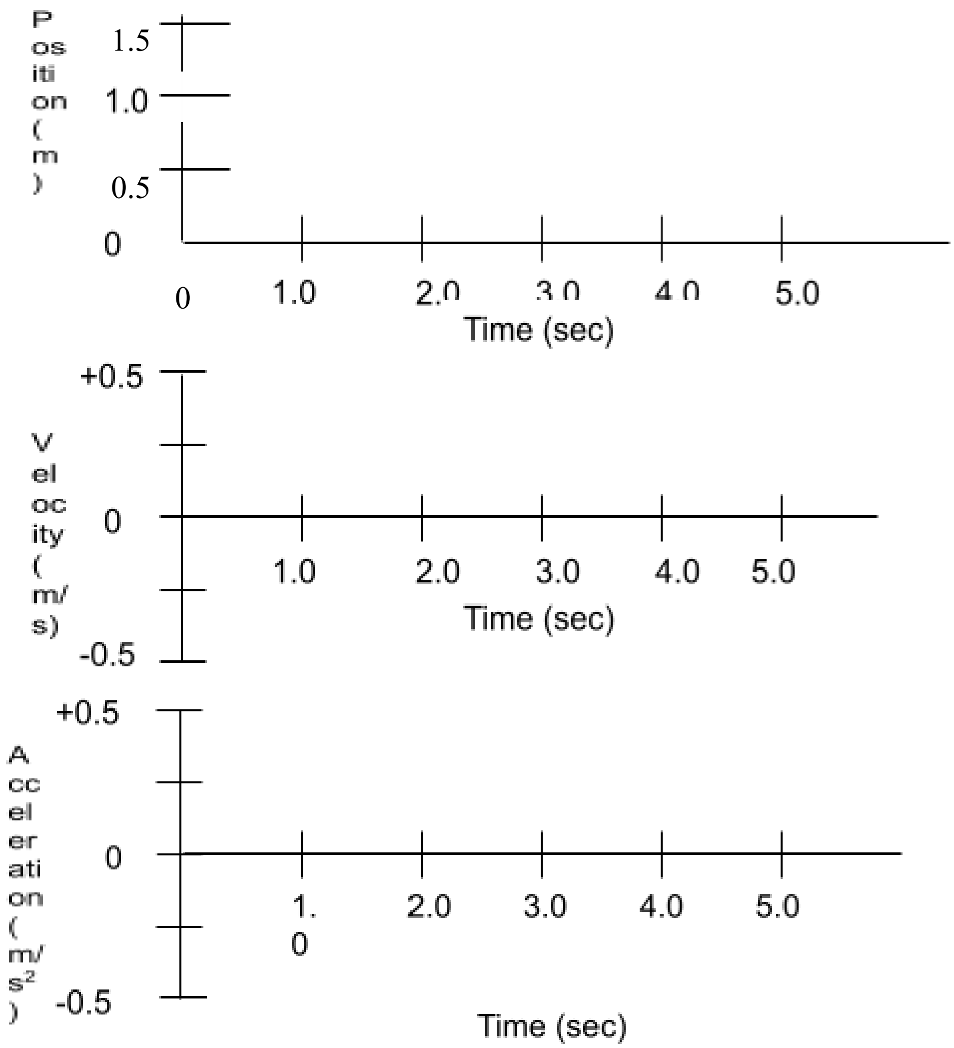
In this portion of the lab, you will observe a cart moving up a ramp and slowing down. A car moving forward, being brought to rest as the brakes are applied is a common example of this type of motion. You will also observe the cart rolling back down the ramp and speeding up and compare these two segments of the motion.

Acitvity 1: Slowing Down

In this activity you will look at the position, velocity and acceleration graphs of the cart moving toward the motion sensor and slowing down, then moving away from the sensor and speeding up.

1. Use the same setup as in the previous portion of this lab, but with the cart initially positioned at the bottom of the ramp.

