WAVES: Teacher Lesson Plan

Subject: Physical Science

Grade Level: 9-12: Integrated Physics and Chemistry (IPC), Physics, and Astronomy

Introduction:

During the videoconference portion of the lock-in, students will be looking at live data being gathered by an astronomer at the observatory. The research involves looking at a white dwarf and analyzing the periodic changes in its light output, looking for signs that indicate a planet may be orbiting it. In order to be engaged in what the astronomer is doing, the students need to understand how waves behave, and how they can be analyzed (specifically using Fourier analysis to extract individual frequencies). To reach this level of understanding, two activities are used together. An activity using slinkys reviews the fundamental properties of waves. And an activity using a computer to interpret sound waves shows how waves can be analyzed.

Student Product:

Students will learn about the basic properties of waves and answer questions to test their knowledge. Then they will experience a demonstration of how waves can be analyzed using a computer and how to extract individual frequencies from a complex wave pattern using Fourier analysis.

Prerequisite:

The first part of this activity is a hands-on lesson covering wave properties and terminology. However, students should have some prior knowledge of the basic properties of waves. This activity should be considered a review of waves with the addition of some new concepts and terminology.

Preparation:

The second part of this activity requires a computer with a sound-editing software program called ***Audacity***. It can be downloaded for free at:

http://audacity.sourceforge.net/

Please experiment with the *Audacity* computer demonstration before presenting it.
Also, please read through the entire teacher guide and student guide beforehand.

Materials:

Whole Class	Per Group (2 Students)
1. Metal xylophone, or set of 3 tuning forks, or windchimes 2. Computer with *Audacity* software 3. Digital projector (to show *Audacity* demo to the class)	1. Slinky

Objectives:

NSES:
Science As Inquiry – Use Technology and Mathematics to Improve Investigations and Communications
Physical Science – Interactions of Energy and Matter

Science TEKS:
112.42 – IPC
(2) Scientific Processes - Methods
  (C) organize, analyze, evaluate, make inferences, and predict trends from data
  (D) communicate valid conclusions
(5) Science Concepts - Waves
  (A) demonstrate wave types and their characteristics
  (B) demonstrate wave interactions
  (C) demonstrate the application of acoustic principles
112.47 – Physics
(2) Scientific Processes - Methods
  (C) organize, analyze, evaluate, make inferences, and predict trends from data
  (D) communicate valid conclusions
(8) Scientific Concepts – Waves
  (A) examine and describe a variety of waves
  (B) identify the characteristics and behaviors of sound and electromagnetic waves

Grading:

The Student Guide has 12 questions (plus one bonus) that the student must answer as they go along. The teacher may provide the students with the answers as the activity progresses. Or the teacher may have the student turn in their guide for a grade after the activity is completed.

Beginning the Activity

Engage

- Ask the class: **"What are some examples of waves that can be found in nature?"** Some typical answers may be: water (surfing), seismic, sound, electromagnetic (light).
- Ask the class: **"What kinds of scientists study waves as part of their research, and what types of waves do they study?"** The students might have trouble giving many examples. Mention that most repeating periodic events in nature can be modeled as waves.
- After they have tried, mention the following examples…pause after each one and ask the class what types of waves that scientist might study:

Geologists: (seismic waves to predict and understand earthquakes and tsunamis)

Chemists: (wavelike nature of electrons and their orbits around atomic nuclei)

Climatologists: (repeating periodic cycles in temperature fluctuations)

Ultrasound scientists: (sound waves to investigate inside people without hurting them)

Physicists: (many bizarre wavelike properties of subatomic particles – quantum physics)

Astronomers: (electromagnetic waves across the entire spectrum, periodic variations in light intensity and peak wavelength)

Explore

Now instruct the students to separate into groups of two. Give each group a slinky and give each student a Student Guide.

Once the materials are distributed, instruct the groups to follow the instructions in the Student Guides. They will answer several questions along the way…each student should fill in the answers in their own guide (in other words - the students fill out the guides individually, not as a group).

The following pages in this Teacher Guide will show the Student Guide pages with helpful comments off to the side…

Emphasize to the students – DO NOT OVERSTRETCH THE SLINKY.

