Name______________________________Date________________Partners______________________________

LAB 12: OSCILLATIONS AND SOUND

Animals can hear over a wider frequency range of humans, but humans can hear over a wide frequency from 20 Hz to 20,000 Hz
(Image from http://archive.museophile.org/sound/)

OBJECTIVES

- To understand the effects of damping on oscillatory motion.
- To recognize the effects of resonance in oscillatory motion.
- To learn wave properties (wavelength, frequency, period, speed).
- To understand about standing sound waves in open and closed pipes.
- To confirm the speed of sound in air by $v = \lambda f$.

OVERVIEW

Oscillations

You have already studied the motion of a mass moving on the end of a spring. You already know how to find the angular frequency of the mass motion if we know the mass *m* and spring constant *k*. We will examine in this lab the mass-spring system again, but this time we will concentrate on damped and resonant phenomena. We will use small and large index cards connected to the mass at the end of a spring to provide damped motion through air resistance.

An example of a simple harmonic oscillator is a mass *m* which moves along the *x*-axis and is attached to a spring with its equilibrium position at $x = 0$. When the mass is moved from its equilibrium position, the restoring force of the spring tends to bring it back to $x = 0$. The spring force is given by

$$F_{spring} = -kx, \quad (1)$$

where k is the spring constant. We have learned that the equation of motion for m becomes sine and cosine functions like

$$x_1 = A \sin \omega t \quad \text{and} \quad x_2 = B \cos \omega t. \quad (2)$$

We can write a more general solution as the sum, $x = x_1 + x_2$. Therefore we may write

$$x = A \sin \omega_0 t + B \cos \omega_0 t \ . \quad (3)$$

where

$$\omega_0 = \sqrt{\frac{k}{m}} \ . \quad (4)$$

A and B are determined by the initial conditions. For instance, if at $t = 0$, $x = 0$, we find that A must be equal to zero. B may be determined from the value of the velocity at $t = 0$.

We will make the simplifying assumption that we will always pull back and release the spring from rest at $t = 0$. If we do this for Equation (3), we must have $B = 0$, and we have

$$x = A \cos \omega_0 t \quad (5)$$

We can write this in terms of the frequency f or period T by remembering that $\omega = 2\pi f$ and $T = 1/f$. We use the general ω instead of ω_0 for this generic equation.

$$x = A\cos\omega t = A\cos(2\pi ft) = A\cos\left(\frac{2\pi}{T}t\right) \quad (6)$$

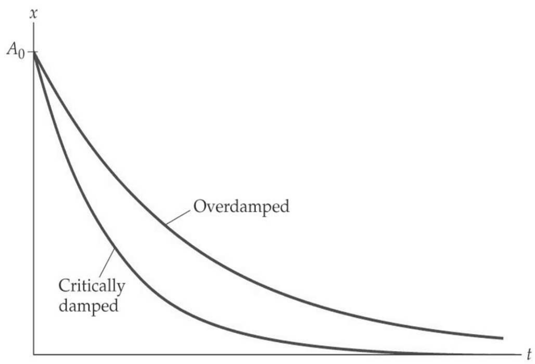

Figure 1: Damped Motion

Damped Oscillations

Most motions in nature do not have simple free oscillations like that of a mass at the end of a spring. It is more likely there will be some kind of friction or resistance to damp out the free motion. In this investigation we will start the free oscillations like we did in Investigation 5 of Lab 6, but we will add some damping. Air resistance is a good example of damping in nature. Other examples of damping include automobile springs, which are damped by shock absorbers to reduce motion caused by cars running through ruts in the road and screen door closures, which use air in a cylinder. The level of damping includes *underdamped*, *critically damped*, and *overdamped* (see Figure 1).

