Chapter 05: Wave Motion and Sound *Physical Science*, Tillery, 13th ed.

Lab 07: Speed of Sound DUE: 14 Mar 2024

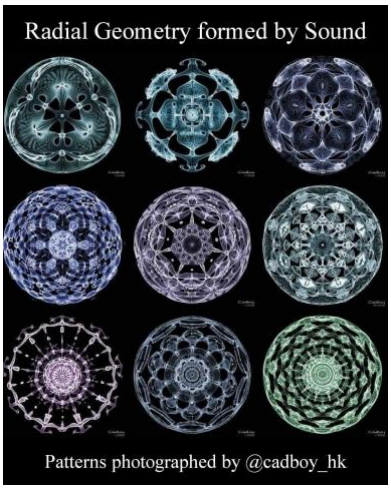
Introduction

How can you see a sound wave? You can't see the air molecules vibrating as you listen to some music. But what if you could take that same sound wave and use it to vibrate a medium that you can see? Spoiler alert: It's been done. And it's beautiful.

Here's a quick 6-minute video that shows you what happens when a musician applies some science to his art. (Hint: Google 'cymatics.')

The sim that we will work on here is, of necessity, much simpler. But the beauty of the complex cymatic patterns means that our simple experiment is realistic. We will measure the speed of sound by vibrating simulated air molecules that we can see, which enables us to measure the wavelength and frequency fairly easily. Once we have those values, calculating the speed is a cinch!

We will be using another PhET simulation (like we did for the Specific Heat lab).



Objectives

- Simulate a single-frequency sound wave propagating through the air
- Measure the wavelengths of sound waves having different frequencies
- Develop a technique to measure the frequencies of the sound waves
- Determine the speed of the sound waves
- Apply the temperature dependence to predict the speed of sound through air at room temperature
- Calculate the average wave speed, and compare it to the known speed of sound through air

Equipment

- Internet-connected device capable of running a browser
- Paper and pen or pencil (you're always going to need these)
- Scientific Calculator

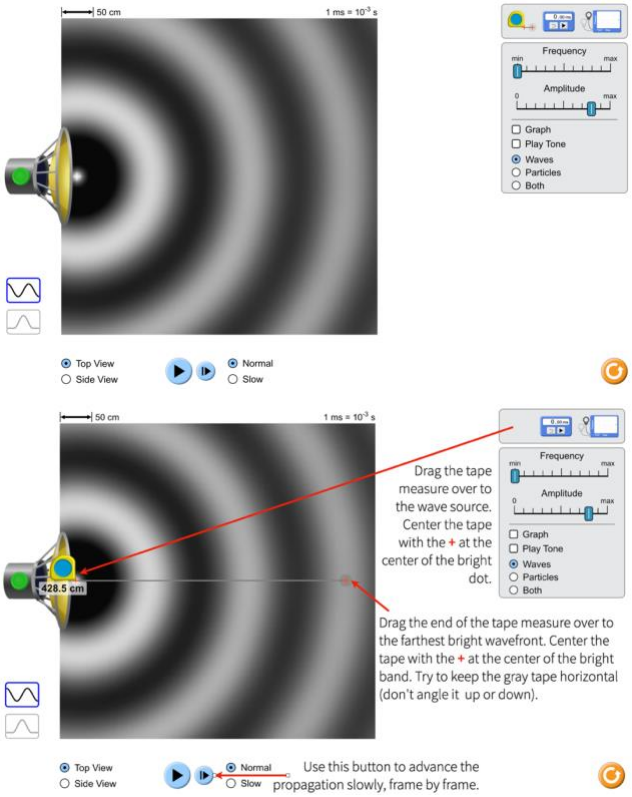
Procedure

1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the simulation at the same time.
2. Do you have paper and pencil handy? Don't forget your calculator.
3. In a browser window, navigate to the PhET Waves Intro simulation. Notice that we are using a different sim site this week, so it operates a little differently! Don't try to start doing the lab yet! Just verify that when you click SOUND the simulation opens properly.
4. Play around with the controls. Notice that the green button on the speaker powers the wave on/off. The blue PLAY button starts/stops the wave propagation. You can adjust the frequency and amplitude by using the sliders, and we have a measuring tape tool and a pressure meter that we will use to measure the wavelength and frequency, respectively.

