# Introduction to Measurement

## Objectives

The purpose of this experiment is to measure the period of a simple pendulum and to use scientific methods to determine the relationships between the period of a pendulum and its length, the mass of the pendulum, and the amplitude of the pendulum's motion. A Motion Sensor (see Fig. 1) is used to record the motion of the pendulum as it swings back and forth, and various software tools are used to determine the period.

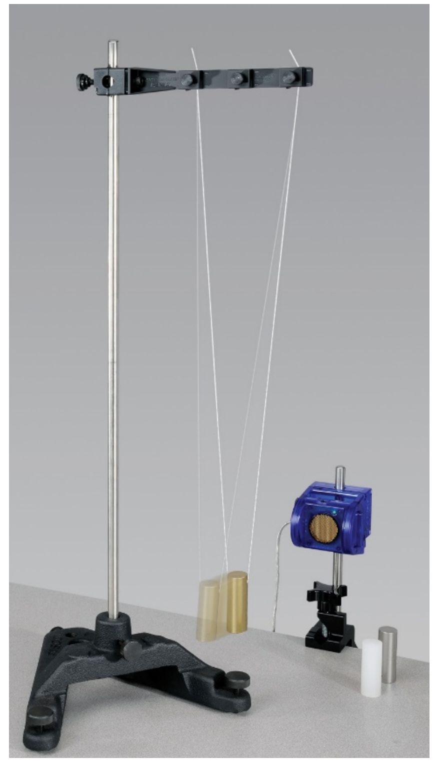


Figure 1: Measuring Pendulum Motion

## Background

A simple pendulum consists of a mass *m* called the pendulum 'bob', attached to a string of length *L* that has negligible mass. When the bob is pulled away from its equilibrium position and released, it swings back and forth. The period *T*, is the amount of time for a complete swing back-and- forth (e.g., from position 1 to position 2 and back to position 1) as shown in Figure 2. The amplitude *A* of the oscillation is measured from the equilibrium position out to the maximum displacement, and is thus half the full swing from position 1 to position 2.

## Equipment

| Qty | Items | Part Number |
|---|---|---|
| 1 | Motion Sensor | PS-2103A |
| 1 | Density Set | ME-8569 |
| 1 | Pendulum Clamp | ME-9506 |
| 1 | Large Rod Base | ME-8735 |
| 1 | Large Table Clamp | ME-9472 |
| 1 | Rod, 90-cm | ME-8738 |
| 1 | Rod, 45-cm | ME-8736 |
| 1 | String, spool | SE-8050 |
| Required but not included | | |
| 1 | Meter Stick | SE-8695 |
| 1 | Balance | SE-8723 |

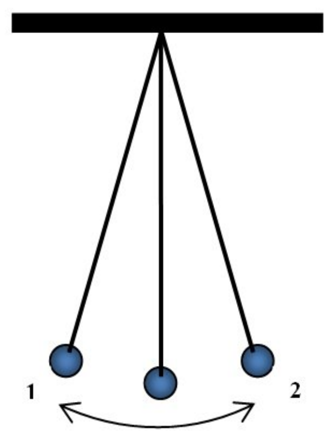



Figure 2: Pendulum Model

## Set-up

1. Attach the 90 cm Rod to the Rod Base and attach the Pendulum Clamp to the rod near the top. Attach a piece of string about 2 meters long to the Pendulum Clamp as shown in Figure 3. Run the string through the hole in the brass cylinder and put the ends of the string on the inner and outer clips of the clamp, so the string forms a 'V' shape as it hangs.

2. Adjust the string so the vertical distance from the bottom edge of the Pendulum Clamp to the middle of the pendulum bob is about 70 cm.

