QPhysics AT QUEENS COLLEGE

PHYSICS 103

LAB 1: DATA COLLECTION & ANALYSIS

INTRODUCTION

This first part of this lab is an introduction to lab procedures, learning to graph in **Excel**, and an introduction to lab assignments on **Blackboard**.

The lab itself deals with the law governing the period T (the time for one complete swing) of a pendulum. For different lengths of the pendulum string L, you will determine the period of the pendulum swing. Using Excel, you will display the data twice: plotting T vs. L and T^2 vs. L. Finally, using the data, you will determine a value for the acceleration due to gravity (g).

BASIC CONCEPTS

Any suspended object that can oscillate (swing back and forth) is a pendulum. An ideal (simple) pendulum requires:

- A point mass on the end of a long, massless string.
- The point at which the string is attached must be stationary.
- No friction anywhere.

Of course, this lab will use a real pendulum- there is friction, the ball is not a point mass, and the pendulum support moves. However, the mass of the string is negligible as compared to the mass of the ball, the ball is very small compared to the length of the string, and friction is small. If you stick to small angle oscillations, the laws for a simple pendulum will work nicely.

The period of a pendulum is the time it takes to swing through one entire cycle, **back and forth**. (The computer interface you are using automatically times a complete period.) The length of the pendulum string is from the point of support to the **center of the ball**. Galileo was the first to realize that, for small oscillations[1], the period T of a simple pendulum depends solely on L (the length of the pendulum string) and g (the acceleration due to gravity). Notice that the period of the pendulum does **not** depend on the angle through which it swings (as long as the angle remains reasonably small) or the mass of the pendulum bob.

We will use Excel to plot points and generate a **best-fit line**. Sometimes this is a straight line $(y = mx + b)$, and sometimes it is an equation such as $y = ax^2$, $y = a\sqrt{x}$, etc. The mathematics of curve-fitting is quite complex, but there are some standard methods to determine the **goodness of the fit**, or how correlated are the y and x data. A common tool is R^2, which lies between 0 (very poor correlation) and 1 (perfect correlation).

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[1] Small is a relative term, however, theoretical modeling of a simple pendulum gives a simple expression for the period using a "small angle approximation". For this lab, we will consider this to be less than 20°.

EQUIPMENT

APPARATUS

- ☐ Computer with Capstone
- ☐ Pendulum assembly
- ☐ 850 Interface
- ☐ Photogate (in channel 1)
- ☐ Meter Stick

PENDULUM ASSEMBLY

To measure the length of the pendulum, L, use a ruler and measure the distance *from the point of support to the center of the ball.*

IMPORTANT: To count the swings of the pendulum, the ball must trigger the photogate, a sensor at the top of the "U" as show in Figure 1. There is an invisible infrared beam across the top of the detector. When the beam is block by the ball or anything else, the sensor is triggered. The red LED at the bottom of the photogate glows when the photogate is triggered. You can use your finger to test this. Therefore, each time you adjust the length of the pendulum, you must check that the ball is swinging in the right place.

There are two clamps to adjust the assembly: one changes the length of the pendulum, and the other moves the photogate itself.

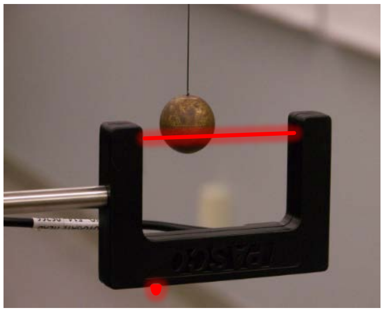

Figure 1: The ball must pass through the infrared beam to signal the timing. Note the red beam is for illustrative effect, the actual beam is invisible. The red LED at the bottom glows when the ball (or anything else) blocks the infrared beam.

PROCEDURES

SETUP

In many of the labs you will do, the computer is directly connected to the sensor (in this lab, to the photogate). This is done through a program called Capstone. There are pre-written Capstone programs for these labs, accessed through an icon labeled "Shortcut to Lab Files". For this lab, select "101 Excel Lab.Cap" and the program will open, ready to use. You should see a graph of “$Period\ (s)$” versus “$Time\ (s)$” like the one shown in Figure 2.

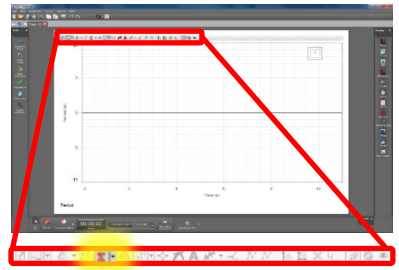

Figure 2: Capstone software highlighting the location of the

IMPORTANT*: Do not open Capstone directly through the program shortcut on the desktop. Only open the program by opening the “101 Excel Lab.Cap” file. If you accidentally opened Capstone directly, exit the program and open the appropriate file. Ask you lab instructor for help if you run into trouble.*

To view data statistics in Capstone, select the statistics tool in the toolbar directly above the graph as show in Figure 2. The triangular symbol (▼) to the right of the button allows you to select options such as minimum, maximum, mean, and standard deviation of selected data. You can find more detailed instructions for the tools in Capstone in Appendix G.

DATA COLLECTION

You will need to measure the period of a pendulum for different lengths ranging from 90 cm to 20 cm in steps of 5 cm. Start by setting the length of the pendulum to 90 cm, and be sure to measure from the point of support to the center of the ball.

- Start the pendulum swinging in a small arc of no more than 20°.
- To start collecting data, press **Record** (●) at the bottom of the Capstone window (as shown in Figure 3). Note that when Record is pressed, the same button changes to Stop and vice versa.
- Stop the data collection after you have collected around 10 data points by pressing **Stop** (■).
- Record the mean (average) value of the period on the data sheet. The mean and any other statistical quantity selected will appear directly on the graph.

