PHY 111L Activity 2

Introduction to Kinematics

Name: _____ ID #:_____

Section: _____ Date: _____

Lab Partners: _____ TA initials: _____

Objectives

1. Introduce the relationship between position, velocity, and acceleration
2. Investigate the special case of constant acceleration
3. Determine the gravitational acceleration $\boldsymbol{a_g}$ using DataStudio sensors (lab report)
4. Introduce more calculations and tools used for analyzing measurements

Materials & Resources

1. Computer with DataStudio software and stop watch
2. Dynamics track with cart and Pasco motion sensor
3. Photo gates configured vertically and gravitational drop ball

Introduction

When an object moves through space, its motion can be characterized by 3 related physical quantities: position, velocity, and acceleration, each having both a magnitude and a direction in space. An object's *position* is simply its location in space, its *velocity* is just how fast it is moving from one point to the next, or the time rate of change in its position value, while its *acceleration* is how much it is speeding up or slowing down, or the time rate of change in its velocity value. In addition to the magnitude and direction of these quantities being defined in terms of a coordinate system in space, like the sun or north star, a map, or divisions on a graph, these quantities also involve *time*; acceleration describes how long it takes for an object's velocity to change, while its velocity describes how long it takes for its position in space to change. The dimensions for each of these quantities are as follows: position is in length with SI units of m, velocity is in $^{\text{length}}/_{\text{time}}$ with SI units of $^{\text{m}}/_{\text{s}}$, and acceleration is in $^{\text{length}}/_{\text{time}^2}$ with SI of units $^{\text{m}}/_{\text{s}^2}$.

The most well-known example of acceleration in nature is gravitational acceleration, which over short enough distances may be considered a constant acceleration. Near the surface of the Earth, the acceleration due to gravity is $\boldsymbol{g}$ = 9.807 $^{\text{m}}/_{\text{s}^2}$. This means that a falling object near the Earth's surface will increase its velocity by 9.807 $^{\text{m}}/_{\text{s}}$ every second that it is allowed to fall freely. This assumes that no frictional or other forces are involved in speeding it up, slowing it down, or stopping the object. So, if the object moves slowly enough through air to neglect air friction, and before it hits the ground and stops, its average velocity is

$$v_a = (v_f + v_i) \div 2$$

where v_a, v_f, and v_i are the object's average, final, and initial velocities, respectively. Now, if $v_i = 0$, then

$$v_a = v_f \div 2$$

Another way to represent the average velocity of an object is its distance (or height) traveled per unit time, then

$$v_a = h \div t$$

Now, setting these two representations for v_a equal and solving for v_f gives the following formula for final velocity

$$v_f = 2h \div t$$

Similarly, when $v_i = 0$, acceleration can be represented as its final velocity per time, then substituting for v_f gives

$$a_g = v_f \div t = (2h) \div t^2$$

which represents the gravitational acceleration on an object that falls h meters in t seconds from rest or when $v_i = 0$.

1. Average and Standard Deviation in Time Measurements

Procedure:

1) Open the DataStudio software on the lab computer and select "Create Experiment."
2) Click on "Experiment" at the top of the screen and select "New Empty Data Table."
3) Try to stop the stop watch as close to *3 seconds* as possible.
4) Enter the actual value in the "X" column of the table.
5) Now try to stop the stop watch at *3 seconds again*, but this time with your eyes closed!
6) Enter the actual value obtained with your eyes closed in the "Y" column of the table.
7) Repeat this process 10-12 times, letting each lab partner have several turns.
8) Be very careful to enter the eyes open and the eyes closed data into the "X" and "Y" columns, respectively.
9) Select "mean" and "standard deviation" from the "Σ" drop-down at the top of the table.
10) Verify that the calculated values for "mean" and "standard deviation" appear at the bottom of the table.
11) Click on "File" at the top of the screen and "Print" out a copy of this table for each person in your group.
12) Record your average (mean) and standard deviation values with correct units and significant figures below:

Time Measurement Results:	Results With Eyes Open	Results With Eyes Closed
Average Time Measurement		
Measurement Standard Deviation		

Recall from the "Data Analysis" lab last week that measurements can be characterized in terms of accuracy, which is represented here by the average (or "mean") values obtained in each case, and precision, which is represented here by the values obtained for standard deviation (or "spread") in each case.

Questions:

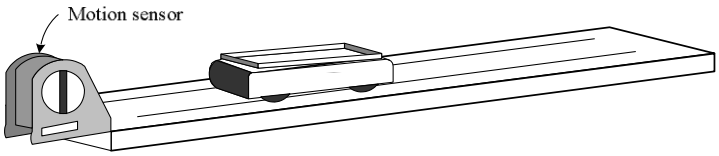
1) In which case, eyes open or eyes closed (circle one), were your results more accurate? Justify your answer.

2) In which case, eyes open or eyes closed (circle one), were your results more precise? Justify your answer.

3) For the eyes open case only, calculate % error using the average as the experimental value and exactly *3 s* as the accepted value. Show your work in the space below.

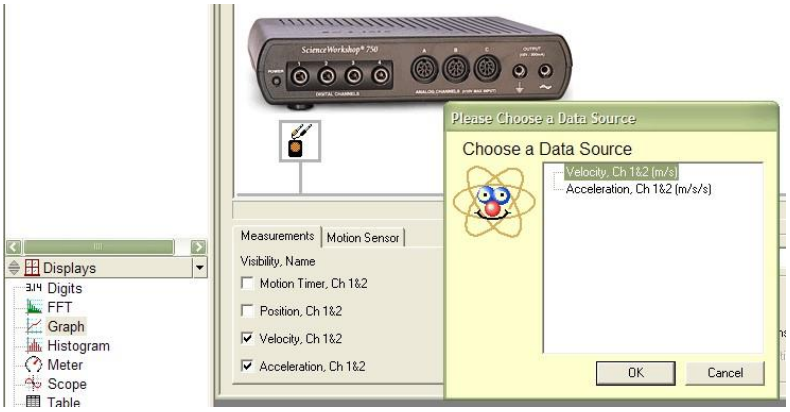
4) Explain whether or not your eyes open results are *valid* by comparing your % error and standard deviation.

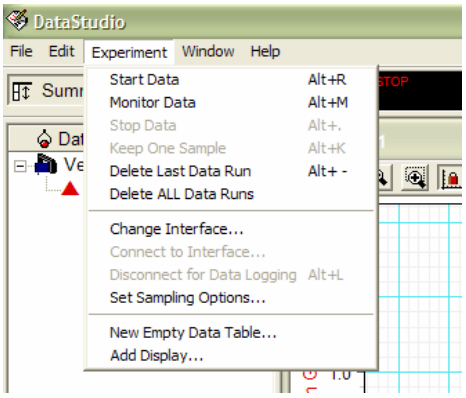
2. *Position, Velocity, and Acceleration*



Procedure:

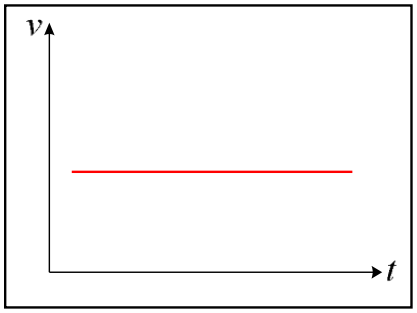
1) Set up the track, cart, and motion sensor as shown.
2) Close the DataStudio application, then re-open it and select "Create Experiment" on the pop-up window.
3) Click on the appropriate channel on the computer image of the interface where the sensor will be attached, choose "motion sensor" in the drop-down menu.
4) Plug the motion sensor leads into the appropriate channels on the interface and verify that the Position, Velocity, and Acceleration boxes are all checked. Click "OK" and select "Narrow" on top of sensor.

