

Chapter 23: Waves

	Instructional Sequence	Learning Goals	National Science Standards	Investigations and Materials
<p>Section 23.1: Harmonic Motion Three 45-minute class periods</p>	<ol style="list-style-type: none"> 1. Complete Chapter 23 Pretest. 2. Complete Investigation 23A: Harmonic Motion 3. Read Section 23.1, pp. 554 to 560, and complete Section Review on page 561. 	<ul style="list-style-type: none"> • Identify examples of simple oscillators. • Compare and contrast harmonic motion with linear and curved motion. • Apply a rule to determine the frequency and period of an oscillator. 	<p>INQ01.1 INQ01.2 INQ01.3 INQ02.3 PS06.1</p>	<p>Investigation 23A: Harmonic Motion</p> <p>Materials (per group): Data Collector and 2 photogates, Physics stand, Pendulum, Graph paper</p>
<p>Section 23.2: Properties of Waves Three 45-minute class periods</p>	<ol style="list-style-type: none"> 1. Complete Investigation 23B: Natural Frequency and Resonance. 2. Read Section 23.2, pp. 562 to 565 and complete Section Review on page 566. 	<ul style="list-style-type: none"> • Describe the properties and behavior of waves. • Calculate the speed of waves. • Identify the parts of a wave. 	<p>INQ01.4 INQ02.4 PS06.1</p>	<p>Investigation 23B: Natural Frequency and Resonance</p> <p>Materials (per group): Data Collector, CPO Sound and Waves, Physics stand</p>
<p>Section 23.3: Wave Motion Three 45-minute class periods</p>	<ol style="list-style-type: none"> 1. Read Section 23.3, pp. 567 to 570 and complete Section Review on page 571. 2. Complete Chapter Assessment, pp. 574 to 576. 	<ul style="list-style-type: none"> • Distinguish between transverse and longitudinal waves. • Demonstrate an understanding of wave interactions. • Distinguish constructive and destructive interference. 	<p>PS06.1</p>	<p><i>Optional Activity</i> Investigation 23C: Waves in Motion</p> <p>Materials (per group): Metal Slinky® toy spring, Meter stick, A length of 1” plastic pipe cut to fit the wave tray, Food coloring, Water, Wave tray with wooden blocks</p>

Technology Resources



Assessment Tools



Lesson Organizer <ul style="list-style-type: none"> Lesson 23.1 PowerPoint Data Collector Resource Video 	Skill and Practice Worksheets <ul style="list-style-type: none"> Period and Frequency, Harmonic Motion Graphs Teaching Illustrations <ul style="list-style-type: none"> 23.1 harm motion graph; 23.1 inert restore force; 23.1 period frequency Graphic Organizers <ul style="list-style-type: none"> Types of Waves 	Chapter 23 Pretest Section 23.1 Review Questions Standardized Test Practice
Lesson Organizer <ul style="list-style-type: none"> Lesson 23.2 PowerPoint Sound and Waves Resource Video Data Collector Resource Video 	Skill and Practice Worksheets <ul style="list-style-type: none"> Waves Teaching Illustrations <ul style="list-style-type: none"> 23.2 freq amp wave; 23.2 wave speed; 23.2 types of waves 	Section 23.2 Review Questions
Lesson Organizer <ul style="list-style-type: none"> Lesson 23.3 PowerPoint 	Skill and Practice Worksheets <ul style="list-style-type: none"> Wave Interference Teaching Illustrations <ul style="list-style-type: none"> 23.3 trans long waves; 23.3 wave interact Graphic Organizers <ul style="list-style-type: none"> Wave Interactions <p>Chapter Activity: Making Waves</p>	Section 23.3 Review Questions Chapter 23 Assessment ExamView® Test Bank Chapter 23 Test

The Book of Waves: Form and Beauty on the Ocean by Drew Kampion

Loaded with fantastic photos, this book includes images from the Pacific to the Caribbean. It also includes personal stories of surfers and sailors who have encountered all sorts of waves and technical descriptions of wave cycles.

Galileo's Pendulum: From the Rhythm of Time to the Making of Matter by Roger G. Newton

Recommended by PBS, this book describes how young Galileo uses his pulse to measure the time required for a pendulum to swing through its arc. Many topics related to harmonic motion are discussed including pendulum clocks, biorhythms, and oscillations of sound and light.

Wave of Destruction: The Story of Four Families and History's Deadliest Tsunami by Erich Krauss

The stories of four Thai families whose lives were forever changed by the 2004 disaster. Krauss, a Thai culture expert, captures the spirit of these survivors and tells their stories in a compelling fashion. A great book for helping students grasp the magnitude of the disaster from scientific, emotional, and cultural perspectives.

Additional Literacy Support

Technology Connection: *Cell Phones: How They Work* (pages 572–573)



Period and Frequency, Graphs of Harmonic Motion, Wave Speed

Investigation 23A: Harmonic Motion

Harmonic motion is motion that repeats. A system with harmonic motion is an oscillator. A cycle is the individual unit of harmonic motion that is repeated. The time it takes to complete one cycle is called the period. The amplitude describes the “size” of a cycle. With a pendulum, the amplitude is often a distance or angle. With other types of oscillators the amplitude might be voltage or pressure. The amplitude of harmonic motion can be represented using a harmonic motion graph.

Systems in harmonic motion always move back and forth around an equilibrium position. Equilibrium is maintained by restoring forces. Any force that acts to pull the system back toward equilibrium is a restoring force. For a pendulum the equilibrium position is the center. The restoring force of gravity always pulls the pendulum towards the center. The pendulum overshoots the center because of its own inertia. This cycle repeats itself over and over. In this investigation, students use a pendulum to explore harmonic motion.

Key Question

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

Objectives

Students will:

- Measure the amplitude and cycle of a pendulum.
- Identify the variables that affect a pendulum.
- Sketch harmonic motion graphs.

Setup

1. One class period is needed to complete the investigation.
2. Students work in small groups of three to five.
3. Set up the Pendulum and become familiar with its operation prior to teaching the investigation.

