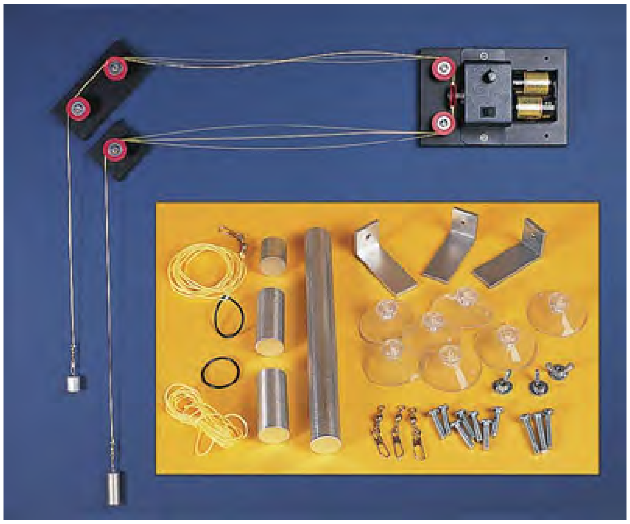
15240 STRING VIBRATOR

Purpose:



To produce vibrations in a string to study standing waves and their dependence on string tension, length, and mass, and the vibration frequency.

Additional Required Materials:

Four (4)	AA cell batteries
Three (3)	"C" Clamps
	Scale or Balance (0.1 gram resolution)

Description:

Vibrating strings provide an interesting and accessible means of investigating wave motion. Many musical instruments rely upon vibrating strings to produce a variety of sounds and pitches. For example, the guitar uses six strings of equal length but varies the weight and tension of each string to produce different notes. The player then presses the appropriate string against a raised bar (called a fret) to effectively shorten the length of the vibrating string to produce yet other notes. You can see in this simple example that weight, tension, and length affect the frequency or musical pitch of the vibrations. We will try to construct a more precise expression for these dependencies.

Familiarize Yourself with the Apparatus:

The String Vibrator consists of a motorized base, a single and double idler pulley. The motorized base is operated from four AA cell batteries. On the cover panel you will notice a power switch and a knob that controls the motor's speed which determines the frequency of vibration for the string.

If the apparatus is to mounted on a bench, locate the three metal angle brackets and affix them to the back of the motorized base and idler pulleys using the machine screws and wingnuts. Place the motorized base on the edge of a lab bench and clamp the bracket to the table with a "C" clamp. On the same edge of the lab bench and about 1 meter to the left of the motorized base, clamp the idler pulleys in a similar fashion (fig. 1).

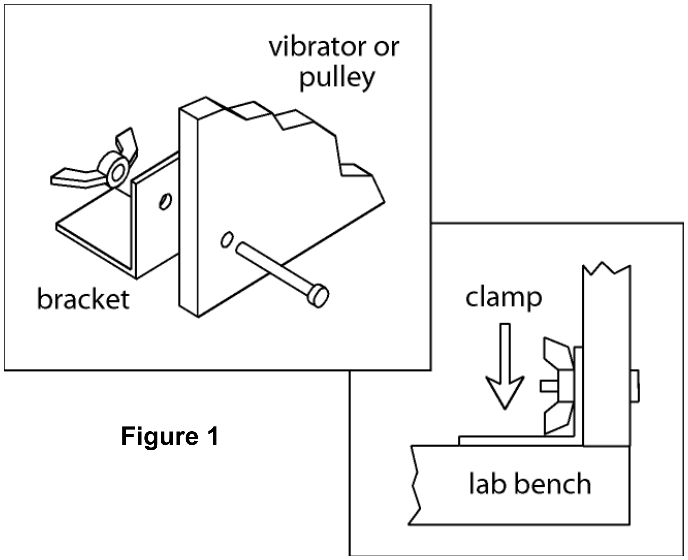


Figure 1

Alternatively, the apparatus may be mounted on any smooth vertical surface using the suction cups provided. Place the screws in the mounting holes of the vibrator and pulleys and thread the cups onto the screws as you would a nut – the plastic of the cups will securely hold the threads.

Next, stretch the O-ring with the strings over the pulley on the motor shaft (fig.2). Place the upper string over the top idler pulley and the adjacent single idler. Hang a medium sized weight from the string. Place the lower string over the bottom idler pulley and hang a second medium sized weight from it. (See setup in Fig. 3).

