KINEMATICS: THE BOUNCING BALL

Name:____________________________________ Section:__________

Partner:____________________________________ Date:__________

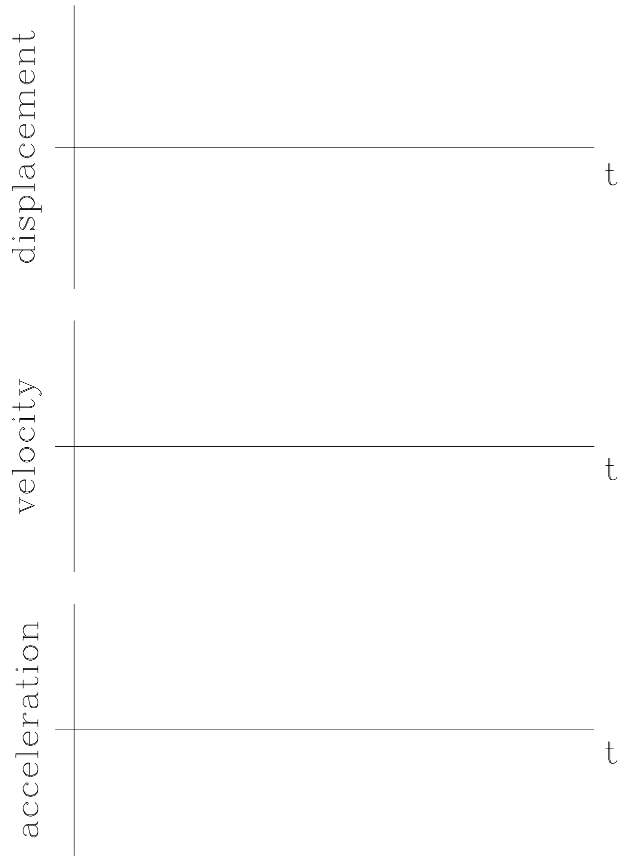
PURPOSE: To understand the graphical relationships between displacement, velocity and acceleration: slopes and derivatives, areas and integrals.

APPARATUS: PC, Universal Lab Interface, ultrasonic ranger, balls

PROCEDURE: In this lab you will use a computer program, `LoggerPro` to analyze the one-dimensional motion of a bouncing ball.

Part I: Adjust the settings for `LoggerPro` so that a plot of displacement vs. time will be displayed on the computer screen. Set the calibration of the distance probe (ranger) so that distance away is negative and make an offset about -1.2 m, such that the floor level is registered as about zero. Set the data collection rate to 40 Hz, and averaging to 7 points. Start by taking data for a bouncing golf ball using the Sonic Ranger. Drop the ball from the height of the table on which the ranger stand rests. REMEMBER: You are studying one dimensional motion so the ball must be bouncing vertically <u>under</u> the ranger. Do not let the ball get any closer than 1/2 m from the ranger or it will not function properly. You will need to get at least two good bounces in your data. Be sure that `LoggerPro` is set so that up is the positive direction. When you are satisfied with your data, transfer it from DATA A to DATA B (this prevents it from being lost if you restart data taking).

A. On the first graph on the following page, sketch the way the displacement vs. time plot appears on the screen for **<u>two bounces only</u>**. Label three times on the graph with the letters U (for up), T (for top) and D (for down). U is a time just after the bounce, T is the top of the trajectory and D is a time just before the next bounce. Bring dotted lines straight down through all three graphs at U, T, and D. Finally, draw the velocity and acceleration curves to <u>predict</u> what the corresponding velocity and acceleration graphs will look like.



B. For the points U, T, and D, explain how you deduced the velocity and acceleration from the displacement curve.

U:

T:

D:

C. Now change the `LoggerPro` settings to display the velocity and acceleration curves in addition to the displacement. Compare your predictions with these curves. If you made an error, be sure to understand why.

D. Focus on the interval T to D, during which the ball drops from the top of its trajectory until just before it hits the floor, and answer the following questions (remember up is positive):

What about your velocity graph shows that the motion was away from the detector?

What about your velocity graph shows that the ball was speeding up? How would a graph of motion with a constant velocity differ?

Is the acceleration positive or negative when the ball is speeding up? What is the sign of the velocity while the ball is speeding up? **What can you conclude about the relationship between the directions of the velocity and acceleration vectors when the ball is speeding up?**

E. Now focus on the interval from U to T, just after the bounce until the ball reaches the top of its trajectory, and answer the following questions:

What about your velocity graph shows that the motion was toward the detector?

What about your velocity graph shows that the ball was slowing down. Is the acceleration positive or negative when the ball is slowing down? What is the sign of the velocity while the ball is slowing down? **What can you conclude about the relationship between the directions of the velocity and acceleration vectors when the ball is slowing down?**

F. Draw in the acceleration vectors for the following two cases:

G. What is the velocity of the ball at its highest point, T?

Is the acceleration at this point positive, negative or zero?