Materials

Each group should have the following:

- Data Collector and 2 photogates
- Pendulum
- Physics stand
- Graph paper

vo·cab·u·lar·y

harmonic motion - a type of motion that repeats in cycles.

amplitude - the amount that a cycle moves away from equilibrium.

pendulum - a device that swings back and forth due to the force of gravity.

cycle - a unit of motion that repeats.

oscillator - a physical system that has repeating cycles. or.i.gin

period - the time it takes for each complete cycle.

Safety



Students should observe general laboratory safety procedures while completing Investigation 23A.

Harmonic Motion Investigation 23A

23A Harmonic Motion

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

Harmonic motion is motion that repeats in cycles. Many important systems in nature and many useful inventions rely on harmonic motion. For example, the phases of the moon and the seasons are caused by Earth's harmonic motion. This Investigation will explore harmonic motion using a pendulum. The concepts you learn with the pendulum will also apply to other examples of harmonic motion.

Materials

- Data Collector and 2 photogates.
- Physics stand
- Pendulum
- Graph paper

1 Setting up the pendulum

Attach the pendulum to one of the top holes in the stand.

Start the pendulum swinging and watch it for a minute. Think about how to describe the motion.

- Write one sentence about the motion using the word "cycle."
- The **amplitude** is the maximum amount the pendulum swings away from its resting position. The resting position is straight down. One way to measure amplitude is the angle the pendulum moves away from center. Write one sentence describing the motion of your pendulum using the word "amplitude."
- Draw a sequence of sketches that describe one complete cycle using arrows to indicate the direction the pendulum is going at that point in the cycle.

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... allows you to write down a number before it changes. Pressing reset a second time starts another measurement.

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Harmonic Motion Investigation 23A

Harmonic Motion

Period

... of ten period.

... description the period.

Count 10 cycles

Divide time by 10
example
period = 15.20 sec ÷ 10
= 1.52 seconds

Pendulum period data: Time for 10 cycles (sec)		
Trial 2	Trial 3	Average
Period of pendulum (average divided by 10)		

with a photogate

... as shown in the diagram. The pendulum breaks the light beam through the photogate. Try to keep the string length close to the part 2.

... set in period mode and let the pendulum swing through the light

... can do two things. If you press reset once the display freezes allowing you to write down a number before it changes. Pressing reset a second time starts another measurement.

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Harmonic Motion Investigation 23A

Harmonic Motion

About what you observed

... the time measurement you get from the Data Collector.

... you get from the Data Collector the period of the pendulum? Explain why the not the period of the pendulum (hint: compare to your results from part 2).

... the time measured by the Data Collector is related to the period of the

ables affect the period of a pendulum?

... ment, the period of the only dependent variable.

... independent variables: the the amplitude of the swing, the string.

... plitude can be changed by the angle that the m swings.

... re washers that you can use to change the mass of the bob.

... th of the string can be changed by sliding it through the slot in the peg.

... the length of the string from the bottom of the string peg to the bottom of bers.

... ment to determine which of the three variables has the largest effect on the fulum. Your experiment should provide enough data to show that one of the as much more of an effect that the other two. Be sure to use a consistent ves you consistent results.

... ee experiments you can do to see what variables affect the period of the Write down one sentence describing each experiment.

... experiments and record the measurements you make to assess the effect of ch variable.

the data

... things you can change (amplitude, mass, and string length), which one has effect on the pendulum, and why? In your answer you should consider how ferates objects of different mass.

... r data so that you can look at the effect of each of the three variables by making a separate graph showing how each one affects the period. To make comparison

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Harmonic Motion

... all the graphs have the same scale on the y-axis (period). The graphs like the example below.

you know

... once among the most common ways to keep time. It is still possible to pendulum clocks for sale today. To make a pendulum clock accurate, the a certain number of periods equals a convenient measure of time. For sign a clock with a pendulum that has a period of 1 second. The gears in ould then have to turn the second hand 1/60th of a turn per swing of the

... design and construct a pendulum that you can use to ensure a time interval of 30 seconds. Test your against the electronic stopwatch.

... ph the period you chose for your pendulum.

... did your pendulum complete in 30 seconds?

... affect the period, why is it important that the cck is heavy?

... cent error in your prediction of time from your The percent error is 100 times the difference diction and 30 seconds, divided by 30 seconds.

... agazine that a watch manufacturer advertises that loses no more than 5 seconds per month. Assume ses the maximum amount (5 seconds) in 31 days. cent error of the quartz watch by comparing 5 mber of seconds in a month.

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Teaching Investigation 23A

What comes to mind when you think of a person being hypnotized?

Students may respond by citing examples of hypnosis being performed in movies or cartoons that they have seen. The desired response is that students will state that the person performing the hypnosis swings an object like a pocket watch back and forth until the person is under the “spell” of the hypnotist.

Let’s take a moment to examine the motion of the pocket watch.

It is a good idea to have a pocket watch or similar object in the classroom so that you can demonstrate this motion to students. Walk around the classroom swinging the pocket watch so that each student is able to see the pattern of its motion.

How is this motion different from the types of motion that we have already learned about?

The pocket watch is moving back and forth. The types of motion that we have already studied involved motion along a line or a curve.

Now, let me call your attention to this globe.

If you don’t have a globe in your classroom, borrow one from a history teacher. Spin the globe around slowly so that each student has a clear view of its motion.

How would you describe the motion of this globe?

The globe spins around and around.

We have now witnessed that objects move in many different ways. Some objects go from place to place along a curve or line, while others spin or move back and forth. The two new types of motion that we have discovered are examples of harmonic motion.

Write the words, *harmonic motion*, on the chalkboard.

Harmonic motion is motion that repeats in cycles. Many important systems in nature and many useful inventions rely upon harmonic motion.

Retrieve the globe and repeat its spinning motion. While slowly spinning the globe, ask students the following question:

Can anyone describe how harmonic motion affects systems in nature like the seasons or phases of the moon?

