Physics For Doing!
Activities for Astronomy

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Welcome to Astronomy!

The exercises in this manual have been developed to support an investigative physics course that emphasizes active learning. Your written work will consist primarily of documenting your class activities by filling in the entries in the spaces provided in the units. The entries consist of observations, derivations, calculations, and answers to questions. Although you may use the same data and graphs as your partner(s) and discuss concepts with your classmates, all entries should reflect your own understanding of the concepts and the meaning of the data and graphs you are presenting. Thus, each entry should be written in your own words. It is very important to your success in this course that your entries reflect a sound understanding of the phenomena you are observing and analyzing.

Contents

1   Measuring and Graphing Horizontal Motion[1]

Name: _____   Lab Partner(s): _____

Objectives

- To explore the nature of horizontal motion.
- To learn to use Excel for graphing and fitting data.

Measuring the Horizontal Motion of a Bowling Ball

A key to understanding how to describe motion near the surface of the earth is to observe horizontal motions and vertical motions separately. Eventually, situations in which an object undergoes both horizontal and vertical motion can be analyzed and understood as a combination of these two kinds of basic motions.

Let's start with horizontal motion. How do you think the horizontal position of a bowling ball changes over time as it rolls along on a smooth surface? For example, suppose you were to roll the ball a distance of 6.0 meters on a fairly level smooth floor. Do you expect that the ball would: (1) move at a steady speed, (2) speed up, or (3) slow down? To observe the horizontal motion of a "bowling ball" you can use a bocce ball which is slightly smaller but quite similar to a regulation bowling ball.

Apparatus

- A bocce ball
- 3 stop watches
- A 2-meter stick
- Masking tape for marking distances
- A smooth level surface (> 7 meters in length)

Activity 1: Horizontal Motion

(a) What do you predict will happen to the position of the ball as a function of time? Will the ball move at a steady speed, speed up, or slow down after it leaves the bowler's hand? Why?

(b) Find a 7 meter length of smooth floor and use masking tape to mark off a starting line and distances of 2.00 m, 4.00 m, and 6.00 m. from the starting line. Then: (1) Bowl the ball along the surface. (2) Measure the time it takes to travel 2.0 m, 4.0 m & 6.0 m. (3) Record the results in the table below.

Note: This is a cooperative project. You will need a bowler, three people to measure the times, and someone to stop the ball. Practice several times before recording data in the table below.

t (s)	x (m)
0.00	0.00

(c) Calculate the average speed, v, in m/s of the bowling ball as it travels the 6.00 meters.

Activity 2: Drawing a Graph of Position *vs.* Time

In this activity, you will graph your data for the position of the ball as a function of the rolling-time of the ball. This graphing should be done both by hand and on the computer.

NOTE on creating graphs: (This applies for the entire course.) Whenever an instruction says "plot variable 1 as a function of variable 2", or "plot variable 1 *vs.* variable 2", variable 2 goes on the horizontal axis (independent variable) and variable 1 goes on the vertical axis (dependent variable). Every graph requires a title (like "Position *vs.* Time") and labeled axes with units in parentheses.

(a) Fill in the units and the scale numbers in the graph below and plot the data you collected, including the (0,0) point listed on the first line of the above table. Sketch a line through the data points.
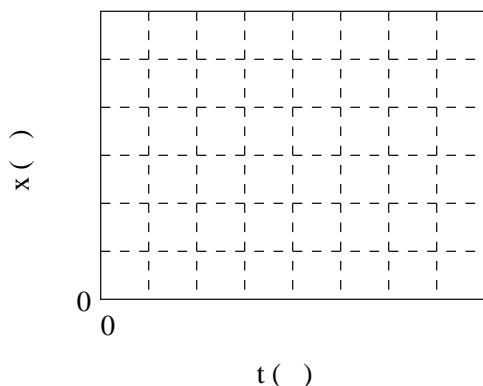
(b) Now use *Excel* on the computer to create the same graph. Just plot the data points; don't try to fit with a line (we will do that in Activity 4). See Appendix A for instructions.

How does the Position of the Ball Vary with Time?

We are interested in the mathematical nature of the relationship between position and time for rolling on a level surface. Some definitions of mathematical relationships are shown in the sketches below. Figure (a) shows a function y that increases with x so that $y = f(x)$. In sketch (b) y is a linear function that increases with x so that $y = mx + b$, where m is the slope and b is the y intercept. In figure (c) y is proportional to x ($y = mx$ where $b = 0$).
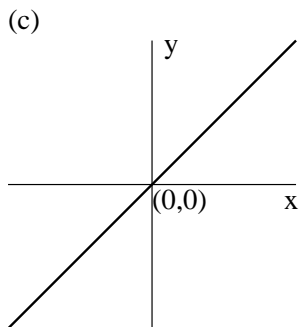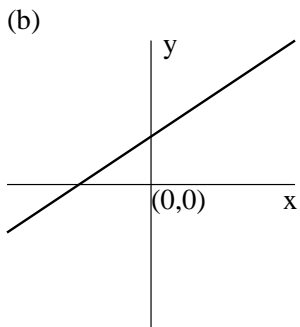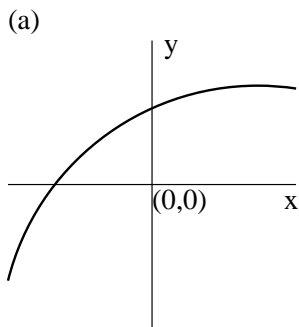
Activity 3: The Mathematical Relationships

(a) By comparing the shape of the graph you have just produced with the sketches shown above, would you say that the position, x, increases with time, t? Decreases with time? Is it a linear function of t? Is it proportional to t? Explain.

(b) How do the results compare with the prediction you made in Activity 1? Are you surprised?

(c) What do you think would happen to the slope, m, of the graph, if the ball had been rolled faster? Would it increase? Decrease? Stay the same?

