Lab Report On Pendulums: PHY180

Joaquin Arcilla

Introduction:

Although pendulums might seem like a device that has zero effect on the day-to-day lives of the ordinary person, it actually affects one major aspect of everyone's lives. Time and the measuring of time allow us to coordinate our activities with other people, and govern how much time we are using for activities and events. For some, time is measured by big clock towers like Big Ben in London that use pendulums to measure seconds, minutes, and hours. How do we know these pendulums remain accurate?

Using a small simple pendulum consisting of a string made out of dental floss, and small binder clippers as weights, this lab shows the variables that may affect a pendulum. The full description of the pendulum used in the experiments can be found in the first lab report. When comparing the starting amplitude of the simple pendulum with the corresponding periods, it was found that the amplitude didn't change the period and the relationship remained constant across different amplitudes. When comparing the mass on the pendulum with the corresponding periods, it was similarly shown that the relationship remained constant and that mass didn't change the speed at which the pendulum swung. This left length as the only variable to affect the period and speed of the pendulum, with the relationship being modeled by a power-law function.

Since pendulum clocks like Big Ben don't use easily deformable string, but rather full metal rods that are not deforming under the applied mass, we can be certain that the time it tells will remain accurate. Since the period of the pendulum will remain the same, the rest of the system based on that pendulum will similarly count seconds, minutes, and hours accurately and precisely.

Lab Report 1: PHY180

Joaquin Arcilla

Experimental Setup:

Due to the fact that I am staying at the Chelsea residence and don't have a lot of decent materials for the construction of the pendulum, I have had to make due with materials that I would not otherwise use. However I do believe that the quality of the materials is high enough that it should not affect the experiments done in this lab. I believe this because the weight of my load is significantly higher than the weight of the actual string, and as such the pendulum should have the expectant arc.

The pendulum consists of four major parts. The first being the base of which the pendulum is attached to. As per the instructions of the lab, this base is a stable spot that will not shift or move while the pendulum is in motion. Due to the limit space at the Chelsea hotel rooms, this base is the top portion of one of my dresser drawers, as shown in figure 1:

By moving the third drawer out (the top one) I have made sure that the string of the pendulum is clear of the other handles below. Because the handle itself (which is the anchor of the pendulum) is curved away from the front face of the drawer, the pendulum isn't obstructed by the drawer itself. This clearing was measured to be 2.5 cm.

The second part of the pendulum is the string, which is attached to the centre of the curved handle using tape. Due to the materials I had on hand, I picked floss to be the string of my pendulum. It is strong enough to hold the weights I used and during the experiment for Q and the data collection, the string showed no sign of deformation.

The specific floss being used is Oral B Essential Floss. The packaging can be seen below in Figure 2:

This string is attached using tape to the Handle, where its gravity pulls it down in roughly a straight line, perpendicular to the floor.

The third part of the pendulum is the weights. Because the floss may not hold under the weight of something immensely heavy, I have chosen to pick a weight that is just heavy enough to satisfy the important quality of the materials: the fact that the weight of weights is heavier than the weight of the string. The weights I am using are binder clippings as seen below in Figure 3:

The clips snap onto the string, securing their connection to the string through the compression created by the shape of the binder clippings. The connection is quite secure and not easily loosened unless by a great enough force or by someone who knows how to use the attached levers to adjust the clips. The clips can be attached to one another similarly and thus the weight itself is adjustable.

The fourth and final part of the pendulum is the measuring device used to calculate the angle of the pendulum. This is a protractor, attached to the handle of the drawer as shown in Figure 4:

The protractor itself is accurate to one degree and as such any measurements done by this tool will have an uncertainty of +/- 1 degree or +/- 0.0175 radians.

All together the pendulum is shown in Figure 5, with all four components attached together to form the instrument:

In Figure 5 specifically, there are two binder clippings as the weight. This is just in order to find the Q value. For tests requiring the changing of mass, the weight will start at one binder clipping.

