Harmonic Motion

Reference Guide

Equipment Setup

Investigation Guides

Pendulum

Pendulum

The Pendulum

This simple pendulum is an ideal tool for teaching and learning the basic concepts of harmonic motion. The concepts of cycle, period, frequency, and amplitude are intuitively illustrated. Students can change three variables: the length of the string, the weight of the swinging bob, and the amplitude (angle) of the swing. The Pendulum has a 7" hardwood face with angle scale graphics for easy determination of amplitude. The length of the string can be varied from 15 centimeters to nearly 1 meter. Used with the Timer and a Photogate, the Pendulum will provide precise measurements of period.

Materials Checklist

- ✔ 1 Physics Stand assembly
- ✔ 1 Hardwood Pendulum face
- ✔ 1 String and bob assembly
- ✔ 10 Washers (masses)
- ✔ 1 Threaded rod with attached black plastic knob
- ✔ 1 Timer unit with power adapter
- ✔ 1 Photogate with red or blue wire

Assembly

Step One: Assemble the Physics Stands

Assemble the appropriate number of Physics Stands (based on how many lab stations are to be set up) by following the instructions on the Physic Stand Setup.

Step Two: Select the desired hole in the Physics Stand

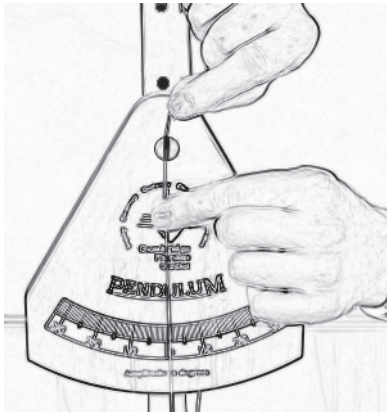
Slide the threaded rod with black plastic knob through the desired hole in the Physics Stand.

Step Three: Secure the Pendulum face to the Physics Stand

Thread the rod with the knob into the back of the Pendulum face, securing the unit to the Physics Stand.

Step Four: Attach the swinging bob

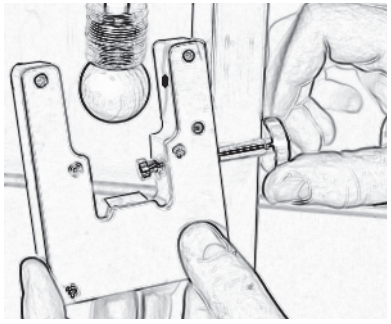
Select the length of string for the swinging bob by sliding the string into the slot in the peg on the Pendulum face. Check the length of the string by measuring from the bottom of the slotted peg to the bottom of the stack of washers on the swinging bob. The washers can be used to add or subtract weight from the swinging bob.



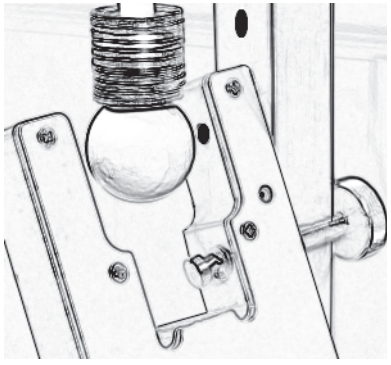
Step Five: Mount the Photogate on the Physics Stand and align the Photogate with the swinging bob

To mount the Photogate to the stand, open the gate by turning the knob counter clockwise. Place the outer edge of the gate against the pole and tighten the knob to pinch the pole between the outer edge of the gate and the knob.

A slight tilt is necessary for the wire of the gate to clear the pole.



Be sure to align the 2 small holes in the gate with the center of the round portion of the swinging bob.



Step Six: Setting up the Timer II with the Pendulum

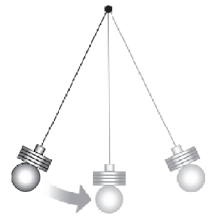
Attach the Photogate to slot A in the Timer using the red or blue wire. Be sure the "A" light is on and that the Timer has been set to period mode.

Note: For detailed instructions on using the Timer and Photogates refer to the Timer and Photogates section in the Equipment Setup.

A-1 The Pendulum

Key Question: How can you change the period of a pendulum?

