National Next Generation Science Standards

Students who demonstrate understanding can:

4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.

MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

AP Physics

3.B.3.1 The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties.

3.B.3.2 The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force.

3.B.3.3 The student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown.

Standards Key

K = Kindergarten
3 = 3rd Grade
(numbered by grade)
MS = Middle School
HS = High School
PS = Physical Science
LS = Life Science
ES = Earth Science

!

3.B.3.4 The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force.

TEACHERS GUIDE

GRADE LEVEL 6+

LARGE CLEAR ACRYLIC PENDULUM WAVE DEMO
ITEM # 3643-00

ENERGY - MOTION

A captivating demonstration for all ages! The Pendulum Wave Demo simulates phases, beats, and frequencies. Features a stand with nine 7/8" (22mm) steel ball pendulums and comes with an initiator stick, which helps to simultaneously release all pendulums. When released, the pendulums will swing back and forth to quickly form a wave pattern and then cycle through different phases. Great for a classroom, as a gift, or for display.

Materials

- **Wave Demo (included)**
  see pages 8-11 for set up instructions
- camera
- transverse wave diagrams
- pendulum diagrams
- energy bar charts
- mass sets
- ring stands with rings
- slinkies
- measuring tapes
- spring scales
- protractors
- stopwatches
- string
- two nuts or washers

Optional:

- *2 meter sticks*
- *4 meters of string (approximately)*
- *8-10 weights (e.g. nuts, washers, identical weights that easily attach to string,)*
- *dissimilar weights*
- *tape, scissors, books*

Goals & Objectives

See Page 12 for National Next Generation Science Standards

Introduction

The simple pendulum, at rest and in motion, demonstrates how a mass accelerates (and decelerates) in response to gravitational force. Students can develop the vocabulary to describe the characteristics and behavior of waves including: crests, troughs, amplitude, wavelength, frequency, period, equilibrium, interference, and resonance. Multiple pendulums, with decreasing string length, in motion simultaneously will create changing visual patterns that mesmerize as they move in and out of sync with each other. Use Newton's second law of motion to explain the observed motion and then use the wave demonstration to show how a wave is formed if the pendulum mass moved perpendicular to its swing pattern. Integrate art and physics with kinetic motion!

History

Galileo Galilei, commonly referred to as the father of experimental science, is credited with first discovering the regular motion of pendulums.

Glossary

Pendulum Wave Demonstration/Wave Demonstration - refers to the complete structure being assembled

ball/steel ball/drilled steel ball - the set includes 9 drilled steel balls (1 inch diameter)

string/line/fly line - the green string included with the set is thick rubber fly line

pendulum (singular) - a pendulum is an assembled set, consisting of one steel ball and knotted fly line

pendula (plural) - same as pendulum, however, pendula refers to multiple assembled pendulum

frame - made up of three clear acrylic parts, one curved top and two triangular side parts that can be assembled to form the Pendulum Wave frame

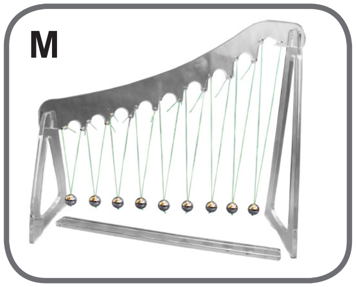
initiator stick - clear acrylic part used to initiate movement of the fully assembled Pendulum Wave Demo by pushing all pendula at the same time. The acrylic part is rectrangular,
approximately 18.5 x 1.5 inches in size. The initiator stick is also used for pendulum adjustments

tubes - refers to the 18 tubes attached to the curved (top) part of the frame, through which the fly line is threaded during assembly.

brass eyelets - the set includes 18 small brass eyelets used to secure the fly line to the frame by pushing them inside the tubes

SET-UP

Do this until all 9 pendula are attached and adjusted. The steel balls should form a straight line, with the same distance from the bottom of the balls to the table **(M)**.



7. When all pendula are attached to the frame, the lines can be adjusted to the exact lengths needed for ideal performance.

8. Use the measurements below to adjust the pendula to the right lengths as needed.

Measurements can be made in the number of swings of each pendulum in a timeframe of 20 seconds, or by the distance (in cm) between the middle of each steel ball to the bottom of the tube it is attached to.

SWINGS IN 20 SECONDS*	LENGTH IN CM*
24	17.2
23	18.8
22	20.5
21	22.8
20	24.8
19	27.4
18	30.6
17	34.6
16	38.8

***from shortest to longest pendulum, left to right**

9. To test the Wave Demonstration, hold the initiator stick against all steel balls and push them backward simultaneously. Then, quickly remove the stick and watch the Pendulum Wave Demo swing through its phases.

