

# Lab 12

## Standing Waves

### What You Need To Know:

**Types of Waves** The study of waves is a major part of physics. There are quite a few types of waves that can be studied. Depending on who you have for lecture you could have already discussed sound waves, water waves, and perhaps even light waves (though that’s more of a 212 topic). In this lab we will be dealing specifically with waves traveling on a taut string.

There are quite a few equations that need to be discussed for the lab. The first one is a very general one that can be used for *any* type of wave. It is the most basic equation for a wave ...

$$v = \lambda f$$

$v$  is the speed of the wave (in meters per second, m/s)  
 $\lambda$  is the wavelength of the wave (in meters, m)  
 $f$  is the frequency of the wave (in hertz, Hz)

In **Figure 1** there is a drawing of a general traveling wave moving to the right with speed,  $v$ . The wavelength,  $\lambda$ , of the wave is defined as the length of one complete oscillation of the wave. It doesn’t matter where the start of this length begins as long as it’s one complete pattern. For example, **Figure 1** shows two different ways of looking at the wavelength. The top wavelength begins at a peak and ends at a peak. The bottom one starts at a “zero” and ends at a “zero”. In both cases  $\lambda$  encompasses one complete wave, even though they each look different. This lab is going to assume that you already understand the concept of frequency.

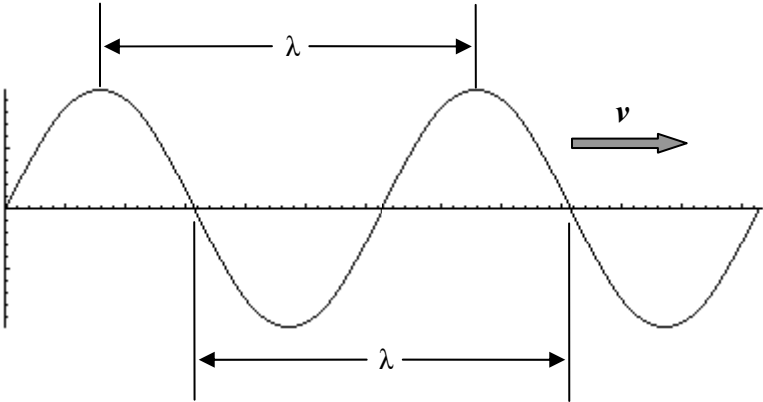


FIGURE 1 – A general wave

**Superposition of Waves** If you take two or more different waves and add them together, or *superimpose* them, they will combine together to form a new wave.

In **Figure 2**, you see two different cases in which two waves can add together. In case **2a**, the two waves are *in phase*, which means that they both have a peak (or valley) at the same time. When these waves are combined the result will give you *constructive interference*. If two waves on a string meet in this fashion we would say that there would be maximum amplitude at this point.

In case **2b**, the two waves are *out of phase* in such a way that *peaks* match with *valleys*. When these waves are combined the result will give you *destructive interference*. If two waves on a string meet in this fashion we would say that there would be no amplitude at this point.

