PHY132 Practicals Week 2 Student Guide

Concepts of this week's Module

- Superposition
- Standing Waves

Waves Module Activity 7

[heavily modified by J.Harlow Jan.2009]

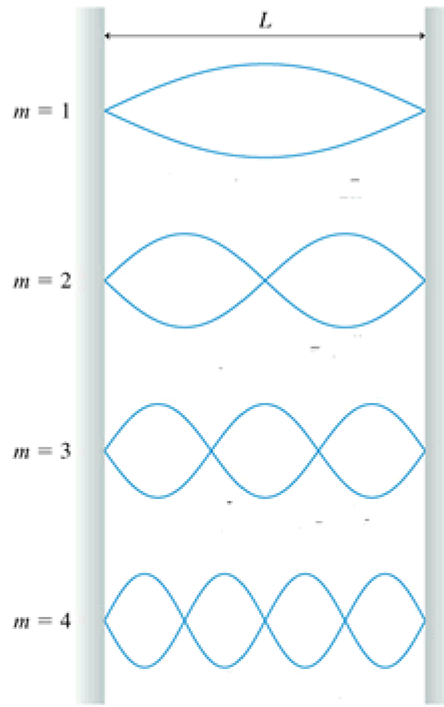
As discussed in the textbook Knight, the speed of a traveling wave on string with tension T_s is

$$v_{string} = \sqrt{\frac{T_s}{\mu}}$$

where μ is the string's mass-to-length ratio

$$\mu = \frac{m}{L}$$

Note that the speed is independent of the frequency. Also please do not confuse the string's mass, *m*, in kg, with the order number of the standing wave, *m*, which is dimensionless.



To the right are shown the first four normal modes of a vibrating string.

Here is a link to a simple Flash animation that shows the actual motion of the string for the first three normal modes:

http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/Flash/sta2fix.html

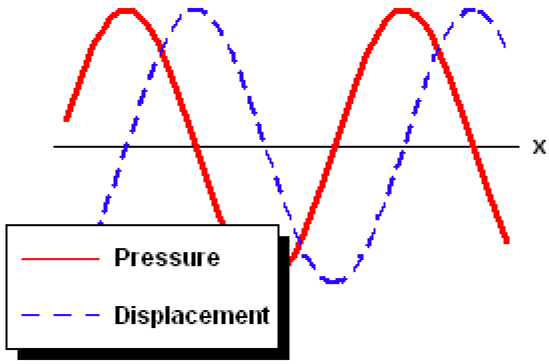
A. When a guitar string is playing the note A_2 = 110 Hz the frequency *f* of the first normal mode is also 110 Hz. The length of the string from the bridge to the nut is 1 m. What is the wavelength of the first normal mode? What is the speed of a traveling wave on the string? Explain why increasing the tension in the string increases the frequency of the note the string plays.
B. What is the wavelength of the *second* normal mode (m = 2) of the string? What is the frequency of the standing wave?
C. What is the wavelength of the *third* normal mode (m = 3) of the string? What is the frequency of the standing wave?

Waves Module Activity 8

As investigated in Activity 2 from Week 1, we can think of a sound wave two different ways:

1. A pressure wave. The pressure oscillates around atmospheric pressure.
2. A displacement wave. The displacements of the air molecules oscillate around their equilibrium positions.

These two waves are 90 degrees out of phase: when one has a maximum or minimum the other is at zero amplitude.