Waves: Building them up and Breaking them down

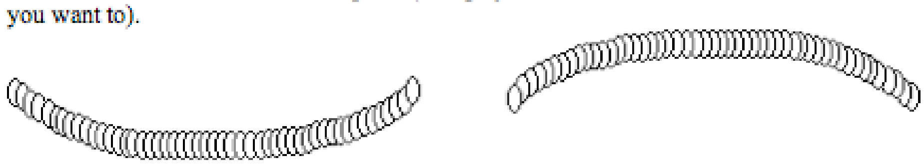
Student Guide

Activity 1: Waves and Slinkys

Before beginning, get into groups of two. Each group will have one slinky, but each student will fill out their own student guide.

Experiment 1:
Begin with the slinky laying on a big table or the floor. Have just one person hold the slinky with one end in each hand, and stretch it out just a little (be careful not to overstretch it). Now start to move your hands forwards and backwards together at the same time - both hands move in the same direction in unison. What you should start to see is one large hump (half of a wave) moving forwards and backwards.

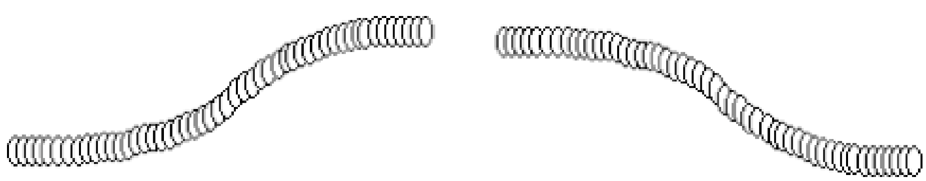
Find the speed that produces a large motion of the slinky for a very small motion of your hands. At this speed, count out loud every time the middle of the slinky gets to its lowest point (closest to you) ; “1,2,3,4,1,2,3,4,1,2…” – count one number every time it gets to the bottom. Try to remember about how fast this tempo is (though you don’t have to time it with a watch, unless you want to).



Now have the other group member try the same process.

Notice again that the center of the slinky moves up and down the most and your hands the least.

Experiment 2:
Now move your hands in opposite directions, that is, move the right hand forwards when the left hand moves backwards and vice-versa. Try to move them in the same tempo (frequency) as in the first experiment. What you should see here is more of an alternating S-shape in the slinky, where one hand is at the highest point and the other hand at the lowest point (this is also half of a wave). This time, count out loud every time your right hand gets to the lowest point: “1,2,3,4,1,2,3,4,1,2…”



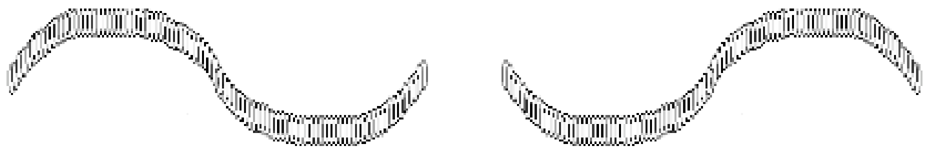
Again, have the other group member try the same process.

Here, the ends of the slinky move up and down the most.
1) What part of the slinky moves up and down the least? ____________________________

1

Answer to question #1) *the middle of the slinky moves up and down the least*

Experiment 3:
This time try to make a full wave. This can be tricky, depending on the length and flexibility of the slinky. Experiment with different hand motions and speeds. Try holding one hand still and moving the other. The idea is to have two humps appear on the slinky; while one hump is up, the other is down – together making one full wave.



Once you get it, count out the tempo of the hand that moves the most – every time it gets to its lowest (closest) point: "1,2,3,4,1,2,3,4,1,2…"

Have the other group member try this as well.

Answer to question #2) *the frequency is faster*

2) Is this tempo (frequency) faster or slower than in the first two experiments? ____________________

The parts of the slinky that move up and down the least are called nodes. The parts that move up and down the most are called antinodes.

On the slinky pictures above, label where the nodes and antinodes are.

Experiment 4:
This time, both partners will work together with one slinky. Have each person hold one end of the slinky, and stretch the slinky out on the floor or a big tabletop (**be careful not to overstretch it!**). Stretch it to about one meter if you can, but if the slinky isn't long enough, only go as long as you can without overstretching it. **Again, do not overstretch the slinky!** One student should hold one end of the slinky still, while the other student moves the other end slowly back and forth. Start slowly then increase the rate at which the slinky is moved back and forth. Notice how the speed affects the behavior of the slinky and the different types of waves that form. Switch roles.

