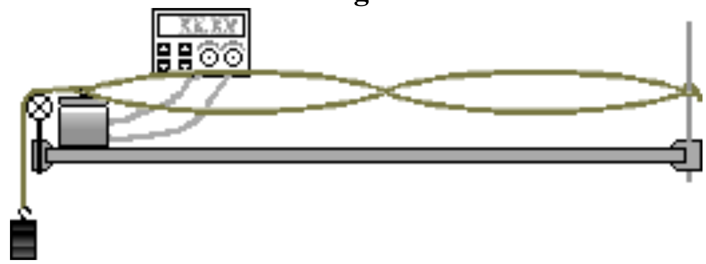
Standing Waves in a Rope

A group of students are conducting experiments to determine the effect of various factors on the speed of a wave. The apparatus, shown in **Figure 1**, includes a rope extending from a metal pole on one end to a pulley on the other. The rope wraps around the pulley and is pulled tight by a hanging mass. A *mechanical oscillator* vibrates the rope. The frequency of vibrations can be controlled by the students. Frequencies are chosen that cause the rope to vibrate as a **standing wave** with fixed points of no vibration called **nodes**.

Figure 1



Experiment 1

In Experiment 1, students hang a 1.0 kilogram mass on the end of the rope. They vary the frequency at which the rope vibrates in order to create standing wave patterns with varying number of nodes. For each frequency, they measure the wavelength and calculate the speed of the wave. Their data is shown in **Table 1**.

Table 1

Trial	# of Nodes	Frequency (Hz)	Wavelength (m)	Speed (m/s)
1	2	62.2	2.25	141
2	3	93.3	1.50	139
3	4	124.4	1.13	140
4	5	155.6	0.90	141

Experiment 2

In Experiment 2, students vary the amount of mass that hangs on the end of the rope. Increasing the mass causes the tightness (tension) of the rope to increase. In each case, they chose frequencies that vibrate the rope with the same standing wave pattern. The measured frequency and wavelengths and the calculated speeds are shown in **Table 2**.

Table 2

Trial	Mass (kg)	Frequency (Hz)	Wavelength (m)	Speed (m/s)
5	0.5	65.9	1.50	99
6	1.0	93.6	1.50	140
7	1.5	114.4	1.50	172
8	2.0	131.9	1.50	198

Experiment 3

In Experiment 3, students vary the rope that is being vibrated. They keep the tension the same from trial to trial and vibrate the rope with the same standing wave pattern. For each rope, they measure the *linear density* (the mass per unit length of the rope). The measured frequency and wavelengths and the calculated speeds are shown in **Table 3**.

Table 3

Trial	Lin. Dens. (kg/m)	Frequency (Hz)	Wavelength (m)	Speed (m/s)
9	0.000345	112	1.50	168
10	0.000492	94.3	1.50	142
11	0.000695	79.1	1.50	119

Questions:

1. Which experiment(s) demonstrate(s) the effect of linear density upon the speed of a wave?
   a. Experiment 1 b. Experiment 2
   c. Experiment 3 d. Experiments 1 and 2

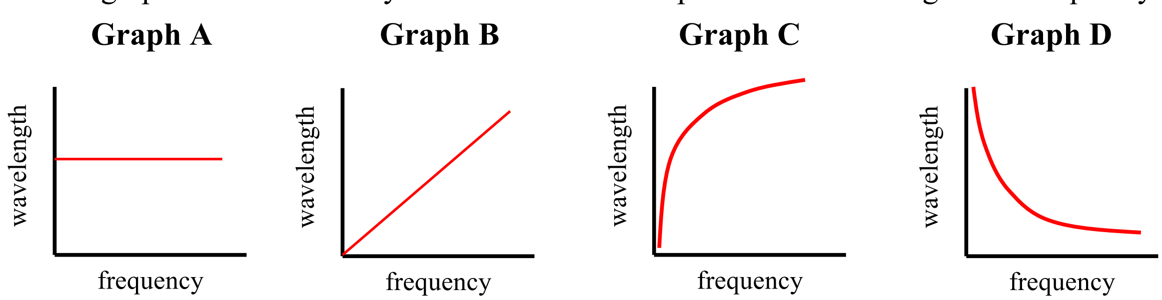
2. Which one of the following quantities is the independent variable in **Experiment 1**?
   a. The wavelength of the waves.
   b. The frequency at which the rope is vibrated.
   c. The speed at which waves travel through the rope.
   d. The amount of mass that hands on the left end of the rope.

