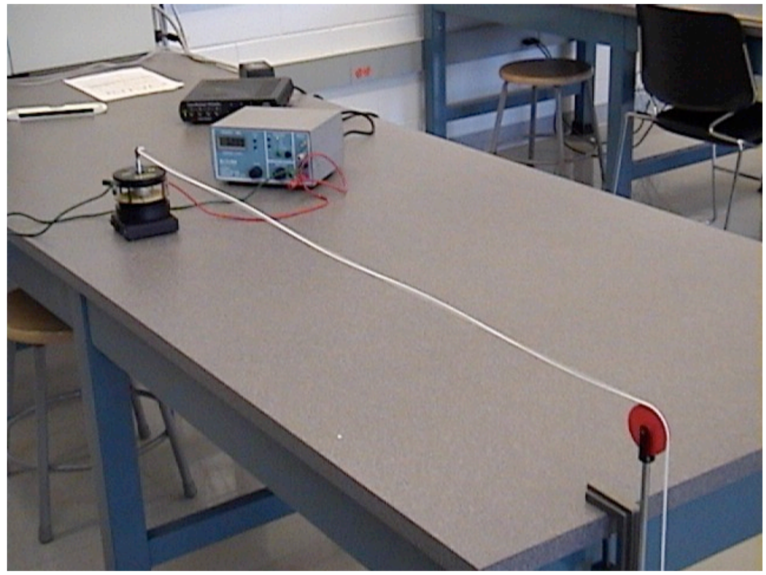
Standing Waves on a String

Object:

To study the effects of tension and frequency on the formation of standing waves on a string.

Reference: Chapter 17 in Cutnell & Johnson.



Apparatus:

1. Electric oscillator w/ function generator
2. String
3. Pulley
4. Mass hanger and masses
5. Meter stick
6. Pan balance

Introduction:

Anything that vibrates is capable of producing a wave. Whereas, a wave is defined as a physical disturbance in space and time with the purpose of transporting energy from one place to another. Waves can take on may different forms, for example, sound waves consist of compressed and stretched out regions of air which propagate through space, enter your ears and make your eardrums vibrate back and forth. In this manner energy from the source is transported to the observer, your ear. Light waves are combinations of electric and magnetic fields that transport energy from some vibrating charges across space and time. For example, form the Sun to the Earth.

In this experiment we will be studying transverse waves on a string. Recall that a transverse wave is one in which the vibrations are perpendicular to the direction of wave motion. We will use a small mechanical oscillator to vibrate the end of the string up and down, thereby producing a wave as depicted in figure 1.

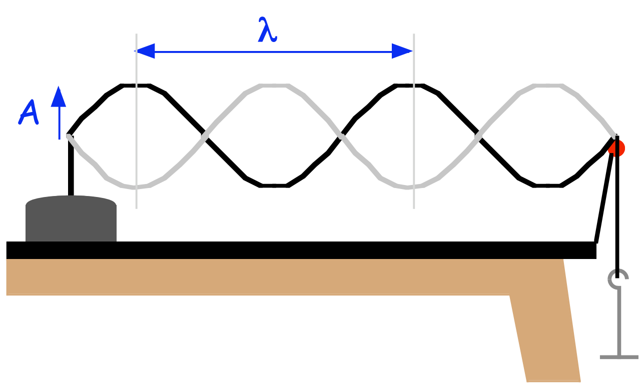


Figure 1: Wave Characteristics

The waves produced are characterized by their wavelength, λ, frequency, f, and wave speed, v. These three variables are related by the simple expression:

$$v = \lambda f \qquad (1)$$

The wave produced by the oscillator propagates down the string towards the end of the table. But when it reaches the end of the string it can't continue! The wave reflects off the far end and starts propagating back towards the oscillator. The point at which the reflection occurs can be considered to be fixed. It rests on the pulley and cannot move up and down.

Now we have two waves on our string, one propagating left to right, and the other right to left. When two waves occupy the same region of space, in this case the same length of string, they undergo interference. If the crests of the first wave overlap the crests of the second, then we have what is called constructive interference; the wave amplitudes add. If, on the other hand, the crests of the first wave overlap the troughs of the second wave, then we have destructive interference; the wave amplitudes cancel each other. We see both of these situations in figure 2.