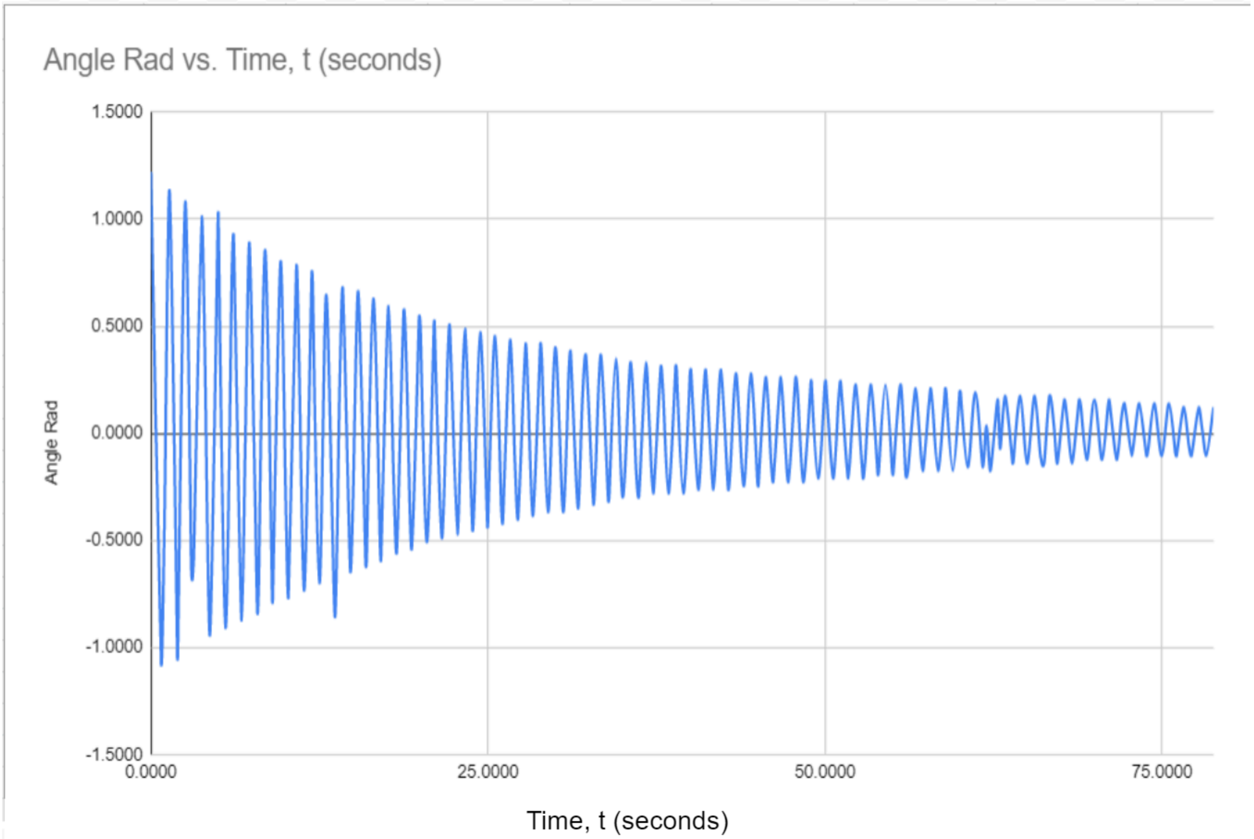
Finding The Q Factor:

The task of finding the Q factor started with the definition of Q as described by the formula:

$$Q = \pi \frac{\tau}{T}.$$

This formula has two inputs that must be defined from the pendulum itself, the period and the tau value. In order to find both the period and the tau value, I gathered experimental data first and then analyzed it.

In order to gather the experimental data, I used my Samsung Galaxy S20 to record the pendulum while it was in motion, but any similar quality video capturing device would've been acceptable. I started the pendulum at an angle of 70 degrees to the left of the vertical (20 degrees according to the protractor) and let gravity take it. Once the pendulum had stopped moving, I stopped the video and put it into the video editing software Corel Videostudio X9 where I could analyze the data frame by frame at a rate of 30 frames per second. Because of this 30 frames per second, I believe the uncertainty to be +/- the time of one of these frames, which in seconds is 0.033 frames. I specifically made sure to remove the first part of my video (before the pendulum started swinging) so that I knew for certain that the angle at t = 0 was 70 degrees. I recorded different angles at different times, putting them into a chart for further use. This chart was then graphed using google sheets(figure 6):



Please note that the x-axis is time (t) and the y-axis is the angle from the vertical (θ).

The most important data points in terms of the period are the starting point at t = 0, and the end of the first cycle, which was when the pendulum had returned to its maximum point on the left. At this second point, the time elapsed was 41 frames which when converted into seconds (41 frames / 30 frames per second) was 1.3667 seconds. Therefore, the period of the pendulum is 1.3667 seconds, T = 1.3667 seconds +/- 0.0330s.