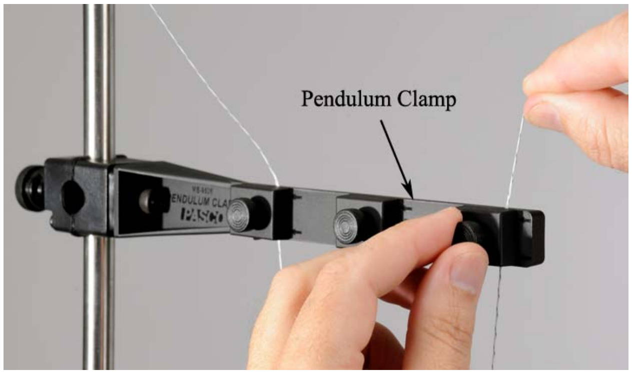


Figure 3: Hanging the Pendulum

3. Using the Table Clamp and the 45 cm Rod, position the Motion Sensor (see Fig. 1) in front of the pendulum so the brass colored disk is vertical and facing the bob, aimed along the direction that the pendulum will swing. Make sure that the range switch on the Motion Sensor is positioned on top. Adjust the Motion Sensor up or down so that it is at the same height as the pendulum bob.

4. Adjust the position of the rod base so that the Motion Sensor is about 25 cm from the pendulum bob. Plug the Motion Sensor into the interface.

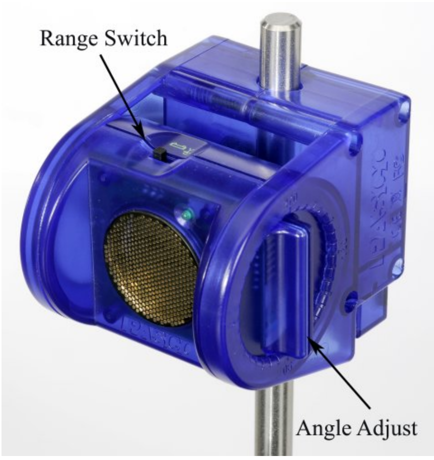


Figure 4: Motion Sensor

## Recording Data

1. Build a graph of Position (m) versus Time (s).

2. Start the pendulum swinging: Pull the pendulum bob away from the Motion Sensor about 5 cm and release. Try to get the oscillation as smooth as possible.

3. Start recording data. When the graph gets too cluttered, stop recording and start again. There are tools in the graph tool bar that allow you to change the graph scale. Make sure the amplitude of the swing is about 5 cm.

4. The Motion Sensor cannot detect objects that are closer than 15 cm. If needed, move the pendulum further away from the sensor.

5. Is the resulting data a smooth sine curve?
   If No, adjust the position of the range switch on top of the Motion Sensor to find which range setting returns the best data. In general, the position with the cart icon is for smaller, closer objects, and the position with the person icon is for larger objects further away.

6. Are there enough data points per period to define the sine wave?
   If No, use the sample rate controls to increase the rate to see the effect. A rate of 50 Hz will work well for this experiment.

7. Try to get a run of data that has a smooth curve with 4 to 6 complete oscillations. You can delete bad runs as necessary: Delete bad runs using the Delete button in the bottom tool bar.

## Measurement Tools

1. Measure the period of the pendulum: Using the Coordinates Tool (from the graph tool pallet), determine the time when the peak in each oscillation occurs and subtract adjacent peaks to get the period. Record your results.

2. Do you get the same answer for the period from all cases?

3. When the Coordinates Tool has been selected, you can right click on the cursor (on the graph) to activate the Delta Tool. Try measuring the period using this tool. Record your results.

4. There are various Curve Fit functions available: Select the Sine fit from the graph tool pallet. Is your data a good fit to a sine wave? The general form of a sine wave is:

   $$y = A\sin\left(\frac{2\pi}{T}x + \varphi\right)$$

   where $T$ is the period. Use the values from your curve fit to calculate the period of the oscillation. How does this compare to your previous answers?

5. In the next section you will vary the length of the pendulum. Predict what will happen to the period of oscillation when you **decrease** the pendulum length $L$. Will the period increase, decrease or stay about the same?

## Part 1 – Varying Length

1. In PASCO Capstone, make a table and create a user-entered data set called “L” for Length in units of (m). In the second column, create run-based user-entered set called “T” for Period in units of (s).

2. Create a calculation:
   Period = period(10,10,1,[Position (m)]) with units of (s)
   Make another table and select the Period calculation in the first column and delete the second column. Then select the mean from the statistics.

3. Use this method to determine the period for various pendulum lengths by recording several periods. Measure from the bottom edge of the pendulum clamp down to the top of the cylinder. The length, L, of the pendulum must be to the center of the "bob", so add half the cylinder's length. Measure values for the length, L, down to 0.1 m. Enter the length and the mean period into the table. Try to keep the amplitude about the same for each oscillation.

