# 3.3: Standing Waves on a String and in a Tube

## Tutorial 3.3: Standing waves

In simulation 2.1, Question 2.1.6 you created a standing wave from two identical waves moving in opposite directions. For standing waves on a string the ends are fixed and there are nodes at the ends of the string. This limits the wavelengths that are possible which in turn determines the frequencies (recall that $v = f\lambda$ and the speed is fixed by the mass, tension and length of the string). The lowest frequency is called the **fundamental** or first harmonic. Higher frequencies are all multiples of the the fundamental and are called **harmonics**. Sometimes the term **overtone** is used to indicate harmonics greater than the fundamental (this can be confusing because the second harmonic is the first overtone, etc.). Harmonics are always multiples of the fundamental frequency but the term overtone can be used for other frequencies which are not necessarily multiples of the fundamental. The various harmonics are also called the **normal modes** of the string, a subject we will come back to later.

Standing waves determine the notes a musical instrument, such as a guitar or piano can play. The available frequencies are determined by the length of the string and the speed of the wave on the string which in turn is determined by the tension and density (thickness) of the string.

Standing waves also occur for sound waves enclosed in tubes. It is these standing waves that determine the frequencies that a wind instrument can play. At the center of a tube open on both ends the air cannot easily move so the fundamental frequency has a displacement node at that point. Because the pressure fluctuates the most at that location there is a **pressure anti-node** there. At the open ends of the tube the air can move more freely so a **displacement anti-node** occurs which is also a pressure node (the moving air prevents much pressure change).

## Standing Waves on a String and Tube

### Questions:

**Exercise 3.3.1**

Play the standing wave simulation for the case of the fundamental. The length of the string is $3.14\text{ m}$. What is the wavelength of the fundamental?

**Exercise 3.3.2**

Describe the fundamental of the tube simulation (bottom). Where do the dots (representing air molecules) move the most? Where do they form a displacement node? Assuming the tube is the same length as the string, what is the fundamental wavelength of the tube open on both ends?

**Exercise 3.3.3**

Use the time in the simulations to find the period and calculate the frequency of the fundamental for both simulations. For a musical instrument this would be the frequency of the tone being sounded by the instrument when it plays its lowest note.

**Exercise 3.3.4**

What is the wave speed of each of the component waves making up the fundamental (the speed determined by $v = f\lambda$)?

**Exercise 3.3.5**

Now click the box for a tube closed at one end. What is the wavelength of the fundamental for a tube closed at one end? How is this different for the case of the tube opened at both ends?

## Exercise 3.3.6

Reset the simulation and look at the second harmonic for the string and tube open on both ends. What is the wavelength and frequency of the second harmonic/first overtone for the string and tube opened on both ends? What is the speed of the component waves?

## Exercise 3.3.7

Try the third and fourth harmonics for the string and tube opened on both ends. What are the wavelengths and frequencies of these waves? What are the speeds of the component waves?

## Exercise 3.3.8

The formula for the wavelength as a function of the length of the string or open tube is given by $\lambda = 2L/n$ where $n$ is a whole number and $L$ is the length of the string. Verify this relationship with the numbers you got in the previous questions.

## Exercise 3.3.9

Now check the box for a pipe with closed end simulation and examine the harmonics. Describe the difference in the node and anti-node pattern. What are the wavelengths for these cases? The forumula for the frequencies of a tube closed on one end are given by $\lambda = 4L/n$ where $n$ is an odd whole number. Verify this relationship with the numbers you got in the previous questions.

## Exercise 3.3.10

Flutes are basically pipes with openings on both ends but clarinets, trumpets and trombones are basically tubes that are closed on one end. Why does this make a difference in the frequencies each instrument plays?

## Exercise 3.3.11

Pressure anti-nodes occur at places where the air is not moving (displacement nodes). What would be the effect of cutting a hole in the tube at the location of a pressure anti-node? Would the standing wavelength be affected? (This is the basis behind using finger holes in wind instruments to play different frequencies.)

## Exercise 3.3.12

Based on what you learned about reflection from boundaries in simulation 3.2, explain what is going on at the closed end where the two waves that make up the standing wave reflect.