RESONANCE & STANDING WAVES

(L-16)

In general, whenever a system capable of oscillating is acted upon by a periodic force whose frequency equals one of the system's *natural oscillatory frequencies*, energy will build and the system's oscillatory amplitude will become greater and greater. This phenomenon is called resonance.

Resonance is often demonstrated by attaching one end of a string to a fixed support and the other to a vibrating motor. The vibrator sets up traveling waves along the string which reflect off the fixed end, causing return waves to propagate back down the string. These superimpose on the newly created waves from the vibrator. How the incoming and outgoing waves interact depends upon how closely the vibrator's frequency matches one of the natural oscillatory frequencies of the string-system. When these match well, resonance occurs and orderly, large-amplitude *standing waves* are observed.

We will use a system similar to the one outlined above to examine resonance and the standing wave phenomenon in more detail.

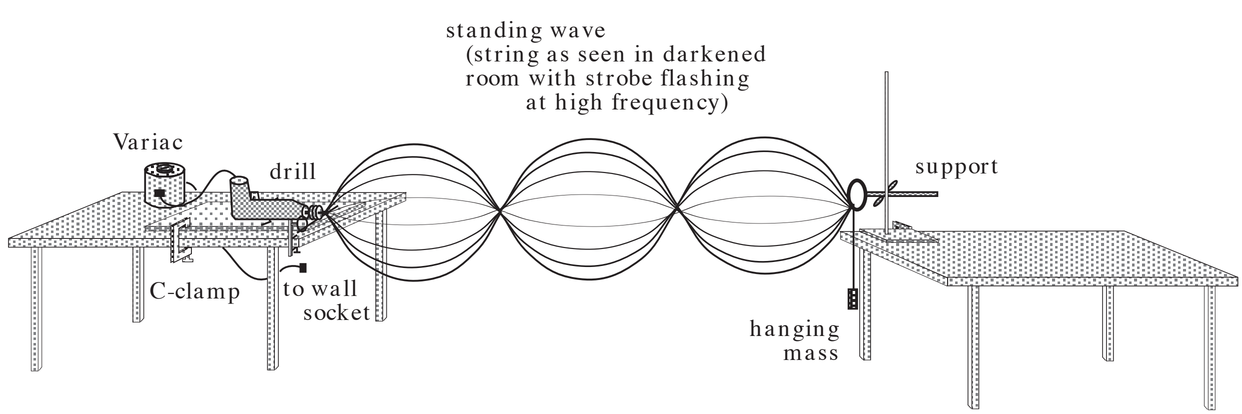
PROCEDURE--DATA

Part A: (the drill . . . no pun intended)

a.) A sketch of the system is shown. At some point you will have to measure:

i.) The total length of the string (call this d) and the string's mass m_t;

ii.) The length L between the *rotator* and the *fixed end* of the string;



and

iii.) The mass m_h of the hanging weight.

b.) In our setup, a drill-attachment will be used to rotate a rope in much the same way *jump-ropers* do. The DRILL'S speed and, hence, frequency will be controlled by a voltage-dividing device called a VARIAC. One member of the group will adjust the VARIAC until the drill produces an *n=2 standing wave* (I'll be demonstrating such a wave at the beginning of the period . . . it will look *something* like the wave shown in the sketch on the previous page).

Once the *n=2 standing wave* has been created, the only data needed will be the DRILL'S frequency. This would be amazingly simple to determine if our drill had a rotation-counter on it (the number of rotations divided by the time for the rotations gives the frequency). Unfortunately, it doesn't. To determine the required frequency, we will have to be tricky.

c.) Background: The approach we will be using requires a STROBE LIGHT, a SOLAR CELL, and an OSCILLOSCOPE.

--First, THE STROBE: A *STROBOSCOPE* produces light that flickers on and off at a prescribed frequency.

--In a darkened room, a STROBE flashing at high frequency will make a rotating rope (a jump-rope) look like a number of individual ropes. Bringing the frequency down eliminates these multiple ropes until there is just one. When the STROBE FREQUENCY exactly matches the frequency of the rotating rope, the rope will appear to stand still in one spot. In other words, to find the frequency of our rotating DRILL and ROPE, all we have to do is darken the room, start the STROBE flashing at <u>high frequency</u>, and decrease the frequency until our rope appears to be standing *single* and *still*. Determining the STROBE'S FREQUENCY for that situation will give us the DRILL'S FREQUENCY.

This frequency determination would be easy if our STROBE came with a frequency-counting meter on it. Unfortunately, it doesn't . . . which means we will have to resort to still more trickery.

--Enter THE SOLAR CELL and OSCILLOSCOPE: SOLAR CELLS are designed to *absorb light energy* and turn it into *electrical energy* in the form of a *voltage*. If placed against the face of a STROBE, the SOLAR CELL will generate large voltage spikes every time the STROBE flashes.

