Name: ________________________________ **Book:** ___ **Period:** ___ **Due Date:** __________
Lab Partners: ____

FINDING *AVERAGE VELOCITY* and *AVERAGE ACCELERATION* - WebAssign

General Procedure: (*The x-axis of our coordinate system is along the air track and + **v** is down the hill.*)

1. Place the air track on a block to elevate the single leg support at one end. Use the front of the cart and the indicator on the track, beginning with zero at the high end, to measure positions (x-values) on the track.

2. Place photogates so that the post-it note on the cart first blocks photogate #1 at the point where the front edge of the cart is at ***x*** = 20 cm and place the second photogate where the front edge of the cart is at successive positions of ***x*** = 40 cm, 60 cm, 80 cm, and 100 cm.
3. (*Remember that the front of the cart is used to determine the position of the cart.*)

4. Start ***LoggerPro3.5*** (Local) and open the file **Vavg_and_Aavg_Part_One** on H:\ in VCDistribution.

5. Ask the instructor to check your air track, photogate, and ***LoggerPro3.5*** (Local) setups before you begin.

6. Record your careful measurement of the width of the post-it note **to the nearest tenth of a millimeter**.

7. Practice releasing the cart from the top of the track until you can get consistent times on each set-up.

8. Record the three time intervals in ***Table I***. **ΔTime 1** is the amount of time the post-it note blocks photogate #1, **ΔTime 3** is the amount of time the post-it note blocks photogate #2. **ΔTime 2** measures the amount of time the post-it note is between the two photogates.

Note: The internal clock starts running at the instant you click on the **COLLECT** button in ***LoggerPro3.5*** (Local), but the moment we call t_i = 0.00 s occurs at the moment the cart enters the first photogate.
Note: directions for +displacement, +velocity, and +acceleration are down the slope, parallel to the track.

Post-it-note width = ______________ mm = _______________ meters

Part One - Average Velocity and Average Acceleration

Data Table I: Data

Cart positions-front *Gate1, Gate2 (cm)*	**ΔTime 1** *(sec)*	**ΔTime 2** *(sec)*	**ΔTime 3** *(sec)*
20, 40	_______	_______	_______
20, 60	_______	_______	_______
20, 80	_______	_______	_______
20, 100	_______	_______	_______

Record the average value for **ΔTime 1** below and use that average value to calculate the velocity at the 20 cm photogate in ***Table II*** on page 2. Before you calculate the average be sure your times are consistent.

Average **ΔTime 1** = _______s

Analysis of Data from Part I:

1. Calculate the instantaneous velocity at each photogate position using ***velocity = displacement / Δt***. The displacement will be the post-it width. The time will be time interval during which the photogate was blocked. The instantaneous velocity is ,therefore, v_i = ***post-it width / ΔTime 1*** every time the cart passes by the 20 cm mark, and the instantaneous velocity is v_f = ***post-it width / ΔTime 3*** for the cart as it passes by the positions at 40, 60, 80 and 100 cm. Calculate the velocities and record them in ***Table II***.

Table II: The Instantaneous Velocity at each Cart Position

Cart position *(cm)*	$x_i = 20$ (Gate #1)	$x_f = 40,$ (Gate #2)	$x_f = 60,$ (Gate #2)	$x_f = 80,$ (Gate #2)	$x_f = 100,$ (Gate #2)
Velocity *(m/sec)*	$v_i = v_{20}$ = ________ (Gate #1)	; v_{40} = ________ (Gate #2)	; v_{60} = ________ (Gate #2)	; v_{80} = ________ (Gate #2)	; v_{100} = ________ (Gate #2)

2. Next, calculate the average velocity between the photogates by dividing the displacement, $\Delta x = (x_f - x_i)$, by the time it takes to get from the position where the front of the cart enters photogate #1 to the position where the front of the cart enters photogate #2; that is **Δt** = ΔTime 1 + ΔTime 2. Use the equation

$$v_{AVG} = \textbf{displacement / time} = (x_f - x_i) / (t_f - t_i) = (\Delta x) / \Delta t = (x_f - x_i) / (\Delta\text{Time 1} + \Delta\text{Time 2}).$$

Your instructor will show you why the time interval you need is calculated as **(ΔTime 1 + ΔTime 2)**.

