Name ______________________________ School ________________________________ Date __________

# Lab H01.2 - Motion of a Simple Pendulum

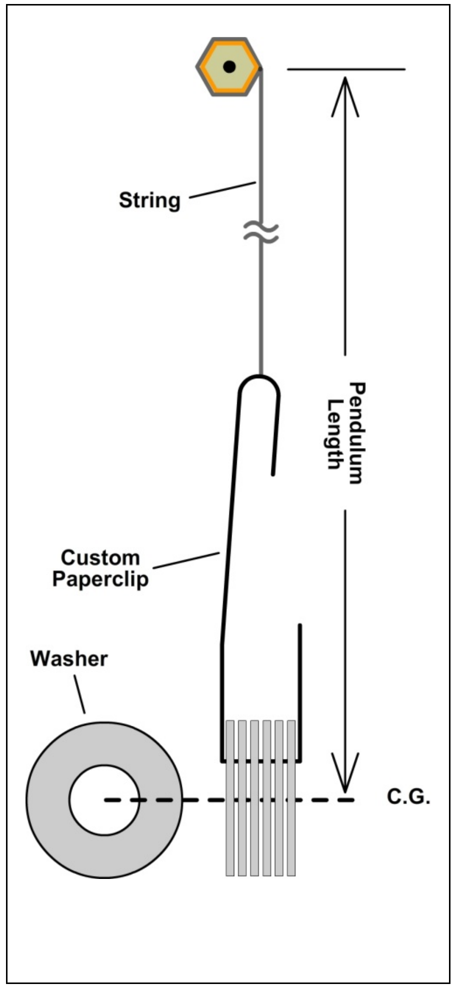
## *Equipment*

You'll build your own low-tech apparatus for this lab using some common fishing gear.

**Items found in your Lab Kit:**
2 meters of fishing line, 6 $^3/_8$" washers ($m_{avg}$ = 49.66 g),
1 large paperclip ($m_{avg}$ = 1.42g)
Logger Pro
PENCIL

**You supply:**
Pencil (six sided), Masking tape, Protractor (*see last page for paper copy)
Watch or clock that can measure seconds
Meter stick or similar metric ruler

With this equipment you'll create a pendulum like the one shown in the picture. Here's how.




a. Tie one end of the string to the top of the paperclip. (**See the "Fishing for Dummies" link on the last page for help in tying a fisherman's knot.
b. Wrap the other end of the string several times around the pencil, and then tape it to the pencil. Turn the pencil a few times to begin wrapping the string on top of the tape. (Ignore the door in the background. The door should be open.)

c. Tape the pencil to the lowest part of the top of a door frame. Two strips of tape should do nicely. When you need to adjust the length of the string you'll just release the tape and turn the pencil to wind the string in or out.
d. Hang one washer on the paperclip. You now have a functional pendulum.

## *Introduction*

Galileo is said to have been the first person to figure out the behavior of a simple pendulum, that is, the relation between the period of a pendulum and its physical parameters. The **period, T**, of any repetitive motion is the time required to complete one **cycle**. If you pull a pendulum to one side and release it, the **time for the complete trip over and back is its period.** Since Galileo's discovery, the pendulum has been an important device for keeping time. It's so reliable that it can even be used to detect the variation in the force of gravity from one point to another on the earth. We want to reproduce Galileo's work in this lab and find out just what does and does not affect the period of a pendulum.

A **simple pendulum** is one where all the mass can be considered to be concentrated at one point far away from the point of attachment. In this lab we will assume that we have a **simple pendulum** where the washers constitute the **"bob"** of the pendulum where the force of gravity acts. For such a circular disk, we can further specify that its center of gravity, C.G., the point where the force of gravity can be said to act, is at its center.

1. What do you think might determine the period of a pendulum? Suggest at least 3 possibilities. State these choices as hypotheses using direct or inverse proportions. Discuss your choices with your partners before finalizing your list. I'll get you started.