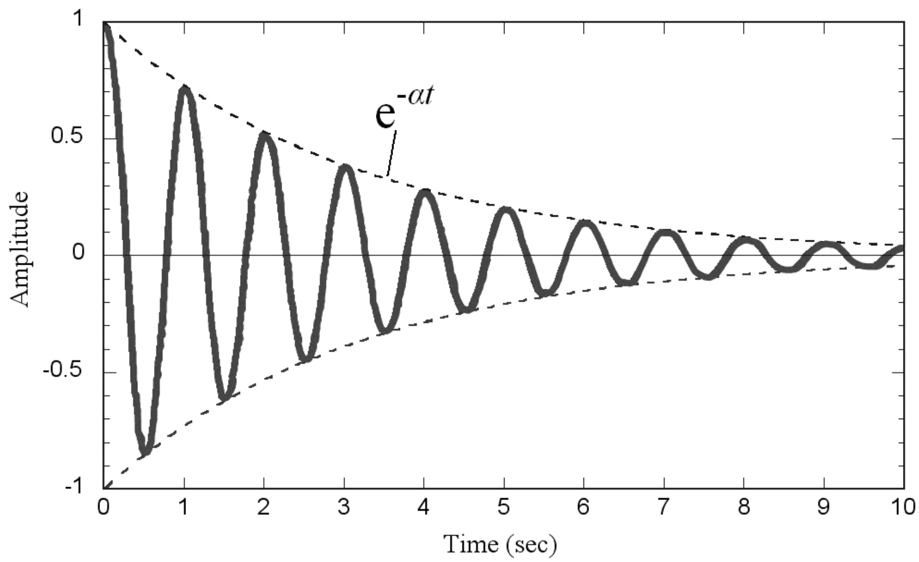

Figure 2: Underdamped Motion. The oscillations are damped by the exponential term.

The general type of friction, which occurs between oiled surfaces, or in liquids and gases, is not constant but depends on the velocity of the object v (cart in this case) .
The simplest form is

$$\text{resistive friction (kinetic)} = f_k = -bv \tag{7}$$

where we call b the *damping constant*. The new equation of motion becomes:

$$ma + bv + kx = 0 \tag{8}$$

where m (mass), b (damping constant), and k (spring constant) are constants, and a (acceleration), v (velocity), and x (position) describe the motion.

We will study underdamping in this experiment, so the motion will look like that shown in Figure 2. This motion is described by

$$x = A\cos\omega t \; e^{-\alpha t} \tag{9}$$

The angular frequency ω term in Eq. (9) is slightly different than the free frequency of Eq. (5), but the difference is too small to be seen in our experiment (so we will ignore it). The $\cos\omega t$ term is observed in Figure 2 (oscillating term), but the amplitude of each oscillation becomes smaller due to the exponential damping term $e^{-\alpha t}$.

Forced Oscillatory Motion

In addition to the restoring and damping force, one may have a separate force that keeps the oscillation going. This is called a **driving force**. In many cases, especially in the interesting cases, this force will be sinusoidal in time.

$$F_{\text{driving}} = C \sin \omega t \tag{10}$$

The equation of motion becomes

$$ma + bv + kx = C \sin \omega t \tag{11}$$

We can use calculus to solve this equation, but we will not do so here. After a few oscillations, the so-called "steady state" solution is

$$x = \frac{\left(\omega_0^2 - \omega^2\right)\sin(\omega t) - \dfrac{b\omega}{m}\cos(\omega t)}{\left(\omega_0^2 - \omega^2\right)^2 + \left(\dfrac{b\omega}{m}\right)^2}\frac{C}{m} \tag{12}$$

It contains a sin *and a* cos function, which tells us that the displacement x is not in phase with the driving term $C \sin \omega t$. To discuss the function of Eq. (12) we consider its variation with the driving frequency ω. First consider low driving frequencies. For $\omega << \omega_0$ (where ω_0 is the free angular frequency), Eq. (12) becomes:

$$x = \frac{C \sin \omega t}{m\omega_0^2} \tag{13}$$

Note that the displacement is in phase with the driving force at low frequencies.

At $\omega = \omega_0$ the displacement is 90° out of phase with the driving force. From Eq. (12) we see that the amplitude would go to infinity if b, the damping coefficient, is zero. In many mechanical systems one has to build in damping, otherwise resonance could destroy the system.

Sound Waves

Waves permeate nature. We define waves as a disturbance that propagates through space. Ocean waves and the self-generated human wave in a sports stadium come to mind. Wind blowing through a field of wheat causes the stalks to sway back and forth creating an image of a wave passing through the field. Sound waves travel through objects, for example air, by causing molecular vibrations, which in turn cause our ear drums to vibrate, which eventually causes a nerve impulse to be sent to our brain. The motion of the wheat stalks and ear drum can be described in terms of oscillations, which we study in this lab.

Sound waves are longitudinal waves (see Fig. 3) of compression (increase in density of molecules) and rarefaction (decrease in density of molecules) in a gas, liquid or solid medium. They are produced when a body such as a tuning fork, violin string, or cone of a loud speaker vibrates and causes a disturbance in the density of the medium. The disturbance is propagated by the interactions of its molecules. The vibration of the molecules is along the direction of propagation of the wave. Only the disturbance is propagated; the molecules themselves merely vibrate about their equilibrium positions.

