BACK AND FORTH

AT A GLANCE

Explore energy transformations in a pendulum and investigate how the mass of the bob and the length of the string affect the period of the pendulum swing.

OBJECTIVES

Students will:

- Learn the energy transformations involved in a pendulum swing
- Describe the gravitational potential energy and kinetic energy of a pendulum
- Describe how the mass of the bob, length of the pendulum string, and initial angle of displacement of the pendulum affect the pendulum's swing

KEY VOCABULARY

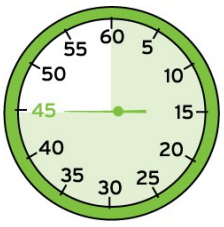
pendulum, pivot, period, equilibrium, oscillation, gravitational potential energy, kinetic energy, energy transformation

SUGGESTED GRADE LEVELS: 4—8

ILLINOIS STATE LEARNING GOALS

Late Elementary
3: A, B; 7: C; 10: A; 11: A; 12: C, D
Middle/Junior High
3: A, C; 7: A, B; 10: A; 11: A; 12: C, D

PACE YOURSELF
45 MINUTES



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ADVANCE PREPARATION

1. Make copies of student worksheet.
2. If time is short, you may want to complete the initial setup portion of this activity. Precut the strings and attach the washers to the strings. Each group should have one single washer pendulum and one double washer pendulum.

MATERIALS

Per Group:
2 pieces of string (40 cm long)
scissors
3 large washers
masking tape
stopwatch
permanent marker
ruler

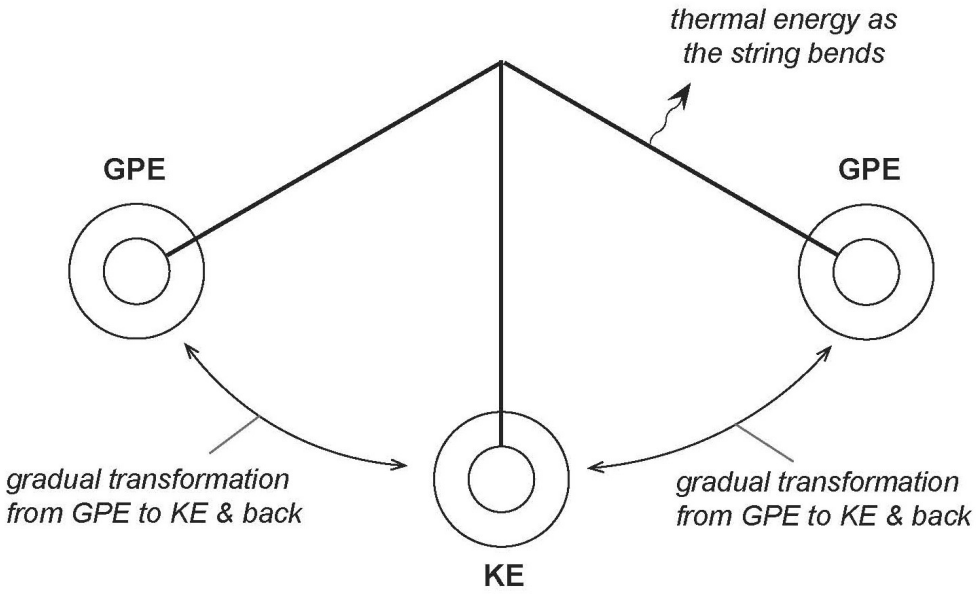
WHAT YOU NEED TO KNOW

Pendulums consist of a mass or bob attached by a string to a pivot point (center of rotation). As a pendulum moves it sweeps back and forth in a circular arc. One full movement, from left to right and back again, is called a **period**.

Pendulums are great ways to visualize energy transformations and energy conservation within a closed system. When a pendulum is displaced from its resting equilibrium position (where it is not moving) work is done on the bob and so it acquires **gravitational potential energy** (GPE). This is the energy an object has because of its position within the Earth's gravitational field. When an object has gravitational potential energy, it is subject to a restoring force due to gravity, a force that will accelerate it back towards the equilibrium position. When the bob is released, the restoring force combined with the bob's mass causes it to **oscillate** about the equilibrium position, swinging back and forth. As the bob begins to move, its GPE is transformed into **kinetic energy** (KE), or energy of motion. When the pendulum is at the part of its period where it is at a 90 degree angle with the floor, its original GPE has been entirely transformed into KE. As it continues to swing and move upward on the arc, the KE is transformed back to GPE. This cycle repeats itself until the pendulum stops swinging. The pendulum system loses energy due to air resistance and heat loss (thermal energy) within

the string itself.

A pendulum swings with a specific period which depends mainly on its length and not on the mass of the bob.