In this Investigation, students are introduced to the vocabulary used to describe harmonic motion: cycle, period, and amplitude. Frequency is not introduced in level A, to avoid confusing students with many new terms and formulas. If students are ready for a more advanced mathematical treatment of this topic, you may choose to start with Level B instead. This activity offers students the opportunity to test a system with three independent variables as they explore which has the greatest effect on the period of a pendulum: mass, amplitude, or string length.



Preparation

You may wish to review with your students how to use the CPO timer in stopwatch mode before beginning the Investigation. Be sure students are comfortable with the terms cycle, period, and amplitude before they begin the activity. The Investigation gives students an opportunity to practice graphing skills. The graph of string length vs. period will be used again in *A-2 Making a Clock*.

Setup and Materials

Students work in groups of four at tables.

Each group should have:

- One physics stand
- One pendulum kit
- One CPO timer or another kind of stopwatch

The Investigation

Time Three to four class periods

Leading Questions

- What is harmonic motion?
- How can you describe and measure harmonic motion?
- Which variable has the greatest effect on the period of a pendulum: mass, amplitude, or string length?

Learning Goals

In this Investigation, students will:

- Learn terms used to describe harmonic motion
- Practice testing a system with three independent variables
- Graph their data
- Draw valid conclusions based on their data

Key Vocabulary linear motion, harmonic motion, cycle, period, amplitude

Teaching Note

You may wish to assign pages 1 and 2 of the Investigation as reading homework, or read and discuss this information during one class period. It is essential that students are comfortable with the new terms introduced in these pages.

Answers for parts 1 and 2 are shown on the next page.

1

Teaching Note

After setting up the pendulum, give students an opportunity to informally experiment with swinging the bob at different lengths. Make sure they can identify a cycle, time a period, and measure an amplitude before moving on to part 2.

2

Teaching Note

HINT: The most difficult variable to control is the amplitude because it decreases with time. Rather than trying to start the pendulum exactly at 15 degrees, have the students always start the pendulum at a larger angle, like 20 degrees. Then have them start measuring the period when the angle has decayed to 15 degrees. Since the pendulum slows down quickly (within a minute), waiting for it to reach a certain angle is much less frustrating than trying to start it exactly on the mark.

Students may recognize that the amplitude changes in ten swings, especially for short pendulums. As long as the amplitude is measured in a consistent manner for each of the ten trials, the decay in amplitude will not distort students' results.

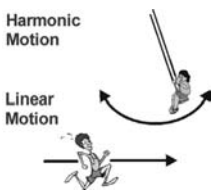
However, to get the most representative value for amplitude, the period can be measured at an **average** amplitude equal to the desired value. For example, suppose you want an amplitude of 15 degrees. You observe that in ten swings the amplitude decays from 15 degrees to 11 degrees, a change of 4 degrees. Make your period measurement as the pendulum swing changes from 17 degrees to 13 degrees. This way the average amplitude during the measurement interval will be 15 degrees.

A-1 The Pendulum

Question: How can you change the period of a pendulum?

In this Investigation, you will:

1. Learn how to describe the motion of a pendulum.
2. Explore how changes in the length, mass, and amplitude of a pendulum affect its motion.



As you watch moving things, you see two kinds of 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 like distance, time, speed, and acceleration to describe linear motion.

The second kind of motion is motion that repeats itself over and over, like a child going back and forth on a swing. This motion is called **harmonic motion**. The word harmonic comes from the word *harmony* which means "multiples of."

Many moving things have both linear and harmonic motion. A bicycle, for example, moves forward, but the wheels and pedals go around and around in harmonic motion.

You will need to learn some new words in order to describe and measure harmonic motion:

The cycle of the pendulum

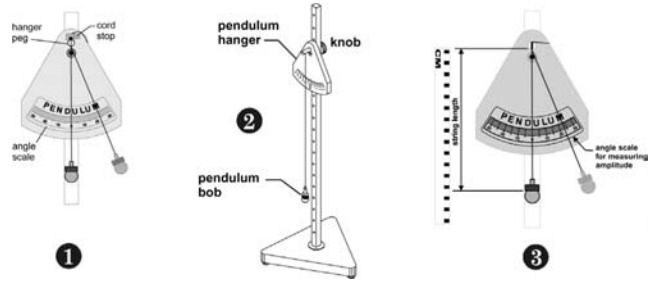
- A **cycle** is one complete back and forth motion. For a pendulum, you could define a cycle as starting when the pendulum is all the way to the left. The cycle would be complete when the pendulum has swung as far to the right as it will go and has come all the way back to the left again.
- The **period** 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 diagram below shows the difference between a pendulum with a small and a large amplitude. For a pendulum, the amplitude is measured as the maximum distance or the maximum number of degrees that it moves from the center.