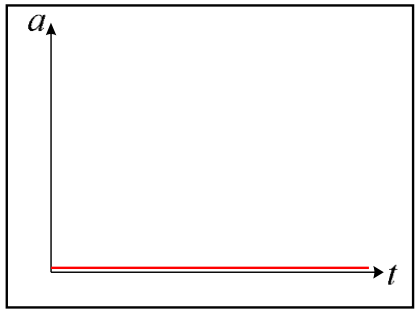


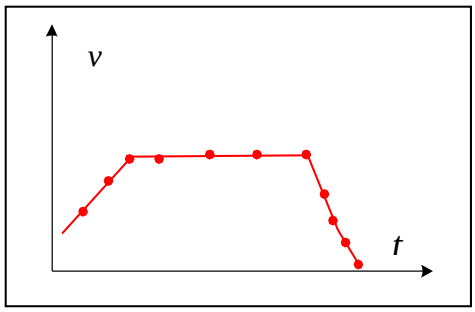


5) Double-click "Graph" from the "Displays" menu and select "Position" as the data source. Then maximize the graph window to fill the screen and drag the "Velocity" and "Acceleration" from the "Data" menu at the top left of the screen onto the bottom of the "Position vs. Time" graph. You should now have all 3 of these graphs showing on the screen: position vs. time, velocity vs. time, and acceleration vs. time. If you do not have all 3, stop now and ask the TA for assistance with setting up your graphs. Be careful not to drag anything onto the time axis at the bottom of your graph, as this will replace time as the independent variable on the graph.
6) Click "Start" in DataStudio and move your cart along the track between 20 cm and 100 cm. You should see graphical representations of your cart's position, velocity, and acceleration on these graphs as it moves.
7) Take a minute to familiarize yourself with how this works and then click "Stop" in DataStudio.
   Note: you can grab the graph axes when the mouse appears as a hand and move the entire plot around or grab the numbers along the vertical or horizontal axes when the mouse looks like a squiggly line to adjust the scale shown on the screen in order to get a better view of your data. You will most likely need to do both of these things before you print out most graphs in this lab, so practice these basic functions now.
8) Click "Experiment" and select "Delete ALL Data Runs" as shown in the illustration above and to the right. This should remove all data from your 3 graphs without removing the graphs themselves.
9) Place the cart at about 50 cm on the track, click "Start", wait several seconds, and then click "Stop."
10) Adjust the location and scale of the graphs as described in 7 above to clearly show the values on all 3 graphs.
11) Print a copy of this data for each member of the group, and then delete this data as described in 8 above.
12) Click "Start" again and move your cart in front of the sensor until you get a nice, flat "plateau" on the velocity graph, which will happen when you move your cart away from the sensor with a *constant velocity*.
13) It may take several minutes to get a good "plateau." Note: this is easier if you do not move your cart too fast.
14) Zoom in on that region of all 3 graphs, as above, and print a copy for each person in your lab group.

Note: your graphs should look similar to those shown below: the first 2 diagrams illustrate the *expected* shape of your velocity and acceleration graphs for both cases (zero and non-zero) of constant velocity; the 3rd one depicts what your actual graph in DataStudio should look like once you have managed to get a nice plateau and correctly zoomed in on it by adjusting the location and scale of your graph, as in 7 above.

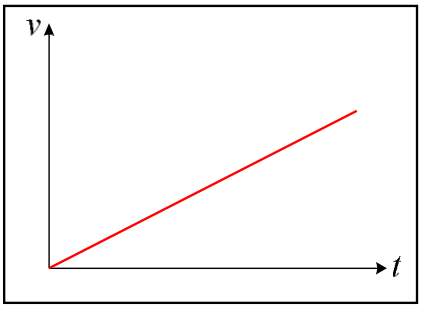


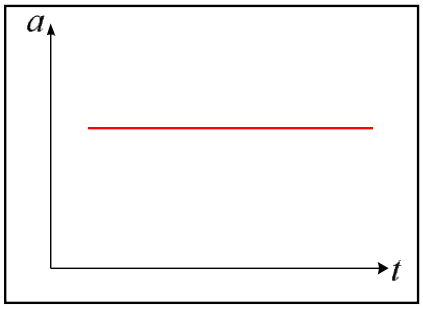


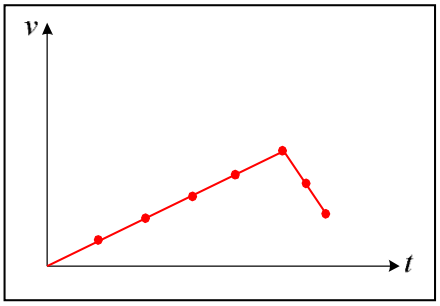


15) Print your graphs for constant velocity, and <u>then</u> delete this data as described in 8 above.

