AN EXPLORATION OF THE SIMPLE PENDULUM

INTRODUCTION:

This first lab activity is an exploration. We want you to experimentally discover something about the motion of simple pendulums. We're not asking that you find or use a specific algebraic formula that might theoretically predict what the period should be. Instead, we want you to follow our suggestions for this exploratory activity and get some general idea about how pendulums behave. To do that you'll be asked to make some measurements, record your data, and then graphically plot it to see if there is some trend or regular behavior. You'll use a computer-automated system called "DataStudio" to make most of these measurements and display the position of the pendulum at various times.

We'll also use this experiment as an example to introduce you to one set of very important statistical ideas; the variability in a measurement and how to express that variability.

Same students might object, saying, "We haven't studied this material in class yet! How can we do this work?" You can! That's the point. An experiment is the way to directly confront the natural world and learn something by experience. When something is totally new in physical science, an experiment is the only way to learn. You think of series of questions that you might want answered and then devise an trial and error experiment to directly answer those questions. Galileo is usually given credit for being the first experimental scientist to learn in this way. Your exploration today is mini-version of his work done over 400 years ago. Of course simple pendula are well understood now. We are just using this as a teaching example.

BACKGROUND:

Galileo and Pendulum Motion…

Galileo "discovered" the laws of pendulum motion in 1584 when he was a 20 years old medical student. He discovered something that doubtless had been casually observed by many people throughout history. However, he was the first to see a specific trend and relationship. The story is that he noticed the motion of a swinging chandelier in the great cathedral in Pisa Italy. He observed that its motion was quite regular. He later "experimented" with swinging objects that he constructed himself. He had to use his pulse beat to do his timing…remember that clocks with minute and second resolution hadn't been invented in 1584. In fact, Galileo was the one that suggested that pendulums could be used to measure the pulse rate of medical patients. It is Christian Huygen that is given credit for building the first pendulum "clock" in 1657, some 73 years after Galileo.

The main point is that Galileo is given credit for the modern experimental method; he would conceive of a question, build an apparatus, do the experiment and then publish the results. He would do this over and over throughout his life. Ultimately, his experiments and observations got him in big trouble, leading to his trial by the church for an assault on its "authority". The specific issue that got Galileo placed under house arrest was the doctrine of an earth-centered universe. Galileo's work with pendula and falling objects was apparently ok. But, when he started looking at the stars and planets with the telescopes he invented and built, and then began writing about astronomy, he became "politically incorrect" for those times!

Computer-Automated, DataStudio…

This experiment will be your introduction to using a new, computer-automated measurement and data reduction system called "DataStudio" manufactured by PASCO Inc. Today you'll use a "motion sensor" to measure where objects are located at different times. The computer can then display this position versus time data. [*The computer can also calculate and display velocities and accelerations…we won't concern ourselves today with velocity or acceleration… Later in the semester you'll use other type detectors with the same computer software to measure forces, time intervals and positions*.]

OBJECTIVES:

You exploratory activity today is designed to guide you through an experimental study of

1. the motion of simple pendulum
2. how the period of a simple pendulum depends on
    a. the amplitude of the swing,
    b. the weight (mass) of the pendulum, and
    c. the length of the string
3. what is meant by a "measurement" and "measurement uncertainty"

The QUESTIONS are…

What do we mean by "periodic motion"?
Does the "amplitude", i.e. distance traveled, change the period?
What effect does the mass have?
Hoe does the length of the pendulum change the period?

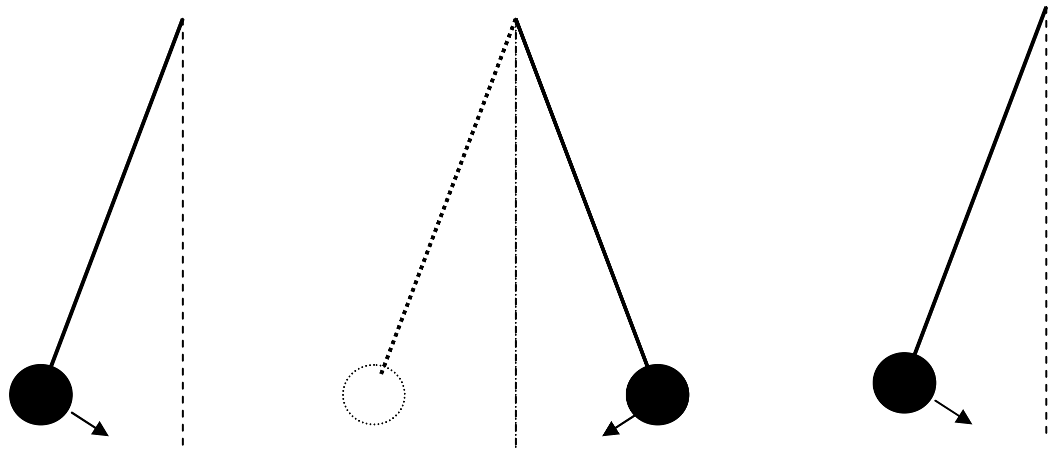
APPARATUS:

Pendulum, Meter Stick, Lab Stand, Computer, Motion Sensor and DataStudio.

