

Name: _____ Book: ____ Period: ____ Due Date: _____ Lab Partners: _____

U NIFORMLY ACCELERATED MOTION

Purpose: To investigate experimentally and graphically the properties of uniformly accelerated motion.

Procedure:

1. Elevate the air track on one end with a wooden block. Put a neat and straight paper flag on the cart.
2. Measure the width of the paper flag and record the paper flag width as **L** in Table #1.
3. Measure the location of the front of the cart when held at the top of the rail. Record this as x_{TOP} in Table #1.
4. Place photogate #1 so the front of the cart is exactly at the 25-cm mark as its paper flag just enters the photogate nearest the elevated end of the air track. Record this position as x_i in Data Table #1.
5. Place the second photogate exactly 10.0 cm below the first photogate (at the 35 cm mark for the first trial; as always this is based on the position of the front of the cart).
6. Open the **LoggerPro3.5 (Local)** in your physics folder.
7. Once in the program, choose File → Open, and open the experiment file "Uniformly Accelerated Motion" in your H:\VcDistribution folder. Once opened, save this file in the root directory of your network H:\ drive.
8. The computer is now ready to run your acceleration trials. You will be measuring three times:

Δ Time 1 - *the time interval during which the paper flag is blocking photogate #1,*
 Δ Time 2 - *the time interval during which the paper flag is between the two gates, and*
 Δ Time 3 - *the time interval during which the paper flag is blocking photogate #2.*

Click on the green Data Collection button.

9. Run three trials to verify the consistency of your results. Carefully release the cart from exactly the same location at the highest point on the track for each trial. The computer will measure the three times for each trial and display across the screen. Times from consecutive trials will appear below the earlier trials.
10. Click the red Data Collection button to stop collecting data. Record the three times from a representative trial into Table #1.
11. Move photogate #2 exactly 10.0 cm further down the track and repeat steps #8 through #10.
12. Continue until you fill Data Table #1.
13. Be sure to note in the appropriate places the width of the paper flag, **L**, the location of the front of the cart when is sitting at the highest point on the track, x_{TOP} , and the position of the first photogate, x_i .

DATA TABLE #1

Width of paper flag: L = _____ m

Position of the front of the cart sitting at the top of the rail: x_{TOP} = _____ m

Position of the front of the cart when it first enters Gate #1: x_i = _____ m

Displacement between the position of the front of the cart as it enters photogate #1, x_i , and the position of the front of the cart as it sits at the top of the rail, x_{TOP} , ready to be released: $x_{TOP} - x_i$ = _____ m

