Waves: Building them up and Breaking them down

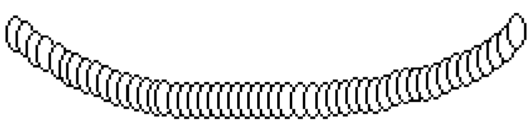
Student Guide

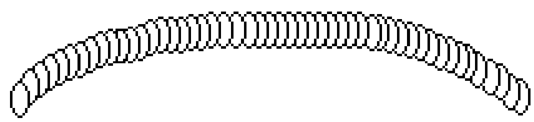
Activity 1: Waves and Slinkys

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).

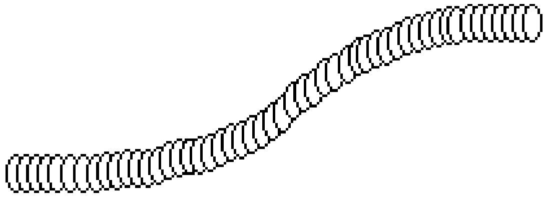


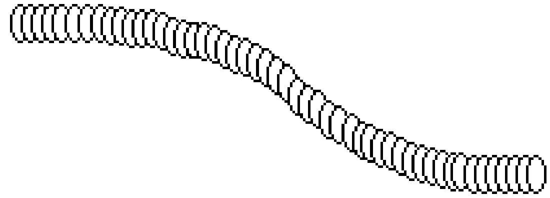


Now have the other group member try the same process.

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…"

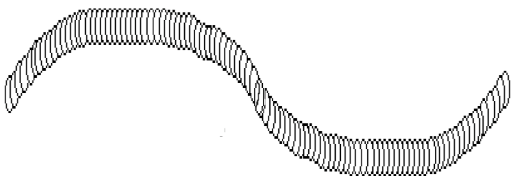


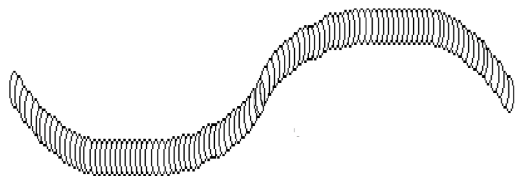


Again, have the other group member try the same process.

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

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.

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

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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.

*****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:

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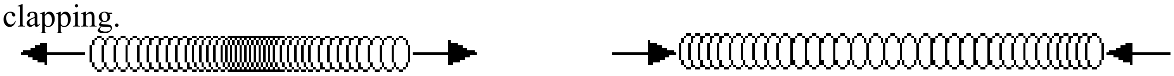
-There are two types of waves: transverse waves and longitudinal waves. What we've been looking at so far are transverse waves. Electromagnetic waves (light) are transverse waves. Sound waves, on the other hand, are longitudinal waves. In the next experiment we will look at longitudinal waves…

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? ____________________________________
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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: ______________________
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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.

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?_______________

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

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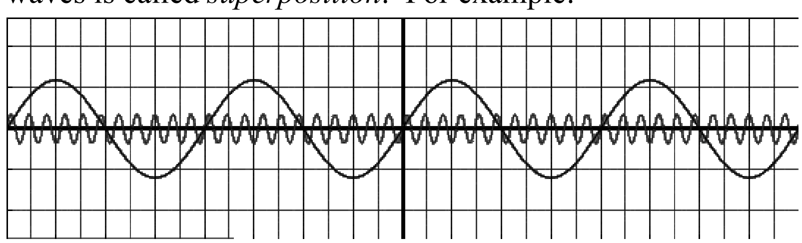
******Stop here and wait for your teacher before continuing to the next section******

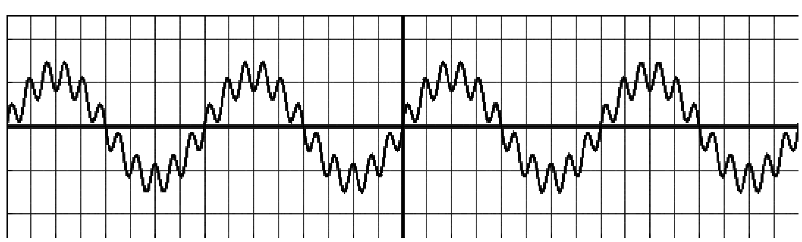
Adding Waves Together: Superposition

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:

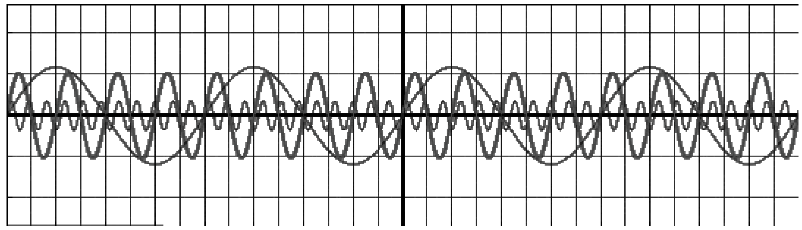
These two waves combine together to make…



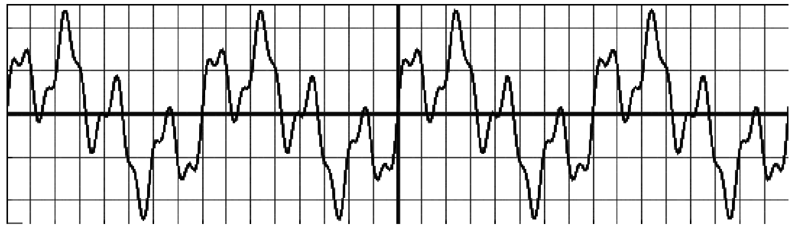
this one waveform →



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.

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.

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

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

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**** 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!)

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!

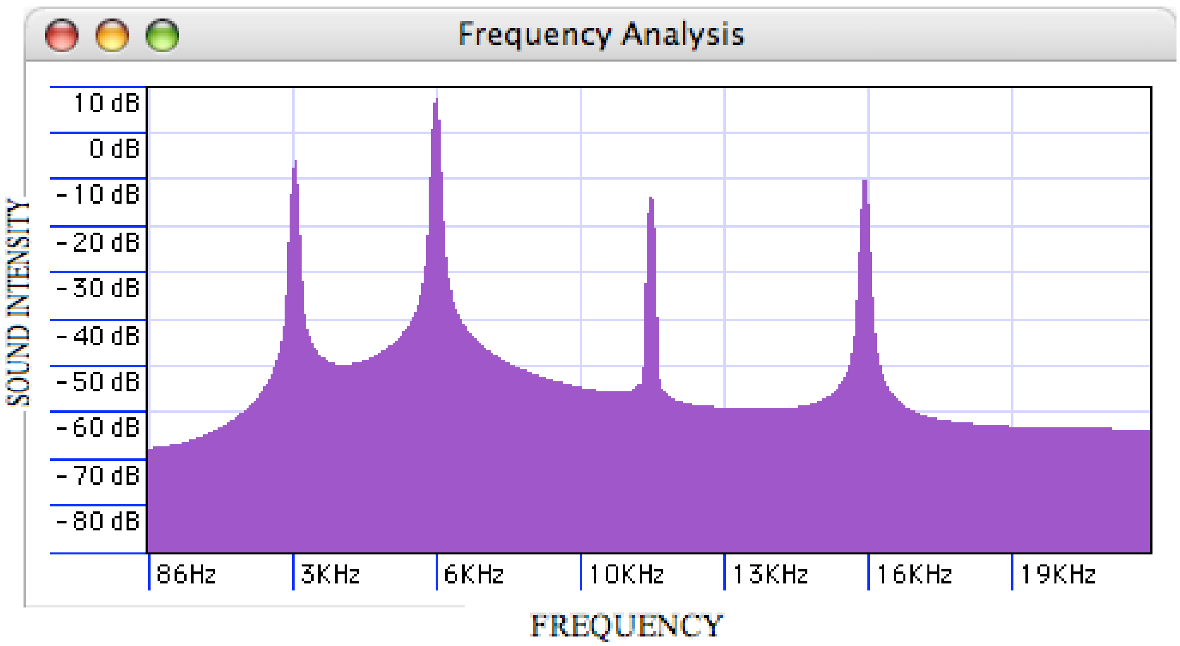
…In the next activity, your teacher will demonstrate a free software application called *Audacity* that does this exact same type of wave analysis.

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

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

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

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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)

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