METHOD:

When the mass of a pendulum is moved slightly to one side and released, it swings back and forth with a very regular motion. This regular periodic motion is called simple harmonic motion and shows up many places in nature. You will study the theory of this type of motion toward the end of the semester. Today you will experimentally investigate the motion itself and will not need to know any theory beforehand.

In this experiment you will measure the <u>Period</u> of the motion of a pendulum. **The Period is defined as the time it takes for one complete swing (out and back) of the pendulum.** [*The period can be measured starting from any arbitrary point and ending at that same point. The time for one complete "cycle" is the same for different starting and ending point. Try it!*]



T = 0 (start) T = ½ period T = 1 period

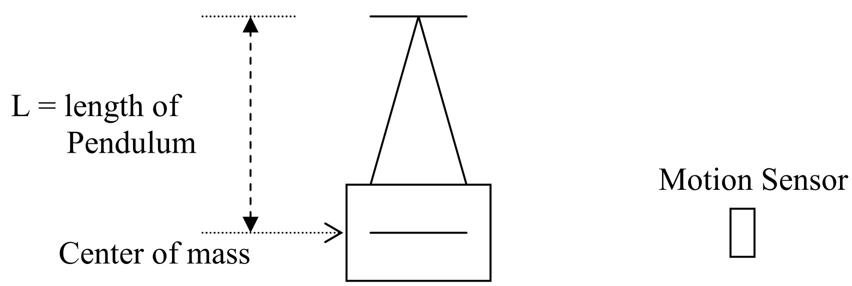
You'll be exploring what happens under three different conditions:

- varying the amplitude of the swing (the distance it travels)
- varying the weight of the pendulum
- varying the length of the pendulum

SUGGESTED PROCEDURE:

I. Initial Set-up and initial trails…

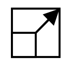
The pendulum's main mass is a short length of 4 x 4 block. That block provides sufficient cross section and a perpendicular surface to return the motion sensor's sonic pulse, thus allowing you to measure the position at different times. Adjust the length of the 4 strings holding the 4 x 4 so that L = 100 cm. Set up the motion sensor approximately 60 cm from the equilibrium position of the 4 x 4 pendulum mass.

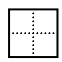


a. Turn on the PASCO interface first, then turn on the computer. If you turn on the computer first, the computer will be not recognized the interface, you should restart computer to make the interface work.

b. Double click the “DataStudio” icon. At the Experiment Setup window, click and drag the “Motion Sensor” from Sensor list to the digital channel 1. Double click sensor icon. At the “Sensor Properties” window, click Tab “Motion Sensor” and then select **20** for Trigger Rate. Click OK to return to the Experiment Setup window.

c. Start the block swinging and then click **Start** button on the DataStudio window to record approximately 10 complete periods and then click **Stop**. The recorded data set will appear as **Run # 1** in the Data List window. Next view the data in graphical form by dragging position data “Run # 1” to **Graph** on Displays list. The graph shows position vs. time.

d. Rescale by click **Scale to Fit** button () on the graph window. This resizes the entire graph.

e. Click **Smart Tool** button (). Note that the cross hair appears, the X and Y coordinates are automatically displayed for you… The X coordinate is shown time, the Y coordinate is shown position.

f. You can manually record the times that correspond to the time intervals from (1) maximum to maximum, (2) minimum to minimum, or (3) equilibrium to equilibrium… *note these intervals should be equal within the limits of your experimental error; are they? Try it*.

Notice also that the graph of motion vs. time looks like a sine or cosine wave… this is what is meant by simple harmonic motion.

Now, you are ready to begin the quantitative parts of this experiment.

II. Measurements

1. Vary Amplitude

During this first part, investigate the effect of the amplitude of the swing on the period of a pendulum. Also, measure the period two different ways and estimate variability.

A. Make a pendulum approximately 100 cm long. Start the block swinging by pulling it 10 cm from equilibrium. Using the “DataStudio” software, record at least 10 complete swings. On graph display, select 10 different complete swings and then measure the time it takes for each complete swing. Record your data. [*In your lab report, you’ll do some statistical analysis of this data. But for right now, just notice that your results in each of the ten trials vary*.]

B. A better way to measure the period is to measure the total time it takes for say 5 to 10 complete swings and then divide by the number of swings. […*the more complete swings you time, the less error you introduce because of the* *resolution in the time measurement…*] Take three sets of data at 10 cm. Calculate the average value of your 3 sets of measurements to determine the average value for the period.