3. Which one of the following quantities is the independent variable in **Experiment 2**?
   a. The wavelength of the waves.
   b. The frequency at which the rope is vibrated.
   c. The speed at which waves travel through the rope.
   d. The amount of mass that hangs on the left end of the rope.

4. Which two trials in **Experiment 1** demonstrate the effect of the doubling of frequency upon the wavelength and the speed of waves in the rope?
   a. Trials 1 and 2 b. Trials 1 and 3
   c. Trials 2 and 4 d. Trials 1 and 4

5. Suppose that the students conduct a trial in **Experiment 1** in which they formed a standing wave with 6 nodes. What approximate frequency, wavelength and speed could be expected for such a trial?
   a. Frequency = 187 Hz, Wavelength = 0.75 m, Speed = 140 m/s
   b. Frequency = 218 Hz, Wavelength = 0.64 m, Speed = 140 m/s
   c. Frequency = 218 Hz, Wavelength = 1.35 m, Speed = 280 m/s
   d. Frequency = 249 Hz, Wavelength = 0.56 m, Speed = 140 m/s

6. Which graph below accurately shows the relationship between wavelength and frequency?



7. When the amount of mass hanging on the left end of the rope is doubled, the tension is doubled. Which two trials in **Experiment 2** demonstrate the effect of the doubling of tension upon the speed of waves in the rope?
   a. Trials 5 and 6 b. Trials 5 and 8
   c. Trials 6 and 7 d. None of the trials demonstrate this effect.

8. Consider **Experiment 2**. When the amount of mass hanging on the left end of the rope is doubled, the tension is doubled. In **Experiment 2**, how does the tension have to be changed in order to cause the speed to increase by a factor of two?
   a. The tension must be doubled.
   b. The tension must be increased by a factor of two.
   c. The tension must be increased by a factor of four.
   d. No matter how the tension is changed, the speed will never double.

9. What frequency, wavelength and speed values might be expected if a trial was conducted in **Experiment 2** with a mass of 4.0 kg hanging on the left end of the rope?
   a. Frequency = 187 Hz; wavelength = 1.50 m; speed = 280 m/s
   b. Frequency = 187 Hz; wavelength = 1.50 m; speed = 396 m/s
   c. Frequency = 264 Hz; wavelength = 1.50 m; speed = 280 m/s
   d. Frequency = 264 Hz; wavelength = 1.50 m; speed = 396 m/s

10. The data in **Experiment 2** was collected for the case of a standing wave consisting of three nodes. Based on the data in **Table 1** and **Table 2**, what frequency, wavelength and speed value could be expected for a standing wave with 6 nodes and a mass of 2.0 kg hanging from the end of the rope?
    a. Frequency = 61 Hz; wavelength = 0.75 m; speed = 198 m/s
    b. Frequency = 132 Hz; wavelength = 3.00 m; speed = 396 m/s
    c. Frequency = 264 Hz; wavelength = 1.50 m; speed = 396 m/s
    d. Frequency = 264 Hz; wavelength = 0.75 m; speed = 198 m/s

11. Which statement best describes the purpose of **Experiment 3**?
    a. To study the effect of changes in tension upon the speed of waves in the rope.
    b. To see what combination of frequency and wavelength make speed the greatest.
    c. To determine the effect of mass per unit length upon the speed of waves in the rope.
    d. To vibrate the rope at different frequencies, to measure wavelength and to calculate speed.

12. Two strings on a guitar have the same length and the same tension. They vibrate with the same standing wave pattern when plucked. But **String A** has twice the linear density as **String B**. How does the frequency at which **String A** vibrates compare to the frequency at which **String B** vibrates?
    a. **String A** and **String B** vibrate at the same frequency.
    b. **String A** vibrates at a higher frequency than **String B.**
    c. **String A** vibrates at a lower frequency than **String B.**
    d. Nonsense! It is impossible to compare frequencies with so little information.

13. The data in **Table 2** were collected with a constant linear density value. Use the data in **Table 3** to estimate a value of the linear density that was used in **Experiment 2**.
    a. Approximately 0.000345 kg/m
    b. Approximately 0.000492 kg/m
    c. Approximately 0.000695 kg/m
    d. Approximately 0.000986 kg/m