18.1 Harmonic Motion and the Pendulum

How do we describe the back-and-forth motion of a pendulum?

Two common types of motion are linear motion and harmonic motion. One kind of motion goes from one place to another like a person walking from home to school. This is *linear motion*. We use words such as *distance*, *time*, *speed,* and *acceleration* to describe linear motion. The second kind of motion repeats itself over and over, like a child going back and forth on a swing. This kind of motion is called *harmonic motion*. The word *harmonic* comes from the word *harmony* meaning "multiples of." Any system that exhibits harmonic motion is called an *oscillator*.

In this investigation, you will:

* experiment with a pendulum and see what you can do to change the period.
* set up your pendulum to measure a 30-second time interval.

Materials List

From Springs and Swings:

* Small stand
* Mass hanger
* Washers
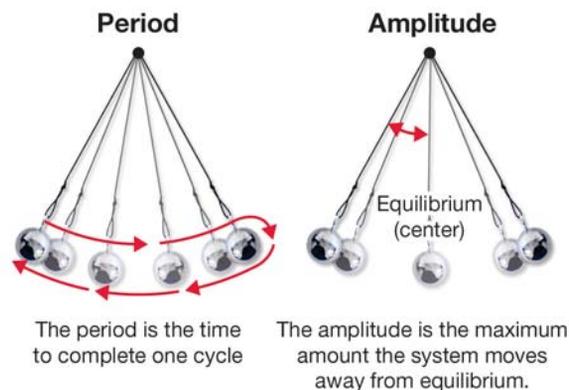* Pendulum string
* Beam breaker

Other materials:

* DataCollector
* Photogate
* Measuring tape

1 A pendulum

A pendulum is an oscillator made from a mass on a string. The mass is free to swing back and forth.

* A *cycle* is one complete back-and-forth motion.

* The *period* is the time it takes to complete one full cycle. The period of a pendulum is the time it takes for the pendulum to swing from left to right and back again.

* The *amplitude* describes the size of the cycle. The amplitude of a pendulum is the amount the pendulum swings away from equilibrium.

Period

Amplitude

The period is the time to complete one cycle

The amplitude is the maximum amount the system moves away from equilibrium.

2 Setting up the pendulum

1. Slide the pendulum string into the bracket at the top of the stand, as shown at right.
2. Attach the mass hanger to the loop end of the pendulum string. You now have a freely-swinging pendulum.
3. Attach the beam breaker to the string just below the bracket, as shown.
4. Attach a photogate to the top of the stand, as shown.
5. Plug the photogate into the A input on the DataCollector. Turn on the DataCollector and choose timer mode from the home screen.
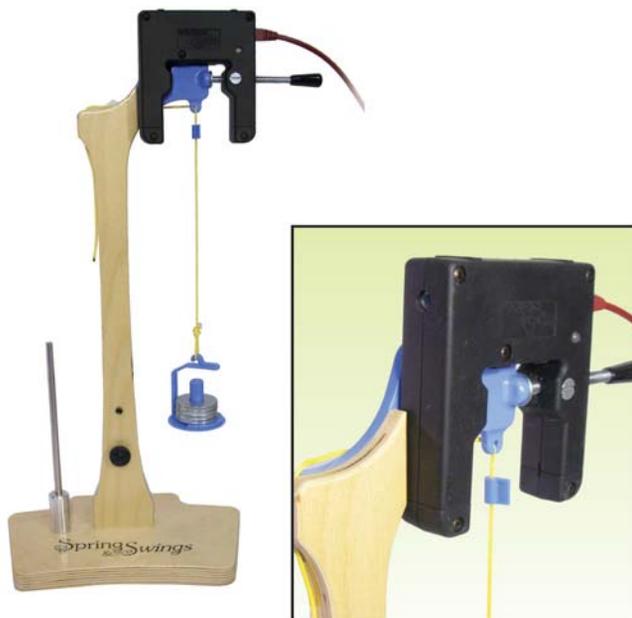
6. In timer mode, choose the period function (p). Period is the time for one cycle. The pendulum breaks the beam once as it swings through its complete cycle. The DataCollector's period readout corresponds directly to the time it takes the pendulum to complete one full cycle.

3 The three pendulum variables

In this experiment, the period of the pendulum is the dependent variable. There are three independent variables: the pendulum mass, the amplitude of the swing, and the length of the pendulum string.

1. Put a few washers on the mass hanger, adjust the string length to about 15 centimeters, and swing the pendulum through the photogate. Notice the period measured by the photogate.

2. The length of the string can be changed by removing it from the slotted bracket and placing it back in. You can change the mass by varying the number of washers on the mass hanger. The amplitude can be changed by varying the starting angle of the pendulum (low, medium, and high angle).

3. Design an experiment to determine which of the three variables has the greatest effect on the period of the pendulum. Your experiment should provide enough data to show that one of the three variables has much greater an effect than the other two. Be sure to use a technique that gives you consistent results. When you are changing a variable, it is a good idea to change it by a lot. For example, when you vary the mass, try experimenting with no washers, 5 washers, and 10 washers. You will only need to change each variable three times to see the effect. Be sure to design and use an appropriate data table.

4 Analyzing the data

a. Of the three things you can change (length, mass, and amplitude), which has the biggest effect on the pendulum, and why? In your answer, you should consider how gravity accelerates objects of different mass.

b. Split up your data so that you can look at the effect of each variable by making a separate graph showing how each one affects the period. To make comparison easier, make sure all the graphs have the same scale on the *y*-axis (period). The graphs should be labeled as shown in the example below:
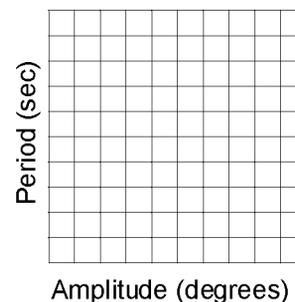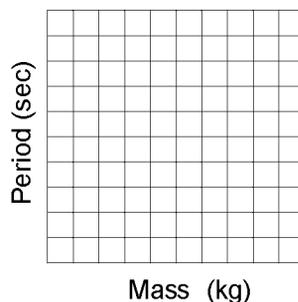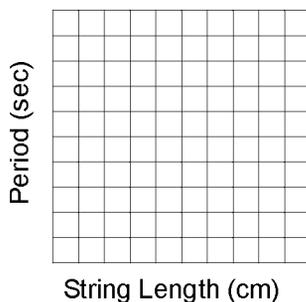
5 Applying what you know

Pendulum clocks were once among the most common ways to keep time. You can still buy beautifully-made, contemporary pendulum clocks. To make a pendulum clock accurate, the period must be set so that a certain number of periods equals a convenient measure of time. For example, you could design a clock with a pendulum that has a period of 1 second. The gears in the clock mechanism would then have to turn the second hand $1/60^{th}$ of a turn per swing of the pendulum.

a. Using your data, design and construct a pendulum that you can use to accurately measure a time interval of 30 seconds. Test your pendulum clock against the DataCollector stopwatch mode.

b. Mark on your graph the period you chose for your pendulum.

c. How many cycles did your pendulum complete in 30 seconds?

d. If mass does not affect the period, why is it important that the pendulum in a clock be heavy?

e. Calculate the percent error in your prediction of time from your pendulum clock.