Lab #4: Measuring Gravity with a Pendulum

SUMMARY: You will construct a pendulum and make a few measurements to estimate the gravitational constant g, which we will be using frequently throughout the semester, and compare it to the accepted value.

Some goals of this lab:

- **a.** To introduce you to recording data and finding out what it can tell you about the world.
- **b.** To give you a better understanding of the physical meaning of graphs
- **c.** To distinguish precision from accuracy, and understand sources of error in your measurements.
- **d.** To learn some statistical analysis techniques.
- **e.** To gain experience working with physical units.

Please refer to the first chapter of your text for more detailed information on these topics.

THE MATH YOU NEED TO KNOW: The mean value of a measurement is straight-forward to compute:

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

where x_i is each measured value, and N is the total number of measurements.

To calculate the standard deviation, we use a formula (see below) that, at its core, adds up and then averages differences of each measurement from the mean. It gives us an idea of the 'spread' in a data set.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

LAB SETUP: Using the materials provided at your station, create a pendulum with some length. The materials available will limit the maximum length somewhat, and a pendulum that is too short may make your data set a little trickier to collect. Your pendulum should look something like Figure 1, although you are free to be creative and try some variation on this basic idea.

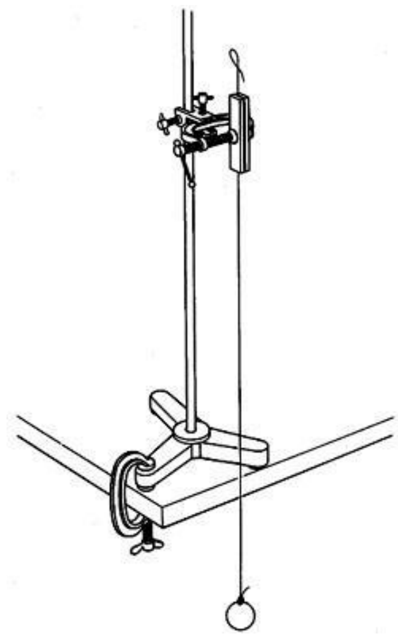


Figure 1. An example of a pendulum constructed with a weight at the end.

MEASUREMENT DEVICES: You'll also find an instrument for measuring length, and you'll be measuring time periods using a stopwatch, cell phone, or wristwatch.

MEASUREMENTS:

1. After you've made your pendulum, measure the length of the string that is connected to the weight. Then pull the weight a little to one side, being sure to start at a small (<15°) angle away from vertical. Let the pendulum swing back and forth, and time the period of its oscillation.
2. Repeat this procedure to fill in the first table below. Do not change the length of the pendulum. The idea here is to show how reproducible your measure is.
3. Change the length (and only the length) of your pendulum and repeat the two steps above to fill in the second table.
4. Change the mass (and only the mass) hanging at the end of your pendulum and repeat steps 1 and 2 above to fill in the third table.

Mass on the pendulum:___________

Measurement Number	**LENGTH** (meters)	**PERIOD** (seconds)	**Calculated *g*** (meters/sec^2)
1			
2	"		
3	"		
4	"		
5	"		

Mean Value for PERIOD	Mean Value for *g*	Standard Deviation of *g*

Mass on the pendulum:___________

Measurement Number	**LENGTH** (meters)	**PERIOD** (seconds)	**Calculated *g*** (meters/sec^2)
1			
2	"		
3	"		
4	"		
5	"		

Mean Value for PERIOD	Mean Value for *g*	Standard Deviation of *g*

Mass on the pendulum:___________

Measurement Number	**LENGTH** (meters)	**PERIOD** (seconds)	**Calculated *g*** (meters/sec^2)
1			
2	"		
3	"		
4	"		
5	"		

Mean Value for PERIOD	Mean Value for *g*	Standard Deviation of *g*

An ideal pendulum swings back and forth with a period (the time to travel through one complete swing) that is dependent on the length of the pendulum. This can be expressed in the following formula:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T = period in seconds, L = length in meters, and g = acceleration of gravity in meters per second squared.

We can solve this equation for g to compute g based on the data we just recorded. Please do so to compute g in the last column of the tables of data above.

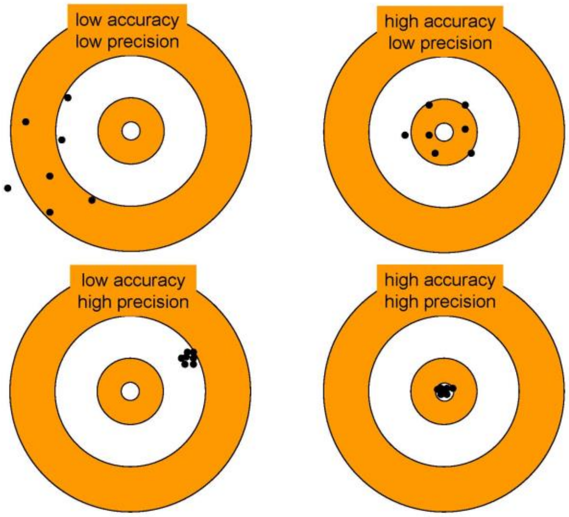
SUMMARIZE MEASUREMENTS – AVERAGE VALUES OF *g* (WITH UNITS):

	Value (m/s^2)	Average Error (average standard deviation)
Average and error from your experimental runs		
Internationally accepted value for "g"		N/A

<u>Lastly</u>, before you start on the questions below, talk to the instructor to have them add your L and T data to the full set of class data that is being compiled. This will give us a larger data set and should allow us to determine g more precisely by graphing these data sets together.