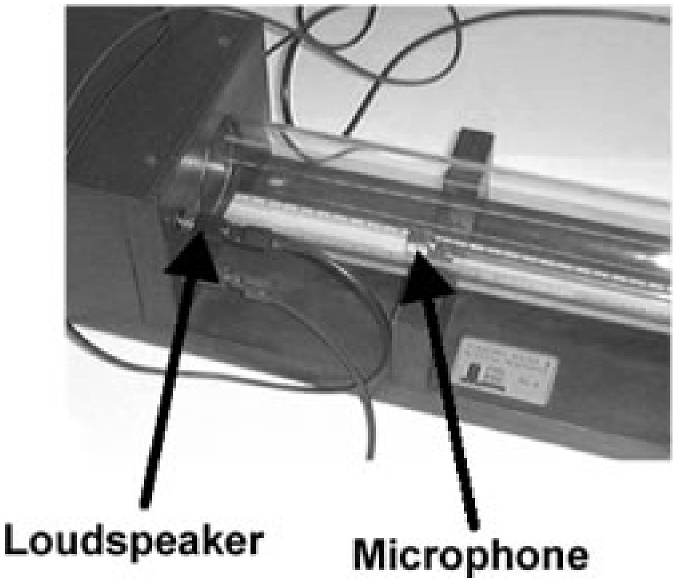


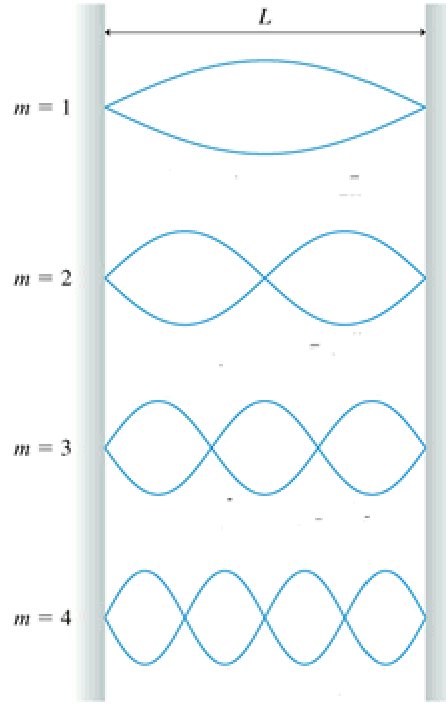
You will want to know that microphones measure the *pressure* wave. You will also want to know that the speed of sound is:

$$v_{accepted} = 331 + 0.61t \text{ (m/s}^2\text{)}$$

where *t* is the temperature of the air in Celsius.

In this Activity you will set up standing sound waves in a tube filled with air. A loudspeaker generates the sound wave. A meter stick inside the tube has a microphone (Sound Sensor) mounted on the end, so the sound wave inside the tube can be measured at different positions. The part of the tube with the loudspeaker is shown in the figure on the next page.





When the tube is closed at both ends, the possible *displacement* standing waves are the same as those for a standing waves on a string that is fixed at both ends: there is a node at each end of the tube. The figure to the right shows the first four possible standing waves. These are the same standing waves that for a string we called *normal modes* in Activity 7, and in fact this is the same figure that appears there!

Be careful not to push the Sound Sensor all the way into the speaker, as the speaker is made of paper!

A. For the tube you have been given, closed at both ends, what are the wavelengths of the shown standing waves? What is the wavelength of the $m = 5$ standing wave which is not shown? Generalise to a formula for the wavelengths for any value of m.
B. For the first two or three displacement standing waves, sketch the corresponding *pressure* standing wave.

Set up the tube on the table with the speaker further away from the computer.
The Data Acquisition Device (DAQ) is designed to interface between the computer and physical apparatus. It has two purposes for this experiment:

A. The DAQ generates a variable voltage which drives the magnet in the speaker and creates a sound. This is the ***input*** signal for the sound-tube.
B. The DAQ amplifies and measures the small variable voltage generated by the Sound Sensor, or microphone. This is the ***output*** signal from the sound-tube, which you will be measuring.

Plug the wire from the Sound Sensor into the **A (ai2) Analog Sensor** plug in the DAQ.

Plug the wire from the Speaker into the **ao0 Analog Output** plug in the DAQ. This connector must be pushed in and twisted clockwise a ¼ turn until it 'clicks'.

On the computer, open the Labview program which generates the output signal to the speaker and also measures and displays the input from the Sound Sensor. This program is at: My Computer → public on 'feynman' (P:) → Modules →Waves→ Speed of Sound Tube
Notes:

- You have to 'Run' the program to get anything to happen (the button with the small white arrow)
- To start the speaker, first click 'Acquire Data' so it turns green, then click on 'Function Generator' so it turns green
- To turn off the speaker click 'Acquire Data' again so it turns off. At this point you can use the cursors to measure the amplitude and period of the wave.

Testing the signal input

C. Make a sound by clicking on the Function Generator button. Adjust the frequency through the range from the minimum frequency to the maxiximum in intervals of about 500 Hz. Record your observations, including what you hear. For one frequency, try the different signal types, and record your observations, including what you hear. For the remainder of this activity, you will be using the Sine Wave.

Testing the Sound Sensor output

D. The graph which is displayed shows the pressure wave as measured by the sound sensor. Remove the Sound Sensor from the tube, keeping it attached to the meter stick. Turn off the Function Generator and try talking (or whistling!) into the sensor. (Please do not shout!!). Record your observations.

Measuring the Speed of Sound

Have the tube closed at both ends by blocking the open end opposite the speaker with the piece of plexiglass provided. Choose the Sine Wave and select a frequency of 570 Hz. [Your instructor may provide a different number but I have found that for these tubes a good standing wave exists for this frequency.]