$x_f - x_i = \text{displacement}$ (meters)	$\Delta\text{Time 1}$ (seconds)	$\Delta\text{Time 2}$ (seconds)	$\Delta\text{Time 3}$ (seconds)
~~~~~	~~~~~	~~~~~	~~~~~
0.350 – 0.250 = 0.100	_____	_____	_____
0.450 – 0.250 = 0.200	_____	_____	_____
0.550 – 0.250 = 0.300	_____	_____	_____
0.650 – 0.250 = 0.400	_____	_____	_____
0.750 – 0.250 = 0.500	_____	_____	_____
0.850 – 0.250 = 0.600	_____	_____	_____
0.950 – 0.250 = 0.700	_____	_____	_____
1.050 – 0.250 = 0.800	_____	_____	_____
1.150 – 0.250 = 0.900	_____	_____	_____
1.250 – 0.250 = 1.000	_____	_____	_____
1.350 – 0.250 = 1.100	_____	_____	_____
1.450 – 0.250 = 1.200	_____	_____	_____
1.550 – 0.250 = 1.300	_____	_____	_____

Average =  $\Delta\text{Time } 1_{AVG}$  = _____ s; Use  $\Delta\text{Time } 1_{AVG}$  for all calculations.

**Analysis:**

1. Estimate the instantaneous initial velocity ( $v_i$ ) of the cart as it passes through photogate #1. You can obtain your estimate of this velocity by dividing the width of the paper flag by the average value of  $\Delta\text{Time}1$ .

$$V_{i-meas} = L / \Delta\text{Time } 1_{AVG} = \underline{\hspace{2cm}} / \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \text{ m/s}$$

2. Calculate the Elapsed time,  $t$ , it took for the cart to move from the point where it first enters photogate #1 to the point where it first enters photogate #2. This will be the sum of ( $\Delta\text{Time}1_{AVG} + \Delta\text{Time}2$ ). Record the Elapsed time for each run in Table #2.

3. We also need to know the final instantaneous velocity of the cart as it passes through photogate #2. Calculate  $v_f$  by dividing the width of the paper flag by  $\Delta\text{Time}3$ . Record the final velocities in Table #2.

*(In determining  $v_f$  and  $v_i$ , you are actually making measurements of the average velocity over the width of the paper flag. Because the paper flag is small, the average velocity over the width of the paper flag is very nearly equal to the instantaneous velocity at the photogate position. This approximation introduces a small, if unavoidable, uncertainty into your results, however. )*

**TABLE #2**

Position (m) ( $x_f$ )	Displacement (m) ( $x_f - x_i$ )	Elapsed time (s) $t = \Delta\text{Time}1_{AVG} + \Delta\text{Time} 2$	Final Velocity (m/s) $v_f = L / \Delta\text{Time}3$
0.350	0.100	_____	_____
0.450	0.200	_____	_____
0.550	0.300	_____	_____
0.650	0.400	_____	_____
0.750	0.500	_____	_____
0.850	0.600	_____	_____
0.950	0.700	_____	_____
1.050	0.800	_____	_____
1.150	0.900	_____	_____
1.250	1.000	_____	_____
1.350	1.100	_____	_____
1.450	1.200	_____	_____
1.550	1.300	_____	_____

### Analysis: continued

4. Construct graph three graphs. First, construct Graph#1 by hand on the graph paper provided. Find the slope and the intercept of the best straight line through the data points. Then use **LoggerPro3.5** to construct Graph#1, Graph #2 and Graph #3. Use the Curve fit option of **LoggerPro3.5** to find the best-fit parameters from each of these graphs, as well.

#### 4A - Graph#1 (by hand) and Graph#1 (LP3)

4A1. Title: **Final Velocity vs. Elapsed time**. Be sure to include Graph #1 and your name in the text box.

4A2. Label the vertical axis **Velocity**. Units: **m/sec**.

4A3. Label the horizontal axis **time**: Units: **seconds**.

4A4. Plot each data point from Table #2. Force the lower left corner of the frame to be at ( -2.0, 0.0 ).

4A5. The appropriate plot is a straight line. Determine the best fit for this line using a ruler on the hand-made graph and the **linear** function under the curve fit menu of **LoggerPro3.5**.

4A6. The y-intercept of the line can be determined from both graphs. This is the initial velocity ( $v_i$ ) at time  $t_i$ .

**b** (by hand) =  $v_i$  (by hand) = _____ m/s; **b** (LP3) =  $v_i$  (LP3) = _____ m/s

4A7. The slope of the line is the acceleration.

**m** (by hand) = **a** (by hand) = _____ m/s²; **m** (LP3) = **a** (LP3) = _____ m/s²

4A8. The 2nd equation of motion.

i) The general form of the 2nd equation of motion is:  $v_f = v_i + a t$