• The period of the pendulum is inversely proportional to the radius of the washer. (Wrong.) ____________

• The period of the pendulum is ____________________________________________

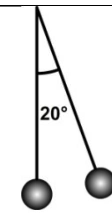
• The period of the pendulum is ____________________________________________

• The period of the pendulum is ____________________________________________

We're going to test 3 likely parameters in this lab. Hopefully your hypotheses are among them.

## *I. Amplitude, $\theta$ - angle of the string from the vertical.*

We're going to look for any relationships that the **period** might have with the **amplitude** of the swing, the **mass** of the bob, and the **length** of the pendulum. We'll start with the relation between the period and the amplitude of the swing. What should we do with the mass and the length during this investigation? In any **controlled experiment** we must vary only one quantity at a time, keeping others fixed. While we'll keep the mass and length of the pendulum fixed, we do need to record the fixed value for each.




Amplitude = 20°

1. Your washers will vary somewhat in mass. But rather than measure the mass of each washer we'll just use an average value. You'll find this value in the equipment list on the previous page. Use just one washer for this part of the lab. Also add in the mass of the paperclip. Record this, in kilograms, in Table 1.

2. Adjust the pendulum's length to somewhere between 1.25 and 1.50 m. (You may want to use a marker to mark on the string to help with this measurement.) In your discussion for question 1 you should have noted that for amplitudes up to 30° the string's top end pivots at one of the vertices of the hexagonal pencil. The bottom of the pendulum is at the center of gravity of the washers. Measure the length of your pendulum and record it in the table. Remember, the last digit is always an estimate.

3. You now want to measure the period of the pendulum when pulled through various angles (amplitudes.) This brings up two questions – how to measure the angle and how to measure the period.

To measure the angle you'll want to attach the protractor to the door frame so that it hangs behind the pendulum. This will be a little tricky, but it works. You'll probably need to use a bit of masking tape.

How could you make the most accurate determination of the period? If you measure the time for one swing cycle you'll have what you want, but the uncertainties in the measurement of the start time and the end time are pretty significant relative to the short time of one swing. If you were to measure the time for 10 swings you'd have the same amount of error since there's only one start and one stop. But the relative error (relative to the total time measured) would be one tenth as much, a much better result. To set this up there is a column in Data Table 1for the full 10 swings and another for the time for one swing, that is, the period, T. That is, T = time for 10 swings/10

It also helps to get the pendulum swinging and then start timing when it gets to one end of its swing. This is better than starting to time it from when you release it.

4. Find the period for 5°. Record your results in Table 1. Although your timer may well measure hundredths of a second, your ability to stop and start it at the correct time is much more limited. We can probably **only estimate tenths of seconds**. Both of your time columns should reflect this uncertainty.

5. What do you think will happen to the period when you increase the amplitude? Why? Explain your reasoning carefully. (This is an introductory lab. Just do your best to come up with an explanation for these predictions.)

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6. Take the necessary data to complete Table 1.

**Table 1 Period vs. Amplitude**

Mass of pendulum (1 washer + 1 paperclip) ________________ kg

Length of pendulum ____________________________________ m

| Trial | Amplitude (°) | Time for 10 swings (s) | Period, T (s) | Sketch Graph 1: Period vs. Amplitude |
|---|---|---|---|---|
| 1 | 5.0° | | | |
| 2 | 10.0° | | | |
| 3 | 15.0° | | | |
| 4 | 20.0° | | | |
| 5 | 25.0° | | | |
| 6 | 30.0° | | | |

7. Sketch a graph of period vs. amplitude in the space provided in the table. How do we describe the relation between these two variables? (Refer back to the last page of the Lab Manual for a review.)

_______________________________________________

8. You're probably surprised at your results. Why do you think that (within error) you found the amplitude to have no effect on the period of the pendulum? Explain your reasoning after discussion with your lab partners.

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Incidentally, the amplitude <u>does</u> have an effect on the period. But it's just a small effect at small angles.

9. What do you think was the major source of error in this part of the experiment? What could you have done to reduce it?

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## *II. Mass*

This time we want to find the effect of the mass on the period. To make sure you've isolated this one variable keep the length the same as in part I and use an amplitude of 10°.