Explain the observed sign of the acceleration at T. (Hint: is the ball slowing down or speeding up just before it reaches the top? Just after? What are the directions of the velocity vector at these times?)

Part II. Now you will be using the `LoggerPro` analysis tools to analyze your data.

A. Select the TANGENT from the ANALYZE pull-down menu. Measure the tangent to the displacement vs. time graph at the points U, T, and D. Do not use points very close to the bounce; the slope there is not calculated correctly due to the averaging.

Tangent at U ______________ Tangent at T ______________

Tangent at D ______________

In what units are these slopes expressed?

What does the slope correspond to physically?

Compare your results to the accompanying velocity data. Do they agree?

B. Measure the slope of the velocity vs. time graph at the points U, T, and D.

Tangent at U ______________ Tangent at T ______________

Tangent at D ______________

In what units are these slopes expressed?

What does the slope correspond to physically? Compare the measured slopes with the textbook value for the acceleration of gravity.

Compare your results to the data on the acceleration vs. time graph. Do they agree?

C. How would your velocity and acceleration graphs differ if this experiment were performed on the moon?

D. Sketch an expanded scale graph that predicts the acceleration for the time interval from shortly before the ball hits the floor to slightly afterwards. Explain your reasoning in making this sketch. Can you observe this effect on the computer plot of acceleration for the golf ball? When the program calculates the velocity and acceleration from the displacement data, it averages over a few neighboring points to smooth out any variations due to small measurement errors. This averaging will also smooth out any really sudden changes such as when the ball hits the floor. Is the width of the acceleration peak consistent with the data rate and averaging you used (show your calculation).

E. Using the "Integrate" function of `LoggerPro`, calculate the area under the velocity vs. time graph from point U to T. Do not use points near the bounce, since the averaging will give a misleading value.

$x_U =$ __________ $x_T =$ __________

area under curve = _______________

What are the units of this "area"? What does this area correspond to physically?

Compare your results to the distance data, do they agree?

What would you expect this "area" to be equal to for the entire bounce? Explain and check your prediction.

F. Now use the integrate function to calculate the "area" under the acceleration vs. time graph from U to D. Again, stay away from the points near the bounce.

$v_U =$ __________ $v_T =$ __________

area under curve = _______________

What are the units of this "area"? What does this area correspond to physically?

Compare your results to the velocity data, do they agree?

Part III. Set up an `Excel` spreadsheet to calculate displacement vs. time for the golf ball for the time interval between the first and second bounces. Rather than use the standard kinematic formulae for constant acceleration, you should perform a numerical integration. Begin at a point after the bounce when the calculated acceleration is about $-9.8\ \mathrm{m\,s^{-2}}$ (*i.e.*, after the averaging no longer includes points before the bounce) and end before the next bounce before the acceleration starts changing to positive. Copy the appropriate golf ball data from `LoggerPro` and paste it into the spreadsheet. In the first row set the calculated position and velocity to the actual values. The new velocity can be approximated by $v_1 = v_0 + a\Delta t$. The new position is then $x_1 = x_0 + \Delta t(v_1 + v_0)/2$. These formulae can be copied down to give the velocity and position at later times. Use `Excel` to plot the displacement vs. time data and your calculation on the same graph. Print this graph for your report. Discuss the agreement or disagreement between the two curves.

Part IV. Take one coffee filter and let it drop under the motion detector. You should find that very quickly the velocity becomes nearly constant, *i.e.*, it reaches terminal velocity. Record this velocity. Repeat for 2, 3, and 4 filters stacked together. Plot mass (in units of coffee filters, *i.e.*, one filter has mass = 1) vs.

terminal velocity. Assume this is described by the relationship $m = k(v_{\text{term}})^n$. What is your best estimate for n (assume n is an integer)? Does the fact that terminal velocity increases with mass mean that air resistance decreases for a more massive object? Why don't you see much effect from air resistance for the golf ball? For your report, type a paragraph or two in which you describe the experiment and which includes the answers to the above questions.

Part V. **Optional** You may find it interesting to do the following much more challenging calculation: Your calculation in Part III assumes that the acceleration is constant. If there is drag – friction due to the air – the acceleration isn't constant. Stokes' Law tells us the drag force is proportional to the velocity (provided the velocity isn't too large). Then by Newton's Second Law, the acceleration is also proportional to the velocity. Calculate the displacement vs. time assuming that $a = g + kv$ where k is a constant. Plot on one graph the displacement vs. time curves for the two cases – drag and no drag. Explore the effect of changing the value of k. For your report print one graph using a large enough value for k that you can see a difference. Be careful. The equations you used in Part III cannot be used directly since the acceleration is not constant. You can easily perform a numerical integration of the equations using a spread sheet, using the same equations you used before, but now acceleration will need to be modified each time as well. Once you've done it for drag proportional to v, try it for drag proportional to v^2. Plot the different cases.