ii) The specific equation of motion is obtained from your theoretical line. It will have a form something like this (*substitute the actual values found on your graph*):

$$y = b + m * x$$

$$v_f = v_i + a t \quad (\text{For example } v_f = 0.342 \text{ m/sec} + (2.11 \text{ m/sec}^2) t)$$

The specific equation will be the same equation, but with your numbers filled in for  $v_i$  and  $a$ .

Write this equation based on the values of  $v_i$  and  $a$  obtained from the linear fit to your data:

Equation of motion =  $v_f = \frac{\text{_____ m/s}}{v_i \text{ (LP3)}} + \frac{\text{_____ m/s}^2}{a \text{ (LP3)}} \cdot t$

4A9. Compare the reference value of  $v_{i-meas}$  obtained in step 1 of the analysis with the graphically estimated value obtained from **LoggerPro3.5** in step A6,  $v_f$  (LP3). Assume the value of  $v_i$  found by **LoggerPro3.5** is the true value. Calculate the %Uncertainty in the graphically measured value of  $v_{i-meas}$ .

%Uncertainty in  $v_{i-meas}$  = _____ %

4A10. Set  $v_f$  equal to zero and solve for the time when the velocity was zero. This will be a negative time because the velocity was zero before the clock started, ie before time  $t_i$ . This time tells you when the cart must have started moving (*the time it was released*) so that it could arrive at photogate#1 at time  $t_i = 0.000$  s.

$0 = v_i \text{ (LP3)} + a * t_{TOP}$ , therefore,  $t_{TOP} = -v_i \text{ (LP3)} / a \text{ (LP3)}$

$t_{TOP}$  = time the cart was released = time at which  $v_f$  was zero = _____ s

**4B - Graph#2 (LP3)**

- 4B1. Title: **Displacement vs. Elapsed time**. Be sure to include Graph #2 and your name in the text box.
- 4B2. Label the vertical axis: **Displacement** Units: **meters**.
- 4B3. Label the horizontal axis: **time** Units: **seconds** .
- 4B4. Enter the data from Table #2. Force the lower left corner of the graph border to read (-2.0, -0.50).
- 4B5. Your plot is a parabola opening upward. Find the best-fit curve using the *quadratic* function.
- 4B6. The computer will offer you a quadratic equation of the form  $y = A \cdot x^2 + B \cdot x + C$ , where x is the time. Select the Quadratic Function from the list. Then use the Define Function button to set **C** = 0.

**C** must be set to zero before attempting the fit. (*We are plotting displacement,  $x_f - x_i$ , so the curve must go through the origin..*)

**B** is the initial velocity of the cart (*the velocity at the position associated with the first photogate*)

**A** = coefficient of  $t^2 = \frac{1}{2} a$  (one-half the acceleration of the cart)

**B** = _____ m/sec =  $v_i$

**A** = _____ =  $a / 2$  therefore,  $2A =$  _____ m/sec² =  $a$

4B7. The 1st equation of motion.

i) The general form of the 1st equation of motion is:  $x_f = x_i + v_i t + 1/2(a) t^2$

ii) When rearranged to solve for displacement instead of position, it looks like this;

$$x_f - x_i = v_i t + 1/2(a) t^2$$

iii) Write the specific equation from the fit to your theoretical curve. It must have a form like this (*incorporating the actual values found on the graph*);

$$y = B \cdot x + A \cdot x^2$$

$$x_f - x_i = v_i t + \frac{1}{2}(a) t^2$$

(For example  $x_f - 0.25 \text{ m} = 0.220 \text{ m/s } t + \frac{1}{2}(0.191 \text{ m/s}^2) t^2$ )

The specific equation will be the same equation with your numbers filled in for  $x_i$ ,  $v_i$  and  $a$ .

Write this equation based on the values of  $v_i$  and  $a$  obtained from **LoggerPro3.5's** quadratic fit to your data and the value of  $x_i$  noted in Table #1:

$$x_f - \underset{x_i \text{ (Table \#1)}}{\hspace{2cm}} \text{ m} = \underset{v_i}{\hspace{2cm}} \text{ m/s} \bullet t + \frac{1}{2} \bullet \underset{a}{\hspace{2cm}} \text{ m/s}^2 \bullet t^2$$

4B8. Compare the reference value of  $v_i$  obtained in step 1 of the analysis with the graphically estimated value obtained from **LoggerPro3.5** in step 4B7. (*We do not know the true value of  $v_i$ . In Analysis step 1 we have an estimate of the true value. We can use that as our reference value. Then we can calculate the %Uncertainty in the graphically estimated value of  $v_i$  obtained in step 4B7.*)

