

Open the simulation at **activities.zornscience.org/standing-waves-lab/**. A vibrator shakes one end of a string, the string runs over a pulley, and a hanging mass pulls it tight. **Cover or ignore the Wave Speed and Fundamental readouts until Part D.** Your job is to find those values yourself.

Goals. By the end of this lab, I can (1) describe a standing wave as the interference of incident and reflected waves and identify its nodes and antinodes, (2) measure frequency and wavelength and use $v = f\lambda$ to find wave speed, and (3) use data to show that wave speed depends on the medium (tension and string density), not on the frequency or the length of the string.

Key equations. $v = f\lambda$ | $\lambda = 2\Delta x$ (Δx = distance between adjacent nodes) | $T = mg$ | $v = \sqrt{T/\mu}$
% difference = $| \text{measured} - \text{predicted} | / \text{predicted} \times 100$

NGSS alignment. HS-PS4-1 (use mathematical representations to support claims about frequency, wavelength and wave speed in different media). Practices: analyzing and interpreting data; using mathematics and computational thinking.

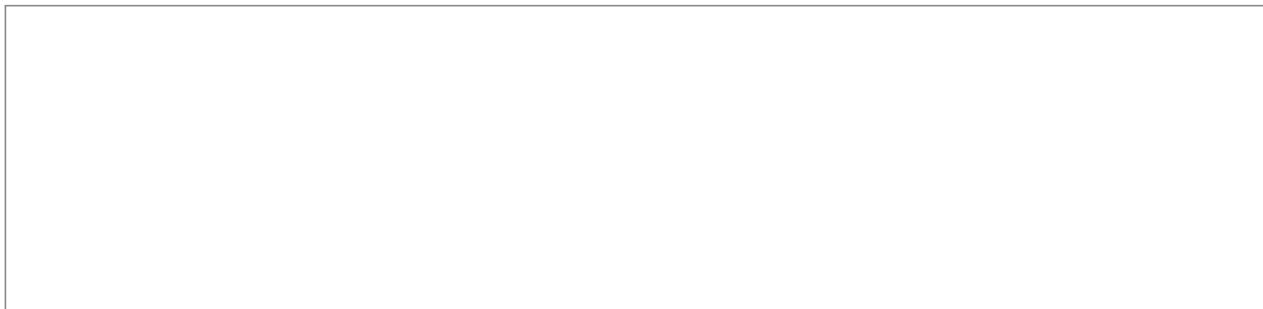
1. **Predict.** A wave travels along one string. If you double its frequency, what do you think happens to its wavelength? What happens to its speed?

Part A. What Is a Standing Wave?

Use the starting settings: hanging mass 200 g, vibrating length 1.20 m, medium cord (2.0 g/m). Press **Start oscillator**.

2. The generator starts at 30.0 Hz. Describe the motion of the string. Is there a clear, steady pattern?
3. Slowly lower the frequency slider (do not use the harmonic buttons yet) until the string forms one large, steady loop. Record the frequency. This is the fundamental frequency, f_1 . $f_1 =$ _____ Hz
4. Turn on **Strobe lock** and **Show nodes & antinodes**, then tune to 26.1 Hz. In your own words, what is a node? What is an antinode?
5. A standing wave does not travel down the string. Explain how two traveling waves produce it. Use the words *reflect* and *interfere*.

6. Tune to the third harmonic (three loops). Sketch the string in the box below. Label every node (N) and antinode (A), and bracket one full wavelength.