In order to find the tau value for the pendulum, I did something similar with the same data. By analyzing the equation:

$$\theta(t) = \theta_0 \, \mathrm{e}^{-t/\tau} \cos\left(2\pi\frac{t}{T} + \phi_0\right)$$

We can see that the equation that the only part of the equation using tau is the exponential function:

$$\theta_0 \, \mathrm{e}^{-t/\tau}$$

Which is an exponential expression representing the amplitude values, which is when the pendulum is at its highest points. We can then use this expression to make an equation for the amplitude. If we were to set tau = the time variable (τ = t) then we can get a simplified equation for the amplitude:

$$\theta(t) = \theta_0 \, e^{-1}$$

Through this, we can see that tau equals the time it takes from the amplitude of the pendulum to lower from θ_o to $\theta_o e^{-1}$.

Since my data started at the angle of 70 degrees (θ_o=70 degrees), I calculated the value of $\theta_o e^{-1}$ to be 25.75 degrees, which is around 26 degrees. When I checked my data for the time it took for the amplitude to lower to this angle, I saw that it happened at 766 frames which converted to seconds is 25.5333. Therefore τ = 25.5333 +/- 0.0330s.

Now with these two values I can plug them into the expression for Q in order to get this theoretical value for Q. Applying the values to the formula, I saw that the Q value was equal to 59.194 +/- 0.0330s, where it was the value of decay in the same plane as the pendulum itself.

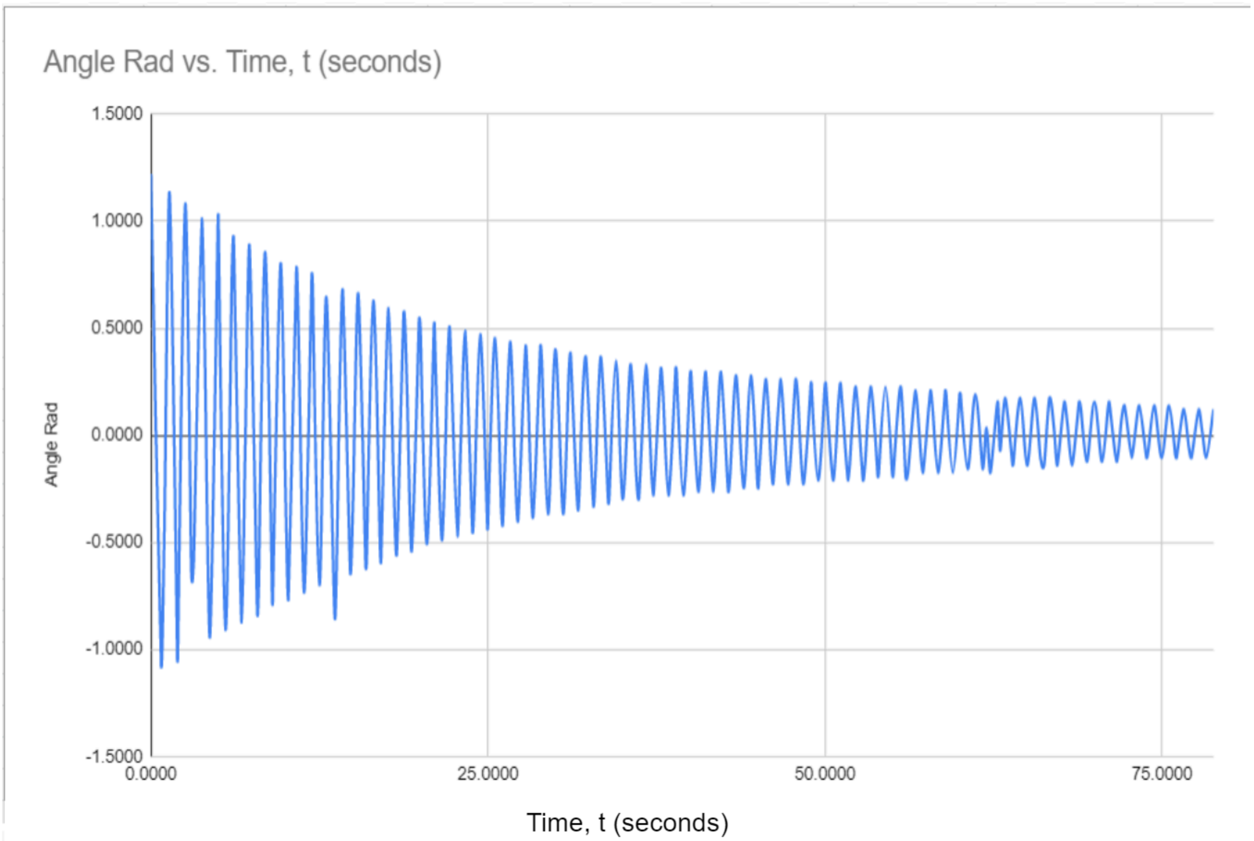
The other method to finding the Q value was experimentally, which I did through a separate trial with the pendulum. Q is defined as the number of oscillations it takes for the amplitude to fall $e^{-\pi}$ of its original amplitude which is about 4% of its starting amplitude. So for this trial I started the pendulum on the right side at 75 degrees (15 degrees on the actual protractor) and I counted the amount of oscillations until the amplitude reached a value of 3, which is 4% of 75. After doing the counting, the experimental value for Q is 77. Because I was measuring the angle using the protractor without the use of the video, the uncertainty of the value is larger since it's harder to see the smaller ticks: +/- 5 degrees or 0.0873 rad. So experimentally, the Q value is 77 +/- 0.0873.