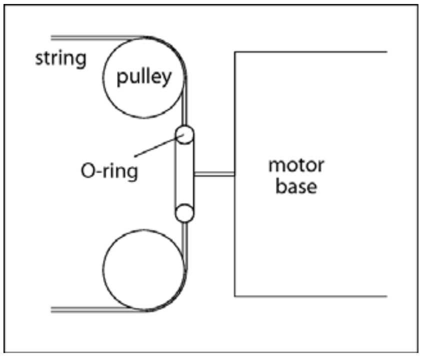
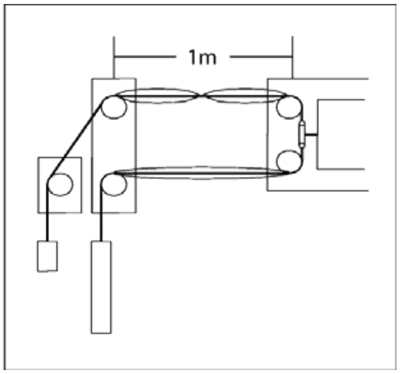


Figure 2

Turn the motor on and adjust the frequency using the control knob. Start with a slow motor rotation and slowly increase the frequency until you see standing waves develop in the string. You may see a single antinode (or lobe) with very low frequencies, but as you increase the frequency, this will vanish and gradually be replaced by a second resonance with two lobes and three nodes (one at each end and the third at the midpoint).



Fiaure 3

Dependence of Nodes on String Tension:

Weigh each of the weights and record these values in a table. Weight A is the largest, B the middle size, and C the smallest.

Place one weight B (medium size) on the string and adjust the motor frequency as necessary to obtain a standing wave pattern with one node located at the middle of the string. Record the number of nodes (including the node at each pulley) and the weight.
Replace the weight B (medium size) with the weight C (small size) and record the weight and the number of nodes. Repeat this procedure with the large weight A.

When you have completed your observations, use the recorded weight to calculate the tension in the string. Plot the number of nodes as a function of the string tension. Is the plot a straight line or a curve? Try plotting the number of nodes as a function of the square root of the tension. Is this plot a curve? Try plotting the number nodes of as a function of the inverse of the square root of the tension. Is this plot a curve or a straight line? When the plot (any plot for that matter) is a straight line, this means that the dependent variable (number of nodes) is directly proportional to the independent variable (1/√Tension).

This relationship can be written as:

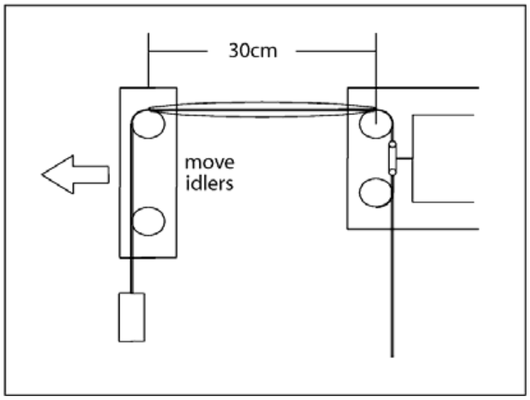
$$\# \text{ Nodes } \alpha \ 1/\sqrt{\text{Tension}}$$

or

$$N \ \alpha \ 1/\sqrt{T}$$

Dependence of Nodes on String Length:

Place the idler pulley approximately 30 cm from the motorized base. Hang one B weight (medium size) from the end of the string (fig. 4). Adjust the frequency of the motor to produce a standing wave with one lobe and a node at each pulley (this is the fundamental for this vibrating string). Record the number of nodes and the string length. Now, slowly move the idler pulley further from the motorized base. Keep the motor running and watch the string for another resonance. When the string again exhibits a standing wave pattern, clamp the idler pulley in place and record the number of nodes and the string length. Continue moving the idler pulley further from the motorized base and locate the next resonance. Record the number of nodes and the string length.



