Making Waves

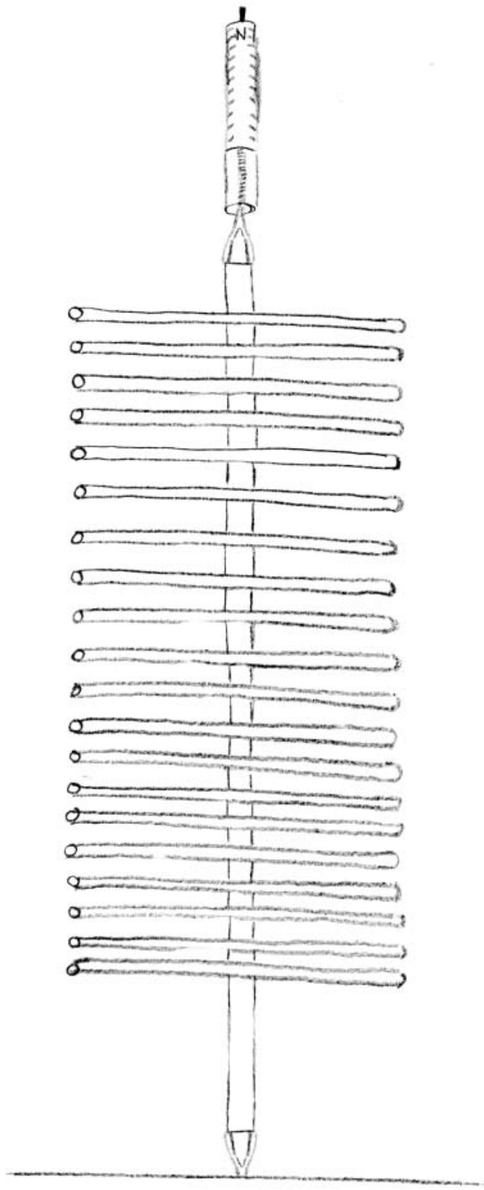
Commentary

In this exercise we will construct a simple "wave machine" similar to those found in Ron Edge's "String and Sticky Tape"©, published by the American Association of Physics Teachers (AAPT). This is an inexpensive book full of many, many simple and cheap projects and is recommended to anyone preparing to teach science. We will use the machine to discover and verify a relationship between frequency and wavelength that is fundamental and applies to ALL waves-sound, light, water, or whatever. We will also use the machine to see whether the velocity of waves somehow depend upon the tension in the tape.

There are two types of waves; longitudinal and transverse. Sound waves are ***longitudinal*** (meaning that whatever is doing the moving is doing so **parallel** to the direction in which the wave is traveling). In the case of sound in air, a "push" is given to the air, resulting in a series of compressions and rarefactions which transport sound energy from one place to another. One can visualize a sound wave as a sine wave by graphing the air pressure as a function of position. Light and waves on our machines are called ***transverse*** waves, meaning that the motion is **perpendicular** to the direction of wave travel. In the case of light, it is the electric field which is oscillating perpendicularly to wave propagation, and for our wave machine, it is rods or straws which are moving in the up and down or back and forth direction while the wave moves along the axis of the machine.

FM radio waves have frequencies of MHz and swings have frequencies of a fraction of ***I.*** Frequency and wavelength. The ***wavelength*** of a wave is the distance between any two like points. These can be minima, maxima, zeroes, or any two identical points. The wave repeats itself after one wavelength, or one full cycle. The ***period*** of the wave is the time it takes to complete one full cycle, analogous to the time it takes a swing to travel back and forth. The ***frequency*** is simply one divided by the period. If the period is expressed in seconds, then the frequency has units of cycles per second, called Hertz (Hz). Radio waves are Hz.

Inquiry



Construct your wave machine in the following manner:

1. Lay a piece of “Magic” tape about four feet long on a table top. Folding the ends back underneath will help to hold it in place.

2. Take as many low-mass soda straws as you need and stick them to the tape at about a ½” - 1” spacing,. With the center of the straw stuck to the tape. You will end up with something that looks like a fishbone. Make your machine about 3-4 feet long and leave some extra tape at the ends to fasted one to a spring scale and one to a heavy object at the bottom.

   - Hang your machine vertically by sticking the top to a solid object. Hold the spring scale (10N ones work best) at the top. Alternatively, you can fasten a paper clip to the bottom and hang washers or other weights from that if you don’t have a scale.

- Next, excite a pulse (wave) by tapping or twisting the top straw. Watch what happens when the wave reaches the bottom and comes back up. Did it get inverted or stay the same when it reflected at the bottom? We will call this travel time the “echo” time. Measure the echo time with a stopwatch and record it in your portfolio. Calculate the velocity of the wave by dividing the distance traveled (twice the length of the machine) by the "echo time". Record the tension and v.

- Now try exciting ***standing waves***. These are the result of traveling waves (pulses) which add to one another (called interference). Do so by holding the end of the top straw and wiggling it back and forth. You will find that at ONLY CERTAIN FREQUECIES (allowed frequencies or "Eigenfrequencies") are you able to establish standing waves! This is the underlying reason for the production of certain musical notes by vibrating systems, including strings, soda bottles, and wind instruments. One partner should measure the wavelength or count the number of waves and divide that number into the length to determine the wavelength. Either guess at the frequency with which you are pushing the straw back and forth OR measure several pushes with a stopwatch and divide the total time by the number of pushes, or pulses to get the period. The frequency is equal to 1/period. Keep the tension in the machine the same throughout this process! Fill in the table below in your portfolio:

Frequency	**Wavelength**

- Now, using the above data, multiply the frequency (in s^{-1} –the units for Hz) by the wavelength in whatever units of length you chose to use (I like Cm). The product equals the velocity of the wave! Is the product always equal to the same value **for a given tension** (I recommend 5 Nt) in the machine? List your values and give your answer below:

- For any type of wave, f x λ = velocity. (The Greek letter lambda is a universal symbol for wavelength.) Did your experiment prove this relationship to hold true for wave machines?

II. Dependence of wave velocity on tension.

- In this exercise, we will now vary the tension in the tape and look for a dependence of velocity on that tension. In order to alter tension, you can either add different weights to the paper clip at the end or attach the tape to a small spring scale.

- For several values of tension, record the velocity (the length of the machine divided by the echo time) as a FUNCTION of the tension in tabular form:

Tension	**Velocity**

- Finish (at home) by graphing the velocity as a function of tension (V vs. T). Do you get a straight line? Calculate the slope of this graph if it is straight and apply Y = mX + b to arrive at a functional relationship and record your work in your portfolio, along with the graph. Does increasing T increase or decrease V?

- Based on your results above, what happens when someone tunes a guitar or piano by turning a tuning peg? If the tension increases wave velocities, from what we saw in section I, what would happen to the frequencies "played" by the string?

III. Now that you have finished making the measurements, you can have fun with the wave machine. Remember inertia, the resistance to acceleration?

- What do you think would happen to the wave speed if you added mass to the straws by clipping a paper clip to the ends of each? Try it if you have time and report what happens. Is your prediction verified?

- What would happen to the wave speed if you lightened the straws by cutting some off of the ends of each one? If time permits, try it and report your findings. Was your prediction verified or not?

- I have two wave machines, one with short straws and one with long ones. If I connect them together in series, the wave from the top one reflects back rather than propagating in the second one (or some fraction does). Try this if you can. How should I construct a third one to attach in between them so a wave will pass smoothly from one to the other? This phenomenon is called ***impedance matching*** and works for many systems. It is why we put bells on the end of instruments, use exponential horns for PA systems, cheerleaders yell through long cones, etc.