

# Lab N: The Pendulum

## Introduction

The discovery of the **pendulum's** properties by Galileo 400 years ago led to modern time-keeping which helped usher in the industrial age. Pendulums allow many simple yet accurate experiments including measuring gravity, characterizing **harmonic oscillators**, and even proving that the Earth spins on its axis. We will study the motion of a simple pendulum to address the following questions:

- How does a pendulum move?
- What determines the **period** of the pendulum's swing?
- Is a pendulum really a simple harmonic oscillator?

## Pre-Lab Questions

1. Draw a diagram of a swinging pendulum and indicate the point(s) where the acceleration is 0 and where the acceleration is highest. Also indicate where the speed is 0 and maximum.
2. Run the pendulum simulation at <http://www.walter-fendt.de/ph11e/pendulum.htm> and verify your results for #1. Briefly explain in your own words *why* the pendulum *oscillates*.
3. According to the simulation, where is the kinetic energy highest? Please explain why that is so given your answers to the previous questions.
4. Write the equation for the pendulum's period  $T$ . What characteristic(s) of the equipment do(es) the period depend on? Verify your result; change the variables in the simulation and note any change (or not) in the oscillation period.
5. Briefly explain why a pendulum makes a good clock.

## Equipment

**Photogates** record the passage of the swinging weight. The weight breaks the beam of light in the photogate, triggering the timers in the computer (Figure 1). All data will be

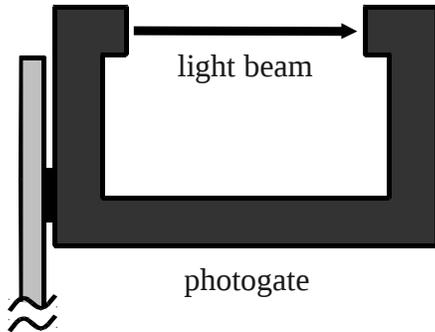


Figure 1.

obtained through the **Pasco interface** and recorded, plotted and analyzed on the **computer**.

You will record the **time** it takes the weight to complete a *full* swing motion down and back. This time is known as the **period**.

The **simple pendulum** is merely a bob or weight attached to a very low mass (so as to be negligible) string, wire or rod. By slightly displacing the weight from its rest position, you will cause the pendulum to swing.

## Theory

A simple pendulum is shown in A pendulum may be approximated **simple harmonic oscillator** as the **displacement** from the rest is small, or the **length**  $L$  is much than the **displacement**  $d$ , such that  $\theta$  is small.

The forces on the bob are the  $mg$ , and the **tension** in the string, from the rest position, the tension weight vectors are not aligned, so net force on the bob of  $F =$  or  $mgd/L$ .

Note that this force is proportional displacement as in a simple oscillator, and so the force is then restoring force,  $F = kd$ , and

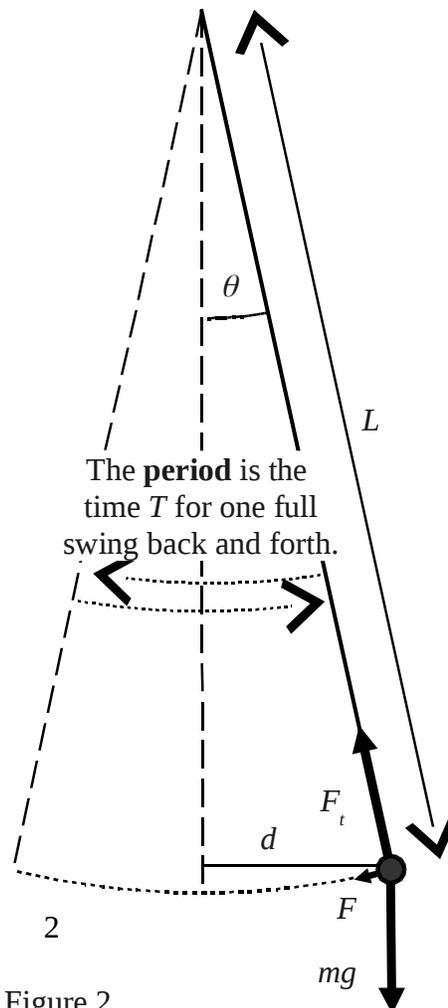


Figure 2.

Figure 2. as a long as position larger the angle

**weight**,  $F_t$ . Away and there is a  $mg\sin\theta$ ,

to the harmonic the

$$k = mg/L .$$

Recall that the **period**  $T$  of a simple harmonic oscillator is  $2\pi\sqrt{m/k}$  so

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

## Procedure

1. Measure the diameter (m) and mass (kg) of the bob twice.
2. Turn on the Pasco interface box. Double-click on the **DataStudio** icon on the computer and choose **Create Experiment**.
3. Click on the first digital **channel port** in the image of the Pasco interface and choose the **Photogate and Pendulum**. In the Measurements tab check “Period, Ch 1” and uncheck all others.
4. Drag the “Period, Ch 1” line in the upper left window to the **Table** line in the lower window.
5. Open a new Excel spreadsheet. Enter the value for bob diameter (m). Make **column headings** for L (m), m (kg), d (m), and T (s).
6. Measure the length (m) of the string twice. Add this length to the *radius* of the bob and enter this sum into the spreadsheet under **length**.
7. Pull the bob back a few centimeters, measure the **displacement**, then carefully let go and allow the bob to swing through the photogate. Click **Start**. Record at least 5 full swings and click **Stop**. Enter the displacement into the spreadsheet. This is Run #1.
8. Change the length of the string and measure the **new length** (m). Again add the bob’s *radius* to this value and enter the sum into the spreadsheet. Repeat #7. Change the length of the string again, record the new length, and repeat the experiment. These are Runs #2 and #3.
9. Pull back the bob an extra few centimeters and measure the new **displacement**. Repeat #7. Without changing the string length, increase the displacement again (but to no more than about 20 cm) and repeat the experiment. Increase the displacement once more and repeat the experiment to end up with periods for **4 displacements**. Enter the displacement values in the spreadsheet. These should be Runs #4–6.
10. Measure the mass and diameter of a **new bob** and enter the values into the spreadsheet. Using the same length (string plus bob *radius*) as in #9, repeat the experiment as in #7 with a small displacement. This should be Run #7 in the DataStudio Table.

## Analysis

1. In the DataStudio **Table**, click the button for “Show Selected Statistics”  $\Sigma$  | and select the **Mean** and **Standard Deviation**, deselect all others. In the spreadsheet record the mean and standard deviation of the period of the pendulum for each Run.
2. Describe how the average period varies, if at all, with different string lengths, displacements and masses. Make sure any variations are *significant*, that is, it's well above the noise (standard deviation). Review your results; how should the period vary according to theory?
3. Make plots of the period vs. string length, period<sup>2</sup> vs. string length, and period vs. displacement.
4. Use the period of one string length to **predict** the periods given other lengths. Review the result; what is the percentage error in your values?

Please save your spreadsheet on the computer. Print the spreadsheet or save it to an external drive to turn in to the instructor.

## Questions

Please answer on a separate sheet.

1. On which part of the experimental setup does a pendulum's period depend *most*?
2. Use this experiment to determine values of  $g$ . Find the average value and compare it to the known value. What is the percentage error?
3. How might this experiment be improved to illustrate better the characteristics of pendulums?