Activity 4: Mathematical Modeling

(a) Create a mathematical model of the bocce ball motion data you collected in Activity 1. This can be done by using *Excel* to fit the data with a trendline. Use a linear fit for this process, and tell the computer to print the equation for the line. See **Appendix A: Excel** for instructions. Be sure to label the graph with a title and axis labels with units. Then print the graph and include it with this unit. Does the line provide a good description of the data?

(b) Write the equation describing the motion in the form Position $x = vt + x_o$, using the numbers from the equation of your graph. Be sure to include units.

(c) Use the LINEST function in *Excel* (see **Appendix A: Excel**) to determine the slope v of the line and the uncertainty Δv in the slope. Then write the velocity as $v = \text{slope} \pm \Delta\text{slope}$, rounding off the numbers as appropriate. Be sure to include units.

(d) Does the speed you determined in Activity 1 fall within your range of velocity values? How would you account for any variation?

Homework

The diagram below shows the graphs of three possible relationships between the time, t, in seconds and the position, x, in centimeters that the object has traveled.
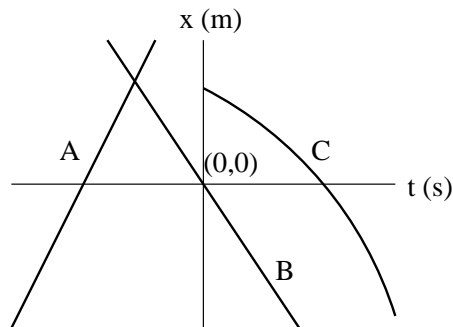
(a) Which graphs represent position as a linear function of time? A, B, and/or C?

(b) Which graphs, if any, show position as proportional to time?

2   Force and Motion I[1]

Name: _____   Lab Partner(s): _____

Objectives

- To understand the relationship between forces applied to an object and its motions.
- To find a mathematical relationship between the force applied to an object and its acceleration.

Overview

In the previous labs, you have used a motion detector to display position-time, velocity-time and acceleration-time graphs of the motion of different objects. You were not concerned about how you got the objects to move, i.e., what forces (pushes or pulls) acted on the objects. From your experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must step on the gas pedal to get the engine to apply a force to the road through the tires.

But exactly how is force related to the quantities you used in the previous unit to describe motion: position, velocity and acceleration? In this unit you will pay attention to forces and how they affect motion.

Apparatus

- Force probe
- Variety of hanging masses
- CS2000 compact scale (for measuring mass)
- Low friction pulley and string
- Motion detector
- Dynamics cart and track
- Pasco 550 Interface
- *Capstone* software (*V_A_F_Graphs.cap* experiment file)

Measuring Forces

In this investigation you will use a force probe (also called a force sensor) to measure forces. The force probe puts out a voltage signal proportional to the force applied to the arm of the probe. Physicists have defined a standard unit of force called the newton, abbreviated N. For your work on forces and the motions they cause, it will be more convenient to have the force probe read directly in newtons rather than voltage. Before the force probe is used it must be calibrated. Before calibrating the force probe, open the *V_A_F_Graphs.cap* file in the *Phys121* folder. To calibrate the force probe, see *Calibrating Force Sensors* in **Appendix ??: Capstone**.

Activity 1: Pushing and Pulling a Cart

In this activity you will move a cart by pushing and pulling it with your hand. You will measure the force, velocity and acceleration.
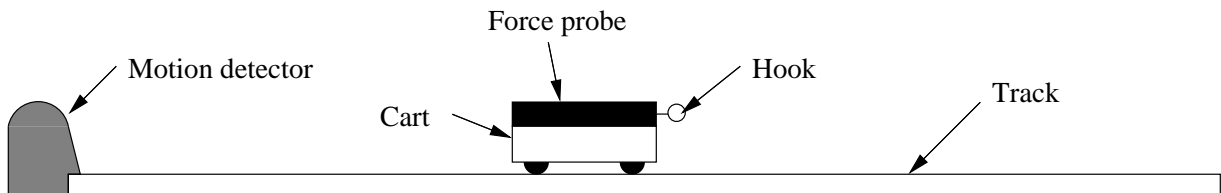

(a) Calibrate the force probe if you haven't already done so. Then set up the cart, force probe and motion detector on the level track as shown above. Measure the mass of the cart and force probe assembly (using the compact scale), and record the result.

(b) Suppose you grasp the hook on the force probe and move the cart forwards and backwards in front of the motion detector. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? That is to say, if you apply a changing force to the cart, will the velocity or acceleration change in the same way as the force?