E. Probe the standing wave with the microphone. Determine the positions of the nodes (where the amplitude is minimum) and antinodes (where the amplitude is maxmimum). You can stop the plotting by clicking on the "acquire data" button, and use the cursors to measure the amplitude in Volts, and the period in seconds. Verify that the period you measure of the output wave from the Sound Sensor is equal to the input signal into the speaker.

F. Determine the wavelength of the standing wave. Please use more than one measurement to do this. Recall the wavelength of a standing wave is twice the distance between adjacent nodes or antinodes, and four times the distance between a node and the nearest antinode. What is your uncertainty in the determination of wavelength? From your knowledge of the input frequency and your measurement of the wavelength, calculate the speed of sound and its uncertainty. How does your value compare with the accepted value given above?

Expt ***Waves Module Activity 9 [If you have time]***

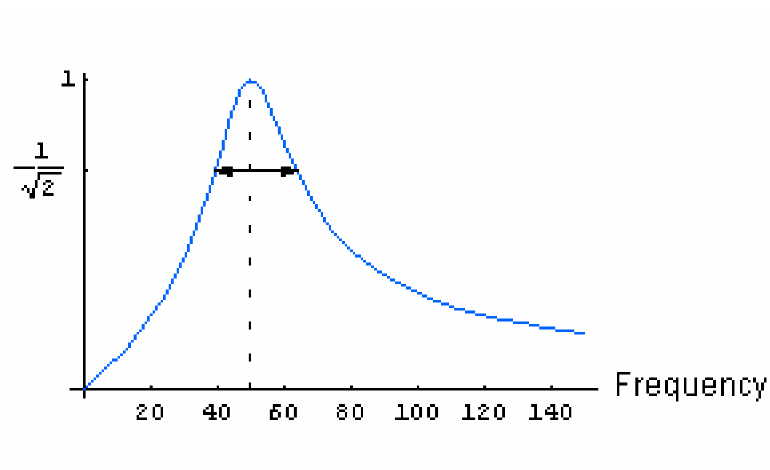
If the apparatus of Activity 8 were perfect, then when the tube is closed on both ends we would not hear any sound outside the tube. Similarly, if the air inside the tube were perfect, all molecule-molecule collisions would be perfectly elastic; this means that as a sound wave travels through the air none of its energy would be converted to heat energy of the air. However, neither the apparatus nor the air is perfect, The *Quality Factor Q* measures the degree of "perfection" of the system.

Say we have a standing wave when the frequency is f_0. For frequencies close to the "resonant frequency" f_0 the amplitude *A* of the sound wave at the position where there was an maximum in the pressure wave is given by:

$$A(f) = A_o \frac{1}{\sqrt{1 + Q^2\left(\frac{f}{f_o} - \frac{f_o}{f}\right)^2}}$$

Note in the above that the amplitude *A*(*f*) is equal to A_0 when the frequency *f* is equal to the resonant freqency .

The figure to the right shows *A*(*f*) for A_0 equal to 1, *Q* equal 2, and for a resonant frequency of 50 Hz. Note that we have indicated the width of the curve where the maximum amplitude is $1/\sqrt{2}$ times the maximum amplitude A_0.



A nearly trivial amount of algebra shows that the amplitude *A* is $1/\sqrt{2}$ times the maximum amplitude A_0 for positive frequencies when the frequency is:

$$f = \frac{f_0}{2Q}(\sqrt{1+4Q^2} \pm 1)$$

Thus, if the width of the curve is Δf, then *Q* is:

$$Q = \frac{f_0}{\Delta f}$$

A. For a given resonant frequency f_0 how does the width of the curve of amplitude versus frequency depend on the Quality Factor *Q*?
B. When the Quality Factor *Q* is zero, there is no resonance, the maximum amplitude is the same value A_0 everywhere. When *Q* is infinite so is the maximum amplitude (at the resonant frequency). Explain.
C. Close the tube at both ends and adjust for a standing wave at 570 Hz. Place the microphone at a maximum in the pressure wave and take data for the amplitude as a function of frequency for frequencies above and below 570 Hz. Calculate the Quality Factor of the tube.

Last revision to this write-up: January 20, 2009 by Jason Harlow.

The Waves Module Student Guide was written by David M. Harrison, Dept. of Physics, Univ. of Toronto in the Fall of 2008.

The figure of normal modes of a vibrating string in Activity 7 is slightly modified from Figure 21.22 of Randall D. Knight, **Physics for Scientists and Engineers,** 2nd edition (Pearson Addison-Wesley, 2008), pg. 640. The same figure is used in Activity 8.

Activities 8 and 9 are based on a Student Guide written by David M. Harrison in October 1999 and revised in June 2001.