Lab 1: Motion with Constant Acceleration and an Introduction to Excel

Introduction:

In class, we defined the motion of an object through is momentum p, which is a product of the objects mass m and velocity v, where $p = mv$. Further, we defined changes in the motion of an object as an acceleration, defined by

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} \quad (eqn\ 1).$$

If we assume that the motion occurs in only one direction, say the x-direction, and is constant in time, then eqn 1 can be used to determine the trajectory, or position, of the object x_f as a function of time t, the derivation of which was shown in class. The trajectory of an object subject to a constant acceleration in the x-direction a_x is given by

$$x_f = x_i + v_{ix}t + \tfrac{1}{2}a_x t^2 \quad (eqn\ 2),$$

where, x_i is the starting or initial position of the object and v_{ix} the initial velocity of the object, which we'll take to be zero for this experiment.

In this laboratory experiment we will experimentally determine if the acceleration of a cart of mass m, released from rest on an inclined track, is constant and therefore its trajectory obeys eqn 2. If the acceleration does in fact obey eqn 2, we'll determine an experimental value for the acceleration due to gravity, g. From eqn 2, we see that there is no factor of the mass m of the cart. Is this accurate? To see if the mass of the cart affects the acceleration of the cart down the incline, we'll vary the mass of the cart as a function of the experimentally determined acceleration and see if the acceleration depends on the mass. We said that we'd like to determine an experimental value for the acceleration due to gravity. We have not discussed this yet, but changes in the motion of an object, an acceleration, are due to forces applied to the object. We will eventually show this to be the case, but the acceleration of the cart down a track inclined at an angle θ measured with respect to the horizontal is given as

$$a_x = g \sin\theta \quad (eqn\ 3).$$

From eqn 3, we have a way to measure the acceleration due to gravity, g from the experimental value of the acceleration a_x down the incline.

Experiment:

1. The setup for the experiment is shown in Figure 1 below. You will need to raise one end of the track by a height h. Measure the height h and the full length of the track, L, and make sure you know the units of your measurements. Record these below with appropriate units.

   $h =$

   $L =$

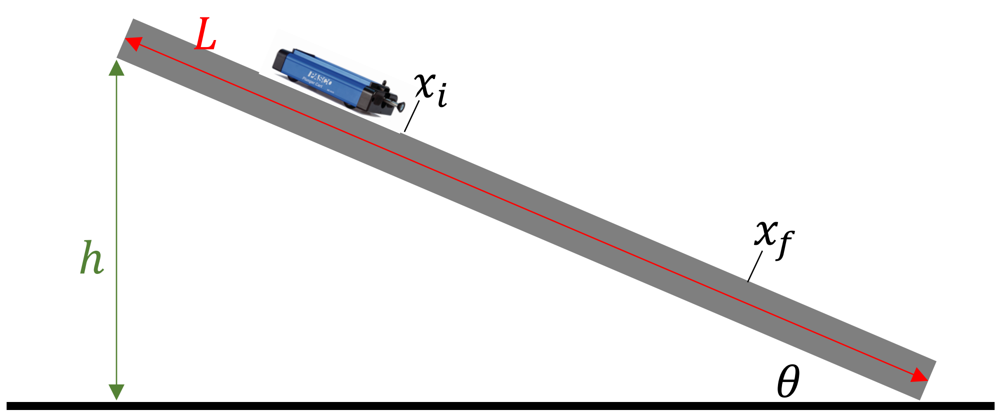

Figure 1: Experimental setup.

2. Open Microsoft Excel and in the first cell of the first four columns type "$t_1(s)$", "$t_2(s)$" "$t_3(s)$" "$t_{average}(s)$" respectively, without the quotes. These cells will be used to measure the time it takes the cart to travel a known distance down the incline and the average time taken. In the first cell of the fifth column, type "$x(m)$". This will be the distance that the cart travels down the incline. That is, in these columns you'll enter values of the time t (measured in seconds) it takes the cart to travel a known displacement, $x = x_f - x_i$ measured in meters. We will measure the time it takes the cart to travel a known displacement three times ($t_1(s)$, $t_2(s)$, and $t_3(s)$) and then calculate the average time $t_{average}(s)$.
3. In the cells of the fifth column enter your displacements, x. These can be anything that you want, but you need to have at least 10 data points, and take $x_i = 0$.