(c) To test your predictions, click the **Record** button, grasp the hook on the force probe and push and pull the cart back and forth 3 or 4 times. Be sure that the cart never gets closer than 0.15 m away from the detector and be careful of the wires. Repeat until you get a good run, and adjust the sampling time and scale of the axes if necessary. Sketch your graphs on the axes that follow.
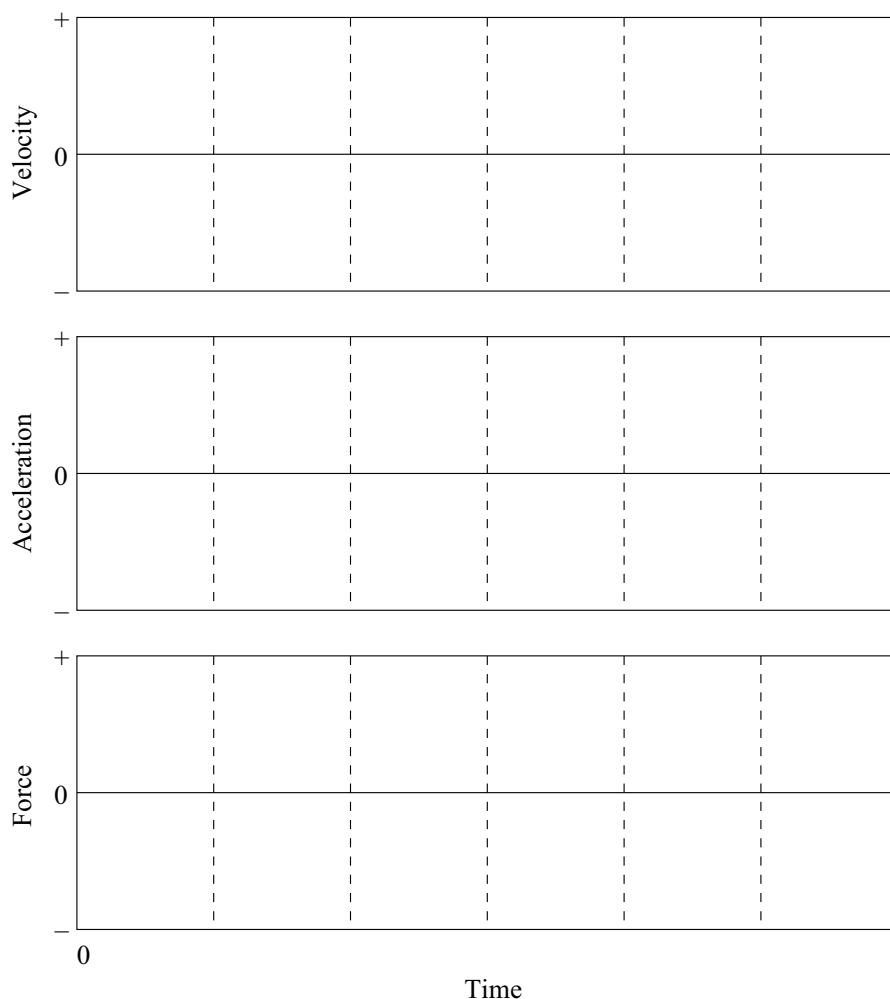
(d) Does either graph—velocity or acceleration—resemble the force graph? Which one? Explain.

(e) Based on your observations, does it appear that either the velocity or acceleration of the cart might be related to the applied force? Explain.

Activity 2: Speeding Up

You have seen in the previous activity that force and acceleration seem to be related. But just what is the relationship between force and acceleration?

(a) Suppose you have a cart with very little friction, and that you pull this cart with a constant force as shown below on the force-time graph. Predict with sketches on the axes below the velocity-time and acceleration-time graphs of the cart's motion.
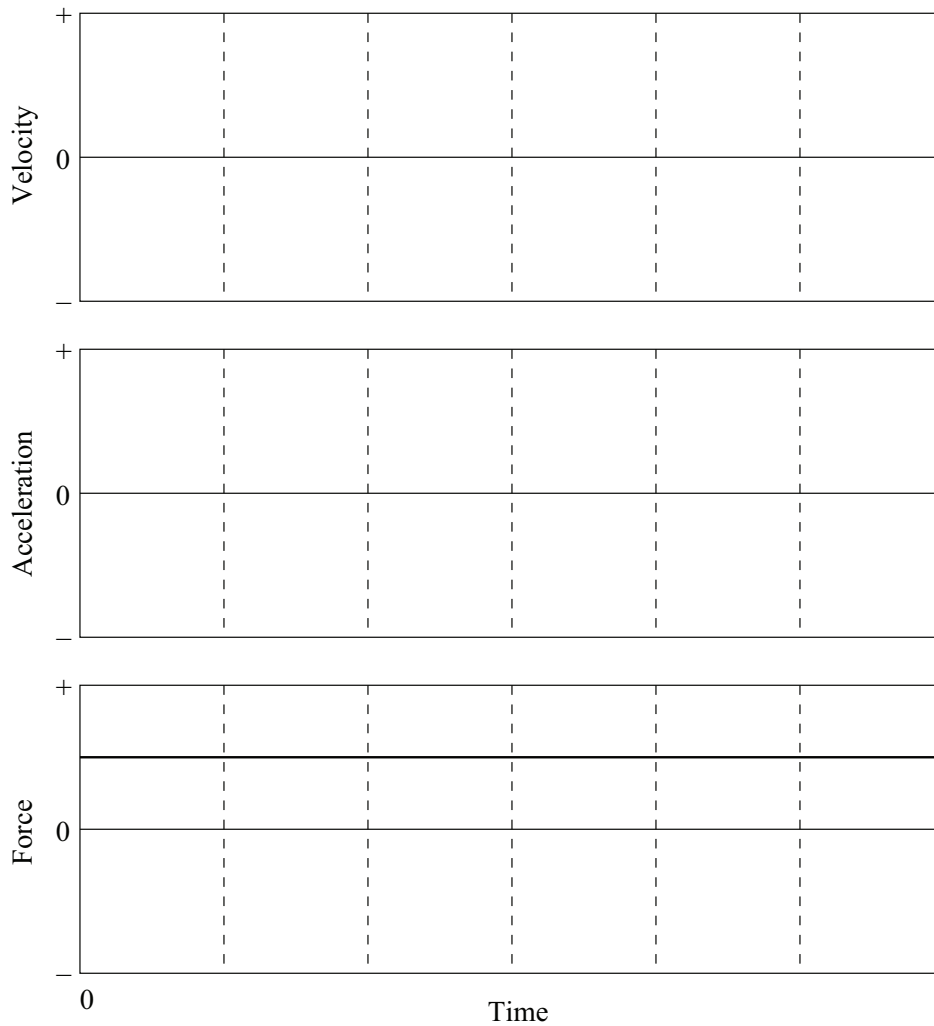

(b) Describe in words the predicted shape of the velocity *vs.* time and acceleration *vs.* time graphs for the cart.
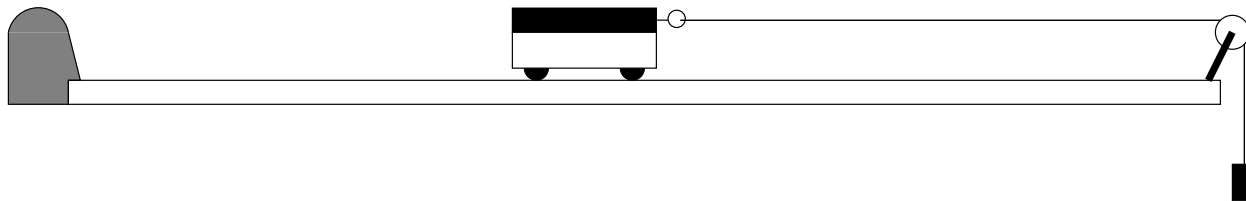
Equipment setup for quantitative measurements of force and motion.