The basic idea comes down to this; a time interval that consists of two consecutive time intervals equals the sum of the two time intervals. Consider three clock times called T_a, T_b, and T_c. When the first interval ends at time T_b and the second interval begins at time T_b, there is no time gap between the two intervals, i.e. they are consecutive intervals. Then, define **ΔTime 1** as $(T_b - T_a)$ and **ΔTime 2** as $(T_c - T_b)$. That makes **ΔTime 1** and **ΔTime 2** consecutive time intervals with no time gap. If we need the larger time interval from T_a to T_c we cannot simply subtract T_a from T_c because we don't know the clock times. All we know are the two consecutive time intervals that completely fill the larger time interval. We can get the difference in those two clock times by adding the two consecutive time intervals:

$$\Delta\textbf{Time 1} + \Delta\textbf{Time 2} = (T_b - T_a) + (T_c - T_b) = (T_b - T_b) + (T_c - T_a) = 0 + (T_c - T_a) = (T_c - T_a)$$

So you see, to get the total time interval we simply add the two consecutive time intervals.

Record the **Δt**'s and the average velocities in ***Table III***. [*Note that (**Δt** = ΔTime 1 + ΔTime 2) is the time interval between the moment the post-it note enters photogate #1 and the moment it enters photogate #2*.]

Table III: Average Velocity between the Cart Positions

Cart Positions *Gate1→Gate2 (cm)*	$\Delta x = (x_f - x_i)$ *(meters)*	**Δt = (ΔTime 1 + ΔTime 2)** *(sec)*	v_{AVG} *(m/sec)*
20.0→40.0	0.200	_______	______
20.0→60.0	0.400	_______	______
20.0→80.0	0.600	_______	______
20.0→100.0	0.800	_______	______

3. As the distance between the cart positions increases how does the average velocity change?

Circle one (Increases) (Decreases) (Constant).

Why would you expect this to be the case? ____

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4. Calculate the average acceleration for the run between the cart positions at 20 cm and 40 cm by using

$$a_{AVG} = (v_f - v_i) / \Delta t = (v_{Gate\ \#2\ at\ 40\ cm} - v_{Gate\ \#1\ at\ 20\ cm}) / \Delta t = (v_{40} - v_{20}) / \Delta t$$

Repeat the analogous calculations for runs between the cart positions 20 cm and 60 cm; 20 cm and 80 cm; and 20 cm and 100 cm. Record the velocity differences, time differences and average accelerations in ***Table IV***.

Table IV: Average Acceleration between the Cart Positions

Photogate positions *Gate1→Gate2 (cm)*	$v_{Gate\ \#2} - v_{Gate\ \#1}$ *(m/sec)*	Δt (from ***Table III***) (sec)	$a_{AVG\ (from\ Gate\ \#1\ to\ Gate\ \#2)}$ *(m/sec²)*
20→40	_______	_______	_______
20→60	_______	_______	_______
20→80	_______	_______	_______
20→100	_______	_______	_______

5. Are your average accelerations changing or constant in ***Table IV***? [*Note: If they are not all approximately constant then either your data or your arithmetic is wrong. "Constant" means they agree on at least the first digit or two in all cases. Check your calculations or repeat the measurements, as necessary.]*

Circle one (Increasing) (Decreasing) (Constant).

Range of acceleration values: Highest = ____________, Lowest = _____________

[Best Estimate of a_{AVG}] = $\left[\Sigma\, a_{AVG\ (from\ Gate\ \#1\ to\ Gate\ \#2)}\right] / 4$ = _______________________ *m/sec²*

6. Why should all of the average accelerations be the same? [*Why are they constant in all trials?*]

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7. In this experiment, and in any situation where acceleration is constant, there is a simple mathematical relationship among the initial and final instantaneous velocities, $\boldsymbol{v}_i$, $\boldsymbol{v}_f$, and the average velocity over the same time interval, $\boldsymbol{v}_{AVG}$. It does not include the time interval, Δt. What is this relationship? State it in the form of an equation solving for $\boldsymbol{v}_{AVG}$. (*You will have to do some guessing and check your own guesses by calculation. You have all the numbers. Guess an equation that includes all three and verify the equality by calculation using your own results from above. You will need this equation during the analysis for Part Two, so you need to get this right. Ask yourself how you generally compute the average of two numbers. If you've been reading the text book you have an advantage over those who have not.*)

$\boldsymbol{v}_{AVG}$ = ____

Think about gravity for a minute. It moves all things down hill. In fact, it accelerates them down hill.

a) What acceleration will gravity impart to an object that is sitting on a horizontal surface?

____

b) What acceleration will gravity impart to an object that is falling straight down?

____

c) Now consider two hills; call them **steep** and **steeper**. If both hills are frictionless, how will the acceleration down the two hills differ, if they do?