It might take several rounds of adjustments to get the Wave Demonstration to perform perfectly.

10. After all adjustments have been made and the Pendulum Wave Demonstration is performing as desired, the extra fly line can be taped or cut, and the eyelets can be pushed in completely.

How it works

All waves are propagated by a vibrating mass – vibrating to and fro like a pendulum. Called oscillation, the pendulums will at times be in phase and at other times be out of phase. When gravity acts on a pendulum in motion it is called a restoring force.

The pendulum at rest is in its equilibrium (zero) position. At rest, the pendulum has no velocity, therefore, no kinetic energy and no gravitational potential energy because it is not in a position above its equilibrium point.

Set in motion, however, the pendulum has a maximum position and therefore maximum potential energy at two points at either end of its arc. The maximum velocity is at the equilibrium point and therefore that is where the kinetic energy is at its maximum.

The pendulum oscillates about the equilibrium point because of the restoring force – gravity. This is called simple harmonic motion.

VOCABULARY

- amplitude
- period
- frequency
- standing wave
- resonance
- wavelength
- nodes
- antinodes
- fundamental frequency
- equilibrium position
- destructive (out of phase) and constructive interference (in phase)

ACTIVITIES

1 Review that frequency is simply how often something happens during a period of time.

> **Note**
>
> It is always best to DO an experiment ahead of time to be able to best present it to the class.
>
> **!**

2 Introduce to the students one piece of string approximately 1 meter long. Cut the string unevenly to produce a short piece and a long piece (65 cm and 35 cm). Attach a washer or nut to each piece of string. Have one student hold each string at the same level in front of the class.

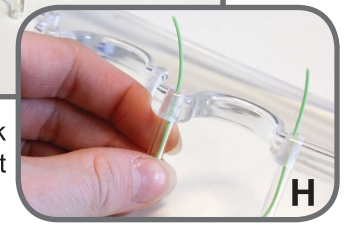
Ask students what will happen to the frequency of each string. How will the frequencies be similar? How will they be different? Which string will have a higher frequency than the other and why?

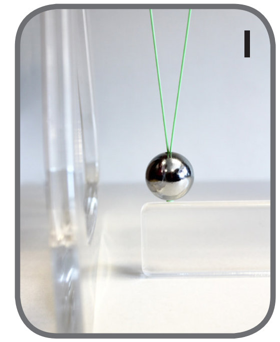
3 Allow students to brainstorm possible answers in pairs for approximately 3-5 minutes. Discuss ideas generated with the entire class.

Conduct the experiment with the small and large string starting the string parallel to the floor and releasing the washer at the same time on the count of three. Count the frequency cycle of each washer (for approximately 30 seconds).

4 Introduce the pendulum wave. Give students time to observe the pendulum wave. What do they observe?

Elicit whole group discussion on what they think will occur. After discussion, using the bar included, start the pendulum wave by starting all pendulums at the same time. Allow students to enjoy the show! Allow students to come up and start the pendulum wave themselves.





4. Prop the initiator stick onto its side and place it underneath the frame.

Start threading the fly lines of a pendulum to the first parallel set of tubes on the frame, as indicated by the circle in image **(G)**.

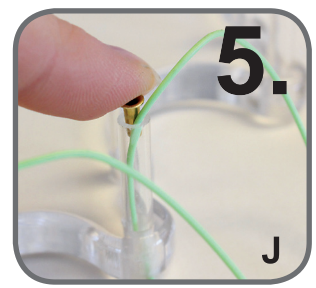
Pass each end of the line through a separate tube so that some of the fly line is extending past the acrylic frame **(H)**.

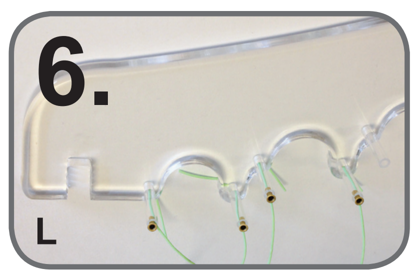
Adjust the length of the line so that the bottom of the ball aligns with the top of the initiator stick **(I)**.

**After the Pendulum Wave Demonstration is completely assembled, the extra lines can be taped to the frame, or cut (do not cut lines until assembly and adjustments are finished).*

5. To keep the pendula in place, push the smaller end of a small brass eyelet into each tube opening, this will secure the fly line **(J)**.