(c) Test your predictions. Set up the pulley, cart, string, motion detector and force probe as shown in the figure above. The cart should be the same mass as before. Hang 50 g from the end of the string. Start the data acquisition. Release the cart when you hear the clicks of the motion detector. Be sure that there is enough slack in the force probe cables to complete the motion and catch the cart before it crashes into the pulley. Repeat until you get good graphs in which the cart is seen by the motion detector over the entire motion. Sketch the actual velocity, acceleration and force graphs for the motion of interest on the axes below and indicate the scale on the axes. Draw smooth graphs; don't worry about small bumps.
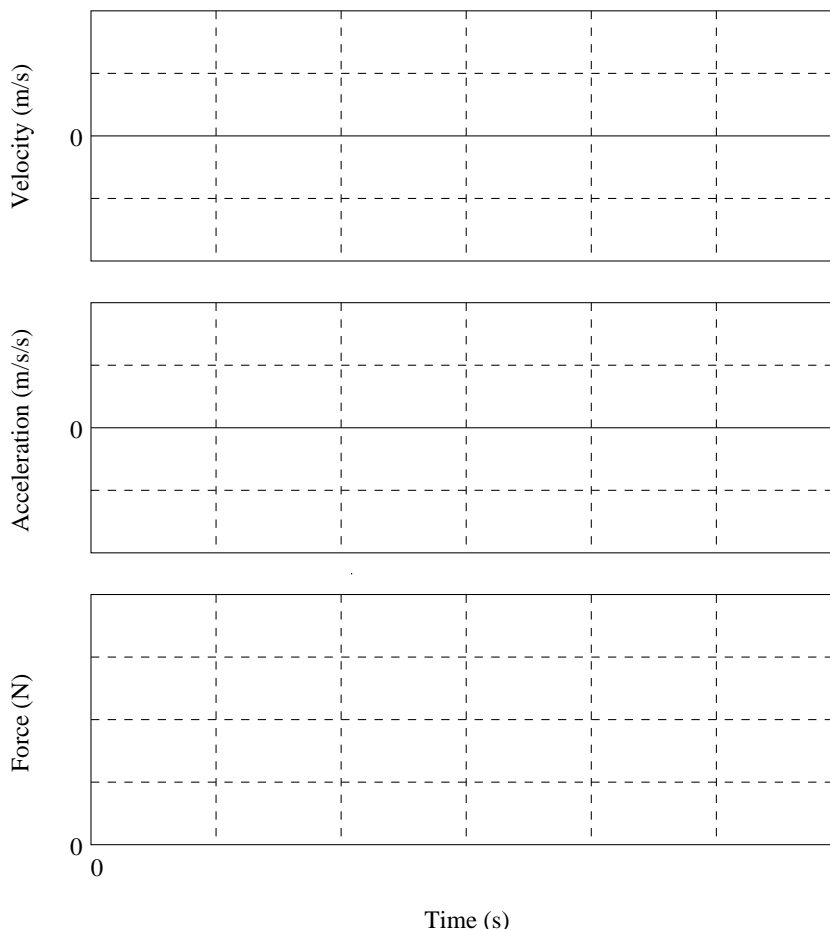
(d) Is the force which is applied to the cart by the string constant, increasing or decreasing? Explain based on your graph.

(e) How does the acceleration graph vary in time? Does this agree with your prediction? What kind of acceleration corresponds to a constant applied force?

(f) How does the velocity graph vary in time? Does this agree with your prediction? What kind of velocity corresponds to a constant applied force?
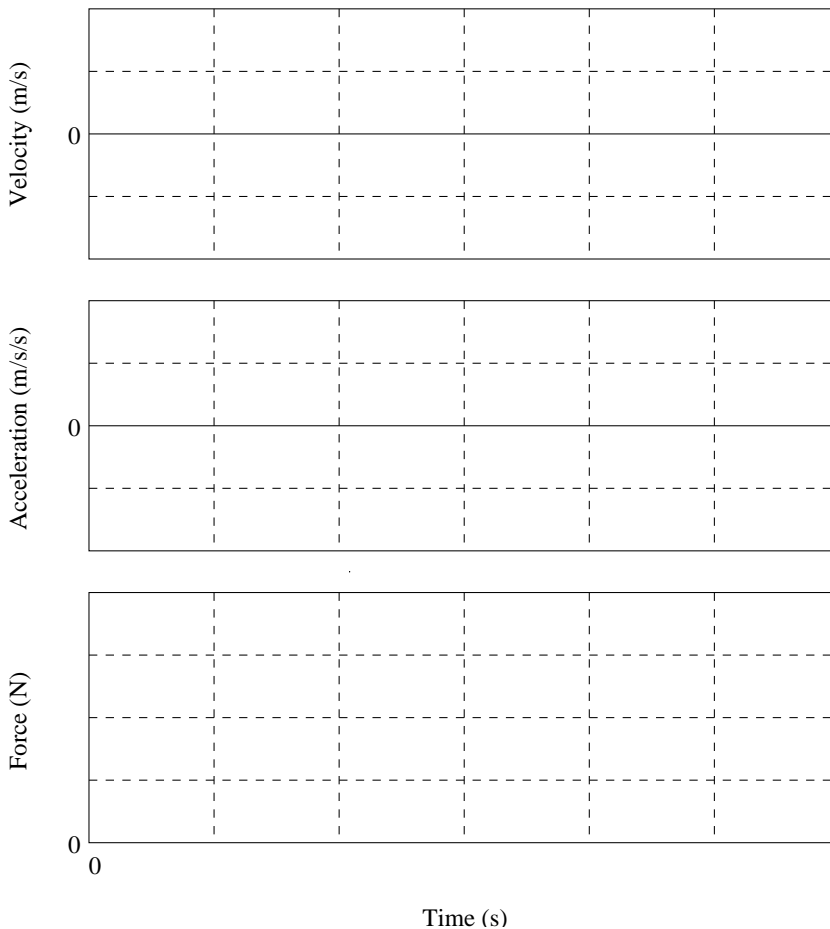
(g) Use the **Statistics** function to determine the average force and the average acceleration and record them below. Find the mean values only during the time interval when the force and acceleration are nearly constant. See **Appendix ??** for details on the use of the **Statistics** function of Capstone.