If students need more room, they can try the experiments on the floor.

****Try this experiment on the floor if you need more room****

Now you and your lab partner will create equal-sized pulses at the same time from opposite ends of the slinky. It may require some practice to synchronize your timing. Try to send the pulses on the same side of the slinky and then try to send the pulses on opposite sides of the slinky. Pay attention to what happens as the pulses overlap.

3) Describe what you see:
____
____
____
____

2

Answer to question #3) *more waves appear on the slinky when you shake it faster, and that those waves have shorter wavelengths (higher frequency equals shorter wavelength). They may also answer that the pulses add to each other or cancel each other out (constructive and destructive interference)*

-There are two types of waves: transverse waves and longitudinal waves. What we've been looking at so far are transverse waves. Electromagnetic waves (light) are transverse waves. Sound waves, on the other hand, are longitudinal waves. In the next experiment we will look at longitudinal waves…

Experiment 5:
Now go back to having one person at a time hold the slinky…First, hold the stretched slinky on a tabletop. Next, begin to move your hands towards each other and then apart, as if you were clapping.

Notice the motion of the slinky.
4) What happens in the middle of the slinky? ______________________________________
____
____

Answer to #4)
The middle of the slinky expands and then contracts.

Now move both hands in the same direction, both to the right then both to the left then both to the right again, and so on back and forth. Notice where the slinks bunch together and where they spread apart (if you're having trouble seeing what is happening, it might help to put a piece of tape on a slink near the middle of the slinky).

5) Describe what you see happening at the ends of the slinky: ____________________
____
____

Answer to #5)
The ends of the slinky expand and contract at opposite moments

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Explain

Now instruct the students to read the **Summary** section for the slinky activity, and then answer questions 6 through 9. Have them stop after answering #9.

Summary:
The places where the slinks bunch together can be thought of as *high-pressure* areas and the places where they spread apart are *low-pressure.*

Sound waves are longitudinal waves like these. But instead of propagating through a slinky, they propagate through the air. They work by compressing air into high-pressure and low-pressure areas. They are sometimes referred to as pressure waves. Sound has to have a medium to pass through, such as air. Because there's no air in space, there's also no sound in space.

The types of waves we looked at in the first four experiments were transverse waves. Many transverse waves propagate through a medium as well (such as water). Any wave that needs a medium to travel through is called a mechanical wave. The only types of waves that don't need a medium are electromagnetic (light) waves. They can travel through the vacuum of space.

In general though, longitudinal and transverse waves, as well as mechanical and electromagnetic waves, are all very similar. They all transfer energy and can be diagrammed and analyzed in the same basic ways.

3

Review:

6) Draw a picture of a transverse wave. Label the wavelength, crest, trough, and amplitude. Also show where a node and an antinode would be:

7) If you want to increase the wavelength of waves in a slinky, should you shake it at a higher or a lower frequency? ________________________

8) What is the general relationship between wavelength and frequency?______________

____

____

9) What is the difference between a mechanical wave and an electromagnetic wave?

____

____

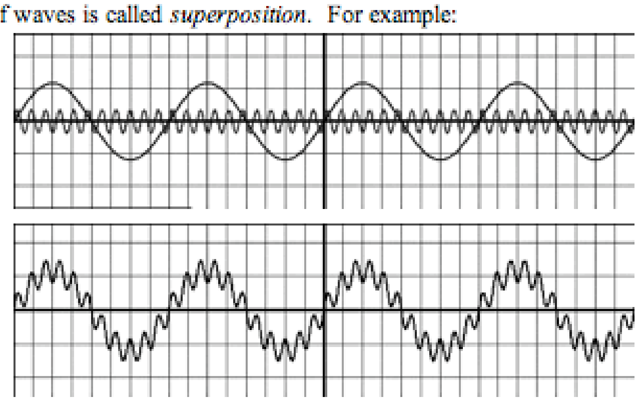
******Stop here and wait for your teacher before continuing to the next section******

Adding Waves Together: Superposition

What do you think happens when two waves meet up in the same medium? Remember what happened when you and your partner both sent pulses down the slinky at the same time? Typically, the result is quite simple: the waves combine together and make one complex waveform. This property of waves is called *superposition*. For example:

These two waves combine together to make…

this one waveform →



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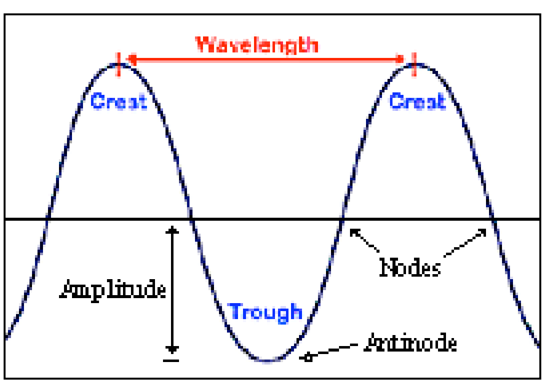
Answers to questions are below…

Instruct students to stop after answering #9 before proceeding to Activity 2 (Analyzing Waves with Audacity).

Once the entire class is done answering #9, have them continue reading the next section: Adding Waves Together…

Answer to #6) *See picture below…(This question assumes prior knowledge of basic wave terminology not covered in this activity)*

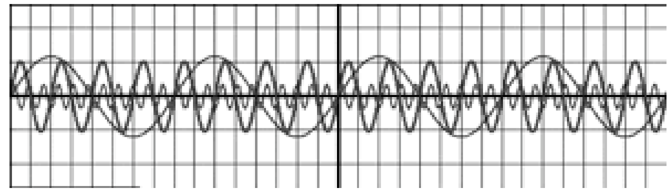


Answer to #7) *you should shake it at a lower frequency*

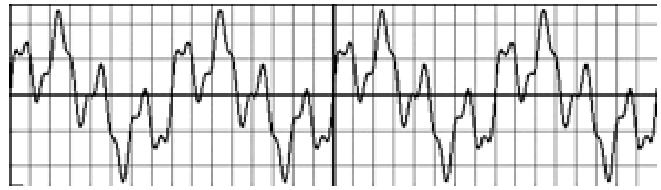
Answer to #8) *wavelength and frequency are inversely proportional, an increase in one corresponds to a decrease in the other.*

Answer to #9) *a mechanical wave requires a medium to travel through (i.e. water, air, ground, a slinky, etc…), an electromagnetic wave does not.*

And if we add another wave into the mix, so that there are now three waves,...



we get this mountainous-looking waveform →



Just three very simple waves can look very complex when you combine them.

Extend

Breaking Down Complex Waves: The Fourier Transform

Astronomers and other scientists often see waveforms like the one above in nature. Many of the waveforms they find are extremely complex - made up of several individual waves combined together, just like in this example. It is common for a scientist to be very interested in separating the waveform into its original separate waves, because understanding the details and origin of just one of the contributing waves might mean a huge breakthrough for science.

Luckily there is a fancy mathematical trick that can break down a complex waveform into its individual wave components. It is called the ***Fourier Transform***. Basically, you break down a complex waveform into an equation, plug that equation into the Fourier Transform, and it spits out the individual waves according to their frequencies.

The students are not required to answer #10 on this page. It is simply some humor intended to keep their attention and interest.

10) Calculate the individual wave frequencies that are found in the last graph above using the Fourier Transform function below (show your work):

$$X(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} x(t) e^{-i\omega t} \, dt$$

____

____

*** *JUST KIDDING! YOU DON'T HAVE TO SOLVE THIS PROBLEM!!!****

(Though you'd be surprised by how just a couple of years of college level math courses will make a problem like this seem like a piece of cake!)

Remind the students to stop after reading this page.

Most scientists who deal with waves know how to solve this type of problem on paper, but they usually don't do it that way. Instead, they program a computer to do it. Computers are much, much better at these sorts of operations. Scientists are more than willing to let a computer do this tedious math for several reasons: it is faster, more accurate, and it doesn't get bored or complain. Plus it leaves the scientists more time to do the fun, imaginative, creative, and innovative parts of their jobs!

…In the next activity, your teacher will demonstrate a free software application called *Audacity* that does this exact same type of wave analysis.

5

*****Please make sure all of the students are finished up to this point before proceeding to the next activity.**

Elaborate

<u>Activity 2: Analyzing Waves with *Audacity*</u>

This activity will focus on a demonstration performed by the instructor. It is much easier to demonstrate to a large class if you use a digital projector. You will be recording a musical note into a computer, and then showing what the sound wave looks like graphically, and how it can be analyzed to gather more information. It is highly recommended to experiment with the Audacity software and practice doing this activity before trying it in front of students.