It should be noted that Because of the method of data gathering, as well as the uncertainty within the trials and experiments, the values aren't all that close. They aren't astronomically different from one another, but there is a significant gap between the two values. With this knowledge, I can see that any measurements done with this pendulum should be done multiple times to verify the values are correct.

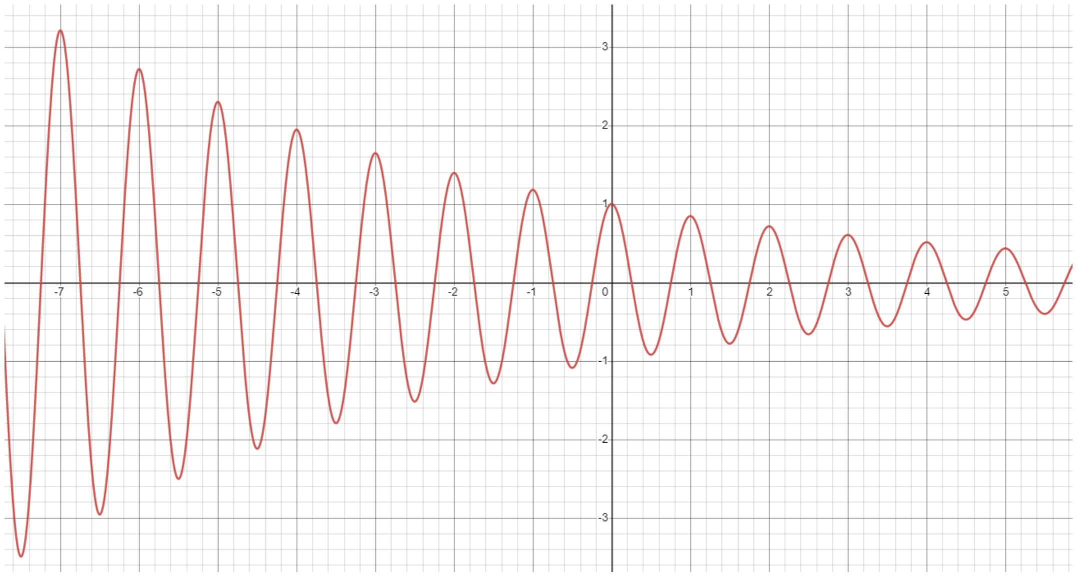
In both cases however, the Q value is high enough that I will be able to measure the period more accurately through more oscillation timings. This also means that the pendulum I have designed for this lab loses energy slowly and the oscillations die out slowly. This will help in the future parts of this lab to calculate and analyze the data, by giving me plenty of data points to work with.

Trial 1 Data:

Above, the experimental method of gathering the data for this graph is explained. In terms of the graphing creation I used google sheets to generate the graph for me. The angle values of the Y-Axis were converted into radians for this graph. This is figure 6:



If we compare this graph to the equation given to us in the lab sheet (figure 7):



We can see that the theoretical equations seem to be accurately representing the experimental data, at least in shape. Both graphs have oscillations and have their amplitudes getting smaller, following the curve of an exponential function. Therefore I believe that the function is an accurate representation of the physics of the pendulum so far.