The seasons and phases of the moon are caused by the Earth’s harmonic motion. The Earth-sun system has an orbital cycle of one year, which creates the seasons. The observed phases of the moon are created by the monthly orbital cycle of the Earth-moon system.

In today’s investigation, you will observe and describe the motion of a pendulum, a system in which a mass swings back and forth on a string. You will also learn how to recognize and describe other examples of harmonic motion.



1 Setting up the pendulum

Gather the materials that are needed to complete the investigation. Refer to your investigation handout for the proper setup of the pendulum.

Walk around to ensure that students have set up the pendulum correctly.

Start the pendulum swinging and watch it for a minute. Think about how to describe the motion.

Allow students time to think about describing the motion. In the meantime, write the words *cycle* and *amplitude* on the chalkboard. Review the meanings of both *cycle* and *amplitude* with students. Demonstrate how to measure amplitude by tracing the path of the angle formed as the pendulum moves away from the center.

Complete steps a-c in part 1 of the investigation.

2 Oscillators and period

Add the terms *oscillator* and *period* to the list of vocabulary terms on the chalkboard.

In this part of the investigation, we will observe an example of another system that demonstrates harmonic motion. This system is called an *oscillator*. Suppose I made the following statement: “As Lillian tried to decide what she should wear on the first day of school, she oscillated between the green tee shirt and the blue blouse.” Who can tell me what the term, *oscillate* means in this instance?

In this statement, oscillate means to be indecisive or to go back and forth about a choice that must be made.

So if we describe the motion of an object as oscillating, how do you think the object moves?

An oscillating object swings or moves back and forth.

Let’s list some examples of oscillators.

Students will offer a variety of responses, for example, oscillating fans, pendulums from grandfather clocks, and vibrating guitar strings. Accept all reasonable responses.

The period of the oscillator is the time it takes to complete each cycle. You can determine the period of an oscillator by following a few simple steps.

Write each of the following numbered steps on the chalkboard.

1. Count out ten cycles of the oscillator.
2. Use a stopwatch to measure the time needed to complete ten cycles.
3. Divide this time by ten to get the time required to complete one cycle. This is the period of the oscillator.

Let’s try a sample calculation. A fan oscillates ten cycles in 34.25 seconds. What is the period of the oscillating fan?

Write the information from the sample calculation on the chalkboard.

The right side of the page contains several blacked-out images and diagrams. At the top, there is a diagram of a pendulum with a vertical line and a bob, with two vertical lines indicating the amplitude. Below this are several rows of blacked-out text. At the bottom, there are two data tables. Each table has a blue header row and a grid of white cells. The first table has four columns with blacked-out headers and four rows of data. The second table is identical in structure to the first.

Steps 1 and 2 have already been done for you. Now all that remains is to divide the time needed to complete 10 cycles by ten.

The period is $34.25 \text{ seconds} / 10 = 3.425 \text{ seconds}$.

Read and complete part 2 of the investigation. You will collect data from three trials. Measure the length of the string used to affix the pendulum. It will be useful to you in the next part of the investigation. Use your stopwatch to determine the time needed for the pendulum to complete 10 cycles. Record the time from each trial in Table 1. Once you have completed three trials, find the average of the data.

Remind students that the average can be found by adding together each of the recorded times and dividing the sum by the number of trials, which in this instance is three.

Record the period of the pendulum in the space provided on Table 1.

3 Measuring period with a photogate

In this section of the investigation, we will use a photogate to measure the period of the pendulum. Use the diagrams in section 3 to help you setup your photogate. Try to keep the string length close to the length that you used in part 2 of the investigation.

Walk around the classroom to ensure that students have the proper setup.

Complete steps 1–4.

Allow time for students to complete this task.

4 Thinking about what you observed

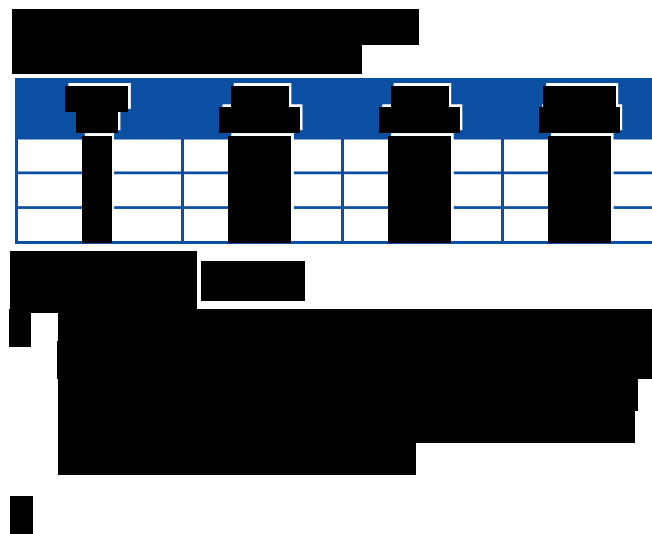
Use the information gathered to answer questions a–c. You may find it helpful to refer to your results from part 2 of the investigation.

Discuss the students' answers to the questions. Clarify any uncertainties before moving on to part 4.

5 What variables affect the period of a pendulum?

Now you will determine which variables change the period of the pendulum. You can change three things about the pendulum, the amplitude, length, and mass. To change the amplitude, pull the pendulum to a greater angle before dropping it. To change the length, adjust the string. When measuring the length, measure from the point where the pendulum connects at the top to the bottom of the washers. To change the mass, add or subtract washers. What is important to remember when conducting an experiment to test a variable?

It is important to only change the variable that is being tested. For example, when testing mass, you must make sure the length and amplitude are kept constant.



Think about how you will test the three variables. Write down a description of the three experiments you will conduct.

Encourage students to be specific when describing their experiments. For example, they might compare the lengths of 20, 30, and 40 cm while keeping the amplitude at 20 degrees and three washers on the pendulum. Motivate students to participate in discussions about their hypotheses: both correct and incorrect. For those which were incorrect, ask students to explain how the data collected helped them to question their hypothesis, and arrive at a different conclusion. This is also a great opportunity to remind students that formulating and testing hypotheses is an important part of the scientific method.

6 Analyzing the data

We can use graphs to help us understand harmonic motion. Everyone should now focus on part 6 of the investigation. The most common type of graph used to express harmonic motion plots amplitude on the *y*-axis versus time on the *x*-axis. Notice that each axis on the graph is labeled with proper units. Which unit of measurement is used to express amplitude for this graph?

The amplitude is measured in degrees.

Which unit of measurement is used for time?

The time is measured in seconds. Point out both the *x*- and *y*-axes and the units to students so that they can see exactly where each is located on the investigation handout.

Why do the words *left* and *right* appear along the *y*-axis?

The pendulum swings back and forth. The words *left* and *right* represent the back and forth motion of the pendulum.

Now, follow the steps in the diagram to sketch a graph showing the motion of the pendulum.

Circulate among your students to ensure that each student is performing the task correctly.

Has everyone plotted amplitude and drawn a smooth curve through the points?

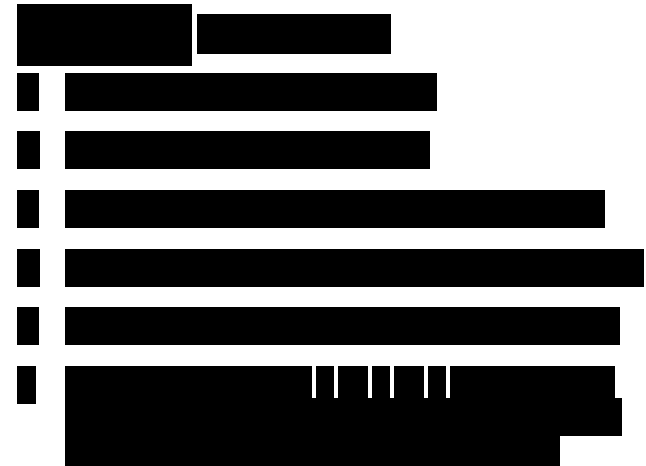
Allow time for students to complete their graphs.

7 Applying what you know

Pendulum clocks were once among the most common ways to keep time. It is still possible to find beautifully made pendulum clocks for sale today. To make a pendulum clock accurate, the period must be set so 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 1/60th of a turn per swing of the pendulum.

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 electronic stopwatch.

Students mark the period they chose for the pendulum on the graph and determine the number of cycles the pendulum completed in 30 seconds. Discuss students' observations and answers to the questions in part 7.



Lesson 23.1: Harmonic Motion

The forward motion of a pedaling cyclist is an example of linear motion. The pedaling action and turning of the cycle's wheels are examples of harmonic motion. In this lesson students are introduced to harmonic motion. They learn to describe the motion of waves in terms of period, amplitude, and frequency. Students also learn to analyze graphs of harmonic motion and discuss applications of natural frequency and resonance.

Start the lesson

Connect to Prior Knowledge: The Motion of a Pendulum

Ask “Who knows what a pendulum is? Where have you seen a pendulum before?” Students will have probably have seen a pendulum in a grandfather clock. A playground swing is also a pendulum. Then ask, “What is special about the motion of a pendulum?” Show students a simple pendulum and give them time to think about how a pendulum's motion is different from linear motion. Sample answers include: a pendulum switches direction, it has a regular pattern to its motion, and it moves both up and down and side to side at the same time.

Motivate: The Metronome

Are any of your students musicians in the school band or orchestra? Ask students if they are familiar with a metronome and its function. Have students research the history of the metronome. Students' research should answer some of the following questions:

- What is a metronome?
- How is the function of a metronome related to harmonic motion?
- How has the design of the metronome changed over time?
- In what ways has scientists' increasing knowledge of electricity influenced the development of metronomes?
- How have design improvements made metronomes more accurate?

Motivate: Invite a Guest Speaker

Ask a local musician to visit your students and talk about how factors related to harmonic motion, like frequency, influence musical performance. Or, if some of your students are musicians, they may be able to lead a discussion and demonstration for their peers. If this is possible, arrange a time to meet with students and help them to develop a lesson plan for the day. As a fun extension of this activity, your students may enjoy a field trip to the symphony or another musical performance.

vo·cab·u·lar·y

linear motion - a type of motion that goes from one place to another without repeating.

harmonic motion - a type of motion that repeats in cycles.

cycle - a unit of motion that repeats.

pendulum - a device that swings back and forth due to the force of gravity.

oscillator - a physical system that has repeating cycles. [or·i·gin](#)

restoring force - any force that always acts to pull a system back toward equilibrium.

period - the time it takes for each complete cycle.

frequency - how often something repeats, expressed in hertz (Hz).

hertz (Hz) - the unit of frequency. One hertz is one cycle per second.

amplitude - the amount that a cycle moves away from equilibrium.

natural frequency - the frequency at which a system oscillates when disturbed.

periodic force - a repetitive force.

resonance - an exceptionally large amplitude that develops when a periodic force is applied at the natural frequency.

Present the content

Demonstration: Resonance

Obtain a tuning fork and an empty soda can. Be sure the can is clean and dry. Tap the tuning fork and have students describe what they hear. Then hold the tuning fork (with the prongs in a horizontal position) over the empty can. Tap it again and have students describe the sound as you move the fork closer to and away from the mouth of the can. Students should observe that the sound increases as the fork is placed closer to the opening of the can.

Why is this so? Tell students that the can is a resonator, meaning that it oscillates naturally at certain frequencies. Because of its shape and hollow opening, the can mimics the hollow body of a violin acting as a resonating chamber. When the tuning fork is placed near the opening of the can, air within the can and the can itself vibrate, resulting in a more intense sound.