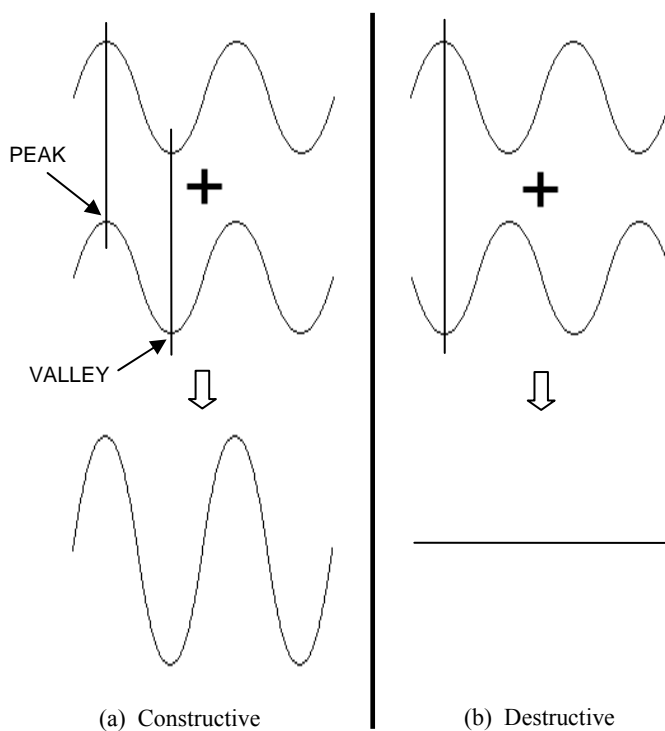


FIGURE 2 – Superposition of two waves

**Reflection of Waves** As stated before, this lab is going to deal with waves traveling on a string that is fixed at both ends. This implies that the string will not be moving at the ends. This may seem like an obvious statement now but it is important later. Let's say that we send a wave pulse traveling to the *left* along a taut string. If the string is fixed at an endpoint then the wave is reflected upside-down. **See Figure 3a.** This will occur no matter if the wave is starting right side-up or upside-down. In **Figure 3b** the wave is traveling to the *right* upside-down and since it is reflecting from a fixed point the pulse is inverted.

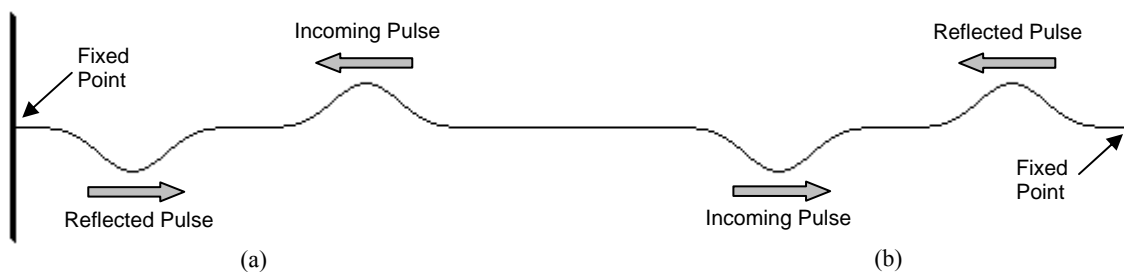


FIGURE 3 – Wave Reflection

**Reflection and Superposition** Let's say we have two pulses moving on a string that is fixed at both ends. The pulses are moving in the same direction and are spaced an arbitrary distance apart. The first pulse hits a fixed point and reflects back upside-down. The reflected pulse is now heading for the second incoming pulse. Keeping in

mind what was discussed in the superposition section of this lab, the two waves will briefly cancel out as they pass through each other.

What do you think would happen if you have a continuous stream of pulses or waves moving back and forth on the fixed string? If the conditions were just right for the speed, wavelength, and tension, it is possible to have waves always meet and cancel at a single point (or multiple points). The result is that you get patterns that appear to be standing still. These are called *standing waves*.

**Standing Waves** There are an infinite number of standing wave patterns that you can create on a fixed string. These are called *harmonics*. In **Figure 4** there are the first three possible harmonic patterns you can have on a string fixed at both ends.

