

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?

Prediction answers vary. (The lab shows the wavelength is cut in half and the speed stays the same.)

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?
The string wiggles with small, messy motion. There is no clear loop pattern and no points that stay still, because 30.0 Hz is not a resonance.
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
 $f_1 \approx 13.0$ to 13.1 Hz (model value 13.05 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?
A node is a point on the string that stays still (zero displacement). An antinode is a point halfway between nodes that has the largest motion.
5. A standing wave does not travel down the string. Explain how two traveling waves produce it. Use the words *reflect* and *interfere*.
Waves from the vibrator travel down the string and reflect off the pulley end. The incident and reflected waves travel in opposite directions and interfere. Where they always cancel (destructive interference) you get nodes; where they add (constructive interference) you get antinodes. At a resonant frequency the pattern stays in place.

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.

4 nodes (both ends, 40 cm, 80 cm) and 3 antinodes (20, 60, 100 cm). One wavelength spans two loops, for example 0 to 80 cm, so $\lambda = 0.80$ m.

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	13.1	1.20	2.40	0.417	31.4
2	2	26.1	0.600	1.20	0.833	31.3
3	3	39.2	0.400	0.800	1.25	31.4
4	4	52.2	0.300	0.600	1.67	31.3
5	5	65.3	0.240	0.480	2.08	31.3

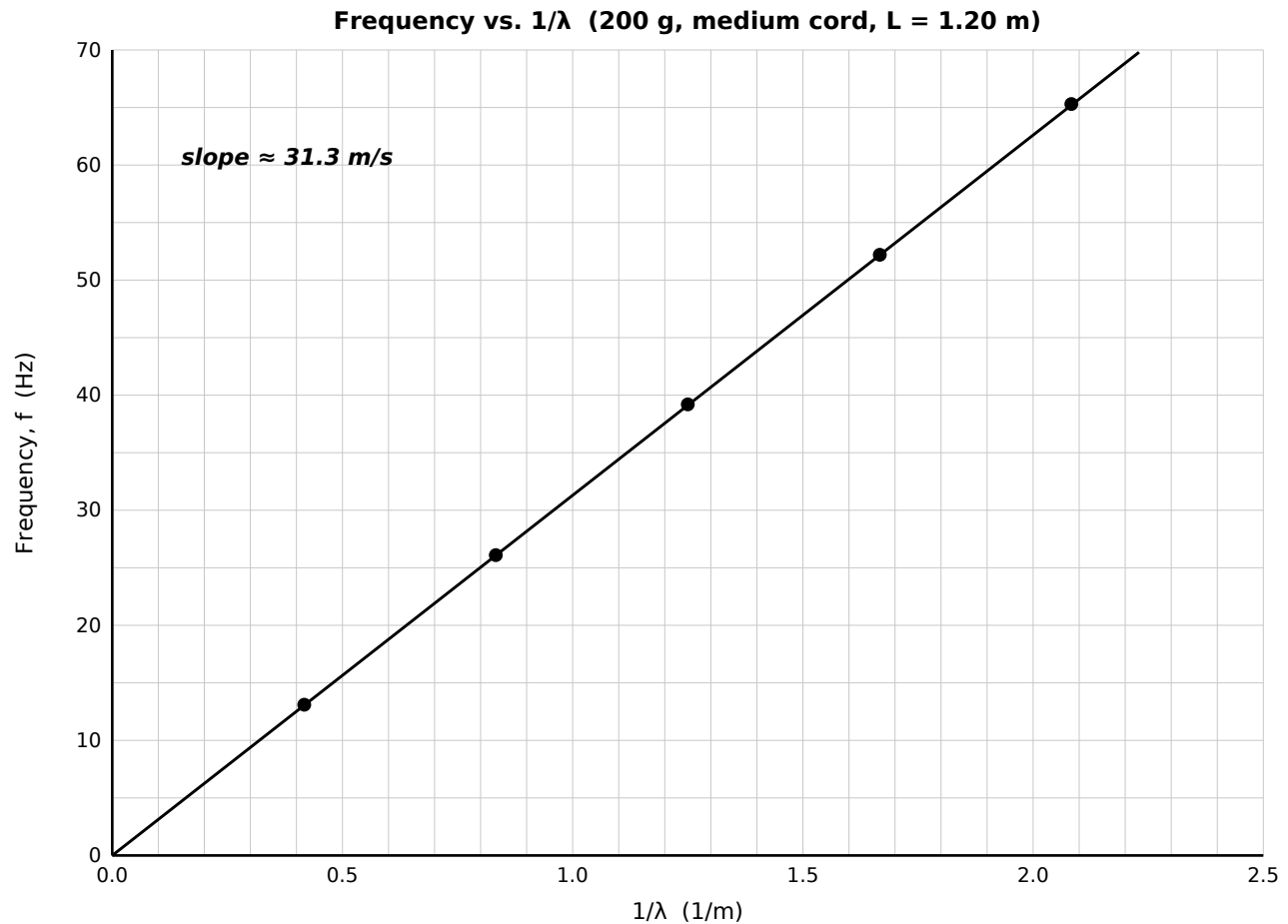
7. Show a sample calculation of v for harmonic 3. Include units.