2. If you were to give the cart a short, gentle push toward the motion sensor it would slow down after the push, since it would be going uphill. Suppose you gave it just enough of a push to make it go up the ramp until it was 0.2 m from the motion sensor before it started rolling back down. Using ***dashed lines*** on the following axes, sketch your predictions for the position-time, velocity-time and acceleration-time graphs corresponding to *the entire motion, from the time the cart is released until it rolls back down to the bottom of the ramp.* Label your prediction graphs in accordance with #3 (on the next page), but using lower case letters a – e.



3. Test your predictions by actually doing the experiment and displaying the position-time, velocity-time, and acceleration-time graphs. You may need to make several practice runs to create a motion that approximates the desired motion. When you have a good set of graphs, copy your results onto the above axes using ***solid lines***. Label each of your graphs as follows:

- A at the spot where you stopped pushing
- B over the region where the cart was rolling freely uphill.
- C at the spot where the cart reached its highest (closest) point.
- D over the region where the cart was rolling freely downhill.
- E at the spot where you started to stop the cart

Questions:

1. Did the shapes of your position, velocity and acceleration graphs agree, qualitatively, with your predictions?
   If not, explain how they differed?

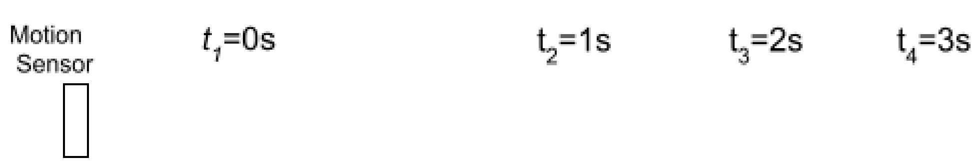
2. Are the signs of position, velocity and acceleration (which indicate direction) what you predicted for each part of the motion?
   If not, explain how and why they differed?

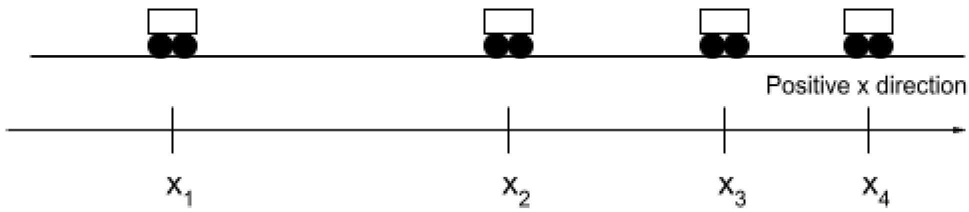
3. Explain how slowing down while moving toward the detector results in the sign of the measured velocity? (Remember, velocity is defined as the rate of change of position with respect to time, and the change in time is always positive.)

4. Explain how slowing down while moving toward the detector results in the sign of the measured acceleration? (Remember, acceleration is defined as the rate of change of velocity with respect to time.)

5. Did the sign of the acceleration change when the cart started rolling back down the ramp?
   Explain why or why not.

6. The diagram below shows the positions of a cart at equal time intervals. At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving away from the motion sensor and slowing down. (Assume that the cart is moving at t_1 and t_4.)





7. Show below how you would find the vector representing the change in velocity between the times 2 and 3 seconds in the diagram above. Remember that the change in velocity is the velocity you would have to add to the initial velocity (vectorially) to obtain the final velocity.

8. Based on the direction of this vector, what is the sign of the acceleration?

   Which direction does the sign indicate for the acceleration (relative to the sensor)?

9. Is this consistent with your answer to Question 4?

   (Note: In everyday language, when the direction of acceleration is opposite to the direction of the velocity, it is simply called "deceleration". There is no need for this term in a mathematical description of motion. The acceleration simply has the opposite sign of the velocity, whatever that may be.)

10. Based on your observations in this lab, state a general rule to predict the sign and, therefore, the direction of the acceleration, relative to the sign and direction of the velocity, if you know the object is speeding up or slowing down.