1. You'll vary the mass by adding up to a total of 6 washers to the paperclip.
2. Find the period for 1 washer. Record your result as Trial 1.
3. What do you think will happen to the period when you increase the mass? Why? Explain your reasoning carefully.

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4. Take the necessary data to complete Table 2.

**Table 2 Period vs. Mass**

Amplitude of pendulum __________________ °

Length of pendulum ______________________ m

| Trial | Mass (kg) | Time for 10 swings (s) | Period, T (s) | Sketch Graph 1: Period vs. Mass |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |

5. Sketch a graph of period vs. mass in the space provided in the table. How do we describe the relation between these two variables?

6. You're probably again surprised at your results. Why do you think that (within error) you found the mass to have no effect on the period of the pendulum? Explain your reasoning after discussion with your lab partners.

So far we've looked at a couple of very likely prospects but come up with null results. Actually null results are great; they tell us what's not important and often they're easier to measure. Let's try another parameter.

## *III. Length*

This time we want to find the effect of the length of the pendulum on its period. To make sure you've isolated this one variable use three washers and an amplitude of 10 degrees.

1. Find the period with a pendulum approximately 1.4-m-long. Remember, the length is from the tie off point to the center of gravity. Record your result as Trial 7 in Table 3.

2. What do you think will happen to the period when you decrease the length? Explain your reasoning carefully.

3. Take the necessary data to complete Table 3. Use a range of lengths from approximately 1.4 m down to .2 m in approximately .2-m increments. This time, measure the time for 10 swings three times for each length and record the average time in the table.

**Table 3 Period vs. Length**

Amplitude of pendulum ________________ °

Mass of pendulum ______________________ kg

| Trial | Length (m) | Time for 10 swings (s) | Period, T (s) | Sketch Graph 1: Period vs. Length |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |

4. Sketch a graph of period vs. length in the space provided in the table.

5. Finally, a non-null result. Why do you think that you found the length to have an effect on the period of the pendulum? Explain your reasoning.

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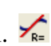
6. The horizontal lines indicating no relation in parts I and II were easy to pick out. This one's a bit trickier. Enter your length and time data into Logger Pro so that you can take a closer look. **Make sure that you follow the data table and graphing guidelines in the lab manual. If you have not already studied the lab manual and done all the activities in it you should stop and do all that work before continuing this lab.**

Could this be a linear relation? Click and drag across the graph to select the whole graph. Click on the Linear Fit button.  Hmm. It could be lousy linear data, but you've probably found in the first two parts that the data was pretty reliable. Let's count that possibility out. But before we move on, let's get a copy of the graphs.

You now need to print out a copy of your data table, graph with linear fit, and linear fit data box. But you don't want a full page graph. Here's how to get just what you need. Open your lab manual to section 2.1. You'll see several cases where I've used the process described below. The only difference is that I used electronic cut and paste. You'll use scissors and tape.

1. Click in the data table. Eight resizing handles  will appear. Click and drag the bottom, middle handle upward until just your data is visible.
2. Do the same with the graph except use the bottom right handle. This will resize the graph in both the horizontal and vertical. Use the figure in the lab manual as a guide to how large the graph should be relative to the data table.
3. Click on and drag the Linear Fit data box to place it to the right of the graph.
4. Print out your graph from Logger Pro by either clicking the printer icon or by using File/Print. You may need to adjust the size of your data table and graph depending on your printer. Tape this to the top of a blank page to send along with your lab. You'll have two more graphs to add to it.

7. Given our assumption above that the data is not linear, is the period directly proportional to the length? ______________

It would be nice if we had some more data for shorter lengths. If we did, we'd see that the graph curves dramatically downward at shorter lengths.

8. From your experience with the apparatus, what would be the problem with getting that (short pendulum) data?

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Look at the last page of your lab manual. There are seven categories of graphs that we find in this course. Assuming that the period vs. length graph does fall dramatically to 0, 0 as stated above, which graph type does this illustrate?