4. Shorten the pendulum length by about 0.05 m and repeat. You might need to adjust the height. As you generate each data pair, enter the values in the table. Create a graph of T vs. L.

## Curve Fits

1. Data is often graphed such that the resulting curve is a straight line. Click on the measurement name on the horizontal axis of your Period versus Length graph and choose the Quick Calcs to change how the Length is plotted. Try $1/L$, $L^2$, etc. Do any of these result in a straight line?

2. Return the horizontal axis to $L$, and try changing the vertical axis. Try $1/T$, $T^2$, etc. You should be able to get the data to be a straight line. Which produced a straight line?

3. Select the Linear curve fit from the graph tool pallet. Record the curve fit coefficients.

## Prediction

In the next section, you will vary the amplitude of the pendulum oscillation. Predict what will happen when you **decrease** the amplitude. Will the period increase, decrease or stay about the same?

## Part 2 – Varying Amplitude

1. Adjust the length of the pendulum so that the distance from the bottom edge of the pendulum clamp to the top of the cylinder is 40 cm.

2. Create another table and create a user-entered data set called “Amplitude” in units of (cm). In the second column, choose “T” for Period in units of (s).

3. Measure the period for an oscillation with an **amplitude** of about 10 cm. The amplitude is measured from the equilibrium out to the maximum displacement. Record your values in the table. Repeat for an amplitude of 8 cm, 6 cm, 4 cm and 2 cm.

## Prediction

In the next section, you will vary the mass of the pendulum bob. Predict what will happen when you **decrease** the mass. Will the period increase, decrease or stay about the same?

## Part 3 – Varying Mass

1. In this section, keep the amplitude of the oscillation and the length of the pendulum constant, but vary the mass by changing to the other bobs.

2. Make another table and create a user-entered data set called “bob” with no units. In the second column, create user-entered set called “Mass” with units of (g). Add a third column and select “T”.

3. Enter in Brass, Aluminum, and Plastic into the “bob” column.

4. For the brass cylinder, adjust the length of the pendulum so that the distance from the bottom edge of the pendulum clamp to the top of the cylinder is 60 cm. Measure carefully and keep this the same for all three bobs. Measure the period for an oscillation with an amplitude of about 6 cm.

5. Remove the brass cylinder and measure the mass of each pendulum bob. Record the values in the table.

6. Use the aluminum cylinder as the pendulum bob, carefully measuring so that the distance from the bottom edge of the pendulum clamp to the top of the cylinder is 60 cm. Measure the period for an oscillation with an amplitude of about 6 cm.

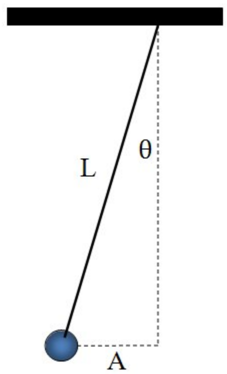
7. Repeat for the plastic cylinder.

## Summary

How good were your predictions? In general, what happens to the period of a pendulum when you change the length, the mass of the pendulum, and the amplitude of the pendulum's motion? Will the period increase, decrease or stay **about** the same?

## For Further Study: Pendulum Amplitude

The amplitude of a pendulum's oscillation is usually measured by the angle through which it swings, not its horizontal displacement. For the last section where you varied the mass, the length of the pendulum was about 60 cm and the max amplitude was about 6 cm. Using trigonometry, calculate the angle of the amplitude. In general, the period of a pendulum is independent of amplitude only if the angle is small (e.g. less than 20°).

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## For Further Study: Calculating "g".

The theoretical formula for the period of a pendulum is given by:

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

Where *g* is the acceleration due to gravity.

By squaring both sides of the equation, you can show that for a graph of $T^2$ versus $L$, the slope of the resulting straight line is given by:

$$\text{slope} = \frac{4\pi^2}{g}$$

Use the slope from your graph of $T^2$ vs. $L$ to calculate $g$, the acceleration due to gravity. Write your result here:

$$g =$$

If you take your pendulum to the moon where gravity is less, what will happen to the period? Why?