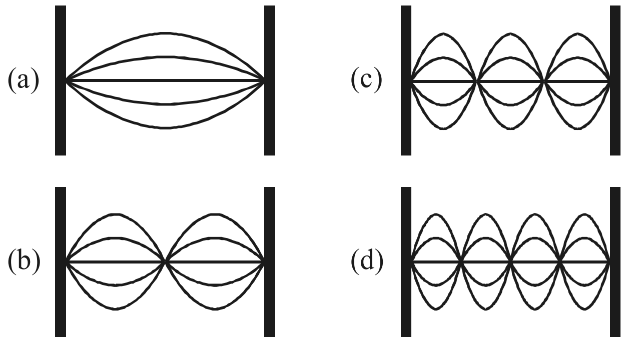
Waves in a String
Finding the Relationship Between Tension and Frequency for Standing Waves in a String

When a stretched string is plucked it will vibrate in its fundamental mode in a single segment with nodes on each end. If the string is driven at this fundamental frequency, a standing wave is formed. Standing waves also form if the string is driven at any integer multiple of the fundamental frequency. These higher frequencies are called the harmonics.



Each segment is equal to half a wavelength. In general for a given harmonic, the wavelength λ is

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

The velocity of any wave is given by $v = \lambda f$ where *f* is the frequency of the wave. For a stretched string:

$$v = \frac{2Lf}{n}$$

The velocity of a wave traveling in a string is also dependent on the tension *T* in the string and a quantity known as the linear mass density μ of the string:

$$\mu = \frac{\text{mass}}{\text{length}}$$

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

If the tension is varied while the length and frequency are held constant, a plot of tension *T* vs. $(1/n^2)$ will give a straight line which will have a slope equal to $4L^2 f^2 \mu$.

The equation for the tension can also be solved for the frequency:

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

If the frequency is varied while the tension and length are held constant, a plot of frequency f vs. number of segments n will give a straight line which will have a slope equal to $\sqrt{\frac{T}{4L^2\mu}}$.

PURPOSE

The purpose of this activity is to investigate standing waves on a string to find the relationship between the frequency of oscillation of the string and the number of segments n in the standing wave. In Part I you will use the wave driver to vary the frequency but keep the length and tension constant.

In Part 2 you will use different hanging masses to change the tension of a string but keep the length and frequency constant.

MATERIALS

(For a class of 28 working in groups of 4)

- function generator/amplifier
- wave driver
- clamp, table and rod
- mass set
- pulley, mounting rod and clamp
- meter stick
- 1 m of string

PROCEDURE

PART I

1. Set up the equipment as shown in Figure 1 below. Do not turn on the power switch of the amplifier until the equipment setup is complete.

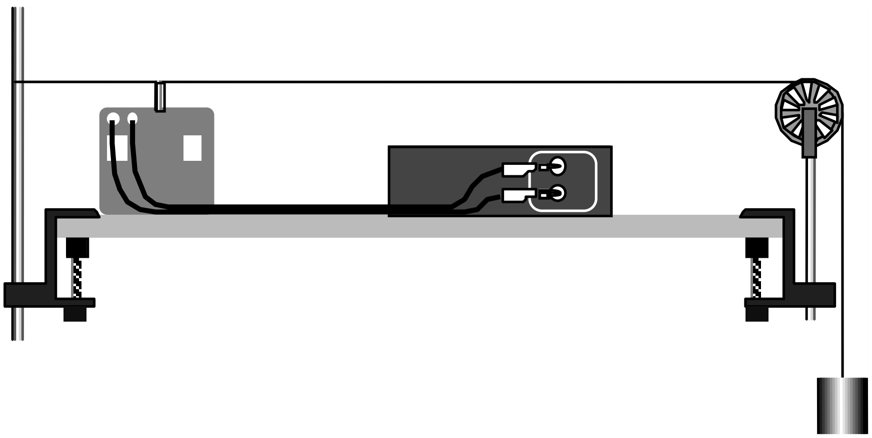


Figure 1

2. Tie one end of a 2-m long piece of string to a vertical support rod that is clamped to one end of a table. Pass the other end of the string over a pulley that is mounted on a rod that is clamped to the other end of the table. Attach about 500 grams of mass to the end of the string.

3. Place the wave driver under the string near the vertical support rod. Insert the string in the slot on the top of the driver plug of the wave driver so the wave driver can cause the string to vibrate up and down. Use patch cords to connect the wave driver into the output jacks of the power amplifier.

4. Use the meter stick to measure the length of the section of the string L that will be vibrating. This length is the part of the string between the driver plug of the wave driver and the top of the pulley. Record this length in Data Table 1 on your student answer page.

5. Turn on the equipment and slowly increase the frequency until the string vibrates with one antinode and is smooth with a large amplitude. This is the fundamental frequency. Record this frequency in Data Table 1.

6. Now increase the frequency until there are two loops on the string (one full wavelength). Record this frequency in Data Table 1.

7. Continue increasing the frequency and complete Data Table 1 for each point that the string vibrates with a whole number of loops and has significant amplitude.

PART II

1. Look at Data Table 1. Place the same mass on the string and set the frequency to the fundamental frequency. Remember, the fundamental frequency is the frequency that produced one large antinode on the string. In other words, make the string vibrate in its fundamental mode (one antinode in the center). Record these values of mass and frequency in Data Table 2. (Be sure to include the mass of the hanger if one is used.)

2. Now change the amount of mass on the mass hanger until the string vibrates in each of the higher harmonics (for 2 segments through 8 segments) and record these masses in Data Table 2.
   Hint: decrease the mass to increase the number of segments.

3. Calculate the tension for each different mass used [tension = (mass in kilograms) × (g), where g = 9.8 Newtons per kilogram].

Name ______________________________

Period______________________________

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DATA AND OBSERVATIONS

PART I: CONSTANT TENSION AND LENGTH, VARIABLE FREQUENCY

Length = _________ m   Mass = _________________ kg   Tension = _____________ N

Data Table 1

Segments, *n*	Frequency (Hz)
1	
2	
3	
4	
5	
6	
7	
8	

Plot a graph of Frequency vs. Segments (n).

PART II: CONSTANT FREQUENCY, VARIABLE TENSION

Frequency = ____________________ Hz

Length = ____________________ m

Data Table 2			
Segments, *n*	**Mass (kg)**	**Tension, *T* (N)**	**$1/n^2$**

Plot a graph of Tension vs. $1/n^2$.

ANALYSIS

For the Data in Part 2, calculate the velocity of the wave at each tension. The velocity of any wave is given by $v = \lambda f$ where *f* is the frequency of the wave. For a stretched string:

$$v = \frac{2Lf}{n}$$

Segments, *n*	**Tension, *T* (N)**	**Velocity, *v* (m/s)**
1		
2		
3		
4		
5		
6		
7		
8		

Make a graph of Tension vs. Velocity for this data. What kind of relationship does this indicate?

CONCLUSION 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 wave increase, decrease, or stay the same when the frequency is kept constant?

4. As the frequency is increased, does the speed of the wave increase, decrease, or stay the same when the tension is kept constant?

5. Suppose that String #1 is twice as dense as String #2, but both have the same tension and the same length. If each of the strings is vibrating in the fundamental mode, which string will have the lower frequency?