Sound waves in a gas, such as air, can be thought of in terms of displacement of the molecules from their equilibrium positions or in terms of the change in pressure from the ambient pressure. The pressure variations are 90° out of phase with the displacement variations (see Fig. 3). The pressure maxima result from positive and negative displacements of molecules on each side compressing the gas in between. These relationships are shown in Fig. 3. .

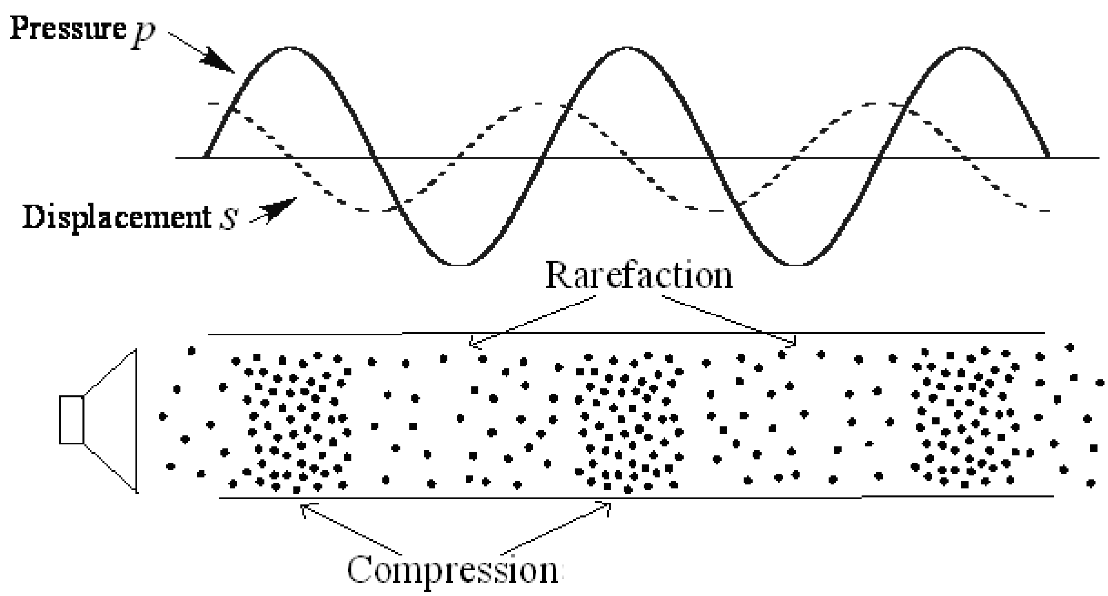

Figure 3. Top diagram shows that pressure and displacement of the molecules is 90^0 out of phase. The molecules oscillate about their equilibrium position. When many molecules are close together, the pressure increases, but the displacement is a minimum.

You have already studied the properties of waves in lecture where the wavelength λ, period T, frequency f, and speed v are defined as

λ = distance over which a wave repeats.

T = time it takes one entire wavelength to pass a given point in space.

f = the number of wave oscillations per unit time = $1/T$.

$$v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = \lambda f\ .$$

The human ear is an incredible device. It can hear over intensity ranges of 10^{12} and has a sensitivity that allows us to hear at a sound pressure of one billionth of atmospheric pressure. We often reproduce sounds using speakers. When the diaphragm of a speaker vibrates, a sound wave is produced that propagates through the air. The sound wave consists of small collective motions of the air molecules toward and away from the speaker.

The air molecules don't actually move far, but rather vibrate toward and away from the speaker at the frequency of the speaker vibrations.

Standing Waves in a Tube

Standing waves are created in a vibrating string when a wave is reflected from an end of the string so that the returning wave interferes with the original wave. Standing waves also occur when a sound wave is reflected from the end of a tube.

A standing sound wave has **displacement nodes** (points where the molecules do not vibrate) and **displacement antinodes** (points where the amplitude of the molecular vibration is a maximum). Pressure nodes and antinodes also exist within the waveform. In fact, **pressure nodes** occur at displacement antinodes and **pressure antinodes** occur at displacement nodes. Since your measurements with sound waves will be made with microphones, which respond to pressure variations, our discussion will mostly be in terms of pressure variations. We will henceforth emphasize the pressure variations and not the displacement.