16) Click "Start" again and move your cart in front of the sensor until you get a straight "hill" on the velocity graph, which will happen when you move your hand away from the sensor with *constant acceleration*. Your graphs should look similar to those shown below for this case:

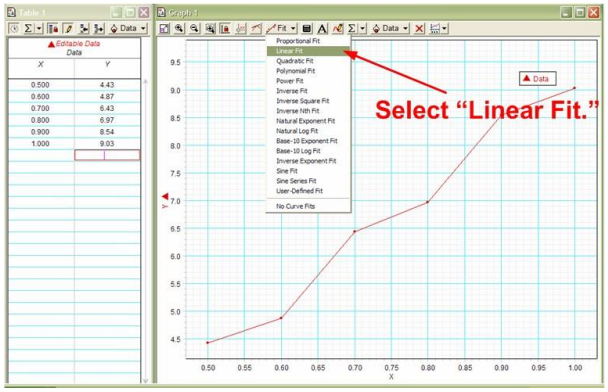


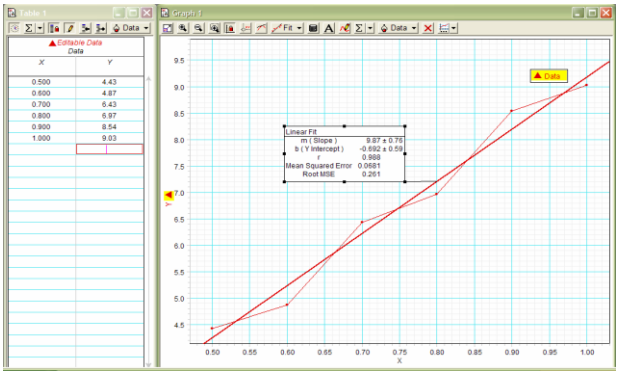




17) Once you achieve a "hill" that is straight, zoom in on it so that it is clear like the one presented in the figure above, and zoom in on the position and acceleration graphs at this point as well.

18) Highlight the straight section of the velocity graph (be careful not to include any part other than the straight portion of the curve), then select "Linear" from the "Fit" drop-down menu as shown to the left below.

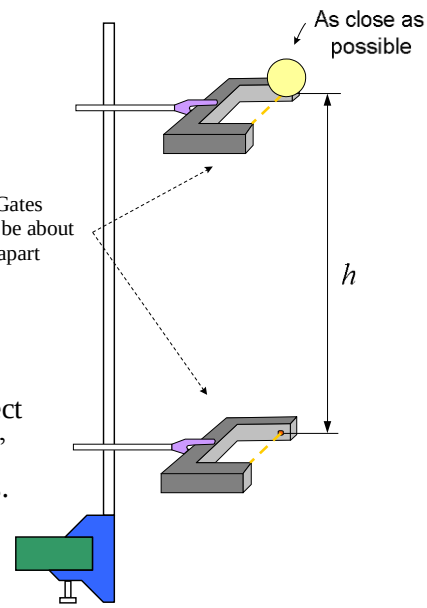




<u>Question</u>:

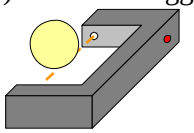
Is the "m (slope)" value from the box that appears on the graph, as shown to the right above, close to the acceleration value estimated from the same time interval of your acceleration graph? Why or why not?