Check for understanding



1. Explain the meaning of harmonic motion in your own words. [REDACTED]
2. The period of a pendulum is 5.0 seconds. What is its frequency in Hz? [REDACTED]
3. The fact that an oscillator has the same period and frequency each time it is set in motion is best described by _____. [REDACTED]

Reteach

Provide ample opportunities for students to practice analyzing graphs of harmonic motion. Use an overhead or the board to draw graphs. Then have students find the period, frequency, and amplitude of oscillators. You may also want to have students work with peers to practice these techniques.

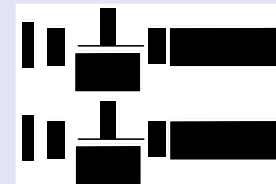
The period (T) of an oscillator is 35.0 seconds. The relationship between the period and the frequency (f) of an oscillator is expressed as follows:



Given this relationship, what will happen to the frequency of the oscillator if T increases to 60.0 seconds?

- a. The frequency of the oscillator will increase.
- b. The frequency of the oscillator will decrease.
- c. The frequency of the oscillator will remain the same.
- d. The frequency of the oscillator is not dependent on its period.

The correct answer is (b). The period and frequency of an oscillator are inversely related. Therefore, an increase in the period (T) of an oscillator results in a decrease in frequency (f). Students can apply the formula to verify that the frequency decreases as the period of the oscillator increases.



Investigation 23B: Natural Frequency and Resonance

While completing Investigation 23A, students observed that the pendulum oscillated at only one frequency for each string length. The frequency at which objects vibrate is called the natural frequency. Almost everything has a natural frequency, and most things have more than one. We use natural frequency to create all kinds of waves, from microwaves to the musical sounds from a guitar. In this investigation students explore the connection between the frequency of a wave and its wavelength.

Key Question

What is resonance and why is it important?

Objectives

Students will:

- Experiment with standing waves on a string.
- Measure frequency and wavelength.
- Identify the relationship between frequency and wavelength.

Setup

1. One class period is needed to complete the investigation.
2. Students work in small groups of three to five.

Materials

Each group should have the following:

- Data Collector
- CPO Sound and Waves
- Physics stand

vo·cab·u·lar·y

natural frequency - the frequency at which a system oscillates when it is disturbed.

resonance - an exceptionally large amplitude that develops when a periodic force is applied at the natural frequency.

fundamental - the lowest natural frequency of an oscillator.

harmonic - one of many natural frequencies of an oscillator.

standing wave - a wave that is confined in a space.

Safety



Students should observe general laboratory safety procedures while completing Investigation 23B.

Natural Frequency and Resonance Investigation 23B

23B Natural Frequency and Resonance

What is resonance and why is it important?

The pendulum oscillated at only one frequency for each string length. The frequency at which objects vibrate is called the natural frequency. Almost everything has a natural frequency, and most things have more than one. We use natural frequency to create all kinds of waves, from microwaves to the musical sounds from a guitar. In this Investigation you will explore the connection between frequency of a wave and its wavelength.

Materials

- Data Collector
- CPO Sound and Waves
- Physics Stand

1 Setting up the experiment

Connect the Data Collector to the sound and waves generator as shown in the diagram. The telephone cord connects the Data Collector and wave generator. The black wire goes between the wave generator and the wiggler.

1. Attach the fiddle head to the top of the stand, as high as it goes.
2. Attach the wiggler to the bottom of the stand, as low as it goes.
3. Stretch the elastic string a little (5-10 cm) and attach the free end to the fiddle head. Loosen the knob until you can slide the string between any two of the washers. GENTLY tighten the knob just enough to hold the string.
4. Turn on the Data Collector and be sure to plug in the AC adapter.
5. Set the wave generator to WAVES using the button. The wiggler should start to wiggle back and forth, shaking the string.
6. Set the Data Collector to measure FREQUENCY. You should get a reading of about 10 Hz. 10 Hz means the wiggler is oscillating back and forth 10 times per second.

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Natural Frequency and Resonance

frequency of the wiggler with the frequency control on the wave generator. As you watch the string, you will find that interesting patterns form at certain frequencies.

Vibrating string

A vibrating string will form wave patterns like those shown in the diagrams. This occurs at a *resonance* of the string. The resonances are called harmonics and are described by the number of "bumps" seen on the vibrating string.

Standing waves

Standing waves only occur at certain special frequencies. These frequencies are called harmonics. The first harmonic is the length of one complete wave. One complete wave is called a wavelength. The string is 1 meter long. If you see two bumps, the wavelength is the length of two bumps. The string is 1 meter long. If you see three bumps, the wavelength is 2/3 meter, since three bumps equal 1 meter.

Energy and amplitude

Standing waves only occur at certain special frequencies. When a periodic force is applied to the string, the amplitude of the wave increases. The amplitude is the height of the wave from the rest position. The amplitude is 1/2 this distance.

Table 2: Frequency vs. amplitude data

Harmonic #	Frequency (Hz)	Amplitude (cm)

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Natural Frequency and Resonance Investigation 23B

About what you observed

As you change the frequency of the wiggler, describe how the frequencies of the different harmonic patterns are related. The first harmonic is the length of one complete wave. One complete wave is called a wavelength. The string is 1 meter long. If you see two bumps, the wavelength is the length of two bumps. The string is 1 meter long. If you see three bumps, the wavelength is 2/3 meter, since three bumps equal 1 meter.

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Natural Frequency and Resonance

ful way to think about pushing a swing. The person pushing applies a periodic force to the swing. Like the string, a swing is a system in harmonic resonance. When the frequency of the push matches the natural frequency of the swing, the amplitude grows large, like the standing wave of a string. Resonance happens when the force applied to a system matches the natural frequency of the system. We use resonance to create waves with specific frequencies, such as in a radio, a microwave oven, or a laser.

In resonance the amplitude builds over time.

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Teaching Investigation 23B

Can you think of any ways that you can make waves?

Encourage students to use their imaginations to describe different ways that they might make waves.

Let's focus on water waves. Suppose I fill a pan with water. What are some ways that I can make waves in it?