WARM UP

Show students a pendulum and ask them to describe the parts (bob, string, pivot. Ask them if they have seen a mechanism like this before. Where? After students come up with a few examples, ask them how to set the pendulum in motion. Set the pendulum moving and ask students to describe what they see. Ask them why the pendulum continues moving past the equilibrium point and up the other side of the arc—what is the energy that propels this movement? After a while the pendulum will slow down and eventually stop. Ask students to speculate why the pendulum eventually came to a rest.

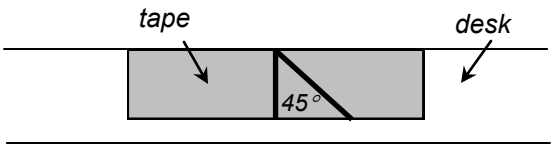
After allowing students to brainstorm ideas, explain the concept of transformation of energy, introducing gravitational potential energy and kinetic energy. Explain that energy is not created not destroyed, but rather transformed into other forms. You may want to use the diagram labeled with the energy transformations (Figure 1) , and use the animation below to illustrate the concepts:

http://phet.colorado.edu/sims/pendulum-lab/pendulum-lab_en.html

ACTIVITY

Initial Setup

1. Place a piece of masking tape on the side of the desk so that the top of the tape is flush with the top edge.
2. Use a permanent market to draw a vertical line in the middle of the tape.
3. Draw a second line beginning at the top of the vertical line and making a 45 degree angle to the right. Your finished setup should look like this:

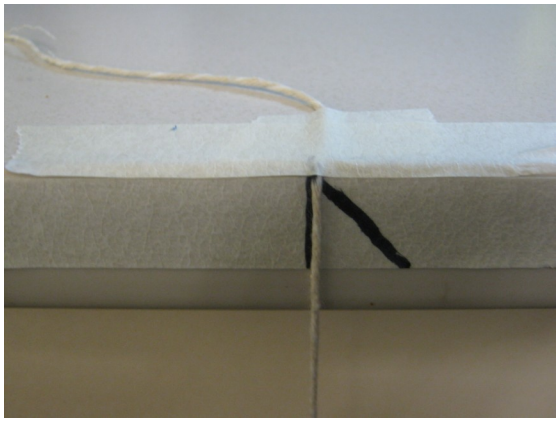


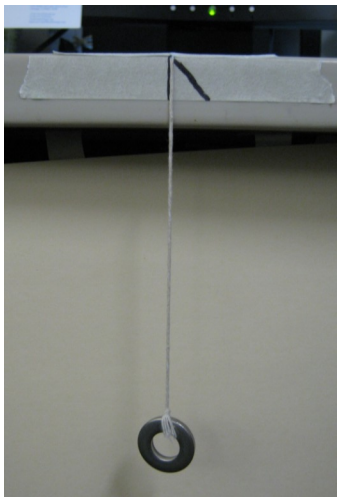
4. Cut a 40 cm length of string.
5. Tie one washer to one end of the string.
6. Measure 15 cm along the string beginning at the place where the string meets the washer. Mark that spot on the string with the marker.
7. Measure an additional 15 cm from that mark, and make a second mark. This is your 30 cm mark.
8. Cut a second 40 cm long string and repeat steps 4-7 using two washers instead of one.

Testing the Pendulums

Tell students that now that they are familiar with how energy within a pendulum is transformed, you will explore how different variables in the pendulum affect how the pendulum moves.

1. Take the pendulum with one washer and hang it off the table so that the 15 cm mark rests on the edge of the desk and the string is parallel to the vertical line on the tape. (see images below)





2. Move the washer up and to the side so that the string matches the 45 degree angle line.
3. Release the pendulum and use the stopwatch to time the period (time to swing back and forth) of 3 swings.
4. Repeat the experiment three times, and calculate the average of the times you measured.
5. Record your data on your student worksheet.

Now Let's Change the Mass

Now we're going to change one independent variable: the mass of the bob. We will not change the length of the string nor the angle of displacement.

1. Take the pendulum with two washers and hang it off the table so that the 15 cm mark rests on the edge of the desk and the string is parallel to the vertical line on the tape.
2. Move the washers up and to the side so that the string matches the 45 degree angle line.
3. Release the pendulum and use the stopwatch to time the period (time to swing back and forth) of 3 swings.
4. Repeat the experiment three times, and calculate the average of the times you measured.

5. Record your data on your student worksheet.
6. How does the change in mass (changing the number of washers) affect the period of the pendulum swing?

Now Let's Change the Pendulum's Length

Now we're going to change a different independent variable: the length of the pendulum's string. Notice that we're going back to a single washer pendulum, and we are leaving the angle of displacement unchanged.

