



## Level A Investigations

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### A-1 Sound

*What is sound and how do we hear it?*

Students are introduced to the relationship between the sounds we hear and their frequencies. They learn that higher frequencies produces sounds that have higher pitches. They also conclude that the human ear cannot hear all frequencies of sound.

### A-2 Musical Sounds

*What is music and how do we make music?*

Students use the sound generator to explore the connection between frequencies and the musical scale. Groups of students play different frequencies together and they hear the difference between major and minor chords. They also discover that certain frequencies sound pleasant together while others do not.

### A-3 Making Waves

*What are some of the properties of waves?*

Students learn what waves are and discover the relationship between frequency and wavelength. Through their experiments they learn that there is an inverse relationship between frequency and wavelength.

## Level B Investigations

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### B-1 Sound

*What is sound and how do we hear it?*

Students explore the properties of sound and the range of human hearing. They discover this range by participating in an experiment that measures human sensitivity to different frequencies. In the process, they learn how to design and conduct an un-biased experiment.

### B-2 Musical Sounds

*Why do we like some sounds and dislike others?*

Students explore the connection between frequencies and notes in the musical scale. They also learn how to calculate the frequencies of notes in different octaves.

### B-3 Standing Waves on a String

*How do we describe waves?*

Students investigate the relationship between frequency and wavelength and discover that they are inversely proportional. They also explore the connection between amplitude and frequency. They conclude that the speed of a wave is the product of its frequency times its wavelength and investigate how the speed of a wave pulse varies with the force applied to an elastic string.

## **B-4 Natural Frequency and Resonance**

*What is resonance and why is it important?*

Students learn that the frequency at which an object tends to vibrate is called its natural frequency. They discover that when the force applied to a system matches its natural frequency, the result is a strong response or wave pattern. This phenomenon is called resonance.

## **B-5 Resonant Sounds**

*How can we create specific sounds?*

Students explore how resonance shapes the characteristics of different sounds. This is because objects tend to vibrate at their natural frequencies. They explore resonance in tuning forks, wine glasses, and glass bottles. Finally, they learn how musical instruments are designed to vary the wavelengths of the frequencies of sound in order to produce notes.

## **Level C Investigations**

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### **C-1 Standing Waves**

*How can we make and control waves?*

Students discover the mathematical relationship between frequency and wavelength. They also explore the connection between frequency and energy, and discover the relationship between amplitude and frequency. They also investigate open and closed boundary conditions for waves.

### **C-2 The Speed of a Wave Pulse**

*What is the speed of a wave?*

Students create wave pulses on a string and observe how they move and what happens at their boundaries. Through their experiments, they discover how the speed of a wave differs from the speed of a moving object. They also explore the effect of changing the string tension has on the speed of a wave pulse.

### **C-3 Natural Frequency and Resonance**

*What is resonance and why is it important?*

Students observe the natural frequency of a system and identify the relationship between amplitude and period. They experiment with different string tensions and discover the relationship between force and natural frequency, and length and natural frequency. They also build their own oscillator and measure its natural frequency.

### **C-4 Sound**

*What is sound and how do we hear it?*

Students explore the properties of sound and the range of human hearing. They discover this range by participating in an experiment that measures human sensitivity to different frequencies. In the process, they learn how to design and conduct an un-biased experiment.

### **C-5 Interference and Diffraction of Sound**

*Does sound behave like other waves?*

Students create resonance, beats, and interference of sound waves. Through their exploration of the properties of sound, students prove to themselves that sound is a wave. They also learn how to control the properties of sound waves for useful purposes.



Question: What is resonance and why is it important?