1

1 Setting up the experiment

A-1

1. Attach the pendulum to one of the top holes in the physics stand.
2. Slip the pendulum string through the slot in the hanger peg. Use the cord stop to keep the string from slipping.
3. Make sure that when the pendulum is not moving, the string lines up with zero degrees on the angle scale. If it doesn't, adjust the pendulum hanger until the angle scale is centered properly.



2 What happens to the period when you change the mass of the pendulum?

You can change the mass of the pendulum by sliding washers down the string. The washers will rest on the pendulum bob. In this experiment, you will start with zero washers. Add two washers each time you repeat the experiment. You will need to keep the string length and the amplitude constant during this part of the experiment.

1. Decide with your group how long you want the string to be. Measure the string from the bottom of the string peg to the bottom of the stack of washers.
   String length: _____
2. Decide with your group how large you would like the amplitude to be. The amplitude is measured using the angle scale on the pendulum hanger.
   Amplitude: _____
3. You will use the timer in stopwatch mode to measure the time it takes for the pendulum to complete ten cycles. Assign one person in your group to count the cycles, and another person to start and stop the timer.

   HINT: Rather than trying to start the pendulum at the exact amplitude you have chosen, start the pendulum at a slightly larger amplitude. Friction will cause the amplitude to get a little bit smaller with each cycle. When the amplitude has decreased to the correct size, start counting the cycles. Record your data in Table 1 on the next page.
4. Divide the time you measured for ten cycles by 10 to find the period of the pendulum. Record your data in Table 1.
5. Repeat the experiment four more times, adding two more washers to the pendulum each time.

1

Student responses are not required for Part 1.

2

Sample data for pendulum with string length of 50 cm and amplitude of 10 degrees:

Number of washers	Time for 10 cycles (seconds)	Period (seconds)
0	14.28	1.43
2	14.17	1.42
4	14.13	1.41
6	14.09	1.41
8	14.11	1.41

Students will find that the effect of changing the weight is very small. In fact, it is within the error in measurement for a manual stopwatch. The timing for ten periods us usually plus or minus 0.1 seconds. This error is larger than the observed variation in the period.
The experiment was not sensitive enough to demonstrate that the weight of the bob had any effect on the period.

If students have studied linear motion, they may know that acceleration due to gravity does not depend on mass. Since gravity accelerates the pendulum bob back toward the center, it makes sense that the motion of the pendulum is not affected by mass.

3

Sample data for pendulum with 8 washers and string length of 50 cm:

Amplitude (degrees)	Time for 10 cycles (sec)	Period (sec)
10	14.08	1.41
15	14.11	1.41
20	14.15	1.42
25	14.21	1.42
30	14.28	1.43

The data shows a slight increase in period as the amplitude increases. The differences in period are again within the 0.1 second variability in timing.

Amplitude has little effect on the period because two opposite effects occur when amplitude is changed. If you increase amplitude, the pendulum has a greater distance to travel. This increases the period. However, because it is released from a higher position, it starts with more energy. More energy means the pendulum goes faster, decreasing the period. The effect of higher speed almost exactly cancels the effect of longer distance to travel back and forth.

4

4a. Adding weight to the pendulum has little effect on its period.

4b. Changing the amplitude of the pendulum has very little effect on its period.

A-1

Table 1: Changing the Mass of the Pendulum

Number of washers	Time for ten cycles (seconds)	Period (seconds)

3 What happens to the period when you change the amplitude?

This time, you will change the amplitude of the pendulum, while keeping its weight and string length constant.