Lab Report 2: PHY180

Joaquin Arcilla

Experimental Setup and Method:

For Lab two, my experimental setup remained the same without any modifications. Once again for the data collection, I used two binder clippings as the weight to prevent significant movement in the axis perpendicular to the pendulum. For time collection this time, rather than recording the actual experiment, I merely used the stopwatch feature on my cell phone, and thus the uncertainty of the time values is my reaction time, calibrated in a separate test outlined below.

The method for gathering the period for this experiment was as follows. I lifted the pendulum weight to the desired angle based on the protractor. When ready, I released the weight letting gravity bring it into the arc motion. After a few oscillations, I started the stopwatch when the weight reached the amplitude on its original side. I then counted out ten periods and stopped the stopwatch once it reached the same amplitude again. I recorded the time it took for ten oscillations and then divided them by ten to get the period.

Because of the Q value of my pendulum, I knew that having many data points would help create a more accurate graph in the end, and so I measured every angle that was a multiple of 10 degrees from 10 degrees to 90 degrees from both sides of the protractor. Angles are measured from the vertical.

I listed all the values in a chart, one side being the initial angle (which was converted from degrees to radians) and the other side being the period associated with the starting angle. The uncertainty of the angle was based on how accurate the protractor could be when visually measured, which was +/- 1 degree or +/- 0.018 radians.

Time Uncertainty Test:
The time uncertainty exists based on a few factors because I had to both start and stop the stopwatch by clicking the button on my phone, and the timing of the button click was based on me visually seeing the weight swing. This means that my hand-to-eye reaction time would be the source of uncertainty for the data collection. In order to measure my uncertainty, I conducted a test with the stopwatch. I started my stopwatch and waited 5 seconds, attempting to get exactly five seconds each time based on the visual cue of the digital clock. This task would simulate the same steps needed to accurately measure the period. Then I took the difference between my recorded time and five seconds to create error margins. I found the absolute values of all the error margins and averaged them. This was the uncertainty for the period values.

Calibrate Time	Error
5.08	0.08
5.21	0.21
5.22	0.22
5.05	0.05
4.98	0.02
5.05	0.05
5.08	0.08
5	0
4.96	0.04
5.12	0.12

In Figure 8, you can see the values I got in this calibration test. The average of all of these was 0.087 seconds, which meant that my period data had an uncertainty of +/- 0.087 seconds.

Asymmetry Test:

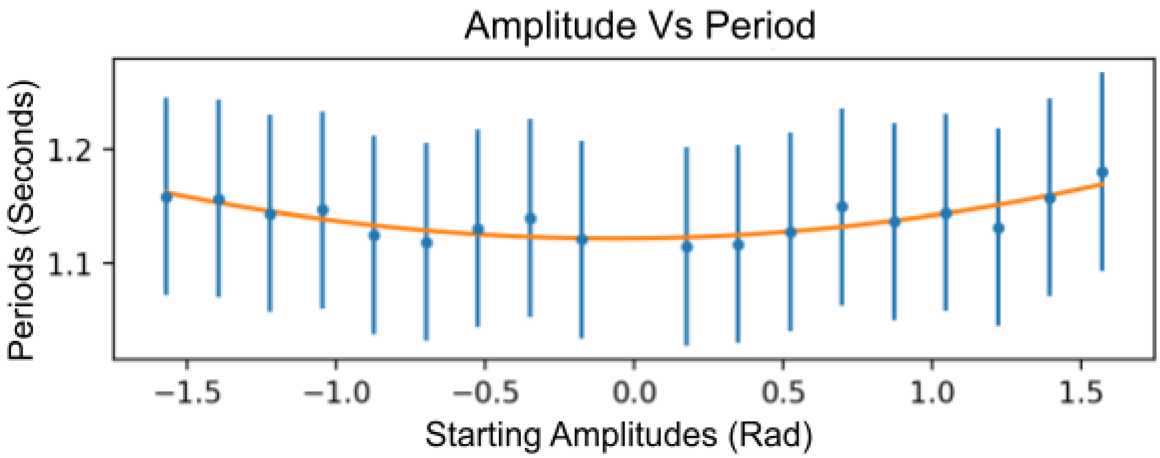
In order to test whether or not my pendulum had any sort of asymmetry, I set the right side of the protractor arbitrarily as positive angles, and the left side of the protractor as negative angles. When I conducted the experiment, as outlined in the earlier section, I compared the negative angles to their corresponding positive angles. For example -0.8726646261 radians (-50 degrees) had a period of 1.137 seconds, and 0.8726646261 radians (+ 50 degrees) had a period of 1.125 seconds. Since the difference between the periods of the positive and negative angles (0.012 seconds in the example above) was within the uncertainty of 0.087 seconds, I conclude that there is no asymmetry in the pendulum, and any deviation of period between the two angles is due to human error.