Activity 3: Acceleration from Different Forces

In the previous activity you have examined the motion of a cart with a constant force applied to it. But, what is the relationship between acceleration and force? If you apply a larger force to the same cart (same mass as before) how will the acceleration change? In this activity you will try to answer these questions by applying a different force to the cart, and measuring the corresponding acceleration.

(a) Suppose you pulled the cart with a force about twice as large as before. What would happen to the acceleration of the cart? Explain.

(b) Test your prediction by replacing the 50-g mass with a 100-g mass and creating graphs of the motion as before. Repeat until you have a good run. Sketch the results on the axes that follow. Don't forget to put the scale on the axes.

(c) Use the **Statistics** function to find the average force and the average acceleration and record them below. Find the mean values only during the time interval when the force and acceleration are nearly constant.

(d) How did the force applied to the cart compare to that with the smaller force in Activity 2?

(e) How did the acceleration of the cart compare to that caused by the smaller force in Activity 2? Did this agree with your prediction? Explain.

Activity 4: The Relationship Between Acceleration and Force

If you accelerate the same cart (same mass) with another force, you will then have three data points–enough data to plot a graph of acceleration *vs.* force. You can then find the mathematical relationship between acceleration and force.

(a) Accelerate the cart with a force roughly midway between the other two forces tried. Use a hanging mass about midway between those used in the last two activities. Record the mass below.

(b) Graph velocity, acceleration and force. Sketch the graphs on the axes in Activity 3 using dashed lines.

(c) Find the mean acceleration and force, as before, and record the values in the table below (in the Activity 4 line). Also, enter the values from the previous two activities in the table.

	Average Force (N)	Average Acceleration (m/s^2)
Activity 2		
Activity 4		
Activity 3		

(d) Using *Excel*, plot the average force applied to the cart as a function of the average acceleration of the cart by fitting the data with a linear function. Include a fourth data point (0,0) (since zero force means 0 acceleration). Label and print the graph showing the best fit, and add it to this unit.

(e) Does there appear to be a simple mathematical relationship between the acceleration of a cart (with fixed mass) and the force applied to the cart (measured by the force probe mounted on the cart)? Write down the equation you found and describe the mathematical relationship in words. What is the slope of the graph?

(f) Use the LINEST function in *Excel* (see **Appendix A: Excel**) to determine the uncertainty in mass of the cart/force sensor combination based on your data points. Write your result as $Mass = m \pm \Delta m$. Be sure and include proper units.

(g) Does your measurement of m from Activity 1 fall within the range indicated in (f) above? If not, what are some possible sources of systematic error?

Comment: The relationship which you have been examining between the acceleration of the cart and the applied force is known as Newton's Second Law, $F = ma$.

Homework

1. A force is applied which makes an object move with the acceleration shown below. Assuming that friction is negligible, sketch a force-time graph of the force on the object on the axes below.
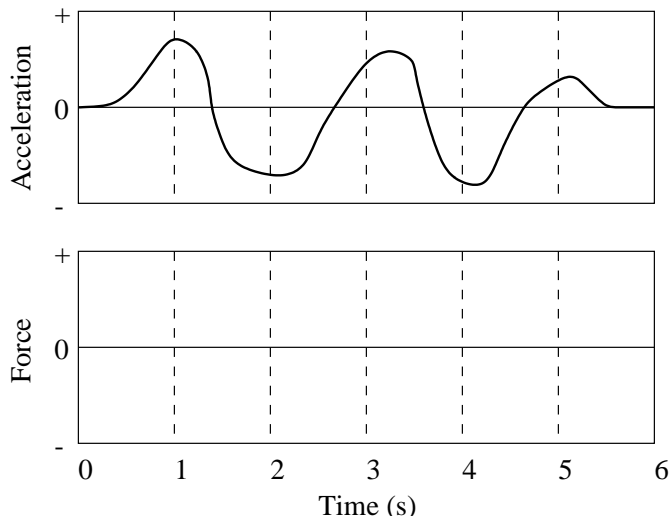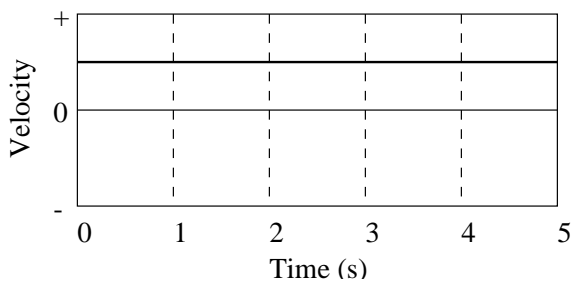
Explain your answer:

2. Roughly sketch the velocity-time graph for the object in question 1 on the axes below, beginning with a *negative* velocity. Remember that acceleration is the *slope* of velocity.
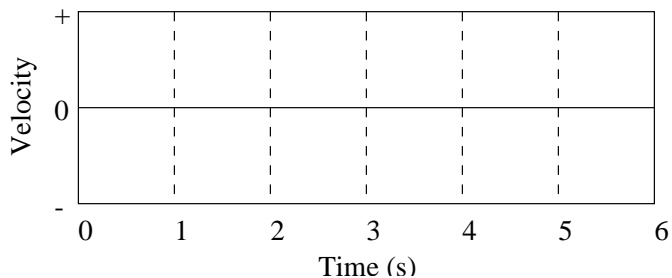
3. A cart can move along a horizontal line (the + position axis). It moves with the velocity shown below.