Circle one of these three: (Both have same acceleration);

(**Steep** has the higher acceleration);

(**Steeper** has the higher acceleration)

Explain [*Hint: Think in terms of acceleration.]*

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8. You may have heard about Galileo's famous experiment dropping two objects of different mass off the leaning tower of Pisa. In that experiment, both objects released at the same time also hit the ground at the same time. What would you expect to happen to the measured accelerations if you repeated all the trials in Part One with a cart that had twice the mass of the cart you used? Or a cart with ten times the mass?

Part Two - Bounce Timing Trials

General Procedure:

For bounce timing we will look at the clock times, which are usually hidden during data collection. Your instructor will show you how to uncover the hidden columns. (*There is a separate file for you to open, known as* **Vavg_and_Aavg_Part_Two**.) The LabPro starts its internal clock when you click the data collection button with the mouse. Every time a photogate changes its state (from unblocked to blocked or from blocked to unblocked) a time is recorded in this column that is normally hidden.

Make sure that photogate#1 is the only one sitting on the track. You do not need to unplug the second photogate from the LabPro, but you may if your wish. You will push the cart up hill so that it passes through the photogate, comes to a momentary stop without hitting the end of the rail, and then returns down the hill and back through the photogate, where you will catch it. It is like a ball bouncing off the floor. Your hand plays the role of the floor providing the upward force. The force of gravity brings the cart to a halt and returns it to your hand for another push.

In Part One two photogates experienced four changes in it state; four times are recorded in the hidden column.

In the bounce timing experiments one photogate experiences four changes in its state, so four times are again recorded. We will name these in the order they are recorded: Time a, Time b, Time c, and Time d (*keep at least 4 decimal digits after the decimal point*). For each trial record these four times in order across one row of the ***Data Table*** below. From these four times you can calculate the three consecutive time intervals that we will call **ΔTime 1, ΔTime 2,** and **ΔTime 3.**

Data Table (LabPro internal clock time in seconds)

Trial #	Time a *(sec)*	Time b *(sec)*	Time c *(sec)*	Time d *(sec)*
1				
2				
3				
4				
5				

To convert these clock times to time intervals you need to calculate the time differences for each of the three consecutive time intervals; Time a → Time b, Time b → Time c, and Time c → Time d:

ΔTime 1 = Time b – Time a
ΔTime 2 = Time c – Time b
ΔTime 3 = Time d – Time c

These times have meanings similar to the ones you saw in Part One. There you were using two photogates instead of only one. The more significant difference is that in Part Two you are calculating the differences for yourself, whereas in Part One ***LoggerPro3.5*** did the calculations for you.

Calculate the time differences as described above (*keep three decimal digits after the decimal point for all of these time intervals*). Enter the results in ***Table V:***

Table V: Data

Trial #	**ΔTime 1** *(sec)*	**ΔTime 2** *(sec)*	**ΔTime 3** *(sec)*
1			
2			
3			
4			
5			

Analysis of Data in Part II:

1. Calculate the initial velocity (going uphill) and the final velocity (going downhill) through the gates. Enter your results in ***Table VI***.

$v_i = -\textit{post-it width} / \Delta\textit{Time 1}$. $v_f = \textit{post-it width} / \Delta\textit{Time 3}$.

Be sure to indicate that v_i is negative because it is moving uphill on the track and we are using positive numbers to indicate displacement, velocity and acceleration directions down the track.

2. Calculate the average velocity of the cart using the equation you developed in Section 7 of **Part One**. Enter your results in ***Table VI***.

3. Calculate the average acceleration using

Average Acceleration $= a_{AVG} = (v_f - v_i) / \Delta t = (v_f - v_i) / (T_c - T_a) = (v_f - v_i) / (\Delta\text{Time 1} + \Delta\text{Time 2})$.

Enter your results in ***Table VI***.

Table VI: Velocity and Acceleration from Bounce Timing Measurements

Trial #	v_i *(m/sec)*	v_f *(m/sec)*	**Δt** **(ΔT1 + ΔT2)**	v_{AVG} *(m/sec)*	a_{AVG} *(m/sec²)*
1					
2					
3					
4					
5					

4. Are the accelerations listed in ***Table VI*** a constant, or nearly so?

Circle one (YES) (NO)

Why or Why not? ____

____

____

5. What are the velocity and acceleration of the cart at the instant when it's at its highest point during a bounce timing trial?

