PHSX 221L **Standing Waves** **Name:**______________________

Object: (1) To study the relationship between resonant frequency and tension for standing waves in a string. (2) To measure the speed of sound in air by observing standing waves in a pipe.

Theory: If a uniform string of linear density μ is put under a tension τ and stretched between two supports it can be caused to oscillate in resonance with a driving frequency f, if that driving frequency matches one of the natural modes of vibration of the string. A natural mode of vibration corresponds to a standing wave pattern in which a node exists at each fixed support. Since the distance between two adjacent nodes is equal to one half wavelength, the length of the string must be equal to an integral number of half wavelengths at resonance.

The speed at which a wave moves through a medium is determined by the medium; for a string v can be calculated from the tension in the string and the mass per unit length. This relationship is Equation 16.4 in Serway. Since the speed of a wave can also be expressed as the product of wavelength and frequency, it is possible to derive a relationship between the string tension, the linear density, the string length, and the resonant frequency. Derive this relationship for f as a function of the others. This relationship will indicate the theoretical slope of the straight line produced when resonant frequency is plotted versus resonance mode index.

Standing waves can also be set up in tubes filled with air. If both ends of the tube are open, the length of the tube is equal to an integral number of half wavelengths (at resonance). Again it is possible to derive an expression for the resonant frequency in terms of the wave speed, the length of the tube, and the mode index. A plot of resonant frequency versus mode index should be a straight line with slope equal to the wave speed divided by twice the tube length. Verify this derivation.

The derivation for an open-closed pipe is similar but there will be a node at the closed end. See section 18.5 in Serway.

The theoretical speed of sound in air depends only on the air temperature (T, in kelvins) and is given to good approximation by

$$v \approx 20.\sqrt{T}. \tag{1}$$

(In actuality, v varies slightly with f, but only very slightly, so we ignore that here.)

Apparatus: You will use an oscilloscope today to detect the resonances in the tube of air. See `<http://www.physics.udel.edu/wwwusers/watson/phys345/lab/scope.html>` and `<http://www.tek.com/Measurement/App_Notes/XYZs>` for an introduction.
As always, sketch all relevant equipment.

Procedure:

1. Set up a string stretched with a known tension and drive it with an oscillator of variable frequency. (Measure μ of the string with a piece of string similar to the vibrating piece.) Adjust the frequency to obtain a sequence of resonances. Plot resonant frequency versus mode index number, compute the slope (least squares fit), and compare with theory.

2. Set up a loudspeaker driven by a variable frequency oscillator and use it to produce resonances in an open-open tube. (Please keep the amplitude knob on the frequency generators below 1/3 full value so as not to overdrive and damage the speakers. Also turn off the microphone when you are through.) Plot resonant frequency versus mode index. The mode is more difficult to determine for the tube than the string; one suggestion is to start with a low frequency and just try not to miss any; another suggestion is to use the equations in your text to help you decide where (in frequency) to look for resonances. From the slope of this plot compute the speed of sound in air, and compare it with the theory in equation 1.

3. Repeat procedure 2 for an open-closed tube.

4. Measure the wavelength directly by moving the microphone along the open-open tube when the oscillator is set to one of the resonance frequencies (say $n = 4$). Use $v = \lambda f$ and compare to theory for v.

5. Draw a few resonance patterns for a square metal plate.

Conclusions: