

Possible Prelab Questions.

Read Lab 2. Study the Analysis section to make sure you have a firm grasp of what is required for this lab.

- 1) A car is travelling with constant acceleration along a straight track. You measure the speed of the car to be 3.3 m/s and then you wait 2 s and measure the speed again, but this time the speed is 2.5 m/s. What is the acceleration of the car between your two measurements?
- 2) A car is travelling with constant acceleration along a straight track. You measure the speed of the car to be 3.3 m/s and then you wait and measure the speed again 2 m down the track, but this time the speed is 2.5 m/s. What is the acceleration of the car between your two measurements?
- 3) Could it be that questions 2 and 3 in the prelab are describing the same situation?

Predictions:

- 4) An unpowered car (without any type of engine or brake system) is slowing as it rolls along a flat track without any wind at a medium speed.
 - a. What is the most likely cause of this car's acceleration?
 - b. If, instead of rolling at a medium speed, a second car was traveling quickly, would you expect a higher acceleration, a lower acceleration, or the same acceleration?
 - c. If the car rolls along the track in the opposite direction would you expect magnitude of the acceleration to increase, decrease, or stay the same?

More on Uncertainty

Lab 1 focused on the idea of uncertainty. However, we did not discuss what happens when we use an uncertain value in a formula.

Here is a simple example to illustrate.

You measure two lengths, $L_1 = (3 \pm 1) m$ and $L_2 = (12 \pm 2)m$ and you would like to calculate the total length $T = L_1 + L_2$.

It could be that $L_1 \approx 2 m$ and $L_2 \approx 10 m$ in which case $T \approx 2 + 10 = 12 m$.

BUT it could also be that $L_1 = 4 m$ and $L_2 \approx 14 m$, in which case $T \approx 4 + 14 = 18 m$.

Evidently, we should write that $T = (15 \pm 3)m$ as the correct solution.

We will need two new Rules (in addition to 1-4 found at the beginning of Lab 1) to handle these two cases.

Rule 5: If two measured values are ADDED or SUBTRACTED, you must ADD the uncertainties to get the uncertainty in the result.

$$\text{if } x = a \pm b \text{ then } \delta x = \delta a + \delta b$$

Example: Imagine you measure two different times, $t_i = (2.53 \pm .02) s$ and $t_f = (2.74 \pm .03) s$, and you are interested in the amount of time between these two measurements, $\Delta t = t_f - t_i$. In this case you would find that

$$\overline{\Delta t} = (2.74 - 2.53) s = .21 s$$

But more importantly the uncertainty in the time between measurements would be

$$\delta \Delta t = (.02 + .03) s = .05 s$$

And now we can report that for this example the time between our two measurements is

$$\Delta t = \overline{\Delta t} \pm \delta \Delta t \text{ OR } \Delta t = (.21 \pm .05) s$$

Rule 6: If two measured values are MULTIPLIED or DIVIDED, you must ADD the FRACTIONAL UNCERTAINTIES.

$$\text{If } y = A * B \text{ then } \frac{\delta y}{\bar{y}} = \frac{\delta A}{\bar{A}} + \frac{\delta B}{\bar{B}} \text{ or } \delta y = \bar{y} \left(\frac{\delta A}{\bar{A}} + \frac{\delta B}{\bar{B}} \right).$$

$$\text{Similarly if } Y = \frac{A}{B} \text{ then } \delta Y = \bar{Y} \left(\frac{\delta A}{\bar{A}} + \frac{\delta B}{\bar{B}} \right).$$

Example: Velocity comes from the formula $v = \frac{\Delta x}{\Delta t}$. If we measure $\Delta x = (4.3 \pm .1) \text{ cm}$ and $\Delta t = (.24 \pm .05) \text{ s}$ then the calculated velocity must be

$$\bar{v} = \frac{\bar{\Delta x}}{\bar{\Delta t}} = \frac{4.3 \text{ cm}}{.24 \text{ s}} = 17.91\bar{6} \frac{\text{cm}}{\text{s}}.$$

But more importantly, the uncertainty follows the equation above,

$$\delta v = \bar{v} \left(\frac{\delta x}{\bar{x}} + \frac{\delta t}{\bar{t}} \right) = 17.91\bar{6} \frac{\text{cm}}{\text{s}} \left(\frac{.1}{4.3} + \frac{.05}{.24} \right) = 17.91\bar{6} \frac{\text{cm}}{\text{s}} (.2316) = 4.15 \frac{\text{cm}}{\text{s}}.$$

But of course δv must obey **Rule 3**, so the uncertainty is rounded up to

$$\delta v = 5 \frac{\text{cm}}{\text{s}}.$$

And therefore v must obey **Rule 4** and be rounded to the same precision

$$v = (18 \pm 5) \frac{\text{cm}}{\text{s}}.$$

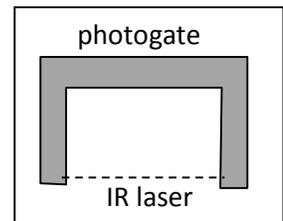
Lab 2

Acceleration due to Friction

In this lab we will experimentally explore the relationship between position, velocity, and acceleration. We will measure the acceleration of a car on a flat track four times to determine what are the important factors that influence the acceleration of a car on a flat track.

Each group should gather the following equipment:

- 1 computer
 - Turn this on immediately as it takes a long time to load. The user name and password are the link blue credentials for the Data Analyst.
 - Also, start the “Logger Pro” software as soon as possible.
 - Open the Lab 2 Template in Excel that can be found in “Course Documents” tab in blackboard. Save this file to the desktop of the computer, you can email it out at the end of lab.
- 1 LabQuest- Looks like a cross between an ipad and a graphing calculator.
- 2 PhotoGates which **each** need
 - 1 cable for connection with the LabQuest
 - 1 stabilizing rod
 - 1 base to hold the stabilizing rod
- 1 “Pasco” car (These cars are surprisingly fragile—DO NOT DROP THEM.)
 - 1 Aluminum box. This attaches to the car and will pass between the photogate arms and block the laser.
- 1 “Pasco” track
- 1 Caliper for measuring small distances
- 1 meter stick or measuring tape for measuring large distances



A 10% penalty will be assessed to any group who does not return all supplies neatly at the end of the lab period.

Introduction

Calculating the acceleration on a “level” track.

We know from experience that if a car is rolling down a level track it will eventually stop due to frictional forces. We would like to know exactly how much acceleration there is when these cars roll down the track. Also we want to know if this acceleration depends on the speed of the car or the direction of travel.

Setup

- 1) Level your track by adjusting the screws on the bottom of the track until the car does not roll on its own when placed at rest on the track. FROM THIS POINT ON DO NOT ADJUST THE TRACK.
- 2) Attach the aluminum box to the car. Make certain that the bottom of the box does not drag on the track.
- 3) Place the two photogates over the track and far from each other. You will need to adjust the photogates such that the box breaks the infrared laser that goes from one arm of the photogate to the other. When this laser is broken a red light should blink on the top of the photogate.
- 4) If all the hardware is plugged in and connected and the computer has already started “Logger Pro,” the two photogates SHOULD be automatically detected.

If the left side of the screen has a spread sheet with columns that are titled—Time, Gate 1, Gate 2, position 1, velocity 2, etc. your photogates have been detected.

IF NOT:

- a) At the top of the screen click “Experiment -> Connect Interface -> LabQuest -> Com1” (If Com1 is not a choice, click whatever is a choice, or ask for help.)
- b) Click “Experiment -> Set up Sensors -> Show all Interfaces.” This will bring up a new window with a picture of the LabQuest.
 - a. Click the white square under “Dig/Sonic 1 -> Choose Sensor -> Photogate”.
 - b. ALSO click “Dig/Sonic 2 -> Choose Sensor -> Photogate”
 - c. Close the window showing a picture of the LabQuest.

On the left side of the screen everyone should now have a spread sheet with columns—Time, Gate 1, Gate 2, position 1, velocity 2, etc. If not, ask for help.

We are only interested in the columns Time, Gate 1, and Gate 2. So please hit the collect button, wave your hand in the photogate, and collect some random data. This should allow you to click on the Position 1 column and delete it. Also delete the Position 2 column so that we are only looking at the three columns we want.

- 5) At the top of the computer screen is the “Collect” button. After pressing the collect button as the car passes through the photogate Logger pro should display the time at which the photogate was blocked (Gate=1) or was subsequently unblocked (Gate=0). Once you are done collecting data, hit the “stop” button to prevent accidental bumps to the photogate from corrupting your data.

WARNING: It takes the computer about 2 seconds after you push the “Collect” button to be ready to take data. So press “collect” wait about 3 seconds then start your experiment.

- 6) Your basic procedure will involve giving the car a push so that it rolls through both photogates. It is extremely important that **there is no interference with the car from the time it enters the first photogate until it leaves the second photogate**. By measuring the velocity at two different points on the track (the photogates), you should be able to measure the acceleration that occurred between those two points. Make sure you obey the first rule of lab work that we discussed in Lab 1:

Rule 1: Every measurement and result has an uncertainty with units.

For example: It is really quite difficult to find the exact location and width of the photogate laser. Therefore instead of spending an hour measuring the exact position of the photogate laser, increase the uncertainty of the distance between the photogates to account for the fact that you don’t know where the laser is.

EXPERIMENT PART 1-Calculating Velocity

Procedure - To calculate the velocity of a car as it passes through **ONE** photogate:

- 1) Measure the length of the box that will block the photogate. Don’t forget that the uncertainty of the box length is increased because we don’t know how much of the laser needs to be blocked for the computer to notice. Record this in Cell A2.
- 2) Push “Collect” and make the car go slowly through ONE photogate so that the large black bar blocks the photogate. Transfer the Time and Gate data from logger pro into the six yellow cells under “SLOW CAR.”
- 3) Using the data in Excel, **create a formula** in the blue cell E6 to calculate the time the car spent in the gate. Because of the crazy large number of digits provided by the photogate, we do not need to worry about the uncertainty in our times and we will set this uncertainty, δt to zero in cell F6.

- 4) Using the fact that velocity is calculated from $v = \Delta x / \Delta t$, check the calculation in Cell G6. Notice, that every time we want to calculate a velocity, we will ALWAYS reference A2, so the equation has $\$A\2 . On the other hand, the Δt will be different every time we take data. Therefore we just use E6 for the denominator of this formula.
- 5) Verify the uncertainty in the velocity formula in cell H6 obeys the formula from RULE 6 dealing with quantities that are divided. Notice, that even though Δt has zero uncertainty right now, we might change that value later, so we will include it in the equation. For now, δv comes entirely from $\delta \Delta x$ although it is not equal to $\delta \Delta x$.
- 6) Repeat part 2), with the car going *quickly* and copy your raw data into the yellow cells under "FAST CAR."
- 7) Do NOT repeat steps 3), 4), and 5) for "FAST CAR." Highlight the cells E5:H6, Copy, highlight E12, and then PASTE and Excel will do most of the work. The only thing we need to check is that each of the equations have been copied appropriately and none of the equations are pointing to the wrong cells.
- 8) **Discuss your results with the instructor.**
- 9) For the remainder of the lab you will be allowing the car to go through both photogates and calculating the speed of the car at BOTH photogates using the above method.

EXPERIMENT PART 2-Calculating Acceleration

Record the following data in a section called "CONTROL RUN." It is possible to measure the acceleration between two velocities (these two velocities are measured at different gates) in two ways. If the separation in time is known, you can use $a_{time} = \Delta v / \Delta t$. If the separation in distance is known, you can use $a_{distance} = \frac{v_f^2 - v_i^2}{2\Delta x}$. We will verify that these two equations give us equivalent results.

- A. Give the car a push so that it passes **quickly** through both gates without any interference. Record the raw data in Excel in the 12 yellow cells under CONTROL RUN.
- B. Use the methods of PART 1 to calculate the velocities at each photogate. And clearly label these velocities as " v_{before} " and " v_{after} ."
- C. Use $a_{distance} = \frac{v_f^2 - v_i^2}{2\Delta x}$ to measure the acceleration between the two gates. Should you use cell $\$A\2 or cell $\$F\2 for Δx in this formula? **In your Procedure section of the lab report, you should explain why one of these cells was selected over the other.**

- D. Because we are still learning excel $\delta a_{distance}$ has been calculated for you.
- E. We would also like to use $a_{time} = \Delta v / \Delta t$ to measure the acceleration between the two gates. But we have not yet defined what we mean by Δt , there are lots of t 's floating around and if we subtract the wrong two we will get silly results.
- F. **Warning:** Δt is a bit tricky because it is the time gap between the first gate and the second gate. Looking at the table below, Δt should be approximately $t_3 - t_1$, or maybe $t_4 - t_2$, but we are not quite certain. Therefore we will calculate both of these quantities, $\Delta t_{min} = t_3 - t_1$ and $\Delta t_{max} = t_4 - t_2$ and use these two to find an uncertainty in Δt

If the computer is giving the following data

Time	Gate 1	Gate 2
t_1	1	
t_2	0	
t_3		1
t_4		0

- G. δa_{time} is being calculated for you. At this point, you should be able to see how and why this formula is entered the way that it is.
- H. Notice that a bar graph that shows $a_{distance} \pm \delta a_{distance}$ as compared to $a_{time} \pm \delta a_{time}$. Because both of these accelerations are referencing the SAME raw data, they MUST agree. If they do not, discuss with your instructor.
- I. In your conclusion section, discuss whether the distance or the time method is a better way to measure the acceleration of a car.
- J. At this point you have just done one experiment and measured the acceleration of the car in two different ways. If the magnitude of the acceleration is between $.02 \frac{m}{s^2}$ and $.1 \frac{m}{s^2}$ you should continue with the experiment, otherwise, consult with the instructor before continuing. **For all further experiments you only need to calculate the acceleration using one of the two methods above but you may do both if you would like.**

PART 3-Comparing accelerations.

A rather important question is "Does the acceleration of the car **significantly** depend on the speed of the car?" Use the techniques of Parts 1 and 2 to measure the acceleration of the car (and its uncertainty) when it passes **slowly and then quickly** through both photogates.

- a) IMPORTANT: You can copy the entire block of cells that have your CONTROL RUN work, scroll down to cell B26 or so, paste, and then label this block of work "ACCELERATION: SLOW CAR". At this point, all of the numbers should be identical between CONTROL RUN and ACCELERATION:SLOW CAR. If not, you have forgotten a \$ (or maybe there is one too many) in some formula.
- b) Copy and paste the time data from Logger pro into the yellow cells for ACCELERATION: SLOW CAR, and excel then does all the work for you.
- c) Clearly record your result by adding a_{slow} to the bar graph you created earlier.
- d) Repeats steps a), b), and c) with the car travelling very quickly through the gates. Record your result by adding a_{fast} to the bar graph you created earlier.
- e) In your conclusion, you should address the question: "Does the acceleration of the car **significantly** depend on the speed of the car?"
- f) Collect the data needed to determine the acceleration of the car as it travels the opposite direction. Record your results by adding $a_{opposite}$ on your bar graph.
- g) In your conclusion, you should address the question: "Does the acceleration of the car **significantly** depend on the direction the car travels along the track?"

Conclusion

Using the "Lab Report Template" (found in blackboard) as a starting point, write a lab report summarizing your main results (as indicated by the highlighted yellow questions).