$\boldsymbol{v}_{\text{Top}}$ = ____________________ $\boldsymbol{a}_{\text{top}}$ = ____________________

6. The direction of the acceleration of the cart as it travels uphill is: *Circle one* [uphill / downhill]

7. The direction of the acceleration of the cart as it travels downhill is: *Circle one* [uphill / downhill]

8. Explain in your own words how it is possible to have an instantaneous velocity of zero and a constant, non-zero acceleration at the same moment during a bounce timing run.

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9. Explain in your own words how it is possible to have a constant, non-zero acceleration and an average velocity of zero over the full bounce in a bounce timing run.

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10. Give a personal example from the real world of #8. [Note: *An air cart on a frictionless track is not a good answer*.]

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Reference Section:

Here are the equations for linear motion for systems experiencing <u>constant acceleration</u> parallel to the direction of motion. These equations are **not true** for systems where the direction is changing or where the force, or the component of the force, that produces the acceleration is not constant. Learn these by heart, you'll be needing them for the rest of the year. (*There are three more linear-motion equations that apply to motion undergoing constant acceleration. We'll discuss these later. There are five variables*; x_f, v_f, v_i, a, *and* t. *Each of the five equations includes four of the five variables, but is missing the fifth. We don't need to consider a special equation with a missing* x_i *because in most practical situations we always know* x_i *if we need it.)*

The Position or Displacement Equation:

$x_f = x_i + v_i t + \frac{1}{2} a t^2$ *(Note that* v_f *does not appear as a variable in this equation)*

which can be written as *(Note that when the acceleration is zero, this reverts to*

$x_f - x_i = v_i t + \frac{1}{2} a t^2$ *that old standby:* $D = R T$, *where* D *is* $x_f - x_i$ *and* R *is* v_i*)*

Velocity Equation:

$v_f = v_i + a t$ *Note that* x_f *does not appear as a variable in this equation)*

Additional Exercises –

From these two equations you can derive three others. Just for practice try deriving them now. Take these two equations and try to eliminate one variable at a time.

Start with the two motion equations and try to eliminate t (fairly easy). Rearrange your result to solve it for v_f^2.

Start with the same two motion equations and try to eliminate a. Rearrange your result by solving the equation for $x_f - x_i$.

Finally, start with the same two motion equations and try to eliminate v_i. Rearrange the result to solve the equation for $x_f - x_i$.

Instructor's Notes:

We use Vernier hardware, Vernier probes and Vernier Software.

The experimental file "**Vavg_and_Aavg_Part_One.CMBL**" was created for use with many of the labs that use the frictionless rail. In our lab, the emphasis is on student analysis and we try to minimize the amount of work done for the students by the software. Soon enough they will learn about how the technology can be used to do most of the work. Here they take responsibility for the full analysis; to the extent we are able control it.

This file can be created in advance and distributed to students' personal folders prior to the lab. Though it is the same file each time, a name more appropriate to each individual lab is used each time it is distributed. Then if students accidentally overwrite the file during one lab, they will still get a pristine copy for the next lab. On our network a subfolder named VCDistribution is created in each student's home folder. We urge them to copy the file into the main folder just in case they mess it up. This way they still have an original to work with later in the lab.

Plug in the power plug for the LabPro. Connect it via the USB port to the computer you will be using to collect the data. Occasionally, ***LoggerPro3.5*** (Local) will lose contact with the LabPro. When that happens simply unplug the LabPro from the power source and then reconnect it. ***LoggerPro3.5*** will detect the LabPro when it wakes up looking for attached probes.

Plug two photogates into the LabPro.

Start ***LoggerPro3.5*** (Local) – Make sure that LoggerPro can find the LabPro and if necessary tell it to scan for photogates. (The old photogates are not auto-detected)

Enter the Setup menu.
--------------------- to be completed later ---------------------
Under the Sensor Setup tab, select Sensor: Photogate from the pull-down menu and Photogate from the calibration menu.

Under the calibration menu you may calibrate both photogates, one at a time, by selecting the icon for the plugs on the display graphic. When you finish, press the OK button to return to the main menu.

Enter the Setup menu again.

Under Data Collection use the Sampling tab to reach the screen where you can specify the length of the object used to break the photogate beam. This is not used too often but it is best to get it now while you are thinking about it. In our labs we use a post-it note that protrudes above the top of our carts. Out post-its are currently 1 inch or 0.0254 m wide. Enter the width of your post-it note or whatever you use to break the photogate beam and press OK to return to the main screen.

The only window we keep on the main screen is a three-column window showing three time intervals. These are labeled Δtime 1, Δtime 2, and Δtime 3. You can set the labels yourself in the setup menu items discussed above. If there are other windows showing, kill them now.