<u>Step 1: Set up</u>

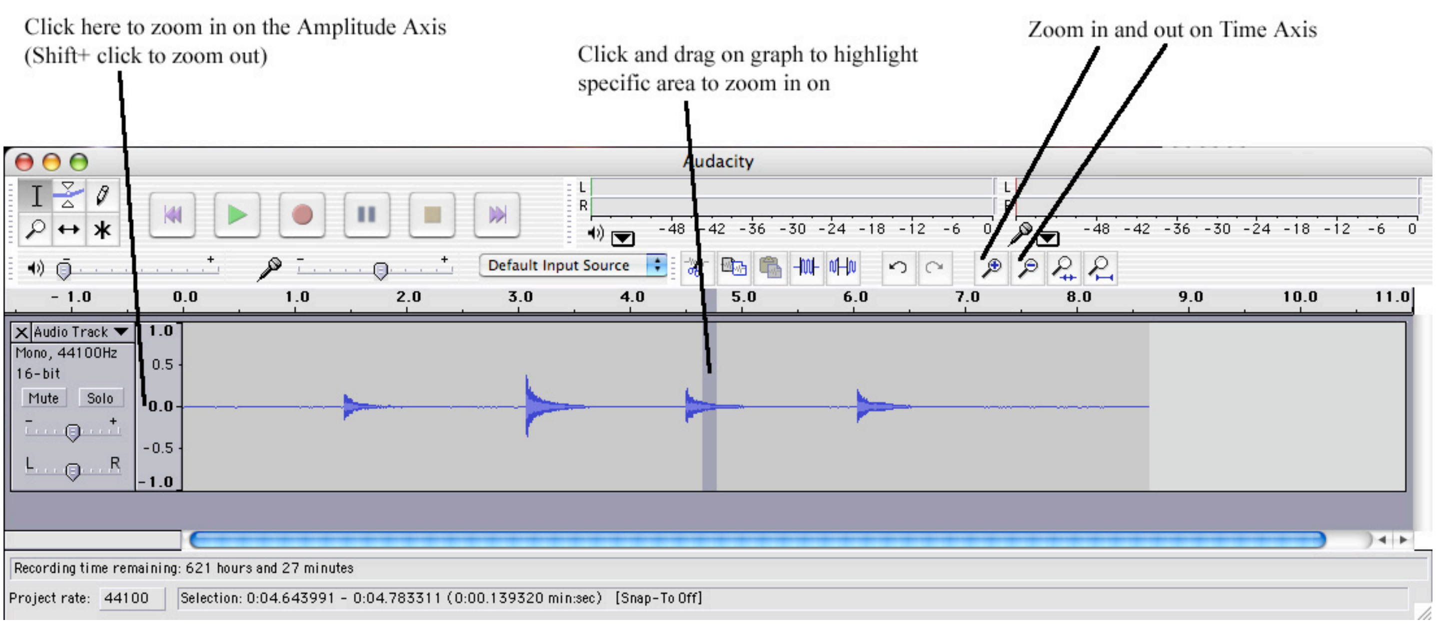
-Open Audacity software to a new window.
-Set up xylophone near microphone.
-Have students read the introduction to the activity.

<u>Step 2: Record</u>

-Make sure everyone in the room is quiet.
-Click the record button.
-Play several notes on the xylophone…do this one note at a time, waiting a couple of seconds between each note. Try to play at least three different notes.
-Click the stop button.

<u>Step 3: Examine</u>

-You should see a graph with a blue line in the middle. The vertical axis is the wave amplitude, the horizontal axis is time (seconds). The dark thick places on the line represent the individual notes you just recorded.



-Zoom in on the graph and look at individual notes. There are two ways to zoom in: on the x-axis (time) and on the y-axis (amplitude). To spread out the x-axis, click on the + magnifier symbol near the right end of the tool bar. To zoom in on the y-axis, click on the scale just to the left of the graph (to zoom back out hold the shift key while clicking on the scale).