Students share ideas.

Consider how ocean waves are created. As the wind blows over an ocean, it pushes against the water. The wind has energy that is absorbed by the water. This energy is what actually creates the wave. You may remember from the previous investigation that waves spread through connections. What is the connection that causes the water wave to move?

Each water molecule absorbs energy from the wind. As each water molecule collides with another water molecule next to it, energy is transferred. This continuous transfer of energy creates the wave.

Now, watch as I apply wind (using my breath) to this pan of water to make waves. How can I control the size of the waves?

The size of the waves created depends on how hard you blow. Blow increasingly harder to make larger waves.

Today's investigation is about making and controlling waves. You will learn about a new kind of wave, called a standing wave. A *standing wave* is a wave that is confined in a space like a vibrating string. You will use a standing wave to explore the connection between the frequency of a wave and its wavelength. You will use a vibrating string because its standing waves are large enough to see easily.

1 Setting up the experiment

In the first part of the investigation, you will set up a standing wave experiment. Take a moment to study the diagram of the equipment being used.

Assemble an example of the equipment for the standing wave experiment before class. Place it in an area where all students can see. Point to the different parts as you explain the proper set up.

You can assemble your setup as I explain the proper technique. Attach the fiddle head in the top two holes of the stand. Attach the wiggler in the bottom two holes. Loosen the knob on the fiddle head and slide the string between the washers. Stretch the string about two centimeters longer than its free length and gently tighten the knob just enough to hold the string. Turn on the Timer using the AC adapter. Set the wave generator to waves. What do you see happening?

The wiggler should start to wiggle back and forth, shaking the string. Confirm that each group is observing this effect with their setup. Assist students as needed.



Set the Timer to measure frequency. The term, frequency, describes how often something happens. Who can tell me the unit of measurement for frequency?

Frequency is measured in hertz (Hz).

You should get a reading of about 10 Hz, meaning the wiggler is vibrating 10 times per second. Vary the frequency between 10 and 100 Hz and see if you can find some interesting standing wave patterns.

Adjust the wiggler frequency on the example setup to show some of the different wave patterns. Walk around the classroom, checking each group's setup to ensure that the string is neither too loose nor too tight. A string that is too tight will result in very small waves with high frequencies. A good measure of tightness (for the string) is getting frequency measurements ranging from 17 to 25 Hz for the second harmonic. This will allow students to see up to and beyond the tenth harmonic. Give students a few minutes to play around and get familiar with the equipment.

2 Resonances of a vibrating string

How might you describe the patterns you observed as you adjusted the frequency?

Students may use a variety of terms to describe their observations of the wave patterns.

Common responses may include words like bumps, wiggles, or waves. Accept all reasonable responses.

At certain frequencies, the vibrating string forms standing wave patterns. The frequencies at which patterns form are called *harmonics*. The first harmonic is called the *fundamental*. We can use a drawing to represent your observations. How many bumps does the first harmonic have?

The first harmonic has one bump. Draw the wave pattern of the first harmonic on the board.

Good answer. You can see that the first harmonic has only one bump. Who can tell me about the second harmonic?

The second harmonic has two bumps. Sketch the second harmonic on the board. Point to each bump in the sketch.

The number of bumps on the string tells you which harmonic it is. Therefore, three bumps would represent the third harmonic, and so on. I want each person to practice drawing the third harmonic.

While each student draws the third harmonic, sketch it on the board. Allow time for students to practice drawing the harmonics.

The third harmonic has three bumps. The places between the bumps are called *nodes*. At a node, the string is not moving. You can touch the string there and the wave keeps going.

Point to the nodes of the third harmonic on the board. Then have students touch the wave at a node.

The places where the wave is widest are called *antinodes*. You can measure the amplitude of the wave at the antinodes. You will learn more about measuring the amplitude of waves at the anti-

nodes later in the investigation. Look at the graphic representing different harmonics of the vibrating string. The string is one meter long. The wavelength, given by the Greek letter lambda, is the length of one complete wave. Use your finger to trace along the pattern of the wave. Without using a meter stick, how can you determine the wavelength of each standing wave?

Help students to see that the total number of bumps equals the length of the string. As they trace along the length of one wave, they can count the number of bumps they encounter. In the case of the third harmonic, one wavelength encompasses two bumps, therefore it is $2/3$ of a meter.

3 Finding the standing waves

In the first part of the investigation you noticed that the standing waves only occur at certain special frequencies. The wiggler applies an oscillating force to the string. When the oscillating force matches the natural frequency, a large response develops. This is called *resonance*. Use the frequency control to find at least the first eight harmonics. Record the frequency and wavelength for each harmonic in Table 1. You should fine-tune the frequency to get the largest amplitude wave before recording the data.

Turning the control knob slowly makes the frequency change in smaller amounts while turning it faster makes the frequency change in larger amounts.

Look for harmonics two through six before looking for the first one. The first harmonic, also called the *fundamental*, is hard to find with exactness. Once you have the frequencies for the others, they provide a clue for finding the frequency of the first harmonic.

Students should notice that the fundamental has a wavelength of two meters because only one-half of a complete wave is on the string and that its frequency is around 10 Hz.

Fill in the third column of Table 1 by multiplying frequency and wavelength for each harmonic.

Help students to see that multiplying frequency and wavelength gives wave speed in units of m/sec.

4 Thinking about what you observed

At what frequencies did you find the different wave patterns? Is there a relationship between the different harmonics?

Lead a discussion of the results. Students should recognize that the frequencies are multiples of the first, which is why the first harmonic is called the fundamental. Some students may also recognize that frequency and wavelength are inversely related. Compared with the fundamental, when frequency doubles, wavelength is reduced to half. If frequency triples, wavelength is decreased to one-third, and so on. By multiplying frequency and wavelength, students should notice that the numbers for each harmonic are nearly the same.

Think about what you observed as you answer questions a–e.