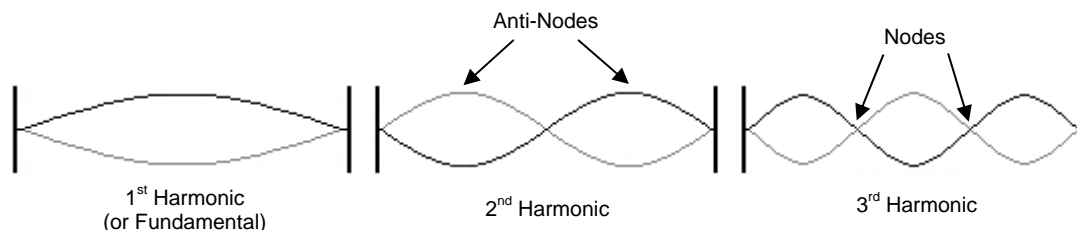


FIGURE 4 – Standing Wave Patterns

The string oscillates up and down such that at one point in time the string will be at the dark position. **See Figure 4.** A short time later the string will be at the lighter position. **See Figure 4.** Points at which the string moves the most are called *anti-nodes*. Points at which the string doesn't move at all are called *nodes*. **See Figure 4.** For example, for the 2<sup>nd</sup> harmonic notice that there are two anti-nodes and *three* nodes. Since the string is fixed at both ends, those are considered to be nodes as well. Also, we refer to the area between nodes as *loops*. For example, the 2<sup>nd</sup> harmonic has two loops in its pattern, the 3<sup>rd</sup> harmonic has three loops, etc.

**The Equations** There are still three more equations to introduce for this lab. The first one is for the *linear density* of the string. You are already familiar with density from the **Density and Buoyancy** lab, but that is a density based on volume (3 dimensions). Linear density is based on 1 dimension (a line). The equation is ...

$$\mu = \frac{m}{L} \quad \left| \begin{array}{l} \mu \text{ is the linear density of the string (in kilograms per meter, kg/m)} \\ m \text{ is the mass of the string (in kilograms, kg)} \\ L \text{ is the length of the string (in meters, m)} \end{array} \right.$$

The second equation is for the speed of the wave traveling on the string. This lab is called **Standing Waves** but the waves only *appear* to be standing still. The waves are actually traveling very quickly back and forth between the endpoints of the string. The equation is .....

$$v = \sqrt{\frac{F_T}{\mu}} \quad \left| \begin{array}{l} v \text{ is speed of the wave (in meters per second, m/s)} \\ F_T \text{ is the tension in the string (in Newtons, N)} \\ \mu \text{ is the linear density of the string (in kilograms per meter, kg/m)} \end{array} \right.$$

The last equation enables you to calculate the wavelength in a different manner. As you can glean for the harmonic patterns in **Figure 4**, there is a relationship between the length of the string and the wavelength that you can create. The equation is ...

$$\lambda = \frac{2L}{n} \quad \left\{ \begin{array}{l} \lambda \text{ is the wavelength (in meters, m)} \\ L \text{ is the length of the string (in meters, m)} \\ n \text{ is the harmonic number (no units)} \end{array} \right.$$

You will be using all of these equations and the standing wave device on your lab bench to examine the relationships between all of the variables.

**The Equipment** On your lab table there is a device that will create standing waves on a string. Attached to the black track is an *oscillator* that creates the waves. See **Figure 5**. The frequency of the oscillator is *constant at 120 Hz*. You will be using this value throughout the lab. One end of a string is attached to the oscillator and the other end is slung over a pulley and attached to a mass hanger. Adding masses to the hanger will change the tension in the string. The string also goes through a *slide block*. If you move the slide block back and forth you change the effective length of the string,  $L$ . See **Figure 5**. The slide block straddles a ruler which you can use to measure the effective length of the string.