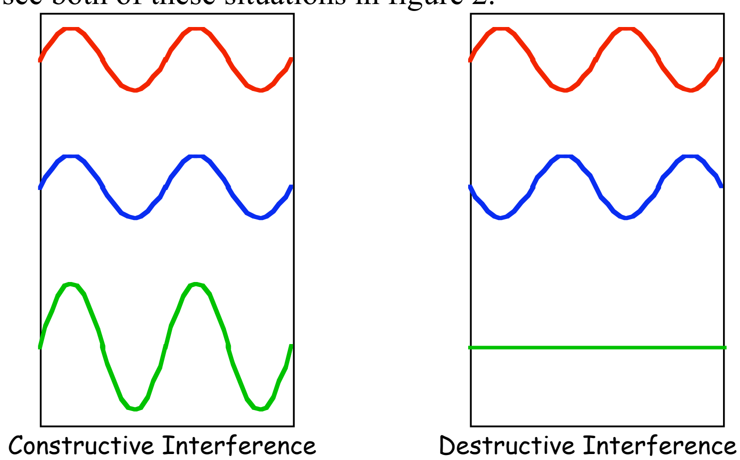


Figure 2: Interference of two waves

As the two waves pass each other, the crests of the first wave will pass by the crests of the second, then troughs, then crest, and this will continue in an alternating pattern. So, when we look at our string we will alternately see constructive interference of the waves and destructive interference of the waves. It will seem to bounce back and forth between the dark and light waves we see in figure 1. We call this superposition of two waves a standing wave. It seems to stand in the same place, but bounces between its two orientations. Note that there are some points along our wave that always have zero amplitude! We call these points nodes, halfway between them we see regions in which we have maximum amplitude. These are called anti-nodes.

Note that there is a node at both ends of the string. With nodes at both ends, we can form waves of various wavelengths between these ends as shown in figure 3.

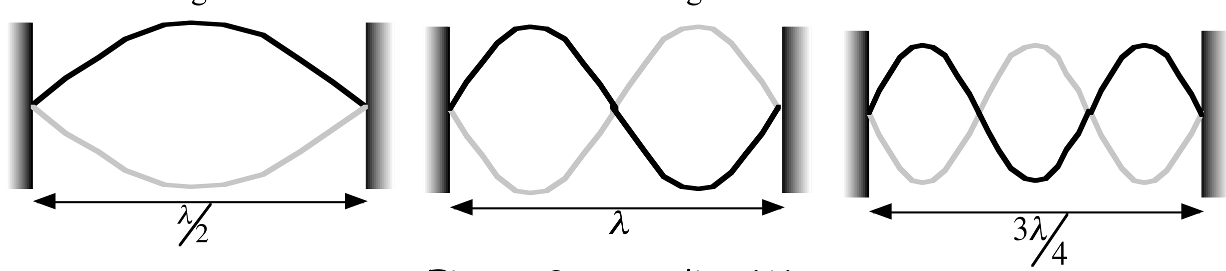


Figure 3: Standing Waves

So, we can fit any number of half wavelengths between the two ends, a distance L apart. We express this mathematically as:

$$L = n\frac{\lambda}{2}; \quad \lambda = \frac{2L}{n} \tag{2}$$

We note that there are only specific values of the wavelength, λ, which will fit between the two ends of the string, depending on the value L and the integer, n.

Recall that the speed of a wave on a string under a tension, T, is given by:

$$v = \sqrt{\frac{T}{\mu}} \tag{3}$$

where μ is the linear mass density (in kg/m) of the string. Putting equations (1), (2) and (3) together, we get an expression relating the tension in the string to the frequency of the wave. This expression depends on the integer n.

$$T = \frac{4L^2\mu f^2}{n^2} \tag{4}$$

Now, we can put a tension in the string by pulling on it, or applying a force on the hanging end as shown in figure 1. Thus, the tension, T, is equal to mg.

$$m = \frac{4L^2\mu f^2}{gn^2} = \left(\frac{4L^2\mu}{g}\right)\frac{f^2}{n^2} \tag{5}$$

Procedure:

Part 1: Fixed Frequency.

1) Set up the oscillator, function generator, and string as shown in the introductory photograph and figure 1.

2) Measure the total mass of the string and the total length of the string. Determine the linear mass density, μ. Record this value.

3) Measure the distance between the oscillator and the node at the end, where the pulley is located, L. Record this value.

4) For a fixed frequency of about 10 Hz, calculate the theoretical values for the required mass needed for the desired number of half-wavelength segments, n. Fill in the second column of the table below accordingly:

Segments, n	$m_{theoretical}$	$m_{experiemntal}$	% Difference
1			
2			
3			
4			
5			
6			
7			

5) Now, experimentally determine the masses required to produce standing waves with the maximum possible amplitude.

6) Make a plot of mass vs. $(1/n^2)$ and find the slope. (It should be a straight line!!)

7) Using this slope, ***calculate*** the linear mass density of the string and compare it to the value measured earlier.

Part 2: Fixed mass.

1) Again, set up the oscillator, function generator, and string as shown in the introductory photograph and figure 1.

2) For a fixed mass of about 250 g, calculate the theoretical values for the required frequency needed for the desired number of half-wavelength segments, *n*. Fill in the second column of the table below accordingly:

Segments, *n*	$f_{theoretical}$	$f_{experiemntal}$	% Difference
1			
2			
3			
4			
5			
6			
7			

3) Make a plot of frequency vs. n and find the slope. (Again, it should be a straight line!!)

4) Using this slope, ***calculate*** the linear mass density of the string and compare it to the value measured earlier.

Questions:

1) As the tension is increased, does the number of segments increase or decrease when the frequency is kept constant?

2) As the frequency is increased, does the number of segments increase or decrease when the tension is kept constant?

3) As the tension is increased, does the speed of the waves increase, decrease, or stay the same when the frequency is held constant?

4) As the frequency is increased, does the speed of the waves increase, decrease, or stay the same when the tension is held constant?