5 Frequency and energy

Waves are useful because they carry energy from one place to another. The energy of a wave can also carry information like a voice signal from a cell phone or a TV picture. How much energy do you think is needed to grow a wave? Do some waves require more energy than others?

Listen as students make predictions about different amounts of energy and the waves each produces.

This part of the investigation looks at how the energy of a wave is related to frequency and amplitude. Set up several wave patterns and measure the amplitude for each harmonic. The amplitude is one-half the width at the widest point. Recall that this is the antinode. Measure at least five different harmonics, with one including the sixth harmonic or higher. Try to make the waves as large as possible before measuring the amplitude. Record your measurements in Table 2.

Prompt the class to remember that waves are widest at the antinodes. Amplitude can be measured easily with a ruler to an accuracy of +/- two millimeters or so.

6 Thinking about what you observed

Use what you observed in part 5 to help you answer questions a and b.

Discuss students' responses to these questions. They should conclude that amplitude decreases as frequency increases. If the amplitude of a wave stays constant, the energy of a wave depends on its frequency. As the frequency increases, the energy also increases. Have students compare the frequencies of different harmonics of the vibrating string. For a standing wave on a string the energy increases because the string must move faster to complete more cycles per second at higher frequencies. The energy of a wave is proportional to its frequency.

7 Resonance

All objects that can vibrate have a natural frequency that comes from the balance between inertia and restoring forces, just as we saw earlier. The natural frequency is important because if we know it, we can predict how an object will vibrate. If we know how an object vibrates we can use it to make waves of specific frequencies. We use the natural frequency to create and control waves. When you vibrate an object at its natural frequency, you get resonance.

Students generally have done this with swings themselves and will give advice like “kick your legs” or “lean back.” Steer the discussion toward the key concept of rhythm. Whatever you do, it must be in rhythm with the natural motion of the swing.

The diagram shows a useful way to think about pushing a swing. The person pushing applies an oscillating force to the swing, just like the wiggler does to the vibrating string. Like the string, a swing is a system in harmonic motion. If the push is applied at the swing's natural frequency, the amplitude grows large, like the standing wave on the string. The response of the swing to a periodic push is an example of resonance. Resonance happens when the force applied to a system matches its natural frequency. We use resonance to create waves with specific frequencies, such as in a musical instrument, cell phone, or microwave oven.

Lesson 23.2: Properties of Waves

Waves are traveling oscillations. They have properties of frequency, wavelength, and amplitude. There are many important applications of waves to our lives. For example, waves carry energy and information, such as heat, light, sound, and cell phone conversations. In this lesson students explore the properties of waves. They also learn to use an equation to measure the speed of waves.

Start the lesson

Connect to Prior Knowledge: Waves Graffiti

Affix sheets of chart paper on the walls or the board throughout the classroom. There should be one piece of chart paper per group. Use a marker to write the word, WAVE, in the center of the paper. As students enter the classroom, have them go to the piece of chart paper nearest their assigned groups and then write a word or phrase that comes to mind when they think of waves.

Motivate: Project Based Learning—Waves

Part One: Have students work in small groups to design and conduct wave-related investigations. Some students may need ideas to get started. Other students may already have ideas or questions about waves that they want to learn more about. Provide guidance to students as needed. It may be beneficial to dedicate one class period to gathering information in the media center or having brief conferences with each group to determine areas in which they need support.

Part Two: An important step in the scientific method is to publish the results of one's investigations. Have students create a newspaper called The Daily Wave (or some other name they create), which will inform its readers about waves. For example, they may include information about the different types of waves, how they function, and the relationship between waves and technology, such as cell phones and mp3 players.

Divide students into teams with different tasks, such as editors, photographers, and writers. Other students may be responsible for the layout, design, and binding of the newsletter. Reserve one section of the newspaper to feature the wave investigations students conducted in part one. Be sure to have students publish their research question, hypothesis, procedures, and results. If space is a factor, then have students negotiate to decide which investigations should be featured. Distribute the newspapers to members of the student body. It may also be fun to have them displayed at a family science night or open house to share with parents.

vo·cab·u·lar·y

wave - a travelling oscillation that has properties of frequency, wavelength, and amplitude.

wavelength - the distance from any point on a wave to the same point on the next cycle of the wave.

Using Silent Graffiti as an Admit

Silent graffiti is a great way to get your students involved in the day's lesson from the moment they come into the classroom. In the example provided, it is being used as an "admit" to class, meaning students must complete the task upon entering the classroom.



When using this strategy on a lab day, be sure to assign investigation groups a day in advance. Therefore, students know exactly where they will be sitting and with whom they will be working. Pre-arrange the chairs or desks in groups to save time. It is also a good idea to have the task written on the board so that students clearly know what to do as they enter. This also prevents you from having to verbalize the assignment repeatedly.

After each student has contributed to their group's graffiti, give them a few minutes to discuss their responses among themselves. Have one person from each group share their ideas and thoughts about waves with the class. Note any recurring ideas, concerns, or misconceptions, and use them to present the lesson in a manner that is interesting to students and helps them master the important concepts.

Present the content

Guided Discussion: A Wave Analogy

Ask students, “Have you ever watched a sporting event, like a football or baseball game, on television where the fans did the wave?” Students might have even participated in a stadium wave at such an event. Ask students to describe what happens. Then tell students to think about the stadium wave in terms of physics. Each person seated in the stadium is at an equilibrium position. Each person within a row then rises, lifts their hands, and returns to their seat. This pattern continues throughout the stadium until every person in each area of the stadium has participated, thus producing a “wave” throughout the stadium. An interesting point about the stadium wave is that no one actually moves beyond his or her seat to create the wave. As a matter of fact, each person simply returns to the position from which they started—equilibrium.

Explain that waves are traveling disturbances. Just as each person in the stadium wave starts and ends in the same position without actually leaving his or her seat, waves are oscillations, moving from one place to another, that don’t involve the movement of matter.

Check for understanding



A wave has a wavelength equal to 160.0 meters and its frequency is 20.00 Hz.