Longitudinal Standing Waves

When longitudinal waves propagate in a gas in a pipe with finite length, the reflected waves interfere with the incident waves (traveling in the opposite direction). The superposition of the waves forms a standing wave. Reflection of the sound wave occurs at both open and closed tube ends. If the end of the tube is *closed*, the air has nowhere to go, so a pressure antinode must exist at a closed end. (This is analogous to a oscillating string fixed at one end.) If the end of the tube is *open*, the pressure stays very nearly constant at room pressure, so a pressure node exists at an open end of the tube. We will be measuring sound maxima or pressure antinodes in this experiment. That is, we will note where the sound is loudest by listening to a microphone.

To more easily understand the phenomena of sound, we encourage you first to review the subject in your textbook. Internet programs are helpful in understanding this phenomenon. See http://www.physics.smu.edu/~olness/www/05fall1320/applet/pipe-waves.html. This applet shows nodes and antinodes for both pressure and displacement. Let's first look at displacement. Make sure "displacement" is chosen. Then click on "both sides closed" (for the ends of the tube). Note what happens to the particles inside the tube. They oscillate back and forth, except at the ends where they are fixed. Then click on "both sides open". Note here that particles at the end of the tube can oscillate. Next look at "one side open". Next choose "pressure" and examine the same three tube conditions. Make sure you understand both pressure and displacement before coming to lab. You have been looking at the *fundamental* mode. Now click on "Higher" bar and observe higher harmonics (one at a time). Compare the nodes and antinodes for displacement and pressure. We will be examining pressure in this lab.

Normal Modes of Air Columns

Many musical instruments, including organ pipes and all the woodwind and brass instruments, use longitudinal standing waves (normal modes) in vibrating air columns to produce musical tones. Organ pipes are one of the simplest examples. There are two simple kinds of pipes, one with both ends open to the air, and one with one end closed to the air, or *closed*. These are the two situations we will examine in this lab.

1. Open Pipe

Let us consider the general problem of normal modes in an air column. The pipe may be a flute, a clarinet, an organ pipe, or any other wind instrument. In Fig. 4 both ends of the pipe are open, so both are pressure nodes (displacement antinodes). (The left side is open because it is open to atmospheric pressure and is therefore a pressure node.) An organ pipe that is open at both ends is called an *open pipe*. The fundamental frequency f_1 corresponds to a standing-wave pattern with a pressure node at each end and a pressure antinode in the middle (Fig. 4a). The distance between adjacent nodes is always equal to one half of a wavelength, and in this case that is equal to the length L of the pipe: $L = \lambda / 2$. The corresponding frequency, obtained from the relation $f = v / \lambda$, is

$$f_1 = \frac{v}{2L} \qquad \text{for an open pipe} \qquad (14)$$

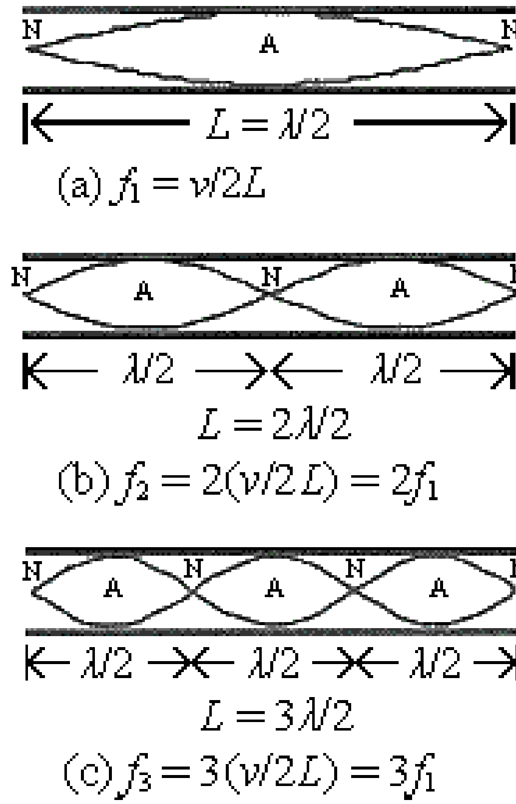

Figure 4. A cross-section of an open pipe showing the first three normal modes as well as the *pressure* nodes and antinodes. Interchange the *A*'s and *N*'s to show the *displacement* antinodes and nodes.