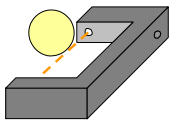
3. *Gravitational Acceleration a_g (Lab Report)*



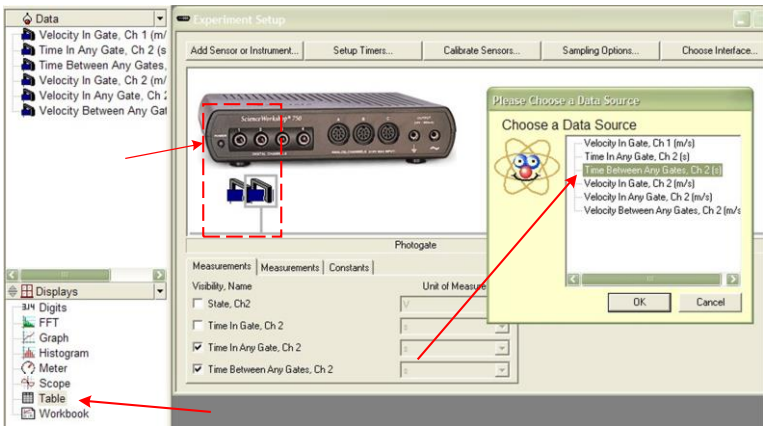
Procedure:

1) Verify that your equipment is set up as shown here in the diagram to the right.
2) Open DataStudio, create an experiment, select a photo gate for the first 2 digital channels, click on "Table" in the "Displays" menu and select "Time Between Any Gates" for the data source, as in the screenshot below.
3) Practice triggering the photo gate with zero initial velocity as follows:





When you interrupt the infrared beam and the red light turns on, as shown to the left, you have triggered the photo gate. In order to implement the $\boldsymbol{v_i = 0}$ condition in the introduction above, lift the object just above the beam so that the light turns off again, then click "Start" and then release the object so that it falls straight through both gates. This will give you the time it takes the object to fall the distance *h*.



4) Use the bubble-level to ensure the photo gates are level and the meter stick to measure the distance ***h*** between the same location on both of the photo gates. Record this value below with correct significant figures and units.
5) Drop the object through the photo gates as described above, click "Stop," and record the "Elapsed Time" as the time ***t*** in the table below.
6) Move the top photo gate down 2 – 3 cm and repeat steps 4 – 6 until columns 1 and 2 in the table below are full.
7) Calculate $\boldsymbol{v_f = 2h \div t}$ for each value of ***h*** and ***t*** in the table and record your values for $\boldsymbol{v_f}$ in column 3 of the table.

Fall Distance, ***h*** (meter stick)	Fall Time, ***t*** (photo gates)	Final Velocity, $\boldsymbol{v_f = 2h \div t}$

8) Close the DataStudio software, then re-open it and select "Enter Data" on the opening screen.

9) Enter your results for $\boldsymbol{t}$ from column 2 above into the "X" column of the new "Data" table and your results for $\boldsymbol{v_f}$ from column 3 into the corresponding "Y" column of the new table. You should see a graph of this data.

10) Select "Linear Fit" from the "Fit" drop-down menu above the graph, as illustrated on page 4 above.

11) Record your values for "m (slope)" and "Mean Squared Error" from the box that appears on the graph as $\boldsymbol{a_g}$ and $\Delta\boldsymbol{a_g}$, respectively with units below:

$\boldsymbol{a_g} \pm \Delta\boldsymbol{a_g}$ = _____ ± _____ ( )

Note: A device's least count, standard deviation, or mean squared error can represent measurement uncertainty.

12) Calculate the percent error between the accepted value $\boldsymbol{g}$ = 9.807 $^{m}/_{s}{}^{2}$ and your measured value $\boldsymbol{a_g}$ below:

% Error = $\left|\frac{measured - accepted}{accepted}\right| * 100\% =$ _____ = _____ %

<u>Questions</u>:

1) Explain why the slope of the final velocity vs. time graph is expected to equal the gravitational acceleration.

2) By comparing your percent error in $\boldsymbol{g}$ to $\Delta\boldsymbol{a_g}$, determine whether this method for finding $\boldsymbol{g}$ is valid. Why?

3) Was your calculated value for gravitational acceleration $\boldsymbol{a_g}$ higher or lower than the accepted value $\boldsymbol{g}$? Explain why below in terms of the measurements that you made in lab today.