Assuming that friction is so small that it can be neglected, sketch on the axes that follow the acceleration-time and force-time graphs of the cart's motion.
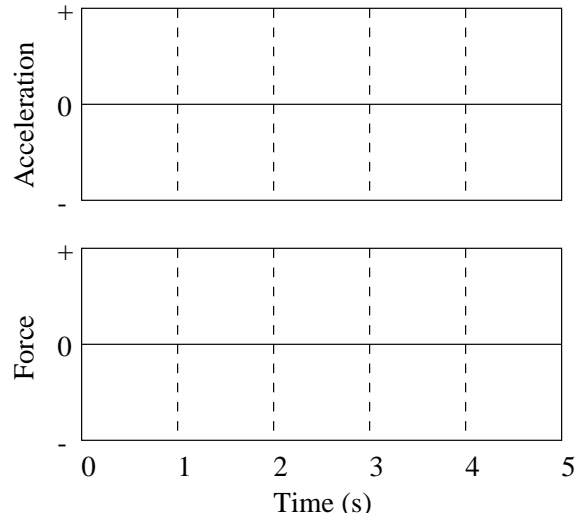
Explain both of your graphs.

Questions 4-6 refer to an object which can move in either direction along a horizontal line (the + position axis). Assume that friction is so small that it can be neglected. Sketch the shape of the graph of the force applied to the object which would produce the motion described.
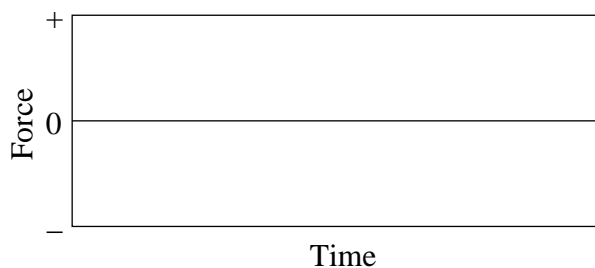
4. The object moves away from the origin with a constant acceleration.
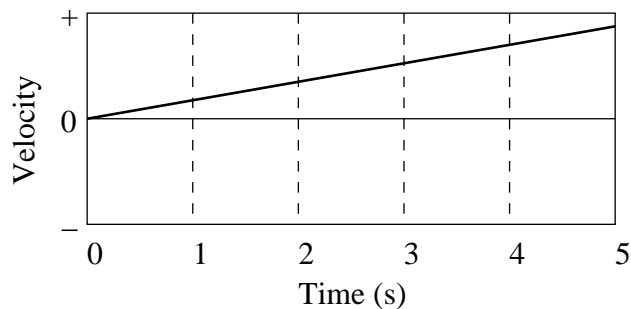

5. The object moves toward the origin with a constant acceleration.

6. The object moves away from the origin with a constant velocity.

Questions 7 and 8 refer to an object which can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity-time graph is shown below.

7. Sketch the shapes of the acceleration-time and force-time graphs on the axes below.
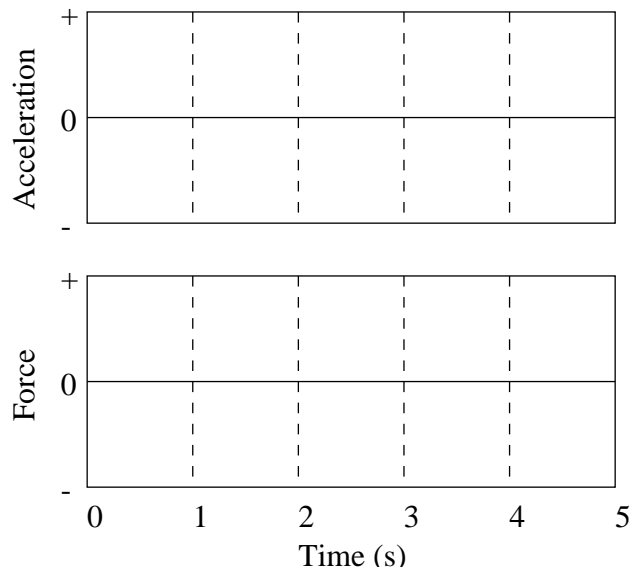
8. Suppose that the force applied to the object were twice as large. Sketch with dashed lines on the same axes above the force, acceleration, and velocity.

Question 9 refers to an object which can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity-time graph is shown below.
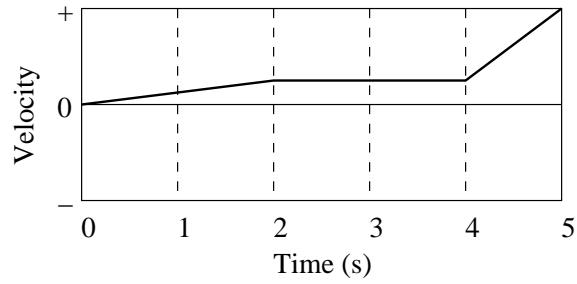

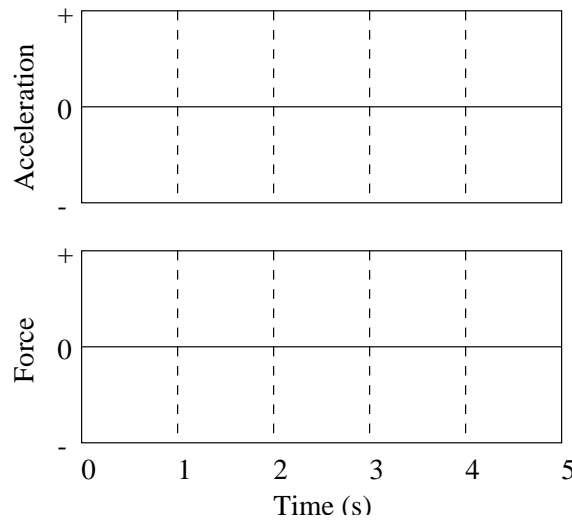9. Sketch the shapes of the acceleration and force graphs on the axes below.