Measuring the Wavelength

Notice that the frequency slider is in the minimum position in my example above. Adjust your frequency to match. The wavelength will also be easiest to measure if the wave amplitude is close to or at maximum. Adjusting the amplitude does not affect either our wavelength or frequency measurements!

To make the first measurement, click the green button to turn the speaker on, and hit the PLAY button. Let the wave propagate across the screen. When you have a small bright dot at the source (like above), stop the propagation to fix the pattern on the screen. Position the tape measure as shown on the left.



How many wavelengths does this measure? One wavelength is maximum to maximum, or center-to-center of the bright bands. The tape here measures exactly three wavelengths, so the measurement $x_1 = 3\lambda_1$.

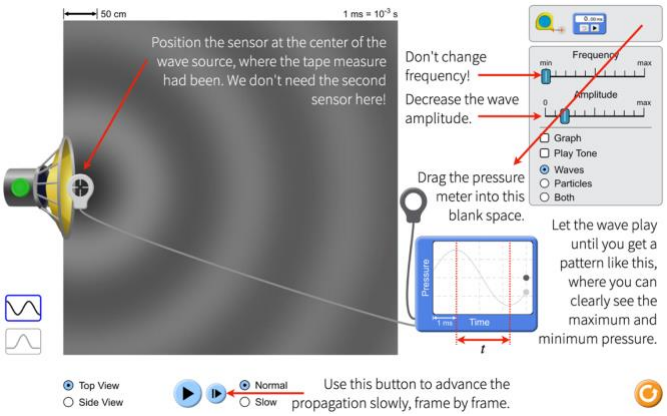
1. The tape measure reads $x_1 = 422.4\text{cm}$, or $x_1 = 4.224\text{m}$. If $x_1 = 3\lambda_1$, what is the wavelength λ_1 of this sound wave?
   A) $\lambda_1 = \frac{x_1}{3} = 1.408\text{m}$ B) $\lambda_1 = 3x_1 = 12.75\text{m}$

Measuring the Frequency

To measure the frequency, stop the sim and drag the tape measure back to the toolbar. At this point, it's helpful to re-start the propagation and stop it when you have the small bright dot at the wave source again (see above).

Now drag the pressure meter off the toolbar, and position one of the pressure sensors right at the center of the bright dot (just like you positioned the tape measure in the last step). Before you try to measure anything, decrease the wave amplitude. You need a smaller amplitude to fit on the screen of the meter!

Click the green button to turn the speaker on and hit the PLAY button. When you get a good pattern on the screen, stop the propagation. A 'good pattern' will be like the one shown, where you can see the maximum and the minimum pressure.



Notice that the pressure graph looks exactly like a wave. That's not a coincidence! Sound waves are pressure waves, and you are seeing the pressure change as the air molecules oscillate. The time marked off on the screen, from maximum to minimum, is exactly one-half of a full oscillation, so the oscillation period $T_1 = 2t_1$.

2. It's hard to read on the small figure above, but very clear on the bigger screen when running the sim. In this example, the time scale is in milliseconds and $t_1 = 2.25\text{ms}$. This is $t_1 = 0.00225\text{s}$. If $T_1 = 2t_1$, what is the period T_1 of this sound wave?
   A) $T_1 = 0.001125\text{s}$ B) $T_1 = 0.0045\text{s}$
3. The frequency of the sound wave is the inverse of the period: $f_1 = \frac{1}{T_1}$. Calculate the frequency of this sound wave.
   A) $f_1 = 222\text{Hz}$ B) $f_1 = 889\text{Hz}$
4. Calculate the speed of the sound wave using $v_1 = \lambda_1 f_1$.
   A) $v_1 = (1.408\text{m})(222\text{Hz}) = 313\frac{\text{m}}{\text{s}}$ C) $v_1 = (12.75\text{m})(222\text{Hz}) = 2{,}830\frac{\text{m}}{\text{s}}$
   B) $v_1 = (1.408\text{m})(889\text{Hz}) = 1{,}250\frac{\text{m}}{\text{s}}$ D) $v_1 = (12.75\text{m})(889\text{Hz}) = 11{,}300\frac{\text{m}}{\text{s}}$

Change the Frequency and Measure Again

Return to your browser window and adjust the frequency slider from the minimum setting to the midpoint setting, exactly halfway between minimum and maximum. Adjust carefully because the slider is continuous (it won't 'click' into place on a tick mark). Use the same method you just used above to measure the wavelength of this new wave. Remember that it's easier to do this part with the wave amplitude at maximum.

