17. Simple Harmonic Motion

Grandfather Clock

Driving Question

How does a pendulum measure time?

Materials and Equipment

For each student or group:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ 2-liter soda bottle with cap
- ☐ Meter stick
- ☐ String, non-stretch, ~2 m
- ☐ Food dye (optional)
- ☐ Tape
- ☐ Funnel
- ☐ Container of tap water (~500 mL)

Safety

Add this important safety precaution to your normal laboratory procedures:

- Ensure that students have enough room to safely swing their pendulums.

Thinking about the Question

If you have ever been in a swing, you know that you can be pushed by a friend or family member or you can move in such a way that you start the swing going on your own. If you start the swing on your own, you can make it go higher and higher by adding your own energy to it at just the right moment in the swing. If you are good at this, you can get the swing going to an exciting height. What happens when it is time to slow down and stop the swing? In your lab group, discuss what happens when you stop adding energy to the swing and just sit in it while it slows down. Be prepared to share your thoughts with the class.

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What is gravitational potential energy?

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What is kinetic energy?

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Watch your teacher's demonstration involving the soda bottle pendulum.

Sequencing Challenge

☐ **The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.**

◯	◯	◯	◯	◯
Suspend the soda bottle from an overhead support, positioning the bottle 20 cm above the motion sensor's screen.	Tie a long string to the neck of the soda bottle and make a secure knot.	Record position data as you allow the soda bottle to make a series of swings back and forth.	Make certain that each lab group member is aware of the safety rules and procedures for this lab.	Fill a 2-liter plastic soda bottle one-quarter full of water and replace the lid.

Investigating the Question

☐ **Note:** When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Part I – Making a simple pendulum

1. ☐ Fill an empty 2-liter plastic soda bottle one-quarter full with water.

2. ☐ Add food coloring to the water in the soda bottle.

3. ☐ Cap the bottle tightly. This part of the pendulum system is referred to as the "bob."

4. ☐ Tie one end of a long piece of string around the neck of the soda bottle, under the ring that protrudes from the neck. Make sure the string is securely tied with a knot.

5. ☐ Tie the other end of the string to the ceiling or to the support provided by your teacher.

Part 2 – Making predictions

6. ☐ Write your predictions for the following:

   a. How many seconds do you think it will take your pendulum to make one complete swing from one side to the other and back again?

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   b. Will it take more time, less time, or the same amount of time to make one complete swing if you pull the pendulum back farther before letting it go?

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   c. How will the amount of time to make one complete swing be affected if you double the amount of water in your soda bottle?

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   d. How will the amount of time to make one complete swing be affected if you change the length of the pendulum's string by shortening or lengthening it?

Part 3 – Grandfather clock

7. ☐ Start a new experiment on the data collection system. �(1.2)

8. ☐ Connect the motion sensor to the data collection system. �(2.1)

9. ☐ Display Position on the y-axis of a graph with Time on the x-axis. �(7.1.1)

10. ☐ Adjust the height of the soda bottle pendulum so that when the motion sensor is placed on the floor beneath it, there is about 20 cm of space between the bottom of the bottle and the metal screen of the motion sensor.

    ☐ **Note:** The motion sensor should be set to the "person" icon.

11. ☐ Begin data recording. �(6.2)

12. ☐ Gently pull the soda bottle back a few centimeters, so it is just beyond the motion sensor, and let it go. Try not to push it or add any extra vibrations to the pendulum. Why is it important to let the pendulum fall on its own without pushing it?

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13. ☐ Allow the pendulum to swing for 20 seconds.

14. ☐ Stop data recording. �(6.2)

15. ☐ Examine your data of position versus time. You may need to adjust the scale of your graph. �(7.1.2) How can you tell from the graph the number of swings the pendulum made in a certain amount of time?

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16. ☐ Begin data recording. �(6.2) This will be your second data run on the same graph.

17. ☐ Gently pull the soda bottle back, this time about twice as far beyond the motion sensor, and let it go.

18. ☐ Allow the pendulum to swing for 20 seconds.

19. ☐ Stop data recording. �(6.2) Based on your data, what do you notice about the number of swings the pendulum made in the second trial compared to the first trial?

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20. ☐ Carefully remove the cap of the soda bottle without disconnecting the pendulum from the system.

21. ☐ Pour in enough water to double the volume. By doubling the volume of the water, what other property of the water do you double?

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22. ☐ Begin data recording. �(6.2) This will be your third data run on the same graph.

23. ☐ Gently pull the soda bottle back a few centimeters, so it is just beyond the motion sensor, and let it go.

24. ☐ Allow the pendulum to swing for 20 seconds.

25. ☐ Stop data recording. �(6.2) Based on your data, what do you notice about the number of swings the pendulum made in this trial compared to the previous trials?