Part B. Frequency and Wavelength

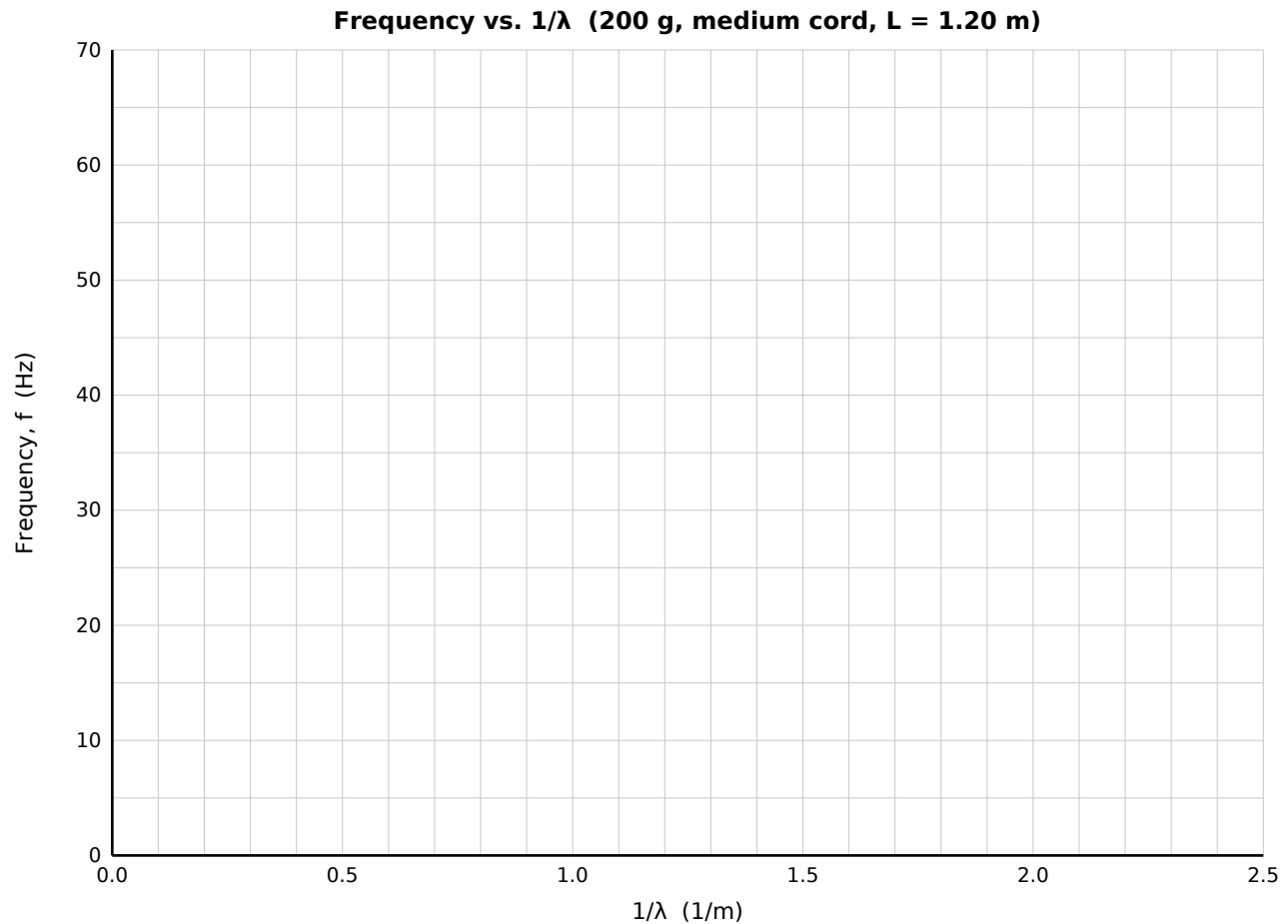
Keep 200 g, 1.20 m and the medium cord. Find the first five harmonics by tuning the frequency slider until the nodes appear (the harmonic buttons can confirm). For each one, place Cursor A and Cursor B on two **adjacent** nodes and record the cursor separation Δx . For harmonic 1, the only nodes are the two ends, so $\Delta x = 1.20$ m. Then calculate λ , $1/\lambda$ and v .

Harmonic n	Loops	Frequency f (Hz)	Δx node to node (m)	$\lambda = 2\Delta x$ (m)	$1/\lambda$ (1/m)	$v = f\lambda$ (m/s)
1			1.20			
2						
3						
4						
5						

7. Show a sample calculation of v for harmonic 3. Include units.

8. As the harmonic number increases, what happens to the frequency? To the wavelength? What stays about the same?

9. Plot f (y-axis) against $1/\lambda$ (x-axis). Draw a best-fit line through the origin and find its slope with units. Since $v = f\lambda$, we can write $f = v(1/\lambda)$. What does the slope of this graph represent?



Part C. Changing the Medium

Now you will change the string itself. Use the **second harmonic** (two loops) for every trial. With $L = 1.20$ m the second harmonic always has $\lambda = 1.20$ m. Check this with the cursors once.

10. **Predict.** If you hang more mass on the string (more tension), will the second-harmonic frequency go up, go down or stay the same? Explain your thinking.

For each trial, set the mass, cord and length, tune to the second harmonic, and record f_2 . Calculate $T = mg$ (use $g = 9.81 \text{ m/s}^2$ and mass in kg) and $v = f\lambda$.

Trial	Hanging mass (g)	Cord (g/m)	L (m)	$T = mg$ (N)	f_2 (Hz)	λ (m)	$v = f\lambda$ (m/s)
1	50	2.0	1.20			1.20	
2	100	2.0	1.20			1.20	
3	200	2.0	1.20			1.20	
4	400	2.0	1.20			1.20	
5	200	1.0	1.20			1.20	
6	200	4.0	1.20			1.20	
7	200	2.0	0.80				

11. Compare trials 2 and 4. The hanging mass (and tension) was multiplied by 4. By what factor did the wave speed change? What does this suggest about how v depends on T ?

12. Compare trials 3, 5 and 6. How does a heavier (denser) cord change the wave speed?

13. Compare trials 3 and 7. Changing the length changed the frequency. Did it change the wave speed? Explain why or why not.

Part D. Check the Model

- 14.** For the Part B string (200 g, medium cord), calculate the predicted wave speed using $v = \sqrt{T/\mu}$. Convert the cord density to kg/m first (1 g/m = 0.001 kg/m). Then find the percent difference between this prediction and your graph slope from question 9.
- 15.** Now uncover the Wave Speed readout in the simulation. Does it agree with your results? In a real lab with a real string, name two sources of error that could make measured and predicted speeds disagree.

Conclusion

- 16. Claim, evidence, reasoning.** What determines the speed of a wave on a string, and what does not? Support your claim with specific data from Parts B and C, and explain your reasoning using $v = f\lambda$.
- 17.** A guitarist turns a tuning peg to tighten a string, and the note gets higher. The thickest strings play the lowest notes. Use your results to explain both observations. (The length of each vibrating string stays the same.)