5. Use the tape measure to mark out four wavelengths, $x_2 = 4\lambda_2$. Record the value of x_2 on the tape measure.
   A) $x_2 = 242.4\text{cm} = 2.424\text{m}$ C) $x_2 = 348.3\text{cm} = 3.483\text{m}$
   B) $x_2 = 292.5\text{cm} = 2.925\text{m}$ D) $x_2 = 382.6\text{cm} = 3.826\text{m}$
6. If $x_2 = 4\lambda_2$, what is the wavelength λ_2 of this sound wave?
   A) $\lambda_2 = 0.606\text{m}$ C) $\lambda_2 = 0.956\text{m}$ E) $\lambda_2 = 9.696\text{m}$ G) $\lambda_2 = 13.93\text{m}$
   B) $\lambda_2 = 0.731\text{m}$ D) $\lambda_2 = 1.008\text{m}$ F) $\lambda_2 = 11.70\text{m}$ H) $\lambda_2 = 15.30\text{m}$

Now find the frequency of the wave. Use the method above, replacing the tape measure with the pressure meter and aligning one probe with the wave source. Like before, adjust the amplitude so that both the maximum and minimum pressure values appear on the meter screen.

For this frequency, you can see an entire cycle (maximum-to-maximum or minimum-to-minimum) on the screen. Remember that you can adjust the propagation frame-by-frame to line up a max or a min with the gridlines for the time scale! For this wave, you can measure the period directly: $t_2 = T_2$, where t_2 is the max-to-max or min-to-min time interval.

7. What is the period T_2 of this wave?
   A) $T_2 = 1.0\text{ms} = 0.001\text{s}$ C) $T_2 = 3.0\text{ms} = 0.003\text{s}$ E) $T_2 = 5.0\text{ms} = 0.005\text{s}$
   B) $T_2 = 2.0\text{ms} = 0.002\text{s}$ D) $T_2 = 4.0\text{ms} = 0.004\text{s}$ F) $T_2 = 6.0\text{ms} = 0.006\text{s}$
8. Calculate the frequency $f_2 = \frac{1}{T_2}$ of the second wave.
   A) $f_2 = 167\text{Hz}$ C) $f_2 = 250\text{Hz}$ E) $f_2 = 500\text{Hz}$
   B) $f_2 = 200\text{Hz}$ D) $f_2 = 333\text{Hz}$ F) $f_2 = 1000\text{Hz}$
9. Now calculate the speed of the sound wave using $v_2 = \lambda_2 f_2$.
   A) $v_2 = 290\frac{\text{m}}{\text{s}}$ B) $v_2 = 319\frac{\text{m}}{\text{s}}$ C) $v_2 = 504\frac{\text{m}}{\text{s}}$ D) $v_2 = 4{,}848\frac{\text{m}}{\text{s}}$

Change the Frequency and Measure Again, Again!

Return to your browser window and adjust the frequency slider from the midpoint setting to the maximum setting, all the way to the right. Use the same method you just used above to measure the wavelength of this new wave. Remember that it's easier to do this part with the wave amplitude at maximum.