Fiqure 4

Plot the string length as a function of the number of nodes. Is the plot a straight line? If it is, then the number of nodes is directly proportional to the string length. This relationship can be written as:

$$\# \text{ Nodes } \alpha \text{ Length}$$

or

$$N \alpha L$$

Dependence of Nodes on Frequency of Vibration:

Move the idler pulley about 1 meter from the motorized base (similar to fig. 4). Hang the light weight C from the end of the string. Begin with a very slow motor speed and slowly increase this speed until the string begins to resonate with a single lobe and a node at each pulley. Record the number of nodes and the frequency of vibration. You can determine the frequency of the vibration by viewing the vibrating string through a hand strobe or using a xenon strobe light to illuminate the string.

With ether method, the string will apparently "freeze" its motion when the strobe frequency matches the string frequency. An alternate method would be to have the string trigger a photogate and calculate the frequency from this data.

Increase the motor speed until the next resonance occurs. Record the number of nodes and the frequency of vibration. Increase the motor speed again and record the number of nodes and frequency for the next resonance.

Plot the number of nodes as a function of frequency. Is this plot a straight line? If it is then you know that the number of nodes is directly proportional to the frequency of vibration. This can be written as:

$$\# \text{ Nodes } \alpha \text{ frequency}$$

or

$$N \alpha f$$

Dependence of Nodes on String Mass:

Hang a single medium sized weight from the end of a single weight string. Position the idler pulley about 50 cm from the motorized base (similar to fig. 4). Adjust the frequency of the motor to obtain a single lobe resonance. Record the string type and the string length between pulleys. Heavier weight strings can be made by twisting two or more single strings together and using the combination as you would a single string. Fasten a single string and a twisted double sting to an "O" ring. Without moving the motor base, idler pulley or changing the motor frequency, replace the single weight string with the heavier (double or tripple) string. Hang a single medium sized weight from each string. Turn the motor back on and move the idler pulley to a new position to produce a single lobed resonance on the multiple string. Record the string type and distance between nodes. Move the idler pulley to produce a single lobed resonance on the single string. Record the string mass per unit length and distance between nodes.

The next step is to determine the mass per unit length of string. Remove the "O" rings and swivel hooks from a length of string. Measure its length (don't forget that there are loops on each end!) then weigh it. Calculate the mass per unit length of the string by dividing the measured mass by the measured length. Multiple strings twisted together will then have a mass per unit length that is a multiple of the single strings mass per unit length. Plot the distance between nodes as a function of the string's mass per unit length. Is this a straight line? Plot the distance between nodes as a function of the square root of the string's mass per unit length. Is this a straight line? Plot the distance between nodes as a function of the inverse of the square root of the string's mass. Is this a straight line? This tells us that the distance between nodes is directly proportional to the inverse of the square root of the mass per unit length of the string.
This can be written as:

$$\text{Distance Between Nodes} \;\; \alpha \;\; 1/\sqrt{mass\ per\ length}$$

$$\text{or:} \qquad L \;\alpha\; 1/\sqrt{\mu}$$

Putting it All Together:

We know from one of our previous experiments that the distance between nodes is directly proportional to the number of nodes (L α N). And we've just found out that L α 1/√μ. Combining these into one equation, we have:

$$L \;\alpha\; N/\sqrt{\mu}$$

Solving for the number of nodes, N, we have:

$$N \,\alpha\, L \cdot \sqrt{\mu}$$

Combining this with the remaining equations results in:

$$N \;\alpha\; f * L \cdot \sqrt{\mu}/\sqrt{T}$$

This equation is more traditionally solved for the frequency, f. This results in:

$$f \;\alpha\; N/L * \sqrt{T}/\sqrt{\mu}$$

or:

$$f = k * N/L * \sqrt{T}/\sqrt{\mu}$$

Where the proportionality sign, α, has been replaced by an equal sign and a proportionality constant, k. The next order of business is to resolve the proportionality constant k.

First, solve the final equation for k. This produces:

$$k = f L/N \cdot \sqrt{\mu}/\sqrt{T}$$

Choose a single string, place the idler pulley about 1 meter from the motorized base and hang a single B weight (medium size) from the string. Start the motor and adjust the frequency until the a single lobe standing wave is visible. Measure the frequency of the oscillation. Substitute these values into the equation for k to determine its value.

Time Allocation:

To prepare this product for an experimental trial should take less than ten minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.

Feedback:
If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.