The other two parts of Fig. 4 show the second and third harmonics (first and second overtones); their vibration patterns have two and three pressure antinodes, respectively. For these harmonics, one half of a wavelength is equal to *L/2* and *L/3*, respectively, and the frequencies are twice and three times the fundamental, respectively. That is, $f_2 = 2f_1$ and $f_3 = 3f_1$. For *every* normal mode, the length L must be an integer number of half-wavelengths, and the possible wavelengths λ_n are given by

$$L = n\frac{\lambda_n}{2} \qquad \text{or} \qquad \lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, \ldots) \qquad (15)$$

The corresponding frequencies f_n are given by $f_n = v/\lambda_n$, so all the normal-mode frequencies for a pipe open at both ends are given by

$$f_n = \frac{nv}{2L} \qquad (n = 1, 2, 3, \ldots). \tag{16}$$

The value n = 1 corresponds to the fundamental frequency, n = 2 to the second harmonic (or first overtone), and so on. Alternatively, we can say

$$f_n = nf_1, \tag{17}$$

with f_1 given by Eq. (14).

2. Closed Pipe

Figure 5 shows a pipe open at the left end but closed at the right end. An organ pipe closed at one end is called a *closed pipe*. The left (open) end is a pressure node (displacement antinode), but the right (closed) end is a pressure antinode (displacement node). The distance between a node and the adjacent antinode is always one quarter of a wavelength. Figure 5a shows the lowest-frequency mode; the length of the pipe is one quarter of a wavelength, $L = \lambda_1 / 4$. The fundamental frequency is $f_1 = v / \lambda_1$, or

$$f_1 = \frac{v}{4L} \quad \text{for a closed pipe.} \tag{18}$$

This is one-half the fundamental frequency for an *open* pipe of the same length. In musical language the *pitch* of a closed pipe is one octave lower (a factor of two in frequency) than that of an open pipe of the same length. Figure 5b shows the next mode, for which the length of the pipe is *three-quarters* of a wavelength, corresponding to a frequency $3f_1$. In Figure 5c, $L = 5\lambda_1 / 4$ and the frequency is $5f_1$. The possible wavelengths are given by

$$L = n\frac{\lambda_n}{4} \quad \text{or} \quad \lambda_n = \frac{4L}{n} \quad (n = 1, 3, \ldots) \tag{19}$$

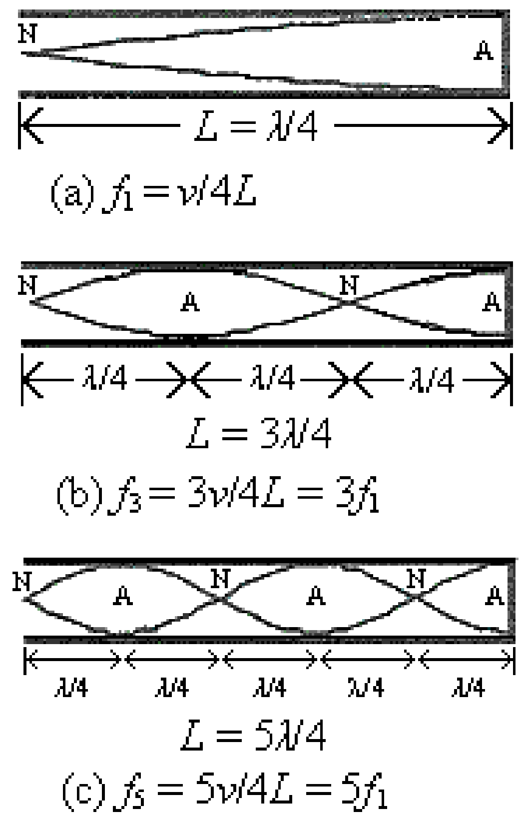

Figure 5: A cross-section of a closed pipe showing the first three normal modes as well as the *pressure* nodes and antinodes. Only odd harmonics are possible.

The normal-mode frequencies for a closed pipe are given by $f_n = v/\lambda_n$, or

$$f_n = \frac{nv}{4L} \quad (n = 1, 3, 5, \ldots) \tag{20}$$

or

$$f_n = nf_1 \quad (n = 1, 3, 5, \ldots) \tag{21}$$

with f_1 given by Eq. (18). We see that the second, fourth, indeed *all even* harmonics are missing. In a pipe that is closed at one end the fundamental frequency is $f_1 = \frac{v}{4L}$ and only the odd harmonics in the series ($3f_1$, $5f_1$,...) are possible.