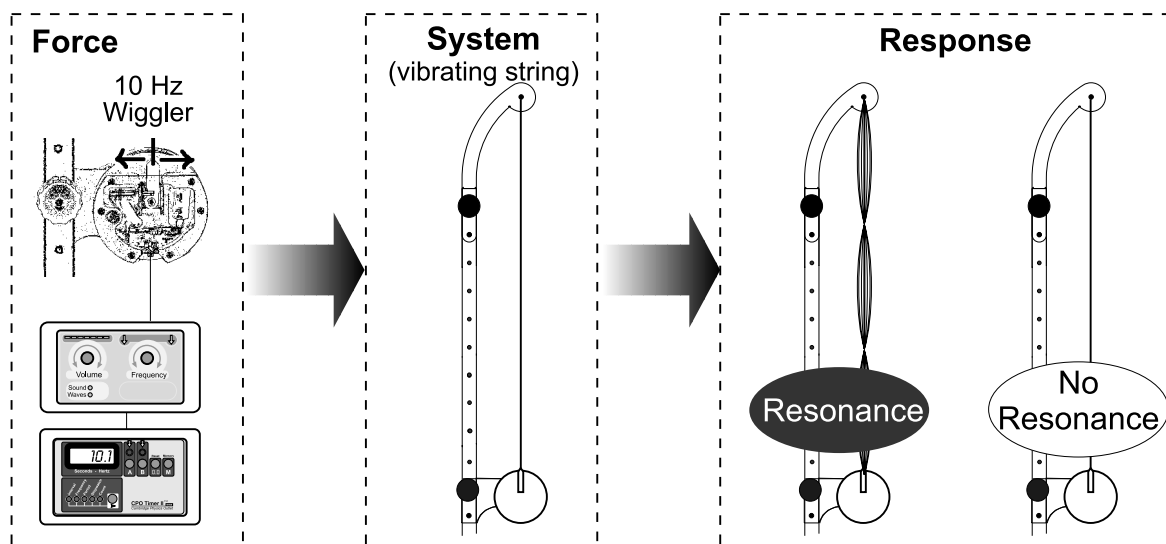
In this Investigation, you will:

1. Learn about natural frequency.
2. Learn what resonance is, and why it is important.
3. Learn how to change the natural frequency of a system.

When you pluck a stretched string, it vibrates. If you pluck the same string 10 times in a row, it will vibrate at the same frequency every time. The frequency at which objects tend to 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 the frequency of a wave and its wavelength.

1

## What is resonance?



The diagram shows a useful way to think about the interaction of the wiggler and the string. The wiggler supplies a driving force to the string. The string is a system that can respond to the force in different ways. If the frequency was just right, the string made a wave pattern. The wave pattern is a strong response to the force applied by the wiggler. At other frequencies, the string did not make a strong wave pattern. When no wave pattern appears, we say the response of the system is weak.

The wave patterns on the string are an example of **resonance**. Resonance happens when the force you apply to a system matches its natural frequency (or a multiple of that natural frequency). When you apply a force matched to the natural frequency of a system, you can get a very strong response. Resonance is the especially strong response we find when we apply an oscillating force at a natural frequency of a system.

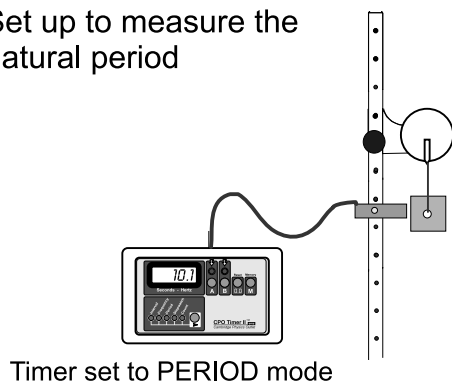
There can be many resonant frequencies for a single system. Typically, resonant frequencies occur at multiples (or fractions) of the natural frequency.

**2**

## The natural frequency of a system

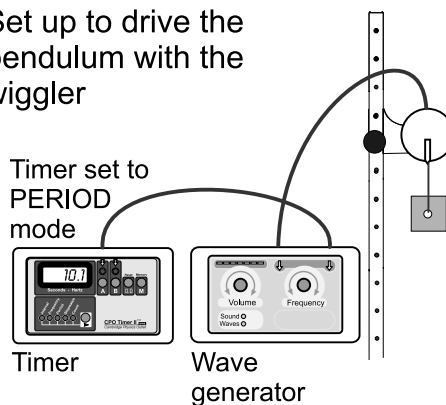
A pendulum is a simple oscillator that has a natural frequency. You may have already learned that the natural frequency of a pendulum depends on the length of the string. In this part of the Investigation, we will observe what happens when we drive a pendulum with a small force at its natural frequency. Because the frequency is very low, we will actually measure the period instead. Remember, the frequency is one over the period.