Appendix A: Introduction to Excel

Microsoft Excel is the spreadsheet program we will use for much of our data analysis and graphing. It is a powerful and easy-to-use application for graphing, fitting, and manipulating data. In this appendix, we will briefly describe how to use Excel to do some useful tasks. The current version is Excel 2013.

A.1   Data and Formulas

Figure 1 below shows a sample Excel spreadsheet containing data from a made-up experiment. The experimenter was trying to measure the density of a certain material by taking a set of cubes made of the material and measuring their masses and the lengths of the sides of the cubes. The first two columns contain her measured results. **Note that the top of each column contains both a description of the quantity contained in that column and its units.** You should make sure that all of the columns of your data tables do as well. You should also make sure that the whole spreadsheet has a descriptive title and your names at the top, as indicated in the sample spreadsheet below.

In the third column, the experimenter has figured out the volume of each of the cubes, by taking the cube of the length of a side. To avoid repetitive calculations, she had Excel do this automatically. She entered the formula `=B5^3` into cell C5. Note the equals sign, which indicates to Excel that a formula is coming. The `^` sign stands for raising to a power. After entering a formula into a cell, you can grab the square in the lower right corner of the cell with the mouse and drag it down the column, or you can just double-click on that square. (Either way, note that thing you're clicking on is the tiny square in the corner; clicking somewhere else in the cell won't work.) This will copy the cell, making the appropriate changes, into the rest of the column. For instance, in this case, cell C6 contains the formula `=B6^3`, and so forth.

Column D was similarly produced with a formula that divides the mass in column A by the volume in column C.

At the bottom of the spreadsheet we find the mean and standard deviation of the calculated densities (that is, of the numbers in cells D5 through D8). Those are computed using the formulas `=average(D5:D8)` and `=stdev(D5:D8)`.

A.2   Graphs

Here's how to make graphs in Excel. First, use the mouse to select the columns of numbers you want to graph. (If the two columns aren't next to each other, rearrange them so that they are next to each other. The variable you want on the horizontal axis needs to be to the left of the variable you want on the vertical axis). Then click
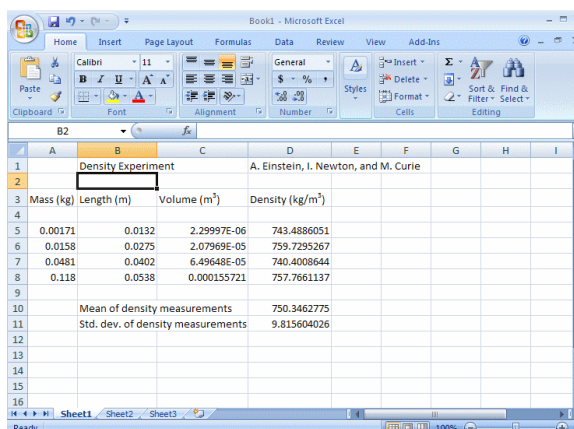

Figure 1: Sample Excel spreadsheet

on the *Insert* tab at the top of the window. In the menu that shows up, there is a section called *Charts*. Almost all of the graphs we make will be scatter plots (meaning plots with one point for each row of data), so click

on the *Scatter* icon, which is the lower one in the group that looks like this ⬚. Several possible scatter plots appear. Select the first one with the same icon as before, and your graph will appear.

Next, you'll need to customize the graph in various ways, such as labeling the axes correctly.

This is done in the *Chart Elements* menu which is accessed by clicking on the plus sign (+) in a box, at the upper right corner of your graph. Click on *Axis Titles*, and places appear for axis titles. Edit the text inside of the two axis titles so that it indicates what's on the two axes of your graph, *including the appropriate units for each.*

Next, give your graph an overall title. Click on *Chart Title* and a box appears around it. Delete "Chart Title" and enter a proper title such as "Position vs Time" or whatever.

Usually you want your graph to contain a best-fit line passing through your data points. To do this, *right* click on one of the data points and select *Add Trendline*. A number of options appear such as "linear", "polynomial", "power", and so on. Select the one you want, and also check the *Display Equation on chart* option near the bottom. You can then drag the equation to someplace else on the chart so you can read it better. Remember that Excel won't include the correct units on the numbers in this equation, but you should. Also, Excel will always call the two variables x and y, even though they might be something else entirely. Bear these points in mind when transcribing the equation into your lab notebook.

Sometimes, you may want to make a graph in Excel where the x column is to the right of the y column in your worksheet. In these cases, Excel will make the graph with the x and y axes reversed. Here's how to fix this problem: Before you make your graph, make a copy of the y column in the worksheet and paste it so that it's to the right of the x column. Then follow the above procedure and everything will be fine.

A.3   Making Histograms

A histogram is a useful graphing tool when you want to analyze groups of data, based on the frequency at given intervals. In other words, you graph groups of numbers according to how often they appear. You start by choosing a set of 'bins', *i.e.*, creating a table of numbers that mark the edges of the intervals. You then go through your data, sorting the numbers into each bin or interval, and tabulating the number of data points that fall into each bin (this is the frequency). At the end, you have a visualization of the distribution of your data.