1. With your group, decide how many washers you want the pendulum to carry.
   Number of washers: _____
2. With your group, decide how long you want the string to be.
   String length:_____
3. With your group, decide on five different amplitudes to measure. Your data will be easier to graph if your amplitudes are spread out evenly. For example, you might want the amplitude to increase by three degrees, or five degrees, between each trial.
4. Follow the same procedure as before to measure the time for ten cycles. Record your data in the table below.
5. Divide the time for ten cycles by 10 to find the period of the pendulum. Record your data in the table below.
6. Repeat the experiment using different starting amplitudes.

Table 2: Changing the Amplitude of the Pendulum

Amplitude (degrees)	Time for ten cycles (sec)	Period (seconds)

4 Examining your data so far

a. How does adding weight to the pendulum affect its period?

b. How does changing the amplitude of the pendulum affect its period?

3

5 What happens when you change the string length of the pendulum?

A-1

The third experiment looks at whether changing the length of the string changes the period. It is important to keep the amplitude and the number of weights constant throughout this part of the Investigation.

1. With your group, decide what the amplitude will be.
   Amplitude: _____
2. With your group, decide how many weights the pendulum will carry.
   Number of weights: _____
3. With your group, choose five different string lengths to measure. Again, your data will be easier to graph if the string length increases or decreases by the same amount between each trial. Record the string lengths you choose in Table 3.
4. Follow the same procedure as before to measure the time for ten cycles. Record your data in Table 3.
5. Divide the time for ten cycles by 10 to find the period of the pendulum. Record your data in Table 3.
6. Repeat the experiment using the four other string lengths chosen by your group.

Table 3: Changing the String Length

String length (cm)	Time for ten cycles (sec)	Period (seconds)

6 Thinking about what you have learned

a. Make a graph of each of your data tables. On each graph, the variable that you changed should go on the *x*-axis. The period of the pendulum should go on the *y*-axis. The scale for the period should be the same for all three graphs. Remember to label your axes. Give each graph a title.

graph

b. Which of the three variables (weight, amplitude, or string length) changed the pendulum's period the most?

c. Suppose you wanted to make a pendulum with a period of exactly two seconds. Describe how you would do this.

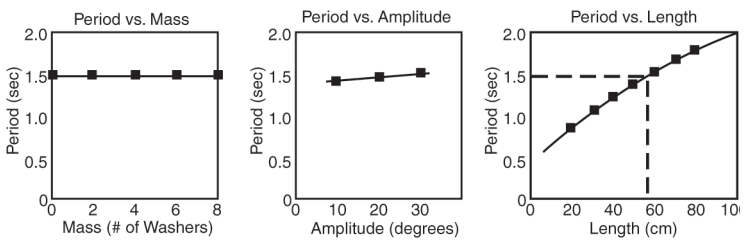
5

Sample data for pendulum with amplitude of 20° and 8 weights:

String length (cm)	Time for 10 cycles (sec)	Period (sec)
10	6.38	0.638
30	10.99	1.10
50	14.21	1.42
70	16.92	1.69
90	19.18	1.92

6

6a. Graphs:



6b. String length has the greatest effect on the period.

6c. For a two second period, I would make the string length a little longer than 90 cm, because increasing string length lengthens the period. I would try a 95 cm string first. If the period was a little more than 2 seconds, I would shorten the string. If it was a little less, I would lengthen the string. I would time the pendulum again and adjust the string length as necessary until I had a period of 2 seconds.

1. The clock, the waves, and the swing are examples of harmonic motion. Students may also include the girl running the race if they specifically mention the swinging of her arms, and the truck if they mention the rotation of the axles or wheels.
2.

Period	1.0 sec	1.2 sec	1.4 sec	1.7 sec
	A	C	B	D

3. As stated in the question, one example is the day/night cycle which has a period of 24 hours. This is caused by the rotation of Earth about its axis. A year has a period of about 365 days. This is due to the orbit of Earth around the sun. The month has a period of about 28 days. This is the time for the moon to orbit Earth.
   Other cycles that students might mention are the tides (with a period of about 12 hours, caused by the combined action of the sun and moon), and seasons, (with a period of one year, caused by the tilt of Earth in its orbit around the sun).
4. Pendulum A has the longest period since it has the longest string length.
5. It is important to remember that the pendulum swings past the pole twice each period. Therefore, there are 10 periods in 18 seconds, so the period is 18 ÷ 10, or 1.8 seconds.

Curriculum Resource Guide: Pendulum

Credits

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