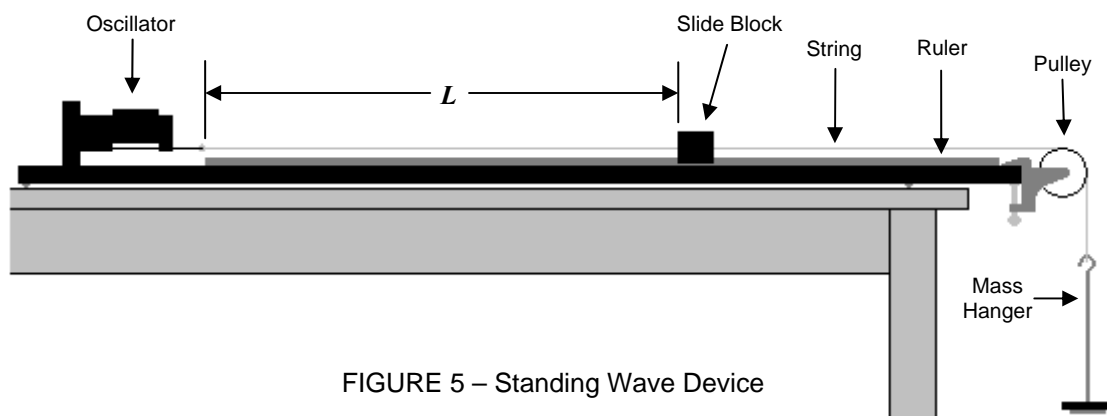


FIGURE 5 – Standing Wave Device

**Tuning** Much of what you will be doing during this lab is “tuning” the string to a certain harmonic. Getting the tuning just right is a slightly detailed process that you will get better at as the lab progresses. There are two different methods in which you will be tuning the string.

**Method 1** The first way to tune the string is by changing the tension in the string. Again, you can do this by adding masses to the mass hanger. Let’s go through an example. You would start by setting the slide block to the location that the procedure tells you. When you plug in the oscillator it’s going to make the entire track vibrate. This in turn makes the slide block want to happily move back and forth on its own. Since, in this case, we want the effective length of the string to stay constant this is not a preferable situation. So, once you have the block set in the desired location, place the 2 kg mass on top of it.

The lab will also tell you which harmonic you are going to try and tune the string to. Let’s say it’s the 3<sup>rd</sup> harmonic (i.e. 3 loops). To start, arbitrarily pick a mass to put on

the hanger, let's say 200 g. After you place the mass on the hanger you may or may not see a pattern form on the string. More than likely, unless you are really lucky, it will not be the 3<sup>rd</sup> harmonic. So, try either slowly pushing down on the hanger or pushing up gently on the hanger. Apply the pressure gradually. As you do this watch the string. If you are pushing down and see, let's say, the 4<sup>th</sup> harmonic (or higher) start to form, then you know that you have too much mass on the hanger. So, take some off and repeat this process. NOTE: When adjusting the mass, you can fine tune it down to as little as 2 g. The string will react to masses that small.

On the other hand, let's say that you are pushing down and you see the 3<sup>rd</sup> harmonic or lower start to form then you know that you don't have enough mass on the hanger. As you get closer to the harmonic that you want you will be applying less force to the hanger. Just reverse this process when you push up on the hanger. You will know that you have it tuned perfectly when the amplitude of the standing wave is at a maximum. The noise that the system makes should also get louder. Hopefully, your TA will go through an example of this process at a lab station before you begin.

**Method 2** The second method used to tune the string is by moving the slide block. Start by setting the mass on the hanger to what the lab tells you. The lab will also tell you which harmonic you want to tune to. You will slide the block back and forth until you see the desired amount of loops for your harmonic. Once you first see the harmonic it does not necessarily mean that it is tuned as good as you can get it. Move the block back and forth in small amounts so that the amplitude of the standing wave is at a maximum. It also helps if you push down slightly on the slide block as you are tuning.

### What You Need To Do:

**Part 1 – Examining the Wavelength** This section will give you some practice on using the device at your table as well as helping you determine your wavelength.

**A)** Move the slide block so that its left edge is at 90 cm on the ruler. Place the 2 kg mass on top of the block. Plug in the oscillator.

**B)** Using **Method 1** in the introduction, tune the string to the 4<sup>th</sup> harmonic. NOTE: If the standing wave ever seems to be fluxing in and out of its maximum amplitude then make sure the mass hanger is not swinging back and forth. This is usually the cause of this problem.