You may need to adjust the pendula later, so there is no need to push the eyelet in all the way at this point, just insert it enough to securely hold the line **(K)**.

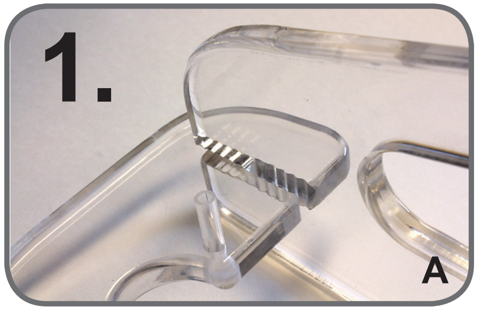




6. Repeat Step 4 and 5 with the remaining pendula, mounting them from left to right on the frame, aligning them to the initiator stick underneath **(L)**.

continued on page 6

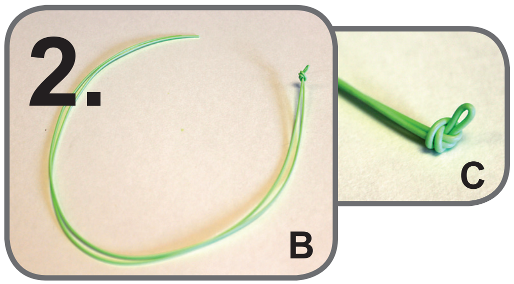
Set-Up Instructions



1. When setting up the Pendulum Wave Demonstration for the first time, the frame of the pendulum needs to be put together.

Interlock the notches on the ends to form the Wave Demonstration structure **(A)**.

The pieces fit tightly, however, they can easily be taken apart for storage.



2. Take a piece of fly line and fold it in half, then tie a knot in the end where the line was folded **(B-C)**.

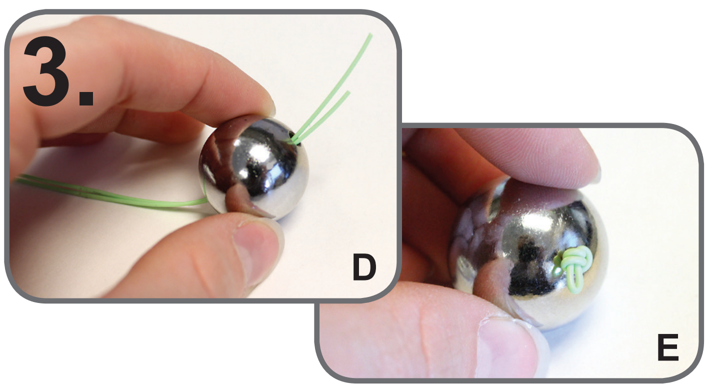
This forms two strings to mount the pendulum to the frame with.

Repeat this process with all 9 pieces.

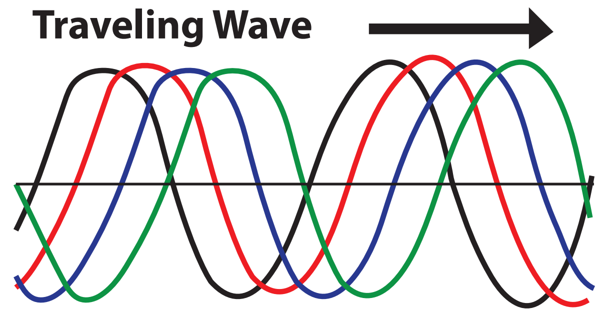
3. Thread both ends of a knotted fly line through one of the drilled steel balls **(D)**.

Pull the ball all the way down to the knotted end so that they fit tightly against each other **(E)**.

Repeat threading the fly line through the remaining steel balls **(F)**.



Activities



5 For activities 6-8 assign different lab groups one of the variables to manipulate and measure the effect on the time it takes to complete one period. Ask them to tabulate and graph their data. Make sure they keep all other variables constant except te one they are manipulating. Groups should present their results to the class. Ask them what their conclusion is and what pattern in their data supports their conclusion.
Do their classmates agree?
The class should evaluate each groups results and conclusions.

6 Collect data for the time it takes for each pendulum to complete one period on the wave demo apparatus.

7 Collect data for the time to complete one period when you increase amplitude (angle of release). Use a protractor to change your angle. For safety, do not do angles greater than 30 degrees from rest.

8 Collect data on period time and different size masses. Be sure to keep string length constant! What other variables can they test?