1. Take the pendulum with one washer and hang it off the table so that the 30 cm mark rests on the edge of the desk and the string is parallel to the vertical line on the tape.
2. Move the washer up and to the side so that the string matches the 45 degree angle line.
3. Release the pendulum and use the stopwatch to time the period (time to swing back and forth) of 3 swings.
4. Repeat the experiment three times, and calculate the average of the times you measured.
5. Record this time on your student worksheet.
6. How does the change in the length of the string affect the period of the pendulum swing?

Now Let's Change the Pendulum's Amplitude

This time we will return the pendulum's mass and string length to the original setup, and change the angle at which we release the pendulum—the amplitude.

1. Take the pendulum with one washer and hang it off the table so that the 15 cm mark rests on the edge of the desk and the string is parallel to the vertical line on the tape.
2. Draw a line beginning at the top of the vertical line and making a 22.5 degree angle to the right. This line will lie exactly between the vertical line and the 45 degree line.
3. Move the washer up and to the side so that the string matches the 22.5 degree angle line.
4. Release the pendulum and use the stopwatch to time the period (time to swing back and forth) of 3 swings.
5. Repeat the experiment three times, and calculate the average of the times you measured.
6. Record this time on your student worksheet.
7. How does the change in the angle of the initial displacement affect the period of the pendulum swing?

CHECK IN

1. How does the change in mass (changing the number of washers) affect the period of the pendulum swing?
2. How does the change in the length of the string affect the period of the pendulum swing?
3. How does the change in the amplitude of the swing (the angle of the initial displacement) affect the period of the pendulum swing?

DIFFERENTIATED INSTRUCTION

With larger groups, or with students who may need more help staying on task, it is useful to review the

answers to the check-in questions using the simulation used in the Warm Up section:

http://phet.colorado.edu/sims/pendulum-lab/pendulum-lab_en.html

This simulation allows students and teachers to manipulate the same variables as in the experiment, and lets you stop the motion of the pendulum in mid-period to explain the concepts further.

For more advanced students, you can introduce the following formulas to have them calculate the velocity of the bob at the bottom of the period's swing:

GPE = mgh where m is the mass of the bob, g is the acceleration due to gravity (9.6 m/s^2), and h is the height from the top to the bottom of the swing

KE = 1/2 mv^2 where m is the mass of the bob, and v is the maximum velocity of the bob

KE = GPE in a closed system

WHAT'S HAPPENING?

The period of swing of a pendulum depends primarily on its length, and the acceleration of gravity. It is independent of the mass of the bob. The reason for this is that the period depends on the maximum velocity at the lowest point (where KE is the greatest), and in turn the maximum velocity depends only on the height at the highest point. Increasing the length on the string will increase the height, but increasing mass will have no effect at all.

Similarly, increasing the angle of the starting point of pendulum oscillation also increases the initial height, and so it also increases the period.

INQUIRY WHEEL OPPORTUNITY

Use your inquiry wheel with your students to brainstorm dependent and independent variables in this experiment. Independent variables are the aspects of the experiment that you choose and manipulate. Dependent variables are the aspects of your experiment that result from those manipulations. The table below gives a few ideas:

INDEPENDENT VARIABLES ***How does the….***	**DEPENDENT VARIABLES** ***Affect ...***
Mass of the pendulum's bob	The time of the period (1 oscillation back and
Length of the string	How long it takes for the pendulum to stop mov-
Amplitude of the swing (angle of re-	
Type of string	
Temperature of the air	

Remember to only change one independent variable at a time. For instance, if you want to measure what variables affect the time of one period, change only the length of the string **or** the mass of the bob, *but*

not both at the same time. If you change both independent variables, you will not be able to discern whether the results are due to the length of the string or the mass of the bob. The inquiry wheel can help you separate the variables so you can test them one at a time and achieve scientifically relevant results.

EXTENSIONS

LANGUAGE ARTS

In 1851, the French scientist Jean Foucault suspended a 67-meter pendulum from the dome of the Pantheon in Paris. When the pendulum was set in motion, Foucault observed that the plane of the pendulum's swing appeared to rotate — 360˚ clockwise in about 32 hours. In reality the swing of the pendulum remained on the same plane, and the Earth rotated underneath it. This was the first demonstration of the rotation of the Earth that did not depend on observation of the skies.

In your own words, explain how Foucault's pendulum demonstrates the rotation of the Earth.

SCIENCE

Grandfather clocks use a pendulum to keep time. If a grandfather clock was running slowly, would you make the pendulum shorter or longer? Explain your answer using the data from your experiment.

RELATED EXHIBITS

- *Science Storms: Foucault's Pendulum.*
- *Jolly Ball*