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26. ☐ Begin data recording. �(6.2) This will be your fourth data run on the same graph.

27. ☐ Gently pull the soda bottle back, this time about twice as far beyond the motion sensor, and let it go.

28. ☐ Allow the pendulum to swing for 20 seconds.

29. ☐ Stop data recording. �(6.2) What effect, if any, does the distance from the motion sensor have on the number of swings the pendulum makes per period of time?

30. ☐ Shorten the string of your pendulum so it is about half its initial length. One way to do this is to tie a loop into the string.

31. ☐ Begin data recording. �(6.2) This will be your fifth data run on the same graph.

32. ☐ Allow the pendulum to swing for 20 seconds.

33. ☐ Stop data recording. �(6.2)

34. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Answering the Question

Analysis

1. How did your predictions from Part 2 compare to your experimental results?

2. Review your data carefully. How many times must the soda bottle bob pass across the motion sensor as it travels through one complete cycle? Explain why this is the case.

3. Draw the pendulum system, including a representation of the pendulum's swing, and label and describe the energy conversions that are taking place. Be prepared to share your drawing and explanations with the class.

4. How much time is required for the pendulum, at the initial length of string, to make one complete cycle?

5. How much time is required for the pendulum, at the shortened length of string, to make one complete cycle?

6. The behavior of a simple pendulum, such as the one you made and used in this activity, is ideal for use as a time-keeper. In fact, the metronome used by musicians is an example of a type of time-keeping pendulum. Another example is a grandfather clock. The behaviors which are most helpful for time-keeping are listed below:

1. The period of a pendulum does not depend on the mass of its bob.
2. The period of a pendulum does not depend on the size (amplitude) of its swing.
3. The square of the period varies directly with the length of a pendulum.

a. What evidence does your data provide that supports the first two behaviors?

b. What further information would you need to know about your pendulum system to be able to discuss the third behavior?

7. A lab group has set up a pendulum system, has conducted multiple trials to measure the time of the swings, and has measured the length of the pendulum, finding it to be 72 cm long. They have done some research on pendulums and discovered an equation that relates the length of the pendulum to its period. The equation is:

$$Period = 2\pi\sqrt{\frac{\text{Length of pendulum (in meters)}}{g}}$$

The students found the following information in their science text: The variable *g* stands for the acceleration due to gravity, and has an approximate value of 9.8 m/s^2.

How much time, on average, does it take this lab group's pendulum to complete each cycle of back-and-forth swing? Show your work. Remember to convert the length measurement to meters.

8. Pendulums will always return to almost exactly the same height from which they were released. What evidence do you have from this lab activity that supports this statement about pendulums?

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Multiple Choice

☐ **Circle the best answer or completion to each of the questions or incomplete statements below.**

1. Motion that repeats itself in a predictable pattern is called:

   A. Simple harmonic motion
   B. Newtonian motion
   C. Chaotic motion

2. The size of a pendulum's swing is also known as the pendulum's:

   A. Amplitude
   B. Period
   C. Cycle

3. Each complete back-and-forth swing a pendulum makes is referred to as a/an:

   A. Amplitude
   B. Period
   C. Cycle

4. The amount of time required for a pendulum to complete one back-and-forth swing is:

   A. The pendulum's amplitude
   B. The pendulum's period
   C. The pendulum's cycle

5. Because of the simple harmonic motion of pendulums, they are useful for:

   A. Maintaining lengths of string under tension
   B. Measuring the passage of time
   C. Demonstrating random motion

6. At the top of its swing, or the maximum distance from equilibrium, a pendulum's energy is:

   A. Entirely kinetic energy
   B. Almost equally kinetic energy and gravitational potential energy
   C. Entirely gravitational potential energy

7. A grandfather clock's pendulum has a small adjustment knob on its bob so that in case it is running fast or slow, it can be adjusted to keep better time. What must this knob adjust in order to change the clock so it keeps accurate time?

   A. The mass of the pendulum (the knob adds or removes mass).
   B. The distance the knob can swing (the knob changes the amplitude)
   C. The length of the pendulum (the knob lengthens or shortens the pendulum)

8. In order for a pendulum to continue swinging, what must be added to it?

   A. Energy
   B. Mass
   C. Time

9. An object that is not being subjected to a force will continue to move at a constant speed, yet the pendulum eventually stops swinging and comes to rest in its equilibrium position. What force or forces cause this simple harmonic motion to stop?

   A. Gravity and friction
   B. Gravity and magnetism
   C. Magnetism and friction

10. Which of the following statements about energy is **not** true?

   A. Energy can neither be created nor destroyed; it can only be transformed from one kind to another.
   B. Gravitational potential energy is stored energy due to an object's position and height above the ground.
   C. Kinetic energy is the one form of energy that is not conserved; it can be both created and destroyed.