9 Camera to capture pictures of the patterns from above and lengthwise. Identify when all the pendulums are in phase, when all the even ones are in phase and the odd ones are too. Beats.

What is the wavelength of each pendulum?
The amplitude?
Can you identify when the pattern demonstrates constructive and destructive interference?

10 Slinky experiment (longitudinal wave). Repeat the experiment from actiities 6-8, but with a slinky using the following variables - amplitude, frequency, and force to determine the effect on speed.

continued on page 10

ACTIVITIES

Student Activities *continued*

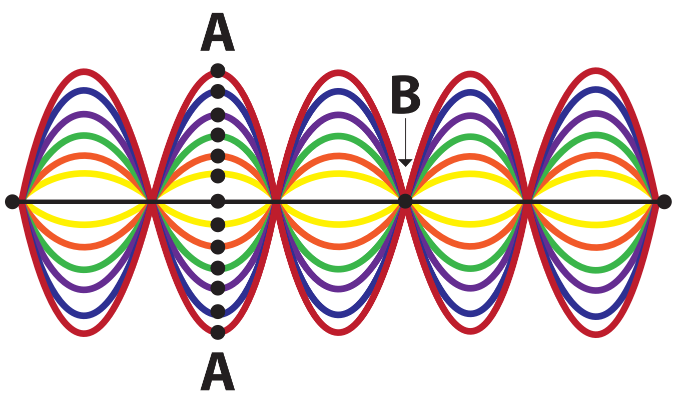
Be sure to keep all variables constant except the one you are manipulating while measuring speed.

What is the amplitude? The wavelength? The period? Frequency?

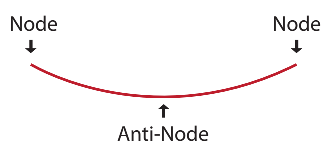
11 Take pictures of the slinky wave pulses. Identify and label the rarefactions and compressions.

Can you create constructive and destructive interference?

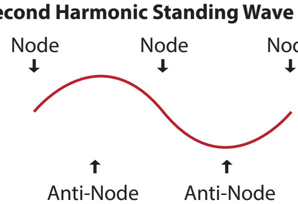
Standing Waves with Beats Below



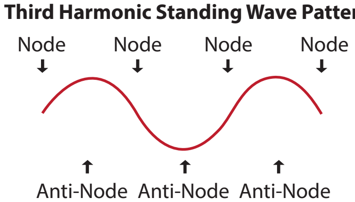
First Harmonic Standing Wave Pattern



Second Harmonic Standing Wave Pattern



Third Harmonic Standing Wave Pattern



DISCUSSION

Additional Discussion and Real Life Applications

1 **Make your Own:**
Make your own pendulum wave with 2 meter sticks (or a meter stick and a ruler or tape measure), 4 meters of string (roughly), 8-10 weights (e.g. nuts, washers, masses that easily attach to string), tape, scissors, and a stack of books. Cut the string into 9 different lengths and attack a similar washer to each string. The first string should be 44 cm. Each subsequent string should be 3 cm less. (44 cm, 41 cm, 38 cm... 29 cm.) Set up the meter stick and support it with a desk or stack of books. At the 10 cm mark on the meters stick, tape the first string. Each subsequent string should be 9 cm apart. You have now created your own pendulum wave!

2 **In your Environment:**
Discuss where in your environment you see examples of frequencies varying. (A playground with different length swings is a perfect example of this. If time and resources allow, visit a playground with different size swings.)

3 **Critical Thinking:**
Brainstorm and experiment. What do you think would happen if the weights were dissimilar but the strings were the same size. Make another pendulum wave with same size strings but different weights.

4 **More Fun:**
Research other pendulum waves too! Here is one that is an art display! *http://largependulumwave.nl/*

5 Transverse waves are only one wave type. The other type is called longitudinal. All waves have the same characteristics and behavior. Label a longitudinal wave diagram. What does interference, resonance, and beats look like for those waves? What examples can you give?

6 What is the relationship between the period and the length of the string? (Longer string – longer period)

What is the relationship between the size of the mass and the period? (no relationship)

What is the relationship between amplitude (angle of release) and period? (no relationship)

7 Final group discussion should conclude only the string length affects the time to complete one period.

Only one variable affected the speed of the longitudinal wave – the fore applied. The force applied also changes the slinky length. Compare that to the pendulum string length.

8 What mass is moving to and from that makes an electromagnetic wave? Is it transverse or longitudinal?

What kind of waves are earthquake waves? Water waves? Sound waves? Students can research and present to peers.