4. Put the cart of mass m at the starting point x_i and hold it at rest. That is, $v_i = v_{ix} = 0$. When you are ready, release the cart from rest and record the time t it takes for the cart to cover the distance x and enter this in to the 2nd cell in 1st column. Repeat these measurements two more times and record the time data in the respective 2nd cells of the 2nd and 3rd columns. Then in the 2nd cell of the fourth column type "=Average(A1:A3)" without the quotes and hit enter. Equivalently you can start typing "=Av…" and Excel will give you options. Select the appropriate one (average) and then highlight the cells you want to take the average of, namely "A1" through "A3" and hit enter. Excel will calculate the average time and display it in the 2nd cell of the 4th column.
5. Repeat step 4 nine more times, once for each displacement you have chosen. Then calculate the average time for each of these displacements. If you don't want to type the average command "=Av…" every time for all 10 data points, click the 2nd cell of the 4th column and if you hover over the lower right-hand corner of the cell, you should see a "+" sign. Grab the + sign and pull it down over all of the cells you want to calculate the average of. This will determine the average of all of the times you have in the respective time columns.
6. From the Excel menu bar, click *Insert* and then find *charts* and choose *scatter*. In the box that opens, right click on the box and choose *select data*. Now, click the small icon on the right-hand side of the "X values" box and select your time data, by dragging down the average time column (column 4 but do not select the title heading in cell 1) and hit enter. Then do the same for the "Y values" by selecting all of the displacements in column 5 (but not the title heading) and hit enter. Then click "OK". You should now have a graph of the displacement x of the cart as a function of time t.
7. We'd like to know the equation of the fit to the data. From eqn 2 we know that the displacement x should vary as the square of the time. To fit the data with an appropriate function, right click on the data on the graph and select "*Insert Trendline*". From the menu that opens, click on "*Power*", and then "*Display Equation on chart*". This will fit a curved line to the data, and if the data obey $eqn2$ with $x_i = 0m$ and $v_i = 0\frac{m}{s}$, you should have an equation that looks like $x = constant \cdot t^{power}$, and the fit will generate a value for $constant$ and $power$.
8. Lastly, in the Excel menu bar click "Add Chart Element" and select "Axis Titles" and then primary horizontal and primary vertical adding what's on each axis to the graph. This labels your plot.
9. From the fit to the data, extract a value for the acceleration of the mass m down the incline and record the value below with appropriate units.

   $a_x =$

10. We also want to see if there any effects on the acceleration due to the mass of the system. To change the mass of the cart, we'll add the black bars to the cart. You should have 4 of these masses, two individual black bars and two sets of black bars taped together. On the scale in the lab room, weight the cart and all of the masses and record the values below with appropriate units. In addition, label a new column in Excel as $mass$ in appropriate units and record these values in the new column.

$m_{cart} =$

$m_{single\ bar\ 1} =$

$m_{single\ bar\ 2} =$

$m_{double\ bar\ 1} =$

$m_{double\ bar\ 2} =$

11. Adjacent to this column of masses from step 10, make a new column and label it a_x in appropriate units. Now from one of your displacement and average time measurements for the cart of mass m, preferably a long displacement one, record the acceleration that you determined by using $eqn 2$. This displacement will remain fixed for this part of the experiment.
12. In order, add one individual black bar, then two individual black bars, and finally two of the taped bars and for each trial, measure the average time it takes to travel your given fixed displacement and record the times in new columns in Excel, making sure to label these new columns appropriately.
13. Using $eqn\ 2$ calculate a value for the acceleration of the cart down the incline for each average time for each mass.
14. From the Excel menu bar, click *Insert* and then find *charts* and choose *scatter*. In the box that opens, right click on the box and choose *select data*. Now, click the small icon on the right-hand side of the "X values" box and select your time data, by dragging down the mass column (but do not select the title heading in that cell) and hit enter. Then do the same for the "Y values" by selecting all of the accelerations (but not the title heading) and hit enter. Then click "OK". You should now have a graph of the acceleration of the cart a_x as a function of the mass of the cart m.

15. Looking at the plot, we should see that the data look like a horizontal line. Select the data by right clicking and select *Insert trendline*. From the choices, for the fit, choose *linear* and click the box to "*Display Equation on chart*". From a fit to the data, what is the value of the slope of the line? Record your value below with appropriate units.

    $slope =$

16. From your measured value of h and L, determine an expression and then a value for $\sin\theta$. From this, what is the angle of inclination of you track? Enter the value below.

    $\sin\theta =$

    $\theta =$

17. Using eqn 3 and either your expression for $\sin\theta$ or the angle θ itself, determine a value for the acceleration due to gravity g_{expt} with appropriate units.

    $g_{expt} =$

Analysis, Post-Lab Questions, and Discussion

Name:

Lab Partner(s):

Due Date: Tuesday, September 22, 2026 at the beginning of lab.

Honor Code Statement:

1. From your plot of the displacement of the cart down the incline x as a function of time t, do the data obey eqn 2? Should they? Explain why or why not.