Set up to measure the natural period



Timer set to PERIOD mode

Set up to drive the pendulum with the wiggler

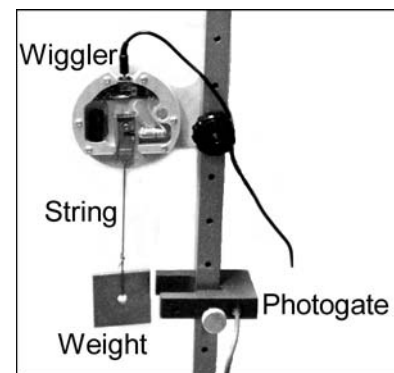


Timer set to PERIOD mode

Timer

Wave generator

1. Set up the wave generator and the wiggler as shown.
2. Thread a string through the wiggler arm and tie a small knot so the end of the string cannot come back through the small hole.
3. Tie a weight to the free end of the string. This makes a small pendulum suspended from the wiggler arm. The length of the string from the wiggler to the weight should not be more than 10-15 cm.
4. Place a photogate on the physics stand as shown.
5. Use the photogate and timer to measure the period of the pendulum. This works best if you swing the pendulum so it breaks the light beam only once per swing. Record the period of the pendulum. This is the natural period of the system.
6. Disconnect the photogate and connect the wave generator to the timer. Set the timer so it measures period.
7. Vary the frequency control and observe what happens as the wiggler gets close to the natural period of the system.
8. See what happens when you drive the wiggler at twice the natural period.


**3**

## Reflecting on what you observed

- a. Explain how the force applied by the wiggler causes the response of the pendulum. Your answer should make direct reference to your observations, and explain why the natural period is important.
- b. Make a rough sketch of a graph showing amplitude vs. period. Your  $x$ -axis (period) should range from zero to at least twice the natural period. The graph will NOT be a straight line or simple curve.

## 4 Force and natural frequency

Sometimes you want large amplitude waves, as on a vibrating guitar string that is making sound. Sometimes you don't want large amplitudes, as in the motion of a tall building in an earthquake.

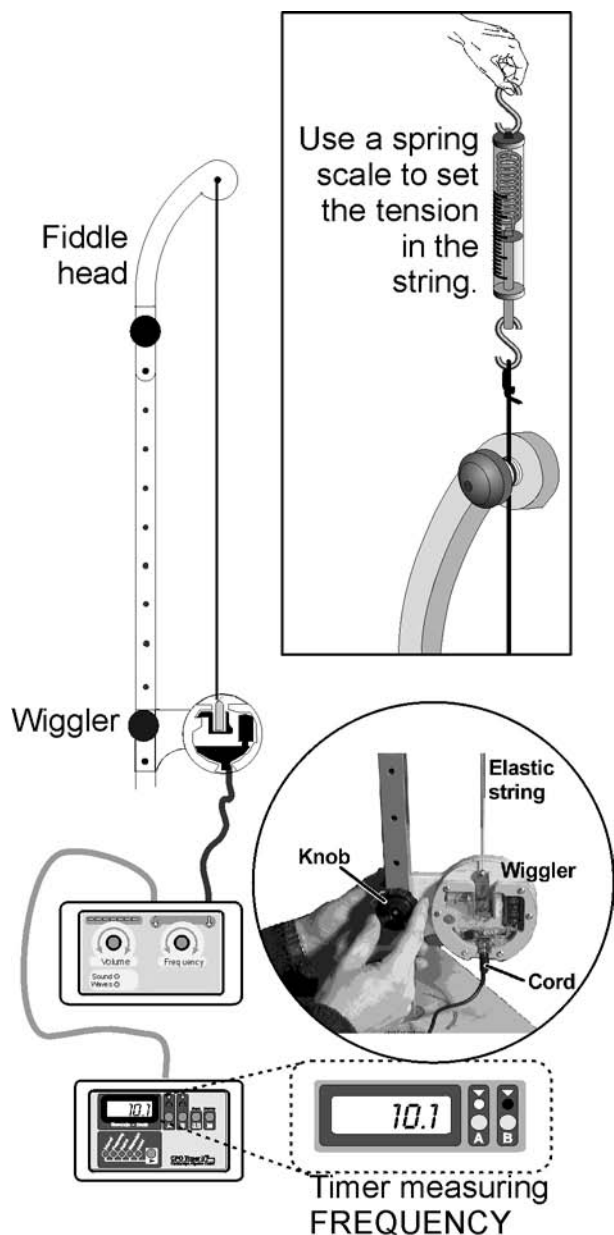
One way to change the natural frequency is to change the force it takes to move the system.