C. Now repeat the process again, but start each swing by pulling the pendulum 5 cm to the side. Again, calculate the average period for the three trials. Does this average period for 5 cm "agree" with the period of the 10 cm swings? *By agree, we mean within the uncertainty, in this case the "range", of your time measurements*. Repeat once again, using pulling the block so that in initially swings approximately 15 cm. Is this period the same? Does the period of a pendulum depend on the amplitude of the swing?

2. Vary Weight

Investigate the effect of the weight of the block on the period of pendulum. Add one block to the pendulum, so the pendulum is double weight. Record 10 complete swings and then calculate the period. Does the weight of a pendulum have much effect on the period of the pendulum?

3. Vary Length

Next, investigate the effect of the length of the string on the period of a pendulum. Carefully measure the period and the corresponding lengths. The length should be measured from the center of the mass of the block to the point of suspension.

A. Measure both the length and the period of each length string you use. Do this for three different lengths, L = 100 cm, 75 cm and 50 cm. Again, you should measure the time it takes for the pendulum to make 5 (or more) complete swings. Repeat the sets of period measurements at least 3 times and find the average value. Use this average value to calculate the period for each length.

B. In your lab report, make a graph and plot the period of the pendulum versus the length of the pendulum. That is, plot the "length" on the X-axis as the independent variable and plot the period as the dependent variable on the Y-axis. Is the relation between the period and length linear? (Is your graph a straight line?) If not, does the period increase faster than linear (like the square – see figure 1) or slower than linear (like the square root – see figure 2)?

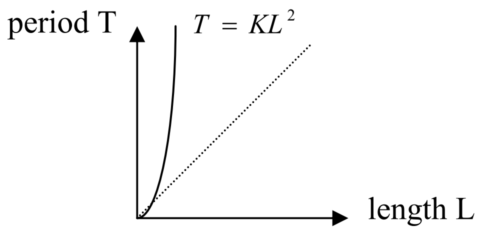


Figure 1

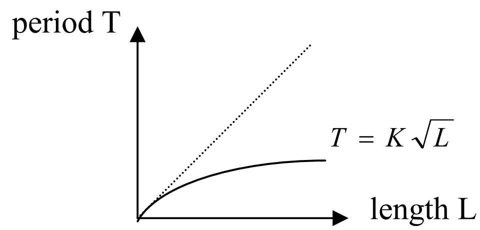


Figure 2

4. Pulse Rate as a clock

Finally, use your pulse to "time" any one your pendulum. Have your partner do the same. Instead of "seconds", you will have measured the period in "heartbeats". *This is what Galileo had to do 400years ago.*

A. Are your results the same as your partners? Why not? Discuss the limitations of using heartbeats to "time" the pendulum's period.
B. What is required then for a clock better than your heart? Does the simple pendulum "beat" more regularly than your heart does? What do you think is in a digital clock that makes it a better, more accurate clock than a clock regulated by a pendulum?

III. Statistical Analysis: Average, Range and Standard Deviation

a. In part 1A of the measurements, you were asked to measure the period by timing just one swing ten times. Find the average, the range and standard deviation of that data. [See the Lab Manual appendix for explanations and examples of those terms.]

b. Compute the average period and range from your data in part 1B. The "range" in this set of three periods ought to be smaller than the range in part 1A. What is the percentage difference between the periods determined in part 1A and part 1B? Is the inaccuracy of the digital clock in the computer a major factor? Why?

Remember, calculation of "standard deviation" is meaningful only when you have large sets of data. By large, most statisticians like to use more than 20 data points. In experimental physics we might calculate standard deviation for as few as 10 points. Below 10 data points, examining the "range", the difference in the high and low values, is a practical measure of the variability in your data. The standard deviation is a better statistical indicator only if calculated from a large set.

SUMMARIZE:

Based on your experimental data in this exploration, summarize what is the single, most important factor that determines the period of a pendulum…and what are the least important factors.

When you "measure" an interval of time between two events using any type of clock, what does that "measurement operation" really mean?

SUGGESTED DATA SHEET

1. Vary Amplitude

A. L = 100 cm

Cycles	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Period	___	___	___	___	___	___	___	___	___	___

Average Period = _____ Range = _____ Standard Deviation = _______

B.

	No. of cycle (n)	Time for n cycles	Period (Time/n cycles)
Run # 1			
Run # 2			
Run # 3			

Average Period = _____ Range = ____

Percent Difference between periods, A & B = ______

C.

No. of cycle (n)	Time for n cycles	Period (Time/n cycles)

2. Vary Weight

one block period = _____

two blocks period = _____

3. Vary Length

L = 100 cm

	Time for 5 cycles	Period
Run # 1		
Run # 2		
Run # 3		

Average Period = _____

L = 75 cm

	Time for 5 cycles	Period
Run # 1		
Run # 2		
Run # 3		

Average Period = _____

L = 50 cm

	Time for 5 cycles	Period
Run # 1		
Run # 2		
Run # 3		

Average Period = _____