24C Sound as a Wave

How can we observe sound as a wave? How can we use the speed of sound and certain frequencies to build a basic instrument based on wavelength?

Waves are a traveling form of energy because they can cause changes in the objects they encounter. Sound waves carry energy that causes human eardrums to vibrate, which the brain interprets as sound. Because it is a wave, sound has both frequency and wavelength. In this investigation, you will use a sound's frequency and its speed to calculate desired wavelengths and use your calculations to build a musical instrument.

Materials

- 10 ft. length 1/2 inch PVC pipe
- Metric ruler
- Pipe cutter (or a saw)
- Sandpaper
- Permanent marker
- Data Collector
- Temperature probe

1 Thinking about sound as a wave

You have learned several important properties of waves. Answer the questions below to review what you have learned.

a. What property of waves describes the distance from any point on a wave to the same point on the next cycle of the wave?

b. What property of waves describes how often something repeats, expressed in hertz?

c. How are the frequency and wavelength of a wave related to its speed?

d. How is the wavelength of a sound wave related to the pitch it produces?

2 Making a prediction

You have been given a long length of pipe. In part three, you will cut two lengths of pipe, one twice as long as the other. You will then use the pipe to produce a sound by blowing over the top of the pipe with your hand covering the bottom, or by tapping the bottom of the pipe on the palm of your hand. Both methods produce a sound with the same pitch. The air inside the pipe vibrates to make the sound you hear when the pipe is played. You may have to practice to get a repeatable sound.

a. Make a prediction about how the sound produced by the two different lengths of pipe will compare. Describe the sound in terms of pitch.

b. Explain the reasoning behind your prediction.

3 Cutting two sections of pipe

1. A good rule to follow when cutting anything is “Measure twice, cut once”. From the end of the pipe measure a distance of 10.5 cm and use a pen or pencil to mark the distance with a small straight line. Depending on the cutting tool you have, follow your teacher’s directions on how to cut the pipe as close to 10.5 cm as possible.
2. Once it is cut, use some sandpaper to remove any rough edges from the cut end of the pipe. It does not need to be perfectly smooth, but there should be no sharp edges.
3. When your first pipe is cut and sanded, measure 21.0 cm from the cut end of the pipe and make a straight line mark. Double check your measurement and once again follow your teacher’s directions on how to cut the pipe.
4. Sand both ends of the 21.0 cm pipe.

4 Using sound as an observation

You are ready to use your pipes to make some sounds. Make some sounds with both pipes and listen to the pitch each one makes. After you have compared the sounds created by each, answer the questions below.

a. Which pipe had a higher pitch, the short pipe or the long pipe?

b. Was your prediction about the pitch produced by two different lengths of pipe correct?

c. How does the pitch relate to the frequency of the sound created by both pipes?

d. How does the pitch relate to the wavelength of the sound created by both pipes?

e. How would the pitch of a pipe longer than 10.5 cm and shorter than 21.0 cm compare to these two pipes?

f. If you were to cut increasingly longer pipes, how would the sound produced by each longer pipe be different from the previous shorter length? Describe the change in terms of frequency and wavelength.

5 Wavelengths based on the speed of sound and frequency

The two pieces of pipe you cut have different pitches. Each different pitch is called a note. Certain notes sound pleasant to the human ear, and notes that sound pleasant can be arranged together to create a musical scale. By using what you know about the relationship between the speed of sound, frequency, and wavelength, calculate the wavelength of the sound wave that will make each note in a series of musical scales. The first task is to calculate the speed of sound in your classroom. The speed of sound depends mainly on the temperature of the air in your classroom. Use the formula to calculate the speed of sound in air for your classroom based on the temperature in degrees Celsius.

$$\text{Speed of sound} = 331\,\text{m/s} + (0.6\,\text{m/s/°C} \times \text{°C})$$

Speed of sound m/s	=	331 m/s	+(0.6 m/s/°C	x	°C in classroom)
	=	331 m/s	+(0.6m/s/°C	x	°C)