**C)** Unplug the oscillator. Leave on the current masses as you will be using them in **Part 3**.

**Question 1** Based on your observations how many loops make up one complete wavelength?

**Part 2 – Examining the Linear Density** There are two different types of string for this lab. One string has a black mark on the string (about in the middle of the string), the other string doesn't have a black mark. Take a moment to identify what type of string you currently have. The two different types are alternated from table to table so

if you want a comparison then look at an adjacent table. If you aren't sure then ask your instructor. You are going to be using the linear density equation to calculate the linear density of each string.

A) Make a chart in your lab report like **Chart 1**.

String	Mass (kg)	Length (m)	Linear Density (kg/m)
Black Mark		10 m	
No Black Mark		10 m	

Chart 1

B) In the back of the lab near the digital scales there are several samples of each type of string, black mark and no black mark. They are wound up and labeled 10 m. Do not unwind the string. Use the digital scale to measure the mass of each type of string and put it in the chart.

C) Calculate the linear density of each string and place it in your chart.

**Part 3 – Relationship Between L and n** For this part of the lab you will be examining how the effective length of the string relates to the harmonic number.

A) Leave the current masses on the hanger, but *remove* the 2 kg block from the top of the slide block.

B) Make a chart in your lab report like **Chart 2**. Note the string type.

C) Plug in the oscillator. Move the block back and forth slightly to make sure that the current harmonic has its maximum amplitude (like **Method 2**). Once this is done, record in the first line of the chart the current effective length and harmonic number.

D) Move the slide block towards the oscillator until you have another standing wave. Use **Method 2**. Record your data in the chart.

E) Repeat this until the slide block reaches the oscillator.

F) Using the equation off to the left, calculate the wavelength for each harmonic you found. Place these values in the chart. You will fill out the rest of the chart later.

**Question 2** Based on your results, what do you conclude about the wavelength? (increasing, decreasing, constant?)

Length (m)	n	$\lambda$ (m)	v (m/s)
Ave. v			
$F_T$			
$\mu$			
v			
% diff.			

Chart 2

$$\lambda = \frac{2L}{n}$$

**Question 3** In examining your data and calculations, what is the relationship between the effective length and the harmonic number in this case? (Inversely proportional, directly proportional?)

**Question 4** In the intro, we discussed the equation  $v = \lambda f$ . Based on this equation, what do you conclude about the speed of the wave? Explain your answer.

**G)** Using the equation in **Question 4**, calculate the speed of the wave for each harmonic and place the values in the chart. Do the results agree with your answer to the previous question? Also, calculate the average speed and place this in the chart.

$$v = \sqrt{\frac{F_T}{\mu}}$$

**H)** There is another equation in the intro that you can use to calculate the speed of the wave. It is off to the left. You need to have a tension value and a linear density for your current string. The latter you already calculated. Go back to **Chart 1** and get the linear density value for your current string and place it in **Chart 2**.

You also need to calculate the tension in the string. Hopefully, at this point in the semester, you already know how to do that. If you don't know, then ask your TA. When you do your calculation make sure you include the mass of the hanger. Also, use the appropriate units so that you get units of Newtons. Place this value in the chart.

**I)** Now that you have the required values, calculate the speed of the wave. Place this value in the chart. Calculate a percent difference between the two values for the speed of the wave. Place this value in the chart. If your percent difference is greater than 10%, then you made an error somewhere and you have to find it.

**Question 5** Looking back at the equations you just used and the results you got, what are the only things that you can do to change the speed of the wave on your string?

**Part 4 – Relationship Between  $n$  and  $F_T$**  For this part of the lab you will be examining how the harmonic number relates to the tension in the string.

**A)** Place the slider at 70 cm and put the 2 kg mass on top of it.

**B)** Make a chart in your lab report like **Chart 3**. Note the string type.

n	m (kg)	$F_T$ (N)	v (m/s)	$\lambda$ (m)	v (m/s)	% diff
2						
3						
4						

Chart 3

**C)** Using **Method 1**, put masses on the hanger to create standing waves for the 2<sup>nd</sup> harmonic through the 4<sup>th</sup> harmonic. Record the mass in the chart making sure you include the mass of the hanger. You will fill out the rest of the chart later. Unplug the oscillator.