--An OSCILLOSCOPE consists of an electron gun and electronic circuitry designed to force a *gun-produced electron beam* to sweep across a fluorescent screen at some prescribed rate (the SWEEP TIME setting on the scope determines this sweep rate in *seconds per centimeter*). When a voltage is inputted into the SCOPE, the electron beam is diverted upward or downward, depending upon the voltage (a measure of the vertical diversion allows one to determine the size of the voltage, though we won't need that kind of data in this lab).

--If we attach the SOLAR CELL to the OSCILLOSCOPE input, the voltage spike generated when the STROBE flashes will be easily registered by the SCOPE. What is useful is that a measurement of *the number of centimeters between spikes* yields the pulse *wavelength* λ in *centimeter/cycle*. Multiplying that measurement by the SWEEP TIME in *seconds/centimeter* gives a number whose units are *seconds/cycle* . . . the units of the pulse's *period T*. As the period of harmonic motion equals the inverse of the motion's frequency (i.e., $T = 1/\nu$), we now have an experimental way to determine the frequency of our oscillating rope.

d.) In a nutshell, our procedure will go something like this:

i.) One member of the group will adjust the VARIAC until everyone agrees he or she has zeroed in on an $n = 2$ *standing wave*.

ii.) The classroom lights will go off and another member will start the STROBE at high frequency (our strobe has two range settings--start high) and decrease it until the string appears as a single rope standing motionless (this may well be found in the strobe's lower range setting).

iii.) With the lights still off, another member of the group will hold the SOLAR CELL (its leads will be hooked into the OSCILLOSCOPE) against the face of the STROBE while still another member adjusts the SWEEP TIME setting on the OSCILLOSCOPE until one or two *full-wave cycles* are shown on the screen.

iv.) The lights will go on. The wavelength will be measured off the OSCILLOSCOPE screen (in *centimeters per cycle*), and the SWEEP TIME setting will be recorded (in *seconds per centimeter*).

v.) Having done all this, the process will begin over again until data is taken for $n = 3$ and $n = 5$ standing waves. If you are into making data tables, this is a great lab for which to do so.

vi.) The last task is to check the data. You will do so by re-taking all the necessary data for an $n = 3$ wave (that is, go through *Steps i* through *v* once again for an $n = 3$ wave). If we have been careful, this data should approximately match that of your first run. If that is the case, we are done. If NOT, re-do THE ENTIRE LAB.

Technical NOTE for instructor: The oscilloscope should be set up to *trigger* off Channel A with a *sweep time* between 20 ms and 50 ms and with *DC coupling*.

CALCULATIONS

Part A: (standing waves)

1.) The expressions you will be deriving below will require knowledge of the wave velocity v. The velocity of a wave moving on a string is $(T/\mu_s)^{1/2}$, where T is the tension in the line (in this case, to a good approximation, that will equal the *weight of the hanging mass* mg) and μ_s is the string's *mass-per-unit-length*.

Using your data and showing your work, determine the velocity of the wave moving down the string in our experiment.

2.) In terms of the system-length L and wave velocity v, derive a *general algebraic expression* for the theoretical "natural" frequency $\nu_{th,3}$ for an $n = 3$ standing wave. Box your final expression.

3.) Use the equation derived above to calculate a numerical value for the theoretical frequency $\nu_{th,3}$ of an $n = 3$ standing wave on our rope. Show your work (i.e., put the numbers in so I can see what-you-used-where).

4.) Without showing your work, repeat *Calculations 2* and *3* for $n = 2$ and $n = 5$ standing waves. Put your results in a table, leaving an extra column for the ν_{exp} results you will determine in *Calculation 5* and another column for % deviations (use a straight edge on your table).

5.) Standing waves exist when the frequency of the force generator (the DRILL in this case) matches one of the natural frequencies of the system. We have determined three theoretical natural frequencies of our system. Now we need to use our data from the STROBE and OSCILLOSCOPE to determine the frequencies at which our system was experimentally observed to stand (call these frequencies $\nu_{3,exp}$ for the $n = 3$ situation, etc.).

a.) Use the data taken from your STROBE LIGHT and OSCILLOSCOPE to determine the DRILL frequency $\nu_{3.exp}$ for your $n = 3$ standing wave. Show your work on this calculation. Place your results in your table.

b.) Without showing your work, repeat the above calculation for $n = 2$ and $n = 5$ standing waves, putting your results in your table.

6.) For each kind of standing wave, do a % deviation between ν_{exp} and ν_{th}. Put your results in the table generated in Calculation #4. Comment on any major discrepancies you may find.

QUESTIONS

I.) Do a neat sketch for the wave form that would have been observed if we had made our system display **(a.)** an $n = 1$ standing wave and, **(b)** an $n = 2$ standing wave.