%Uncertainty in  $v_i =$  _____ %

4B9. The **Vertex** - The vertex of a parabola is the lowest (or highest) point on the parabola. It represents the point (in time and space) when the **velocity is zero**. The velocity was zero for a moment as the cart was released at the top of the rail. From your *Displacement vs. Elapsed time* graph estimate the time and displacement at the vertex. Use the *Analyze-Interpolate* menu option in *LoggerPro3.5* to locate the lowest point on the parabola. This point is known as the vertex of the parabola.

Record the coordinates of the vertex here. Both will be negative numbers (*negative time and negative displacement*). Coordinates of vertex:

$$(\Delta t_{\text{vert}}, \Delta x_{\text{vert}}) = (\text{_____s}, \text{_____m}) = (\Delta t_{\text{TOP}}, \Delta x_{\text{TOP}}) = (\Delta t_{\text{TOP}}, x_{\text{TOP}} - x_i)$$

The coordinates of the vertex are:  $\Delta t_{\text{vert}}$  (*the time interval between the cart's release and its arrival at photogate#1*) and  $\Delta x_{\text{vert}}$  (*the displacement of the cart from the point where it enters photogate #1 back to the point of its release*).

Earlier you found the displacement of the cart at the vertex,  $\Delta x_{\text{vert}} = (x_{\text{TOP}} - x_i)$ . You also know  $x_i$ , the position of the cart at time  $t_i$ , as it is about to enter photogate #1. Now solve for the position of the cart at the top of the rail, i.e. for its position at the vertex. This position will be a positive number (*There are no negative positions on the rail*).

$$\Delta x_{\text{vert}} = (x_{\text{TOP}} - x_i), \text{ therefore, } x_{\text{TOP}} = \Delta x_{\text{vert}} + x_i.$$

$$x_{\text{TOP}} = \text{position of the cart at the vertex} = \text{_____ m}$$

Because we do not know the true times on the clock, we use an assumed clock that starts at zero at the moment when the cart enters photogate #1. On that assumed clock, the vertex time-coordinate,  $\Delta t_{\text{vert}}$ , measures the value of  $t_{\text{TOP}} =$  the time on the clock when the cart was released.  $t_{\text{TOP}}$  will be a negative number since it refers to a time on the clock before time zero.

$$\Delta t_{\text{vert}} = t_{\text{TOP}} - t_i = t_{\text{TOP}} - t_{\text{Gate\#1}} = t_{\text{TOP}} - 0 = t_{\text{TOP}} = \text{_____ s}$$

How do we know the velocity is zero at the vertex (*at  $x_{\text{TOP}}$ ; at the release point*)?

- i) _____
- ii) _____

4B10. The **Vertex** again - You recorded the starting position of the front of the cart at the top of the rail, at position  $x_{\text{TOP}}$ , in Table #1. You can locate  $x_{\text{TOP}}$  independently by finding the vertex. The x-position of the vertex is  $x_{\text{TOP}}$ . Enter both your initial observation of  $x_{\text{TOP}}$  and the estimate of  $x_{\text{TOP}}$  from the vertex here.

The True (observed) position at the top =  $x_{\text{TOP}} =$  _____ m (Data Table #1)

Graphically Estimated position at the top =  $x_{\text{TOP}} =$  _____ m (from question 4B9)

Does the true position at the top,  $x_{\text{TOP}}$ , agree with the graphical estimate from the vertex on **Graph 2**?

Circle one (Yes) (No)

What is the %Uncertainty in  $x_{\text{TOP}}$ ? Assume the reference position is the one you recorded in Data Table #1.

%Uncertainty: _____

**4C - Graph#3 (LP3)**

- 4C1. Title: **Final Position vs. Elapsed time**. Be sure to include Graph #3 and your name in the text box.
- 4C2. Label the vertical axis: **Final Position** Units: **meters**.
- 4C3. Label the horizontal axis: **time** Units: **seconds**.
- 4C4. Enter the data from Table #2. Force the lower left corner of the graph border to read (-2.0, 0.0).
- 4C5. Your plot is a parabola opening upward. Find the best-fit curve using the *quadratic* function.
- 4C6. The computer will offer you a quadratic equation of the form  $y = A \cdot x^2 + B \cdot x + C$ , where x is the time. Select the Quadratic Function from the list.