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What you should have is a **quadratic proportion with a side-opening parabola**. To confirm this you need to linearize it by plotting $y^2$ vs. x, or specifically, $T^2$ vs. L. You should be able to do that using what you've learned from the lab manual. But here's one last tutorial on **linearization of data**.

1. You have T vs. L data. You want $T^2$ vs. L data. Thus you need to create a new column containing the square of each T value.
   Select "Data/New Calculated Column"
   In the New Calculated Column requester enter: Name: "Period Squared" Short Name: "$T^2$" Units: "$s^2$"
   Still in the NCC requester, under Equation:
   Click Variables and choose "Period," type *, choose "Period" again.
   This will insert the following: "Period" * "Period"
   Click Done.
2. Click the y-axis label "Period." In the list that appears, click Period Squared.
   This should give you a linear set of data for Period Squared vs. Length.
   Drag across the graph to select all the data and click the Linear Fit icon. You should have a very nice fit.
3. Print out your data table, graph with linear fit, and linear fit data box, and tape it below the first graph.

9. Using the slope and y-intercept from the Linear Fit data box, write the equation describing your data in y = mx + b form. Be sure to substitute $T^2$ for y, etc. And don't forget the units.

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10. Look at your $T^2$ values in your data table. Do you think that the y-intercept is small enough to be ignored? Discuss this with your partners. What do you think and what's your reasoning?

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If your y-intercept is small enough to be ignored, write your equation below in y = mx form.

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11. Check this out with your raw data. Pick any experimental length value from your data table and see if your equation approximately produces your experimental T value. Show your work here.

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12. If you quadrupled the length of a certain pendulum, the period should _____________. (Double, halve, etc.)

Hopefully your equation was able to reproduce your data reasonable well. This is the beauty of equations. They sum up the behavior of a system in a tidy little bundle.

We do have two remaining tasks – looking for possible meaning in the proportionality const A, and adding units. But before doing that we need to look at one last factor.

## *IV. One last factor, g*

Discuss items 1 & 2 with your lab partners.

1. Suppose you took your pendulum to the top of a high mountain or better still to the moon. What effect would you expect to find? Specifically, where would the period of a pendulum have its greatest value, on the earth or on the moon?

______________________

2. What would be the period of a pendulum in deep space where the force of gravity is zero? _________________________

We don't have any means for measuring this relationship although you'll see it mathematically derived later in the course. Either analysis will show that the period depends on the local value of the acceleration due to gravity, g which is the acceleration of an object dropped in a vacuum at that location. The exact relationship is

$$T \propto g^{-\frac{1}{2}} \qquad \text{where } g \approx 9.8 \text{ m/s}^2.$$

## *V. The mathematical relationship between T and L*

We've found that

$$T^2 \propto L \text{ and } T \propto g^{-1/2}$$

We could also write this as

$$T^2 \propto L \text{ and } T^2 \propto g^{-1} \text{ or } T^2 \propto 1/g$$

When something is proportional to two different things it's also proportional to their product. So

$$T^2 \propto L \times \frac{1}{g} \quad or \quad T^2 \propto \frac{L}{g}$$

To convert this to an equation we need a constant of proportionality.

$$T^2 = k\frac{L}{g}$$

This would just be the slope of the line if you plotted $T^2$ vs. L/g. You can do this by adding a new column of L/g values. Create this graph and paste a copy below the first two on your graph page. It would be a good idea to compare notes with your lab partners before proceeding to make sure that your new column of data makes sense.

To write the final equation in terms of T instead of $T^2$, take the square root of both sides. This will give you the following equation with a new constant, k' where $k' = k^{1/2}$.

$$T = k'\sqrt{\frac{L}{g}}$$

The magnitude of k' = _________________

Or k' = ______ π

Write your final equation in terms your value of k'. ______________________

Here are a couple of useful links referred to in the equipment section.

* See "Fishing for Dummies" at http://www.dummies.com/WileyCDA/DummiesArticle/id-373.html for help in tying a Fisherman's Knot.

* See http://www.eece.ksu.edu/~hkn/files/protractor.pdf or one of the other links found when you Google "protractor" to print out a paper protractor. If you have plastic one you might want to use it;)