Fitting Data and Finding The B and C Coefficients:

Now that I had the data of starting amplitudes and their corresponding periods, I could plot the data on an Amplitude Vs Period graph. Using the python code I got this line of best fit, fitted as a power series function:

$$T = T_0 + B\theta_0 + C\theta_0^2 + \ldots$$

This was the graph:



Through the python program, I found the B value of my data to be 0.00234 +/- 0.0024 and the C value of my data to be 0.0178 +/- 0.0029. Since the B value is smaller than its uncertainty, these values can be noted as experimentally zero because the uncertainty can reduce the value to be zero. C, although not experimentally zero, is very small, and would have little effect on the data. Keeping this in mind, I believe that the period of each starting amplitude should be the same value in a perfect system with a perfect method of experimenting and recording data. The average of the period is 1.14 seconds +/- 0.087 seconds which I think is a good estimate for the period of all the starting amplitudes.

Conclusions:

Since the B and C values of the graph are experimentally zero, the curve of best fit can be reduced to a line based on the value of T_0. I believe T_0 to be the value of 1.14 seconds +/- 0.087 seconds based on my data. Based on the python code, the value of T_0 is 1.12 +/- 0.0037. These values are close enough to each other to show that the periods are experimentally the same across all possible values of the starting amplitude.

This leads me to the conclusion that the pendulum's period is not related or dependent on its amplitude because experimentally, it has the same period for every starting amplitude. The prediction that the period is not based on its amplitude is correct based on the experiment I have conducted, and the data I have collected.

Lab Report 3: PHY180

Joaquin Arcilla

Length vs Period:

Experimental Setup and Method:

For this experiment, since the length was the only variable that was meant to be changed, I made sure that every controllable variable was kept as a constant. I started the pendulum at the same starting amplitude, 80 degrees, and kept the mass the same, which was two binder clips.

When I collected data for string length, I changed the length of the string by folding the string around the fulcrum point until I got the desired length. I measured the string with a 30 cm ruler, which was accurate to the millimeter, leading me to my uncertainty for the length of +/- 0.001 m. I tried my best to have regular intervals of string shortening but it wasn't perfect.

For measuring the corresponding periods, I measured it the same way I measured it in lab 2, which was measuring 10 oscillations of the pendulum and then dividing them by 10. Because I had already calculated my reaction time offset in the previous lab, I just re-used that uncertainty which was +/- 0.087 seconds. Once again because of my high Q value, I knew that I could measure multiple oscillations and trust that the period would remain the same.

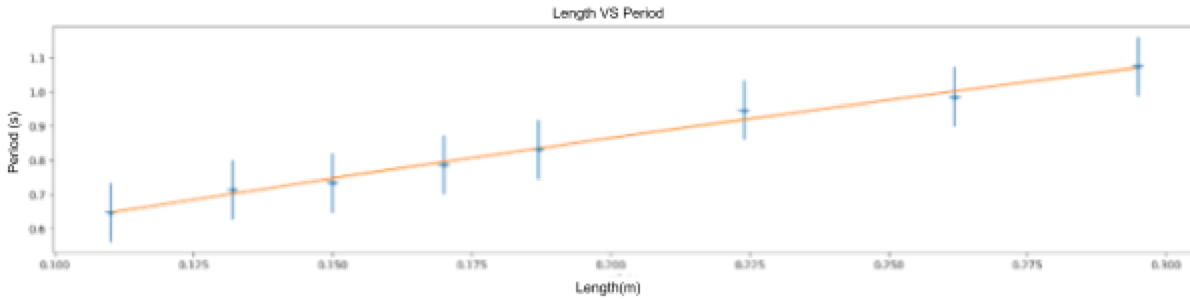
Although the previous experiment revealed that amplitude does not affect the period, I wanted to measure all the periods based on the same starting amplitude to be certain. Since C was found to be a small value in the previous lab, I was not too concerned about being accurate with the starting amplitude since the starting amplitude wouldn't affect the period too much.