1. Loosen the knob on the fiddle head and attach a spring scale to the end of the elastic string.
2. While the knob is loose, stretch the string until the spring scale indicates the force that you want for the string tension.
3. Gently tighten the knob to hold the string without changing the tension.
4. Adjust the frequency of the wave generator until you have the third harmonic wave. Remember to fine-tune the frequency until the amplitude of the wave is as big as it can get.
5. Record the frequency in the data table.

Repeat steps 2-5 for each different string tension.

**Table 1: Frequency vs. string tension data**

Harmonic	Tension (N)	Freq. of 3rd (Hz)	Nat. freq. (Hz)
3	0.5		
3	1.0		
3	1.5		
3	2.0		
3	2.5		
3	3.0		



## 5 Applying what you learned

- a. Make a graph showing how the natural frequency changes with the tension in the string. The natural frequency is the fundamental, which is one-third the frequency of the third harmonic.
- b. What happens to the natural frequency as you increase the tension of the string? In your answer, discuss why this is useful in tuning a musical instrument such as a guitar or piano. You may need to do some research to investigate how guitars and pianos are tuned.
- c. As the tension is increased, making the string stiffer, what happens to the amplitude of the wave? An earthquake is like the wiggler in that it makes the ground shake back and forth with a certain frequency. How do your results relate to making tall buildings sway less in an earthquake? In answering, you should consider what happened to the amplitude of the wave when you increased the tension in the string.

## 6 Length and natural frequency

The natural frequency of objects often varies with their size.

1. Set the fiddlehead to different heights on the physics stand, with the wiggler at the bottom.
2. Use the spring scale to set the tension in the string to 1 newton. Keep the same tension for every different height.
3. Find the frequency of the third harmonic for each different length. Calculate the natural frequency from the frequency of the third harmonic.

Table 2: Frequency vs. String Length

Harmonic Number	String Length (cm)	3 <sup>rd</sup> Harmonic Frequency (Hz)	Natural Frequency (Hz)
3			
3			
3			
3			
3			
3			

## 7 Applying what you learned

- a. Graph the natural frequency vs. the length of the string. The natural frequency is the frequency of the fundamental, which is one-third the frequency of the third harmonic.
- b. How long would the string have to be to get a natural frequency of 1 Hz at a tension of 1 newton?

## 8 Making your own oscillator

Things oscillate because of the interaction of restoring forces and inertia. To make a mechanical oscillator, you need to provide some kind of restoring force connected to a mass that has inertia. A rubber band with a steel bolt tied to the middle makes a perfect oscillator. So does a wok and a tennis ball. Rubber bands, strings, elastic bands, and curved tracks all can provide restoring forces. Steel marbles and wood blocks have mass to create inertia.

1. Create a system that oscillates. You may use anything you can find, including springs, rubber bands, rulers, balloons, blocks of wood, or anything else that may be safely assembled.
2. Draw a sketch of your system and identify what makes the restoring force.
3. On your sketch, also identify the mass that creates the inertia.

To change the natural frequency of your oscillator, you need to change the balance between force and inertia.

$$\text{Natural Frequency} \propto \frac{\text{Restoring Force}}{\text{Mass (Inertia)}}$$

To DECREASE the frequency...	To INCREASE the frequency...
increase the mass, or	decrease the mass, or
decrease the restoring force	increase the restoring force

- a. Estimate or measure the natural frequency of your oscillator in Hz. You may use photogates or stopwatches to make your measurements. Describe how you made your measurement and write down some representative frequencies for your oscillator.
- b. Describe and test a way to increase the natural frequency of your oscillator. Increasing the frequency makes the oscillator go faster.
- c. Describe and test a way to decrease the natural frequency of your oscillator. Decreasing the frequency makes the oscillator move more slowly.

**C-3**

# Natural Frequency and Resonance



Question: What is resonance and why is it important?

**1** What is resonance?

There are no questions to answer in part 1.

**2** The natural frequency of a system

Follow the procedures in your Investigation guide. There are no questions to answer in part 2.

**3** Reflecting on what you observed

- a. Explain how the force applied by the wiggler causes the response of the pendulum. Your answer should make direct reference to your observations, and explain why the natural period is important.

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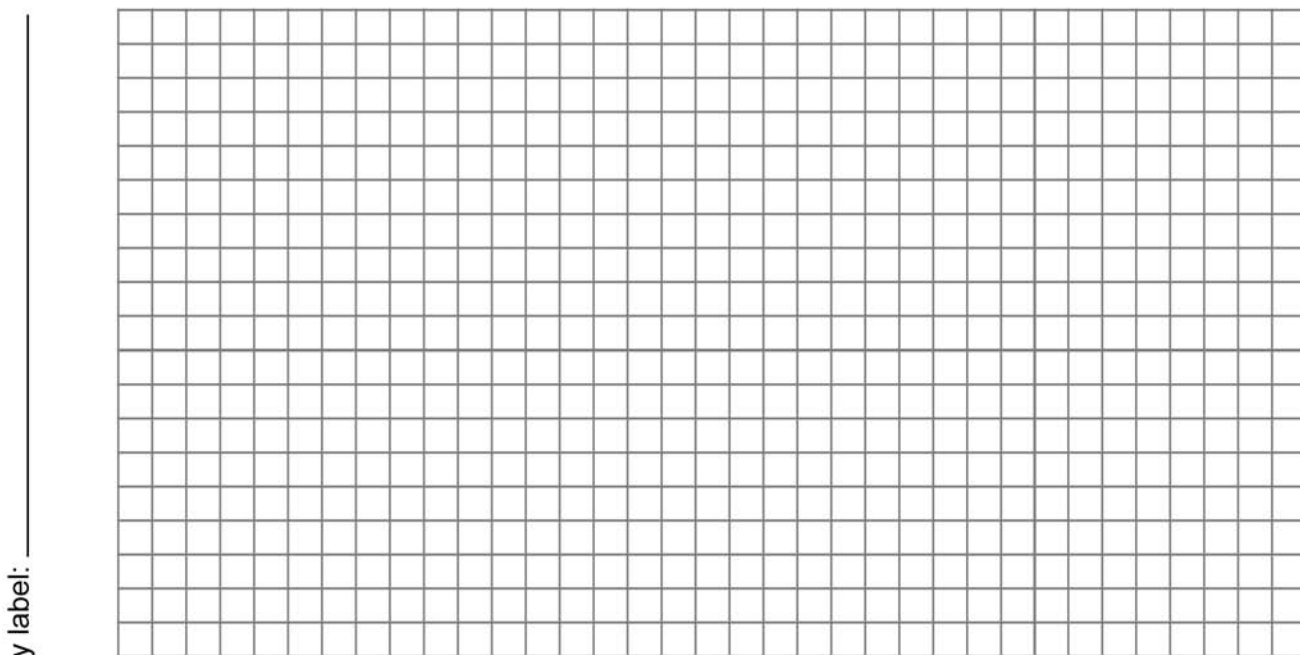
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- b. Make a rough sketch of a graph showing amplitude vs. period. Your  $x$ -axis (period) should range from zero to at least twice the natural period. The graph will NOT be a straight line or simple curve.

Title: \_\_\_\_\_



x label: \_\_\_\_\_

**4 Force and natural frequency**

Record the frequency in Table 1.

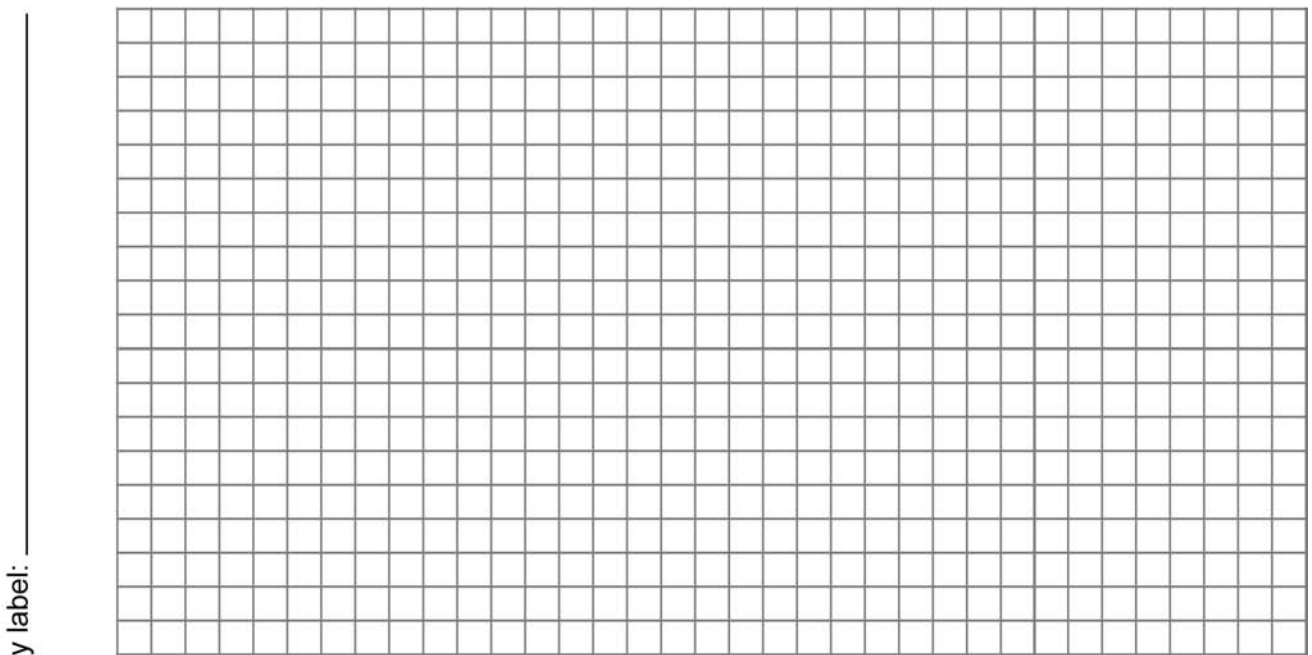
**Table 1: Frequency vs. string tension data**

Harmonic #	Tension (N)	Frequency (hz)
3	0.5	
3	1.0	
3	1.5	
3	2.0	
3	2.5	
3	3.0	

**5 Applying what you learned**

- a. Make a graph showing how the natural frequency changes with the tension in the string. The natural frequency is the fundamental, which is one-third the frequency of the third harmonic.

Title: \_\_\_\_\_



x label: \_\_\_\_\_



**6 Length and natural frequency**

Record your data in Table 2.