**D)** Calculate the tension in the string for each harmonic using the mass data that you took. Place the values in the chart.

**Question 6** What do you conclude about the relationship between the harmonic number and the tension in the string?

**E)** Calculate the speed of the wave based on the tension and place these values in the first speed column in the chart.

**F)** Using the wavelength equation, calculate the wavelength for each of the harmonics and place these values in the chart.

**G)** Calculate the speed of the wave based on the wavelength and place these values in the second speed column in the chart.

**H)** Calculate a percent difference between your two velocities. If your error is more than 10% then you must go back and find your mistake.

**Question 7** Based on your data, what do you conclude about the relationship between the tension and the speed of the wave?

**Part 5 – Relationship Between  $\mu$  and L** For this part of the lab you will be examining how the linear density of your string relates to the length of the string. You will be sharing your data with another table for this part.

**A)** Make a chart in your lab report like **Chart 4**. Under the “Your Data” column, put in the linear density of your string. You will fill out the rest of the chart later.

Your Data		Other Table's Data	
Linear Density	Length	Linear Density	Length

Chart 4

**B)** Put a 200 g mass on the mass hanger. (So there is total of 250 g including the hanger.)

**C)** Remove the 2 kg mass from the block. Slide the block until you have a 2<sup>nd</sup> Harmonic pattern on your string.

**D)** Record the current effective length of the string in your chart under “Your data”.

**E)** Go to an adjacent table (or any other table that has a string other than the one you currently have) and get the data they took for this part of the lab. Place these values in the chart. If nobody else is at this point yet then go on to the next part and come back to this later.

**Question 8** Based on your data, what is the relationship between the linear density of a string and the length of your standing wave if you hold the tension constant?



**Part 6 – Relationship Between L and  $F_T$**  For this part of the lab you will be examining how the length of the string relates to the tension in your string.

**A)** Make a chart in your lab report like **Chart 5**.

**B)** Hang from the string a total of 150 g (including the mass hanger).

**C)** Plug in the oscillator and move the slide block until you achieve a 2<sup>nd</sup> Harmonic standing wave.

Mass (kg)	Length (m)	Tension (N)
0.150		
0.250		
0.350		

Chart 5

**D)** Measure and record the effective length of the string. Repeat this procedure for the other masses in the chart. Unplug the oscillator.

**E)** Calculate the tensions for these masses and place them in the chart.

**Question 9** What do you conclude about the relationship between the length and the tension in the string?

$$v = \sqrt{\frac{F_T}{\mu}}$$

$$v = \lambda f$$

$$\lambda = \frac{2L}{n}$$

**Part 7 – Analysis** There is no data that you need to take for this part of the lab. So, if you are out of time in your lab period, then you can do the remaining work at home. For **Part 3** through **Part 6**, you examined the relationship between two measurements. Now you are going to confirm these results.

**A)** Combine the equations on the left into one single equation that does not contain either the wavelength or the speed of the wave.

**B)** For **Part 3** through **Part 6** write out the equation from **A)** in linear form. If you don't remember how to do this then look back at the **Graphical Analysis** lab from the beginning of the semester.

For example, in **Part 3** of the lab you were examining the relationship between **L** and **n**. **n** was the independent variable because you were controlling it. You then measured **L** which was your dependent variable. So, you will “massage” your equation so that **n** is part of the “x” in the linear form and **L** is part of the “y” in the linear form.

**C)** For each part of the lab state if your results agree with the relationship for the variables in your “massaged” equation. You must explain why as well.

### What You Need To Turn In:

On a separate sheet of paper from this lab manual answer all of the questions, including all of the charts that you are asked to make.