Figure 3: The Record botton is located at the bottom of the Capstone window. Once selected, the botton turn into the Stop botton.

Repeat this process, decreasing[2] the length of the pendulum by 5 cm each time, and stopping when the length of the pendulum is 20 cm.

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[2] The reason for starting at 90 cm and subsequently decreasing the length by 5 cm rather than starting at 20 cm and increasing is because the longer length measurements in this apparatus is easier to set up than the shorter lengths. This way, by the time you’re at the shortest length, you’ll already be an expert!

DATA ANALYSIS

Enter the data you collected into Excel. Your First column, column A, should be titled "$Length\ (cm)$", and the second column (B), "$Period\ (s)$".

NOTE*: It is always best practice to include the units in the header of a data table. In addition, Excel will not be able to interpret numbers if units are included in the same cell.*

In order to gain insight on how the period of a simple pendulum depends on its length, it's useful to visualize the data by plotting it on a graph[3]. A sample plot of Period versus Length is shown in Figure 4 with a linear fit that passes through the origin. The simplest type of dependence is a linear relationship. In fact, this is the easiest dependence to see by eye. Figure 4 clearly indicates a nonlinear dependence of the period on its length.

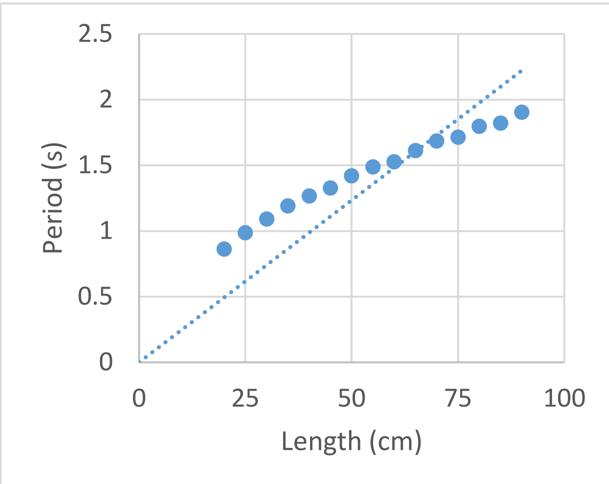

Figure 5: Plotting the period of the pendulum versus its length does not reveal a linear relationship.

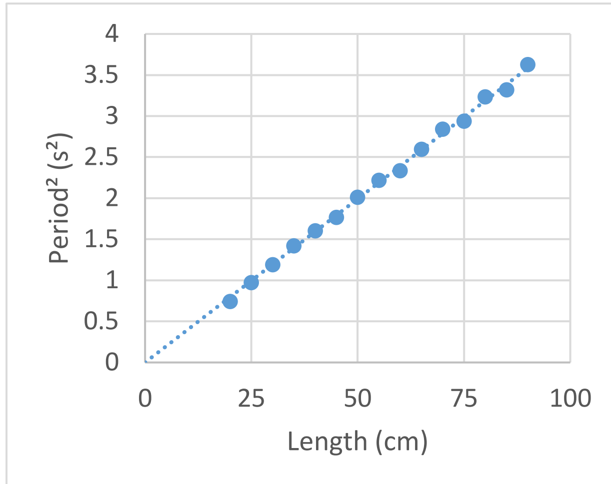

Figure 5: By plotted the square of the period versus length, the relationship can clearly be described as linear.

The question of how does the period of a pendulum depend on its length still remains. In attempting to answer this, you should try to **linearize the data**. This technique involves manipulating data in some meaningful way[4] that yields a linear relationship when it is plotted. For these data, plotting the square of the period versus its length reveals a linear dependence (Figure 5). This means we can say, with confidence, that the square of the period is **proportional to** its length, i.e., $T^2 = mL$, where m is the constant of proportionality.

- In the third column (C) in you Excel spreadsheet, fill the cells with the values of the period squared.
- Create **two separate** graphs: $Period\ (s)$ vs. $Length\ (cm)$, and $Period^2\ (s^2)$ vs. $Length\ (cm)$
- Add a linear trendline that passes through the origin by setting the **Set Intercept** option to zero.
- The graphs should show the equation and the R^2 value, both displaying three significant figures.
- The format of the graph should appear similar to those in Figure 4 and Figure 5.
- Be sure to add **Axis Titles** with appropriate units.

[3] See Appendix E for more information on using Excel

[4] It's not always obvious in what how to manipulate the data, however, a theoretical model often gives insight as to what dependence is expected.

Arrange the two graphs in your spreadsheet such that they and the data will print on **one page**. Use the **Print Preview** tool to assist with this. Make sure you put your name near the top of the sheet. Use Print the graphs.

Theory that will be covered later in the course predicts for the graph of the linearized data, the slope should be $m = 4\pi^2/g$, where g is the acceleration due to gravity. The equation on your graph should be $y = mx$. Record the value of the slope of the linear graph on your data sheet use this value to calculate the acceleration due to gravity, g. Be sure to show all work: the formula you used and your calculations.

NOTE*: Since L is in cm and T is in seconds, g will come out in cgs units- cm/s^2.*

The accepted value for the acceleration due to gravity is 980.2 cm/s^2 in New York City[5]. Calculate the percent error[6] for the value you obtain from your measurements.

$$\text{Percent Error} = \left|\frac{\text{Experimental Value} - \text{Accepted Value}}{\text{Accepted Value}}\right| \times 100$$

DON'T FORGET TO PRINT THE SPREADSHEET WITH YOUR DATA AND GRAPHS!

[5] The acceleration due to gravity depends on your location on Earth as well as altitude.

[6] Appendix C provides a detail description of various error calculations.