Start by entering your raw data in a column like the one shown in the left-hand panel of Figure 2. Look over your numbers to see what is the range of the data. If you have lots of values to sift through you might consider sorting your data is ascending or descending order. (You don't need to do this if you can easily see the range of data.) To do this task, choose the column containing your data by clicking on the letter at the top of the column, go to *Data* in the menubar, select *Sort*, and pick ascending or descending. The data will be rearranged in the order you've chosen and it will be easier to see the range of the data. For an example, see the middle column of data in the left-hand panel of Figure 2.

Now to create your bins pick a new column on your spreadsheet and enter the values of the bin edges. Bins should be of equal size with the bin edges given by simple numbers. Make sure the bins you choose cover the range of the data. See the left-hand panel of Figure 2 again for an example.

You now have the ingredients for making the histogram. Go to *Data* in the menubar, select *Data Analysis* (on the right) and choose *Histogram*. Click *OK*. You should see a dialog box like the one in the right-hand panel of Figure 2. Click in the box labeled *Input Range* and then highlight the column on the spreadsheet containing your data. Next, click in the box labeled *Bin Range* and highlight the column on the spreadsheet containing the bins. Under *Output Options*, select *Chart Output* and click *OK*. The histogram should come up. If it doesn't, go to *Insert* in the menubar and select the histogram icon in the *Charts* section (the first icon in that section). Change the horizontal axis label to whatever you are plotting (including units). The vertical axis should already be labeled "Frequency". Change the chart title to an appropriate title for whatever you are plotting. The result should look like the right hand panel of Figure 3.
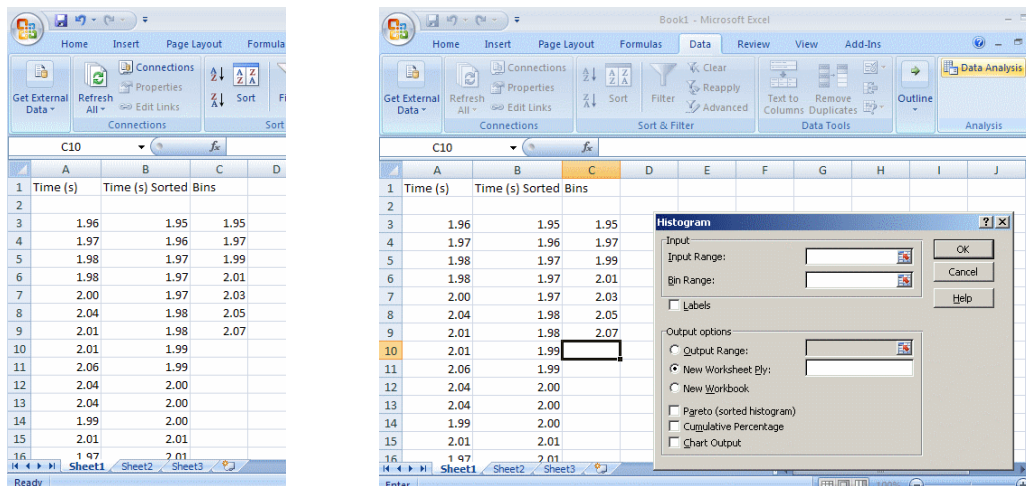

Figure 2: Column data and bins (left-hand panel) and dialog box (right-hand panel) for making a histogram in Excel.
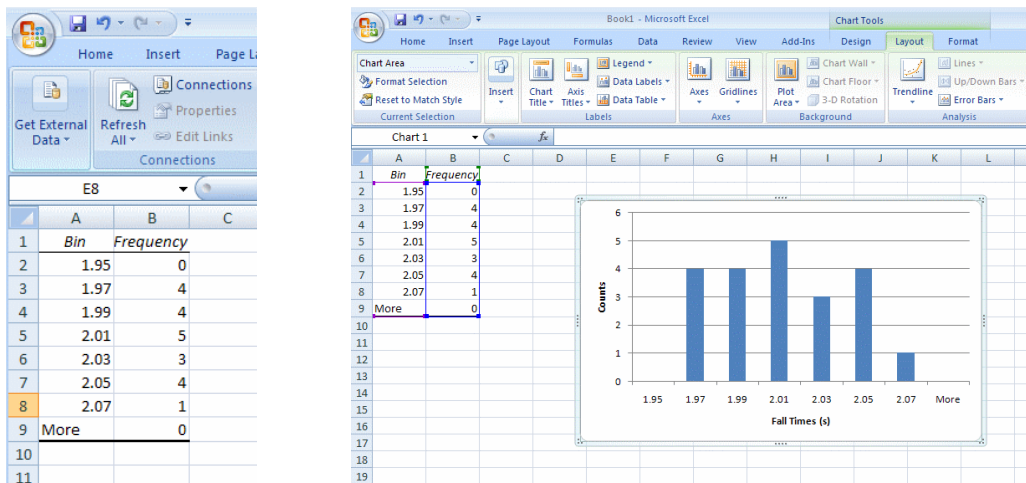

Figure 3: Newly-created worksheet (left-hand panel) and final plot (right-hand panel) for histogram worksheet in Excel.

A.4   LINEST

LINEST is a function in Excel which gives a LINear ESTimate of the slope and the uncertainty in the slope for any linear data set. It can also give the y-intercept and the uncertainty in the y-intercept. The uncertainties are based on the scatter of the data points about a perfect straight line. To use LINEST in Excel, perform the following steps:

1. Select a 2 x 2 group of cells (not including any cells with data)

2. In the function line type =LINEST(

3. Select range of y values

4. Type comma (,)

5. Select range of x values

6. Type comma (,)

7. To estimate both the slope and the y-intercept: Type 1,1)

   OR, to estimate only the slope, forcing a y-intercept of zero: Type 0,1)

8. Hold down Control AND Shift buttons, and press Enter

9. The result should look like this (if you typed "1,1"):

slope	intercept
Δslope	Δintercept

Δslope represents the uncertainty in the slope value. You will still need to round off both numbers, depending on the relative magnitudes of the two numbers. It is also common practice to express both numbers to the same power of 10.