10. Use the tape measure to mark out six wavelengths, $x_3 = 6\lambda_3$. Record the value of x_3 on the tape measure.
    A) $x_3 = 445.0\text{cm} = 4.45\text{m}$
    B) $x_3 = 367.7\text{cm} = 3.677\text{m}$
    C) $x_3 = 288.4\text{cm} = 2.844\text{m}$
    D) $x_3 = 212.5\text{cm} = 2.125\text{m}$
11. If $x_3 = 6\lambda_3$, what is the wavelengthλ_3 of this sound wave?
    A) $\lambda_3 = 2.225\text{m}$
    B) $\lambda_3 = 1.483\text{m}$
    C) $\lambda_3 = 1.112\text{m}$
    D) $\lambda_3 = 0.890\text{m}$
    E) $\lambda_3 = 0.742\text{m}$
    F) $\lambda_3 = 0.636\text{m}$
    G) $\lambda_3 = 0.556\text{m}$
    H) $\lambda_3 = 0.494\text{m}$

Now find the frequency of the wave. Use the method above, replacing the tape measure with the pressure meter and aligning one probe with the wave source. Like before, adjust the amplitude so that both the maximum and minimum pressure values appear on the meter screen.

For this frequency, you can see an entire cycle (maximum-to-maximum or minimum-to-minimum) on the screen. Remember that you can adjust the propagation frame-by-frame to line up a max or a min with the gridlines for the time scale! For this wave, you can measure the period directly: $t_3 = T_3$, where t_3 is the max-to-max or min-to-min time interval.

12. What is the period T_3 of this wave?
    A) $T_3 = 1.50\text{ms} = 0.00150\text{s}$
    B) $T_3 = 1.75\text{ms} = 0.00175\text{s}$
    C) $T_3 = 2.0\text{ms} = 0.002\text{s}$
    D) $T_3 = 2.25\text{ms} = 0.00225\text{s}$
    E) $T_3 = 2.5\text{ms} = 0.0025\text{s}$
    F) $T_3 = 2.75\text{ms} = 0.00275\text{s}$
13. Calculate the frequency $f_3 = \frac{1}{T_3}$ of the third wave.
    A) $f_3 = 364\text{Hz}$
    B) $f_3 = 400\text{Hz}$
    C) $f_3 = 444\text{Hz}$
    D) $f_3 = 500\text{Hz}$
    E) $f_3 = 571\text{Hz}$
    F) $f_3 = 667\text{Hz}$
14. Now calculate the speed of the sound wave using $v_3 = \lambda_3 f_3$.
    A) $v_3 = 290\frac{\text{m}}{\text{s}}$
    B) $v_3 = 317\frac{\text{m}}{\text{s}}$
    C) $v_3 = 329\frac{\text{m}}{\text{s}}$
    D) $v_3 = 336\frac{\text{m}}{\text{s}}$

Predict and Compare

Now let's calculate a prediction for what we think the speed of sound should be. The speed depends on the temperature:

$$v = 331\frac{\text{m}}{\text{s}} + 0.6T$$

where T in this equation is the temperature in $°C$. Assume that room temperature is $T = 20°\text{C}$.

15. Calculate the predicted value for the speed of sound, v.
    A) $v = 319\frac{\text{m}}{\text{s}}$
    B) $v = 331\frac{\text{m}}{\text{s}}$
    C) $v = 337\frac{\text{m}}{\text{s}}$
    D) $v = 343\frac{\text{m}}{\text{s}}$

Use your three experimental values v_1, v_2, and v_3 to calculate the average wave speed, v_{avg}:

$$v_{avg} = \frac{v_1 + v_2 + v_3}{3}$$

16. What is your calculated average speed, v_{avg}?
    A) $v_{avg} = 320\frac{\text{m}}{\text{s}}$
    B) $v_{avg} = 328\frac{\text{m}}{\text{s}}$
    C) $v_{avg} = 336\frac{\text{m}}{\text{s}}$
    D) $v_{avg} = 343\frac{\text{m}}{\text{s}}$

How accurate is your experimental result? To find out, let's calculate a percent error, which compares our experimental value to our prediction. The smaller the percent error, the better our results!

$$\%error = \left[\frac{v - v_{avg}}{v}\right] \times 100$$

where v is the predicted value from Question 15, and v_{avg} is the experimental average from Question 16.

17. What is the percent error in your average value?
    A) $\%error = 2.7\%$
    B) $\%error = 4.7\%$
    C) $\%error = 6.7\%$
    D) $\%error = 8.7\%$
    E) $\%error = 10.7\%$
    F) $\%error = 12.7\%$
18. A percent error below 5% would be a good experimental result. Are your results within this limit?