1. Calculate the speed of the wave. [redacted]
2. What is the period of the wave? [redacted]

Reteach

Draw a wave (showing several complete cycles) along the x -axis of a two-dimensional plot on the board. Label each axis with values from zero to 10. Have students use different colored chalk to label the crests, troughs, and several wavelengths. Then have students determine the period, frequency, and amplitude of the wave. Then ask questions like, “Suppose the length of the wave is increased. How will this affect the frequency of the wave?” Provide additional opportunities for students to practice using the wave speed equation.

Waves



Use the questions provided below as guided practice for understanding the relationship between frequency and wavelength, and for applying the equation to determine the speed of a wave.

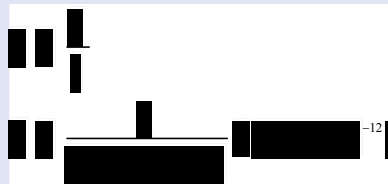
1. What is the speed of a wave if its wavelength is 35.0 meters and its frequency equals 12.0 Hz?



2. A wave travels at the speed of light, 3.0×10^8 m/s. What is its wavelength if its frequency equals 6.250×10^{11} Hz?



3. What is the period of the wave in question #2?



Lesson 23.3: Wave Motion

This lesson is all about how waves move. Students learn what happens when waves encounter other objects, including other waves.

Start the lesson

Connect to Prior Knowledge: Wave Motion

Ask students to think about what happens when a wave comes in contact with an object or another wave. What do they think happens. Have your students share their ideas by completing this sentence: *When a wave makes contact with another wave or surface, it...*

Students may not have the exact vocabulary to describe wave interactions, so it is also okay if they finish the sentence by drawing a picture of what they think happens.

Motivate: Wave Interactions Skit

Create four teams among your students. Assign one wave interaction to each team and allow time for students to plan how they will use a 5–7 minute skit to teach their interaction to the class. A sample rubric for assessing students' skits is provided below.

Category	3	2	1
Content Knowledge	All of the content was correct. Each student showed solid knowledge of their interaction.	Most of the content was correct and most students were knowledgeable of their topic.	There were many inaccuracies in content. Few students seemed knowledgeable of the topic.
Props/Visuals	The props were related to the wave interaction and helped to make the content clearer and the overall presentation better.	The props were somewhat related to the wave interaction but were not used in a way to make the content more understandable.	No props or visuals were used.
Organization	The skit was well-organized and followed a logical sequence. Each team member had a role.	The skit was somewhat unorganized OR only a few team members had a role in the skit.	The skit was very unorganized and difficult to follow.
Duration	The skit was within the time limits.	The skit was over or under time by < 1.5 min.	The skit was more than 1.5 min over or under.
Entertainment Factor	Very entertaining. The skit was fun to watch.	The skit was sort-of fun to watch.	The skit was somewhat boring.

vo·cab·u·lar·y

wave front - the leading edge of a moving wave.

plane wave - moving waves that have crests in parallel straight lines.

circular wave - moving waves that have crests that form circles around a single point where the wave began.

reflection - the process of a wave bouncing off an object.

refraction - the process of a wave bending as it crosses a boundary between two materials.

diffraction - the process of a wave bending around a corner or passing through an opening.

absorption - what happens when the amplitude of a wave gets smaller and smaller as it passes through a material.

transverse wave - a wave is transverse if its oscillations are not in the direction it moves. or·i·gin

longitudinal wave - a wave is longitudinal if its oscillations are in the direction it moves. or·i·gin

constructive interference - when waves add up to make a larger amplitude.

destructive interference - when waves add up to make a smaller, or zero amplitude.

Present the content

Guided Discussion: Constructive and Destructive Interference

Have students read page 570. Ask students, “What does it mean to construct something?” Construction is all about building. For example, homes, buildings, roads, and bridges are all examples of things that are constructed. Focus students’ attention on Figure 23.18, an example of constructive interference. Point out that each wave, A and B, travels along the string and they eventually make contact. At this point they combine (or build up), resulting in a larger amplitude. Then ask, “What is the result when something is destructed?” Students should think about destruction in terms of something being torn down or destroyed. As students follow along, refer to Figure 23.19 to demonstrate how the opposing pulses result in a “destroyed” amplitude.

Check for understanding



When a wooden dowel is placed in a clear glass of water, it appears to be broken. This is an example of refraction, one type of wave interaction that can occur at a boundary. Name at least two more types of wave interactions and give an example of each.

Reteach

Active Learning: Making Wave Pulses

It may be difficult for students to envision what happens when waves come in contact with one another. Have students use elastic string (about three meters in length) to make wave pulses. Take one end of the elastic string and make a knot for attaching a spring scale that can measure 5 N of force. Stretch the string so that the scale reads 1 N. The partner should rest the other end of the string against the top of a chair, pull the string down about 10 centimeters, and then release it. Students should be able to observe the wave pulse moving down the string toward the spring scale. Explain to students that this is an example of a transverse wave.

A relatively low amount of tension (absolutely no more than 3 newtons) should be maintained on the string. While the string is being stretched both ends need to be securely held in place. Letting the string go while under tension should be avoided at all times. Any knots tied in the string should be checked to be sure they will not come undone when the string is stretched.

Wave Interactions Skit

Get students involved in the process of peer evaluation. Add the total points from your assessment of each skit to the average from peer reviews. Using this method, the total possible points is 30.

You may also include space on the rubric for students to compliment each group by citing one thing they really liked about their skit.



Addressing Misconceptions about Water Waves

Water waves are usually quite familiar to students. When describing the motion of waves, students often think water actually moves forward in a straight line with waves. Water in waves move in a clockwise circular motion. The radius of these circles get smaller as the depth of water increases.

Have students imagine following the path of a single drop of water. What might they observe? The drop of water bumps into another drop of water. With each collision, the water drop passes along its energy to the next water drop and so forth. The result is that the energy of the wave is carried and moves forward.