**C** is the initial position,  $x_i$ .

**B** is the initial velocity of the cart (*the velocity at the position associated with the first photogate*)

**A** = coefficient of  $t^2 = \frac{1}{2} a$  (one-half the acceleration of the cart)

**C** = _____ m =  $x_i$

**B** = _____ m/sec =  $v_i$

**A** = _____ =  $a / 2$  therefore,  $2A =$  _____ m/sec² =  $a$

4C7. The 1st equation of motion.

i) The general form of the 1st equation of motion is:  $x_f = x_i + v_i t + \frac{1}{2} (a) t^2$

ii) Write the specific equation from the theoretical fit to your data. It must have a form like this (*incorporating the actual values reported by curve-fit.*);

$$y = C + B \cdot x + A \cdot x^2$$

$$x_f = x_i + v_i t + \frac{1}{2} (a) t^2$$

(For example  $x_f = 0.25 \text{ m} + 0.220 \text{ m/s } t + \frac{1}{2} (0.191 \text{ m/s}^2) t^2$ )

The specific equation will be the same equation with your numbers filled in for  $x_i$ ,  $v_i$  and  $a$ .

Write this equation based on the values of  $x_i$ ,  $v_i$  and  $a$  obtained from **LoggerPro3.5's** quadratic fit to your data:

$$x_f = \frac{\quad}{x_i} \text{ m} + \frac{\quad}{v_i} \text{ m/s} \bullet t + \frac{1}{2} \bullet \frac{\quad}{a} \text{ m/s}^2 \bullet t^2$$

4C8. Compare the reference value of  $x_i$  from Data Table #1 with the graphically estimated value obtained from **LoggerPro3.5** in step 4C7. (*We know the true value of  $x_i$  because we set the first photogate's position. We will use that as our reference value. Then we can calculate the %Uncertainty in the graphically estimated value of  $x_i$  obtained in step 4C7.*)

%Uncertainty in  $x_i =$  _____ %

**CHECKLIST FOR A CORRECTLY DRAWN GRAPH** (when working by hand)

Provided as a thoughtful guide for those who are now lucky enough to use **LoggerPro3.5** instead of having to draw all their graphs by hand. Much of this information still applies when using a program like **LoggerPro3.5** so take these tips and suggestions to heart when you try to pretty up your graphs. Keep it simple.

_____ Do you have a title? (This will always be *vertical axis* vs. *horizontal axis* and should include your name and the name of the graph – Lab 4-Graph#1 or Lab 4-Graph#2 in this lab.)

_____ Are your axes correctly labeled? (e.g., Average Velocity, Time, Distance, etc.)

_____ Are the independent and dependent variables plotted on the proper axes? The independent variable should always be plotted along the horizontal axis (time for example), and the dependent variable should be along the vertical axis. [Time is almost always the independent variable if it is one of the known variables.]

_____ Are the units of the axes indicated? (i.e., meters, seconds, m/sec, etc.)

_____ Have you chosen a size for your axes so that the data points fill most of the page? (Graphs that are crowded in the corner are hard to interpret.)

_____ Can you justify using (0,0) as a data point? If so, then add it to the data set.

_____ Did you put numbers along both axes?

_____ Did you mark your data points with small x's, o's or another distinctive symbol?

_____ Did you draw the straight line or smooth curve that best fits the data points? (This is the most important skill in graphing, because it is a form of analysis.)

_____ **Never connect the dots.** Draw only theoretical lines through the data, not through individual data points. It's OK for children draw connect-the-dot pictures, but not for a scientific report. Each of your data points is only approximate. There is some error or uncertainty in each point. By constructing the best straight line or the best smooth curve through the "heart" of the points, you are taking this uncertainty into account. If you connect the dots you are saying, in effect, that every point you plot is true and exact. In math class, you can connect the dots because each point is in fact error free. In science there are errors in every measurement. The distance of a data point from the smooth curve depends on the error or uncertainty in that point relative to the error or uncertainty in the data set taken as a whole. The best line or curve is one way of "looking at" and allowing for error or uncertainty in the data set taken as a whole.