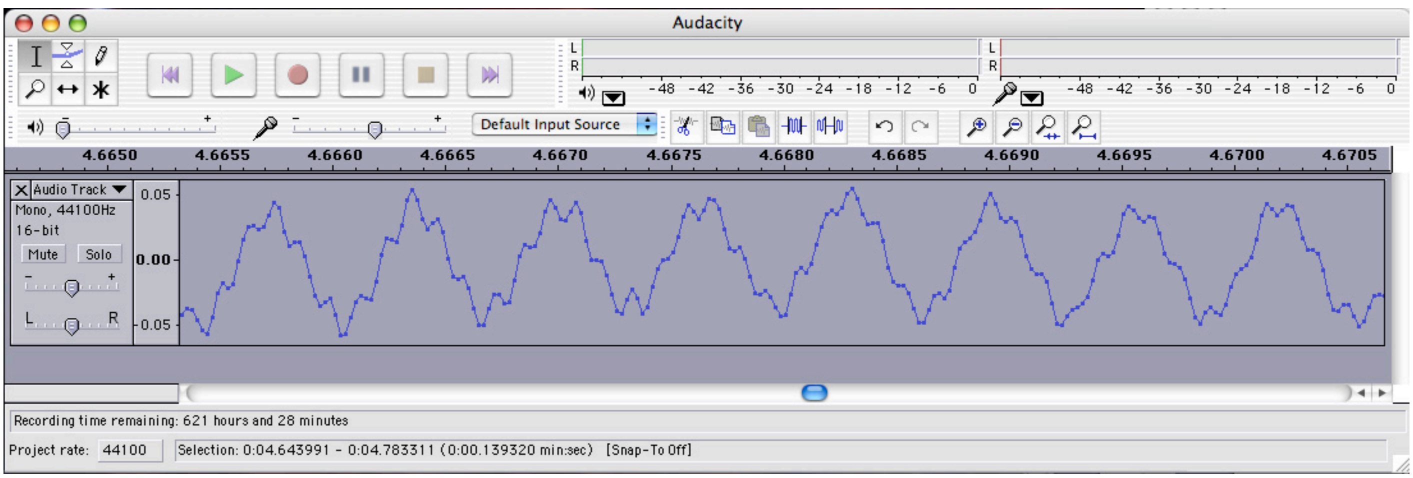
Step 4: Focus On One Note

-Move the cursor over the middle of one of the notes and click it. Now zoom in on that note (click the + magnifier near the right end of the toolbar). As you zoom in farther, you will start to see the note spread out into a waveform (to make the amplitude of the waveform appear larger, click on the scale on the left side of the graph). If you scroll left to right along the waveform, you will see that the amplitude slowly diminishes in time.

-Explain to the students that this graph represents the pressure wave created in the air when you played the note.

-Highlight a small section of one note: While zoomed on a note, click and drag the mouse to highlight about 0.10 seconds of the sound. **Make sure to highlight a section that is closer to the tail end of the note. If you take a sample from the beginning of the note, extra noise from the mallet and bouncing key can interfere with the true tone.**

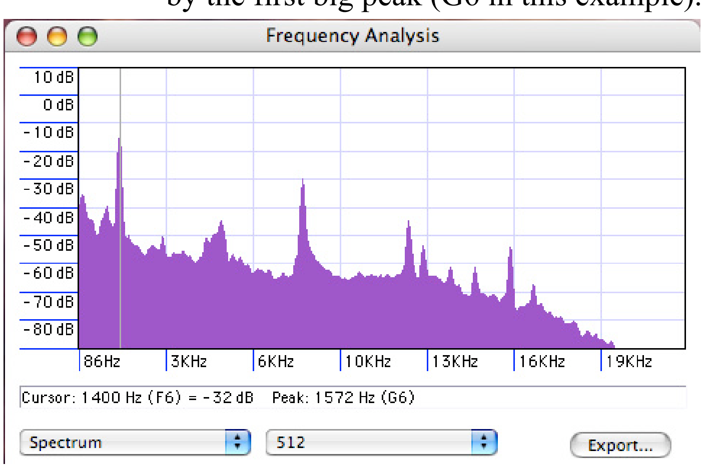
-Look at the highlighted waveform section in detail and show the students what this waveform looks like up close.



Step 5: Analyze The Note

-Plot the Frequency Spectrum: Keep the small section highlighted. On the Audacity bar at the top of the screen, click on “Analyze” and then click on “Plot Spectrum” in the pull down menu. A small window will appear.