Fitting Data and finding k, L0, and n:

After conducting the experiment and recording the data, I graphed my data on a Length vs Period graph using the supplied Python code. The data was then fitted onto a power-law function:

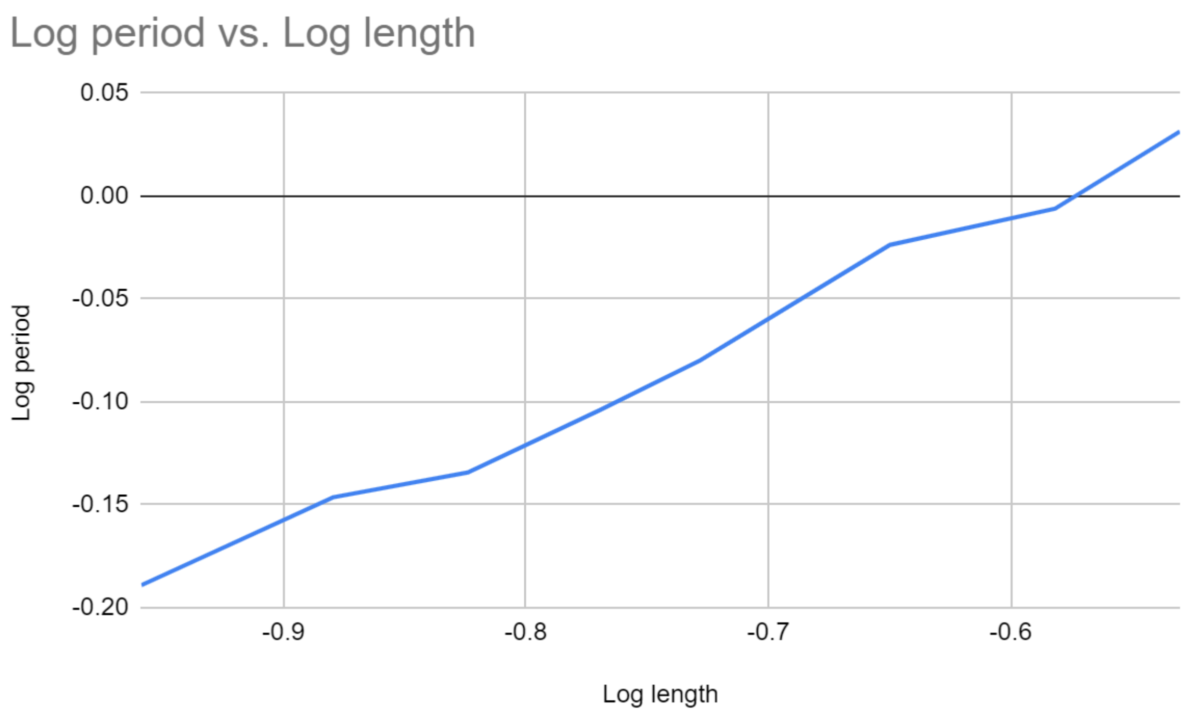
$$T = k(L_0 + L)^n$$

The regular graph was this:



Through the Python program, I found that the value of the variable K from the fitted line was 2.1907 +/- 0.234 which is experimentally 2 within its uncertainties. The value of L0 was 0.0622 +/- 1.044 which is experimentally 0 within its uncertainties. Finally, the value of N was 0.6938 +/- 0.2877 which is experimentally 0.5 within its uncertainties.

To better illustrate this, here is the log-log plot of the data:



Conclusion:

From the experiment and the data collected, I see that when the data is fitted in a power-law equation, the values of the variables in the equation match the expected result as given in the lab handout. Because the period did change when the string length was changed, the pendulum is affected by the length of the string. On top of that, the change of the period can be modeled with the power-law function described earlier, based on the experiment conducted.

Overall, the expectation presented in the lab matched the behavior my pendulum exhibited. String length is the deciding factor when it comes to how fast the pendulum moves.

Mass vs Period:

Experimental Setup and Method:

For the Mass vs Period experiment, I made sure to keep the variables, other than mass, the same. I dropped the pendulum at an amplitude of 80 degrees and kept the string length at the height it was for the Amplitude vs Period experiment.