<u>QUESTIONS</u>:

1. **Errors in the measurements**.
   - **a.** Recall the concepts of precision and accuracy that were introduced in your previous science courses, and which are explained in the diagram below. List one part of our measurement of *g* that may reduce accuracy, and one that may reduce precision. Explain briefly.



   - **b.** Is the accepted value of *g* within the 'error bars' (i.e. plus or minus your standard deviation) of your measurement? By what percentage does your value differ from the accepted value?

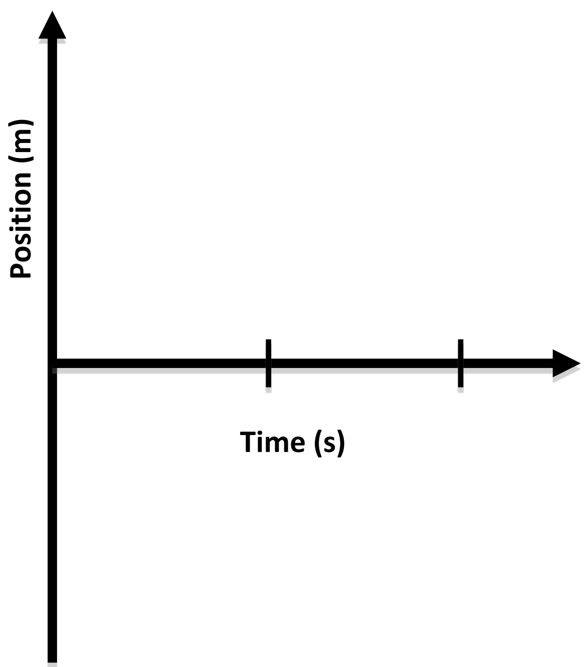
2. Looking critically at the experimental techniques.

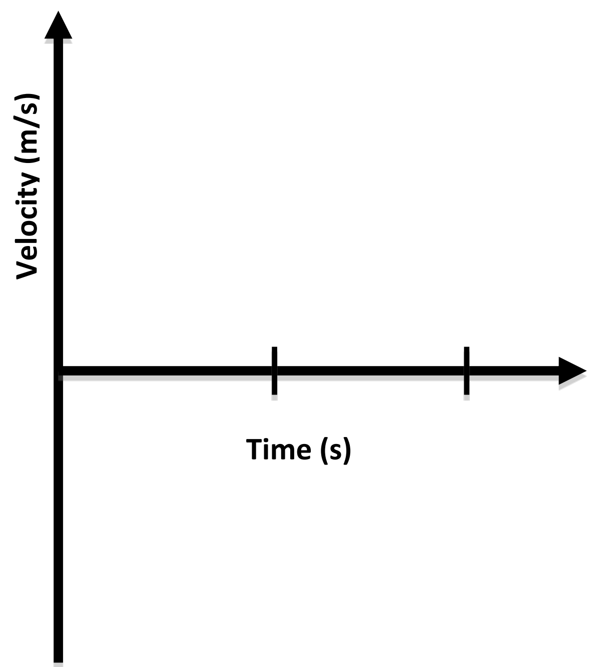
a. If the weight is pulled to make a large angle with respect to the vertical, the period will be (larger / smaller) for a given L. This will result in an estimated value of g that is (larger / smaller) than the actual value (circle your answers). Briefly explain your conclusion.

b. What is the most appropriate way to measure the length of the pendulum? (Hint: It is not just measuring the length of the string). Answering this may require a little research or some further experimentation. Please explain your answer.

3. Graphing position and velocity.

a. Plot (roughly) the x-position as a function of time for the pendulum. Time is 0 at the moment the weight is released. Also plot the weight's velocity as a function of time. Change the time axis labeling as needed such that it fits a couple periods of our pendulum's motion.





b. Mark on the graphs the moments when the acceleration is largest.

c. By looking at a velocity vs. time graph, how would you tell if an object had changed direction?

4. Application to the world outside of physics lab.

Imagine (or research) and then describe *two* possible applications of this technology for measuring gravity. Is there a scenario a real-life scenario (or in science fiction) where you might find a measurement of local gravity helpful? Feel free to be creative here, but your answer must be grounded in the physics we discussed.

5. Comparing experiment to theory

Consider your experimental data set and the calculations you made based on those measurements.

(a) Does the equation that relates the length and period of a pendulum to g predict the results you measured after you changed the length of your pendulum? Explain your reasoning.

(b) When you changed the mass but not the length of your pendulum, did it affect your measurements of the pendulum's period? If so, what caused this change? If not, why didn't the change of mass affect your data?