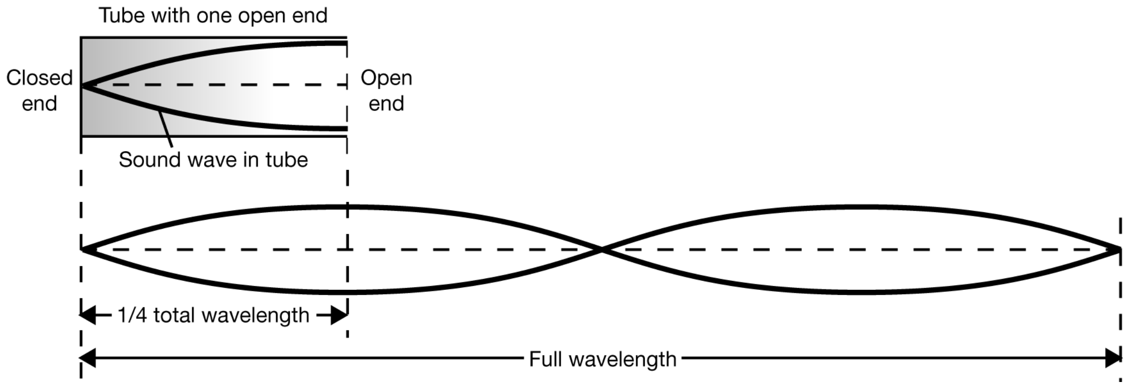
Each note in all musical scales corresponds to a particular frequency. These notes and their frequencies have been musically established for thousands of years. Once you have calculated the speed of sound in your classroom, you can begin to calculate the wavelength of the sound waves needed to create the frequencies that make the musical scales we will use. Fill in your speed of sound on Table 1, and use the frequencies provided to calculate the wavelengths.

Table 1: Calculating wavelengths needed based on speed of sound and frequency

Speed of sound (m/s)	÷	Frequency (Hz)	=	Wavelength (m)
	÷	349	=	
	÷	392	=	
	÷	440	=	
	÷	466	=	
	÷	523	=	
	÷	587	=	
	÷	659	=	
	÷	698	=	
	÷	784	=	
	÷	880	=	
	÷	892	=	
	÷	1049	=	
	÷	1174	=	
	÷	1318	=	
	÷	1397	=	

6 Creating sound from a pipe with one closed end and one open end

The two pipes you've made have one closed end and one open end when they make sound. The air inside the pipe vibrates to make the note you hear when the pipe is played. Air in a tube like this vibrates in a specific way. The vibrations of the sound wave resonate in the pipe, amplifying their perceived volume. The length of the sound wave created by each pipe is actually 4 times the length of the pipe, as shown in the diagram below.



a. How would you calculate the length of pipe needed that would create a note of a specific frequency based on your calculated wavelengths from the previous section?

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b. If the temperature in your room went up by 10 °C, how would that change the length of pipe you need to cut to make a note of 440 Hz compared to the current temperature of your classroom?

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7 Cutting the remaining pipe

Fill in the wavelengths of sound you calculated from Table 2 to make the frequencies needed at your classroom's temperature. The frequencies are now also labeled with the notes they make in the musical scale. Use your answer from question a. above to calculate the length of pipe needed to make each note in the scale. Once you have calculated the length of pipe needed in meters, convert your calculation to cm and fill in the last column of Table 3. Your teacher will assign some notes to your group and you will cut those specific lengths of pipe. Use the length of pipe calculations in cm to measure and cut the lengths of pipe assigned to your group. You may be able to use the two pipes you made earlier. They may need to be trimmed to fit the particular lengths you need. Follow the instructions of your teacher to cut the pipe. Use a permanent marker to label each pipe with the corresponding note it creates.

Table 2: Calculating the length of pipe for the required frequencies

Note in scale	Frequency (Hz)	Wavelength of note (m)	Length of pipe (m)	Length of pipe (cm)
F	349			
G	392			
A	440			
BFlat	466			
C	523			
D	587			
E	659			
F	698			
G	784			
A	880			
BFlat	892			
C	1049			
D	1174			
E	1318			
F	1397			

8 Playing some music

Your teacher will have some scripted music that you can play. Look through the song to see what notes will be played. That way you can collect all the pipes you will need during the song and have them ready to go. With members each playing one or two pipes, your group should be able to cover all the notes in a song. Melody and harmony are different parts of the song that work together to make the song more interesting to listen to. Get your pipes ready and follow the beat of the conductor. Good Luck.

9 Challenge

a. There are some notes on the scale that have the same name but different frequencies. What is the relationship between these notes in terms of their frequencies and their wavelengths?

b. What do we call the group of 8 notes that are arranged in increasing or decreasing pitch, starting with one note and ending with the note of the same name but different frequency? (For example, from F 349 to F 698).

c. How does the concept of different lengths of pipe creating different notes relate to musical instruments, like the trombone?

d. What is the difference between how air in a tube with one open end vibrates and how a plucked string vibrates?

e. **EXTRA CHALLENGE:** The diagram in part 6 shows a sound wave with a node at one end and an antinode at the other end resonating in the tube. This represents the 1st harmonic of the air column in the tube. The column of air vibrates at several harmonics at once, but the 1st one is the one that creates the most sound you hear. Each harmonic has a node at one end and an antinode at the other due to one end being open and one end being closed. What would the next harmonic wave look like, what harmonic would it be, and what would its wavelength be in reference to the length of the tube?