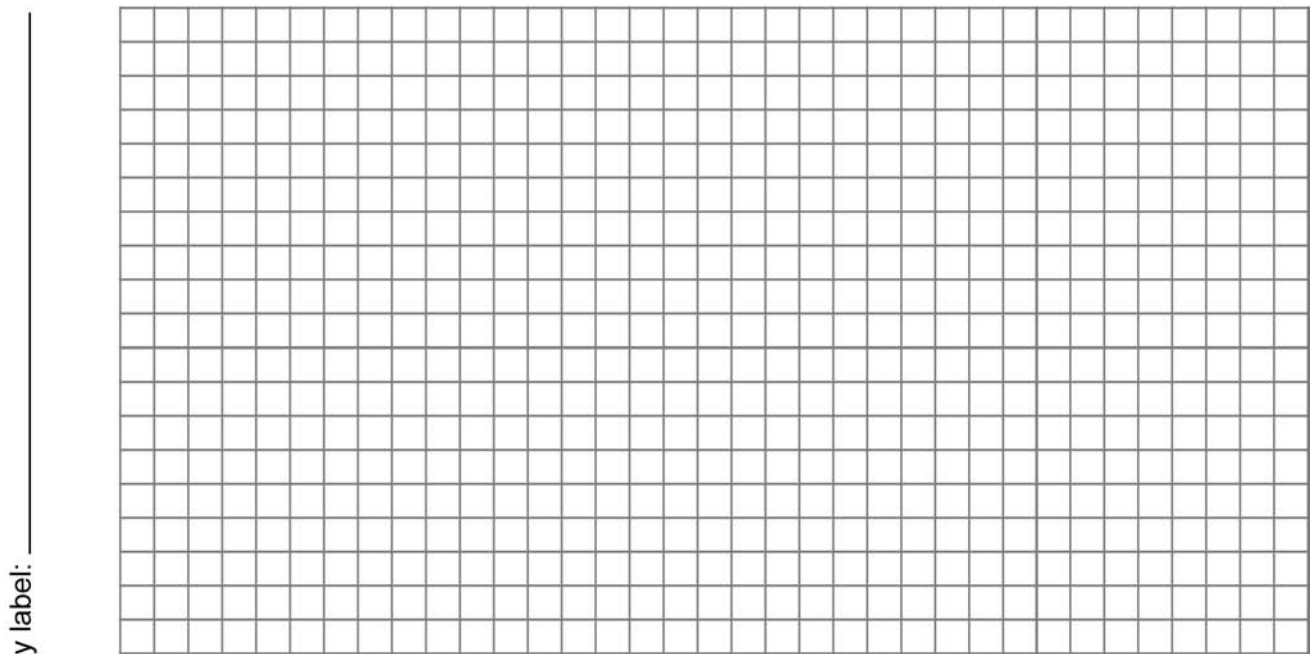
**Table 2: Frequency vs. string length data**

Harmonic #	String length (cm)	Frequency (hz)
3		
3		
3		
3		
3		
3		

**7 Applying what you learned**

- a. Graph the natural frequency vs. the length of the string. The natural frequency is the frequency of the fundamental, which is one-third the frequency of the third harmonic.

Title: \_\_\_\_\_



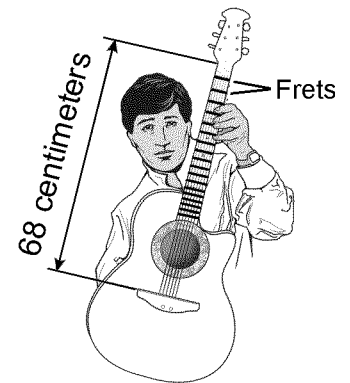
x label: \_\_\_\_\_

- b. How long would the string have to be to get a natural frequency of 1 Hz at a tension of 1 newton?

\_\_\_\_\_

# Questions

1. A guitar string is divided by frets. When you hold your finger on each fret, you make the length of the string shorter. This makes the wavelength shorter. Suppose your guitar string is 68 centimeters long and vibrates with a natural frequency of 120 Hz. What length of string would you need to make it vibrate at 180 Hz, which is 1.5 times higher?




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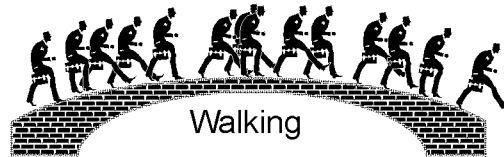


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2. Marching is when many people walk exactly in step with each other. Tromp, tromp, tromp, every foot falls at exactly the same moment with a steady frequency. It has been known since early times that troops should never march across a bridge. When soldiers cross a bridge they all walk with a different pace. Discuss why marching across a bridge is a bad idea, knowing what you know about resonance.




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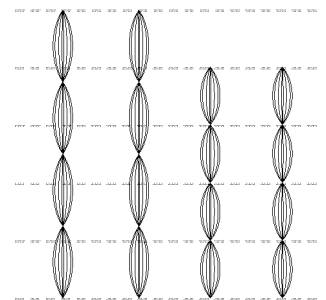
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Questions 3 and 4 refer to the diagram on the right.

3. Is the frequency of experiment (a) higher or lower than the frequency of experiment (b)? Explain the physical reasoning in your answer.




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4. If experiment (b) has a frequency of 200 Hz, calculate the frequency that experiment (d) should have.

	a	b	c	d
Length	1 m	1 m	0.8 m	0.8 m
Tension	1 N	2 N	1 N	2 N

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**Extra space for notes:**

## Curriculum Resource Guide: Sound and Waves

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