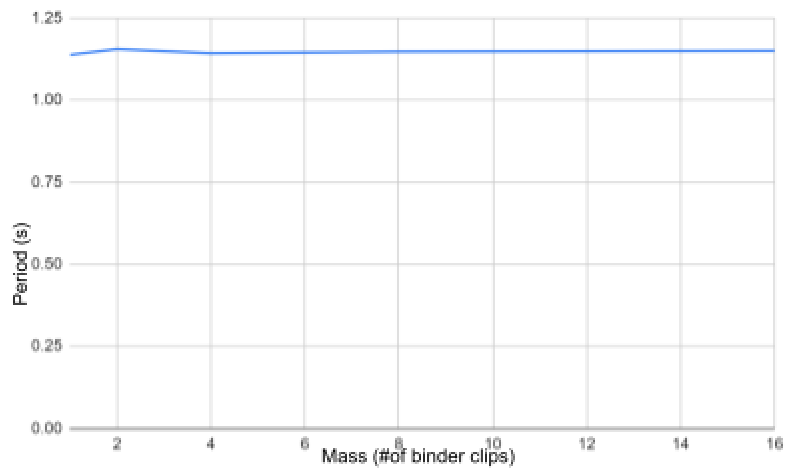
For the mass values, I started with one binder clip and then added more clippings on top of it, placing them in a way that kept the centre of mass of the pendulum the same (to the best of my ability). Because the binder clips were counted, there was no uncertainty for the mass values. The amount of weight I put on was based on the powers of two, going from 1 to 16. With five data points, I had enough data to analyze, as well as meet the constraints of the lab assignment.

To measure the period, I once again measured 10 oscillations of the pendulum with each weight/mass value and then divided the time by ten to get the period. Similar to the two previous two experiments, the uncertainty for the period time was based on my own reaction time which is +/- 0.087 seconds.

The effect on period by changing the mass:

Before conducting the experiment, I was aware that changing the mass of the pendulum would cause a deformation in the string and therefore change the length of the string. Based on the previous experiment, I can expect that major changes in string length will cause the pendulum to speed up or slow down, which will mean a faster or slower period.

I conducted the experiment and then graphed the data without any data fitting. The graph was this:



The graph here is mostly a straight line, similar to the results from Amplitude vs Period if there was no curve of best fit. It would seem that the changing of mass had less of an effect on period then changing amplitude, although that could be because of some experiment error and the uncertainties.

Conclusion:

Based on the fact that my data looks to be a straight line, meaning that the period time didn't change all that much from weight to weight, I believe that the mass didn't change the period of my pendulum. I suspect this is because of the materials I was using. The string of my pendulum was floss which must have been strong enough to resist deforming under the small weight of the multiple binder clippings.

Therefore the only thing across the three labs that changed the period of the pendulum was the length of the string. No matter the starting amplitude, or the mass of the string (for small masses) the period will remain the same for the pendulum.

Overall Conclusion:

During the three pendulum experiments, my pendulum was tested against the theoretical models that govern our understanding of pendulums. In all three measured relationships, *Amplitude vs Period, Length vs Period, and Mass vs Period*, my pendulum performed exactly as expected within the uncertainties of my design. When the Amplitude and corresponding Periods were measured, the relationship matched a horizontal line on the graph or a constant relationship. This was the expected result since the assumption is that the amplitude does not affect the period of the pendulum. When the lengths of the string were graphed alongside their corresponding periods, they were shown to have a power-law function for their relationship, both demonstrated in the exponential graph as well as a linear graph on the log-log plot. This reflected the assumption that the length of the string would affect the period in a T = 2(L + 0)^0.5 relationship. Finally, when the pendulum was tested with multiple masses, the resultant periods showed that mass didn't affect the pendulum either, at least with the masses I was using for the experiment. Therefore overall, the only variable to affect the period of the pendulum and therefore its speed, was the length of the string.

Although the experimental setup was effective, it was greatly hindered by the fact that I was doing the experiment in my hotel room at the Chelsea Hotel and not in an actual laboratory. Some of the uncertainties could have been reduced during the experiment, to therefore have more accurate results. Since the period was being measured multiple times, having something better than the human eye and a stopwatch that is better than a cell phone would greatly improve the data collection and reduce the uncertainty. Another thing that could've been changed is that I, the human, had to start the pendulum off at whatever amplitude I desired. This may not have been fully accurate because of my human error, or just because of my perspective with the pendulum. Having some way to be certain the pendulum has no initial force and the angle it starts at would also reduce the uncertainty in the experiment.

Now understanding how this pendulum works, I can start thinking about the simple and complex pendulums I see in my daily life. A playground swing or a pendulum clock can be analyzed with the knowledge I have gained from this experiment. Speaking of the latter, knowing that the only thing that affects a pendulum clock is the length of the pendulum, made me realize why we use pendulum clocks. Because nothing changes the period of a regular pendulum clock, it remains an accurate time keeper when it has energy. The pendulum then helps the gears measure time accurately, which is probably why we use the pendulum clock instead of other devices with periodicity as our major timekeepers.