2. From your plot of the displacement of the cart down the incline x as a function of time t what is the equation of the fit to the data? Comparing your fit to $eqn2$, what should be the value of the $power$? How does the value of $power$ from $eqn2$ compare to your value? Calculate a percent difference.

$$\% = \left|\frac{power_{eqn2} - power_{graph}}{power_{eqn2}}\right| \times 100$$

3. From the fit to the data for your plot of the displacement of the cart down the incline x as a function of time t what does the $constant$ term equate to in $eqn2$? From the fit to the data and using $eqn2$, what is the acceleration a_x of the cart down the track with appropriate units.

   $a_x =$

4. How reasonable of a value do you think this acceleration is? Explain.

5. In the plot, we fit the data on the displacement of the cart down the track x as a function of time t with a power as this is what eqn 2 dictated. How do we actually know the data fit a power and not some other mathematical form? To determine that the data actually fit a power relationship with the power of the time term equal to 2, we do the following. Take you plot and make two copies of it. You can do this by selecting the plot and then performing a copy (*cntrl C*) and paste (*cntrl V*) commands. On one of the copies, select the y-axis by right clicking on it and select "*Format Axis*". In the menu that opens, select "*Logarithmic scale*" and hit enter. This plot is called a ***semi-log*** plot as only one axis is logarithmic. On the second copy change both the x- and y-axes to logarithmic scales. This plot is called a ***log-log*** plot since both axes are now logarithmic. Looking at both the semi-log plot and log-log plots of the data, which one looks linear? You should find that the log-log plot looks linear. Does the log-log plot in fact look linear compared to the semi-log plot. Explain.

6. There are two mathematical forms that the data could model. One is an exponential function ($y = Ae^{\pm Bx}$ $\quad eqn\ 4$) and the other is a power law ($y = Ax^n$ $\quad eqn\ 5$). In both expressions, A is called the proportionality constant and in the exponential equation B is a constant with units the inverse of whatever x is measured in. For the power law, n is the exponent, or power of the variable x. Assuming B is positive, take the natural logarithm of $eqn\ 4$ and write the equation below. Show your work below.

$eqn\ 6 \quad \ln y =$

7. Take the logarithm of $eqn\ 5$ and write the equation below. Show your work below.

$eqn\ 7 \quad \log y =$

8. If your data obey an exponential function then the data should be linear on a semi-log plot and not linear on a log-log plot. Conversely, if the data obey a power law function, then the data should be linear on a log-log plot and not on a semi-log plot. The equations you wrote in steps 6 and 7 are the linear forms of the exponential ($eqn\ 6$) and power law ($eqn\ 7$) functions respectively. Looking back at the semi-log and log-log plots of the data of the displacement of the cart down the incline x versus time t which plot is linear and thus what type of function must the data obey, an exponential or power law? Explain.

9. From the plot (semi-log or log-log) that linearizes the data, what is the equation of the fit to the data and from the fit to the data, what are the values for the slope and y-intercept?

10. From the fit to the data in question 9 how does the slope of the line compare to the slope of eqn 7? Comment on your result.

11. From the fit to the data in question 9 and eqn 7, using the y-intercept of the line determine the acceleration of the system. How does this acceleration compare to the acceleration a_x that you determined from the original plot of the displacement of the cart down the incline versus time? Comment on your result.

12. From whichever plot linearizes your data does the result support $eqn\ 2$? Explain why it does or why it does not.

13. From your plot of the acceleration of the cart a_x as a function of the mass m for various masses added to the cart, is the acceleration of the cart constant as the mass of the cart varies? Should it be? Explain why it is or why it is not.

14. From your plot of the acceleration of the cart a_x as a function of the mass m for various masses added to the cart, what is the equation that fits the data and from this equation, what is the slope of the line that fits the data? Does the acceleration of the of the system depend on the mass of the system? Explain.

15. How does the acceleration of the cart a_x compare to the acceleration of the cart determined by varying the mass of the cart $a_{x,mass}$? Calculate a percent difference. The percent difference between two measured things given by:

$$\% = \left|\frac{a_1 - a_2}{\frac{1}{2}(a_1+a_2)}\right| \times 100 = \left|\frac{a_x - a_{x,mass}}{\frac{1}{2}(a_x+a_{x,mass})}\right| \times 100$$

16. Using eqn 3 and the acceleration of the cart down the incline, what is the experimental value of the acceleration due to gravity, g_{expt}? How does this compare to the known value of the acceleration due to gravity? Explain and calculate a percent difference. The percent difference between a measured (experimental value) and a known (theoretical or actual value) is given as:

$$\% = \left|\frac{actual - experimental}{actual}\right| \times 100$$

17. What are some sources of uncertainty in your experiment? Be sure to explain where the source(s) comes from and how that source may affect any of your measurements.