-This window basically shows which frequencies are found in the waveform. The vertical axis represents decibels, while the horizontal axis represents frequency (in Hertz). As you move the mouse over the different peaks, the info bar underneath will tell which musical note is associated with each frequency - E8, G6, D#7, A9, etc…(the letter represents the note and the number is the octave). The actual note that you recorded is usually represented by the first big peak (G6 in this example).



(Note: The explanation of why there are several frequencies related to each note is quite complicated and too advanced for this activity. Plus, the frequencies that show up will vary depending on whether or not you use a xylophone, tuning forks, or chimes. In this activity, the focus is on understanding how waves in general can be analyzed and interpreted, rather than the specific properties of acoustic waves.)

Step 6: Two Notes At The Same Time!

-Start with a brand new window (On top menu bar click File → New).   Hit record. While recording: play one note –pause -, play a **different** note –pause-, and then play both of those notes simultaneously. Stop recording. ***Make sure to get a good clean recording of all parts…redo it if you need to.***

-Now analyze the first two notes separately, noting to class which notes were played (i.e. saying which note the first big peak in the spectrum represents). For example, if you recorded D6 and then A6, the first plot would have its first big peak on D6 and the second plot would have its first big peak on A6.

-Next analyze section where both notes were played simultaneously. This plot will have two big peaks close to eachother. These two peaks will represent the two previous notes (for example D6 and A6 would be the first two big peaks).

-This step really shows the beauty of the fourier transform. It is a perfect demonstration of how the fourier transform can separate a complex waveform into its individual contributing frequencies.

If there is time, repeat the experiment with different notes. ***Or have two students try singing different notes separately and then together, and then analyze each part – This is a lot of fun!!!***

Evaluate

After you are finished with the demonstration, instruct the students to answer the last questions in the student guide…

Answer to #10) _4_

Answer to #11) _3 kilohertz, 6 kilohertz, 11.5 kilohertz, 16 kilohertz_

Answer to #12) _the 6KHz wave represents the loudest contributing pitch because it has the largest amplitude_

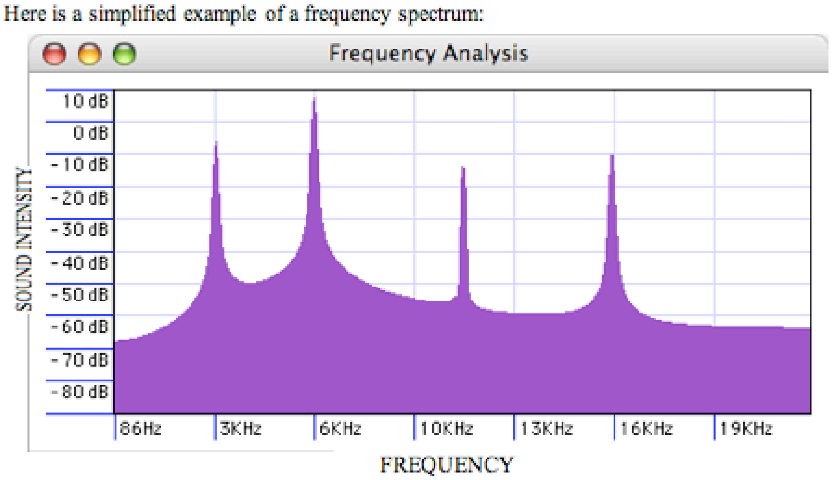
Answer to Bonus question: _the frequency peaks would be shifted to the right (higher frequencies) if the object were moving towards you._

Activity 2: Analyzing Waves with *Audacity*

Audacity is a digital audio editor, one of the many that are available for personal computers nowadays. This program has the ability to download sound files and edit them in many different ways (mix them, cut and splice them, add effects, etc…). In this activity, we are going to focus on the abilities of the program that are the most scientifically useful. Your teacher will be using a microphone to record sounds into *Audacity* and then applying the software's Fourier Transform program to analyze those sounds (i.e. plot the frequency spectrum of the recorded sound wave).

-Please watch and pay close attention to the teacher's demonstration before answering the following questions…

Here is a simplified example of a frequency spectrum:



10) How many individual waves contributed to the waveform that is analyzed in this example

____

11) What are the individual frequencies of the contributing waves?

____

12) Which wave represents the loudest contributing pitch (frequency)?

____

Bonus Question: If the object that created these waves suddenly began moving towards you, how would the appearance of this graph be changed? (hint: think of the Doppler shift)

____