$$v = f\lambda = (39.2 \text{ Hz})(0.800 \text{ m}) = 31.4 \text{ m/s}$$

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

Frequency increases ($f_n = n f_1$) and wavelength decreases ($\lambda = 2L/n$), so f and λ are inversely related. The wave speed stays about the same, about 31.3 m/s, because the string (the medium) did not change.

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?



Points fall on a straight line through the origin. Slope ≈ 31.3 m/s (accept about 31 to 32 m/s). The slope is the wave speed, v .

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.

Predictions vary. (Data show the frequency goes up, because a tighter string carries waves faster.)

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	0.491	13.1	1.20	15.7
2	100	2.0	1.20	0.981	18.5	1.20	22.2
3	200	2.0	1.20	1.96	26.1	1.20	31.3
4	400	2.0	1.20	3.92	36.9	1.20	44.3
5	200	1.0	1.20	1.96	36.9	1.20	44.3
6	200	4.0	1.20	1.96	18.5	1.20	22.2
7	200	2.0	0.80	1.96	39.2	0.800	31.4

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 ?
 v went from 22.2 to 44.3 m/s, about 2 times. Multiplying T by 4 doubles v , so v depends on the square root of T ($v \propto \sqrt{T}$).
12. Compare trials 3, 5 and 6. How does a heavier (denser) cord change the wave speed?
A heavier cord slows the wave. Light cord (1.0 g/m): 44.3 m/s. Medium (2.0 g/m): 31.3 m/s. Heavy (4.0 g/m): 22.2 m/s. Multiplying the density by 4 cuts the speed in half ($v \propto 1/\sqrt{\mu}$).
13. Compare trials 3 and 7. Changing the length changed the frequency. Did it change the wave speed? Explain why or why not.
No. v stayed about 31.3 m/s. A shorter string gives a shorter wavelength (0.800 m instead of 1.20 m), so the resonance frequency goes up, but the product $f\lambda$ is the same because the tension and cord did not change.

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.
 $T = (0.200 \text{ kg})(9.81 \text{ m/s}^2) = 1.96 \text{ N}$; $\mu = 0.0020 \text{ kg/m}$. $v = \sqrt{(1.96 / 0.0020)} = 31.3 \text{ m/s}$. Percent difference = $|31.3 - 31.3| / 31.3 \times 100 \approx 0\%$ (anything under about 1% is excellent).
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.
Yes, the readout shows 31.32 m/s. Real-lab errors: judging exactly when the string is at resonance, locating nodes with a meter stick, the string stretching (changing μ), friction in the pulley, a vibrator end that is not a perfect node, and the mass value or g being slightly off.

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 $v = f\lambda$.
Claim: wave speed depends on the medium (the tension and the cord density), not on frequency or length. Evidence: in Part B the frequency changed from 13.1 to 65.3 Hz but v stayed about 31.3 m/s; in Part C, 4 times the tension doubled v (22.2 to 44.3 m/s) and 4 times the density halved v (44.3 to 22.2 m/s); changing L from 1.20 to 0.80 m left v at 31.3 m/s. Reasoning: the medium sets v . When the frequency changes on the same string, the wavelength adjusts so $f\lambda$ stays equal to v .

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.)

With the same length, the wavelength of each harmonic is fixed ($\lambda = 2L/n$), so $f = v/\lambda$ rises and falls with v . Tightening raises the tension, which increases v , so the frequency (pitch) goes up. Thick strings have a larger mass per length, so v is smaller and the frequency is lower.