

Part I: Boundary Conditions

For this activity, open the PhET Interactive Simulation called Wave on a String.

<http://phet.colorado.edu/en/simulation/wave-on-a-string>

If you already have this simulation open from the earlier activities, please close the window and re-open it to reset everything.

1. Move the “Damping” slider over to “None”, choose “Pulse” in the top left corner, and set the “Pulse Width” slider to “0.35 s”. Click the green pulse button (just about where it reads “Amplitude”) once to create a single wave pulse. What happens when the wave pulse reflects off of a fixed boundary?
2. Click “Restart”. Change the boundary to “Loose End.” Follow the same procedure as above to create a single wave pulse. What happens when the wave pulse reflects off of a loose end?
3. Complete the following sentences: When the wave pulse arrives at a fixed boundary, the string exerts a(n) _____ (upward/downward) force on the boundary surface. By Newton’s _____ Law, the boundary surface exerts a(n) _____ (upward/downward) force on the string. Therefore reflections on fixed boundaries _____ (are/are not) inverted. If we were to create a standing wave on the string, the boundary would be a location of a _____ (node/antinode).

Part II: Standing Waves, One Fixed End

4. Click “Restart”, click the blue “Pause” button, and change the boundary to “Fixed End.” Change the mode in the upper left to “Oscillate.” Make sure your settings all still read Amplitude = 0.75 cm, Frequency = 1.50 Hz, Damping = None, Tension = High. Click the blue “Play” button and observe the motion for a few minutes. Describe the motion. Is it a traveling wave, a standing wave, or something else?

The oscillator is creating a rightward-traveling wave. When that wave reaches the fixed right end, it is reflected and creates a left-going wave. That wave also reflects off of the oscillator at the left end. We have many overlapping traveling waves, which interfere with one another. We can use this knowledge to make a standing wave.

5. Click the blue “Pause” button and the “Restart” button. Now set the boundary to “Loose End” and the “Amplitude” to 0.02 cm (this will cause the oscillator end to be essentially a fixed end). Use the “Rulers” feature to determine the distance between our two boundaries. $L = \underline{\hspace{2cm}}$ cm. The simplest possible standing wave that we could make with this setup is one in which the fixed boundary (the oscillator) is a node, and the loose end is the adjacent anti-node. Draw a picture of this standing wave when the anti-node is at maximum displacement (either up or down).

6. What is the wavelength of the wave you just drew, in cm?

7. In a previous activity, you found that we could control the wave speed by changing the tension. The tension setting is currently on “High”. Looking back at the previous activity, what is the wave speed at this setting?

8. What frequency should you choose to produce your desired wavelength at this speed?

9. Try it out. What do you observe?

10. Okay, it’s a standing wave, but it’s pretty boring. The next simplest possible standing wave that we could make would include *one* more node somewhere along the string, in addition to the node at the left end. Draw a picture of this standing wave when the anti-nodes are at maximum displacement.

11. What is the wavelength of this new wave, in cm? What frequency should produce this wave?

12. Try it out. (Be sure to click “Restart” first to clear the previous wave.) What do you observe?

13. The next wave would include two nodes along the string. Use the same procedure as above to create this wave.

14. Let's number the three waves you just created $n = 1, 3,$ and 5 for their level of complexity. Since the values are integers, the variable n is called the *harmonic number*. Complete the following sentences: To create a standing wave with one fixed end and one free end, the wavelength must be

$\lambda = \underline{\hspace{2cm}}$ (an equation in terms of n, L)
and the frequency must be

$f = \underline{\hspace{2cm}}$ (an equation in terms of $n, L,$ and v^{wave}).

An $n = 1$ corresponds to the “fundamental mode” or “first harmonic” of the string.

Part III: Standing Waves, Two Fixed ends

You just worked with standing waves with one fixed boundary and one free boundary. This is the type of sound wave made by some wind instruments, such as a clarinet. Another option is to have two free ends; a flute is an example of such an instrument. The third option is to have two fixed boundaries. This is what you'd create with some musical instruments, such as a stretched violin, piano, or guitar string, or the stretched membrane of kettledrums (timpani).

In the case of two fixed boundaries, you would have standing waves that look like the figure to the right. The equations that govern this case would be, for $n = 1, 2, 3 \dots$:

$$\lambda = \frac{2L}{n} \quad \text{and} \quad f = \frac{v^{wave}}{\lambda} = n \frac{v^{wave}}{2L}$$

15. Your instructor has provided equipment that can generate standing waves with two fixed ends. You may change the frequency of the oscillations. Devise a method to use the provided equipment to measure the wave speed of the string. Explain your method and your results here.