INVESTIGATION 1: OSCILLATIONS

You have already studied oscillations with a mass and spring in Investigation 5 of Lab 6 on Work and Energy. In Activity 5-1 you measured the spring constant using the apparatus shown in Fig. 6. We don't need the force probe that is shown in Fig. 6 in the present investigation.

The spring is hooked to the hook clamp at the top, and the motion detector placed below measures the position of the index card.

In Activity 5-2 you examined the conservation of energy with air resistance provided by the card taped to the bottom of the mass. We are more interested now in studying the oscillations themselves, not the energy. We will examine, in particular, the damping of the motion with the air resistance and the phenomena of resonance when we drive the motion with an external oscillator that replaces the force probe.

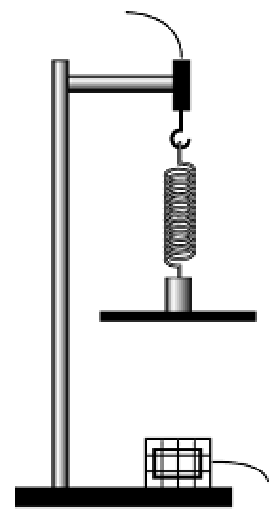

Figure 6

You will need the following:

- masking tape
- motion detector
- 50-g mass
- spring
- index cards (two sizes)
- hook clamp and supports to suspend spring

ACTIVITY 1-1: DAMPED OSCILLATIONS

1. Set up the apparatus as shown in Figure 7. The spring is connected to a hook clamp that is slid onto the upper rod. Tape a 3" x 5" index card on the bottom of

the 50 g mass. Make sure the index card is level. The motion detector should be on narrow beam and should be centered directly below the index card.

2. Open the experiment file **L12.A1-1 Damped Oscillation.** This file will have an automatic stop after about 20 s. It can be increased if needed.

Prediction 1-1: We need the index card to allow the motion detector to see an object that can reflect the sound waves from the motion detection. Imagine that if we set the spring in oscillation without the index card that the mass would oscillate sinusoidally for a long time with little damping. In practice, of course, the motion will always damp out somewhat. Do you think the index card adds additional damping due to air resistance? What do you predict would happen if we used a larger index card?

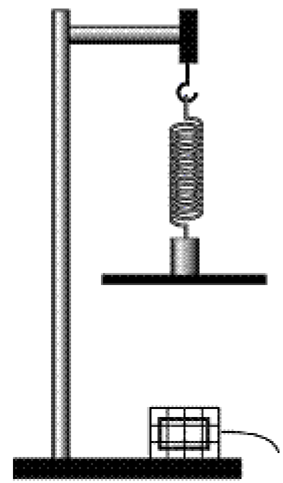

Figure 7

3. Start taking data with the mass at rest a few seconds and then have one student ***lift up*** the 50 g mass about 10 – 13 cm (don't measure!) and let go. You want the mass to oscillate straight up and down without much side motion. We find the subsequent motion is better when we lift the mass initially rather than pulling it down. You should see the oscillations in *Data Studio* but they will be diminished over time by an exponential function. You may see a few spikes in the data where the motion detector missed seeing the card. Try taking data a few times until you obtain clean data. Keep this data run for analysis and **print** out one copy for your group.

4. Determine the period and frequency of the sinusoidal motion. Describe what you did and show your work below. Try to be as precise as possible. The delta function of the Smart Tool may be useful here.

Period ______________ Frequency ____________________

Question 1-1: Try to estimate the damping term α from the time constant of the exponential damping of your motion. The time constant is the time it takes to decrease to e^{-1} of the motion at a given point. So the damping term α will be (time constant)$^{-1}$.

Describe how you find the damping term α and give your value.

Time constant ____________ Damping term α ______________

Prediction 1-2: You will next repeat step 3 with a larger index card. How do you think your values for period and damping constant will change?

5. Now replace the index card with the larger one and repeat steps 3 and 4 above. **Print** out your data for your group. In order to save time, you do not need to determine the period and damping constant from your data.

Question 1-2: Eyeball your two data graphs for the small and large index cards. Judge by looking at the data how the period and damping constant compare for the two index cards? Did they agree with your **Prediction 1-2**? Discuss your eyeball values for the two experiments and how they did or did not change.

DISCONNECT THE SPRING FROM THE TOP AND PLACE THE SPRING AND MASS ON THE TABLE!

INVESTIGATION 2: PROPERTIES OF WAVES

In this investigation you will measure the frequency, wavelength, and period of a wave.

The materials you will need are:
- PASCO function generator
- Computer system with PASCO interface

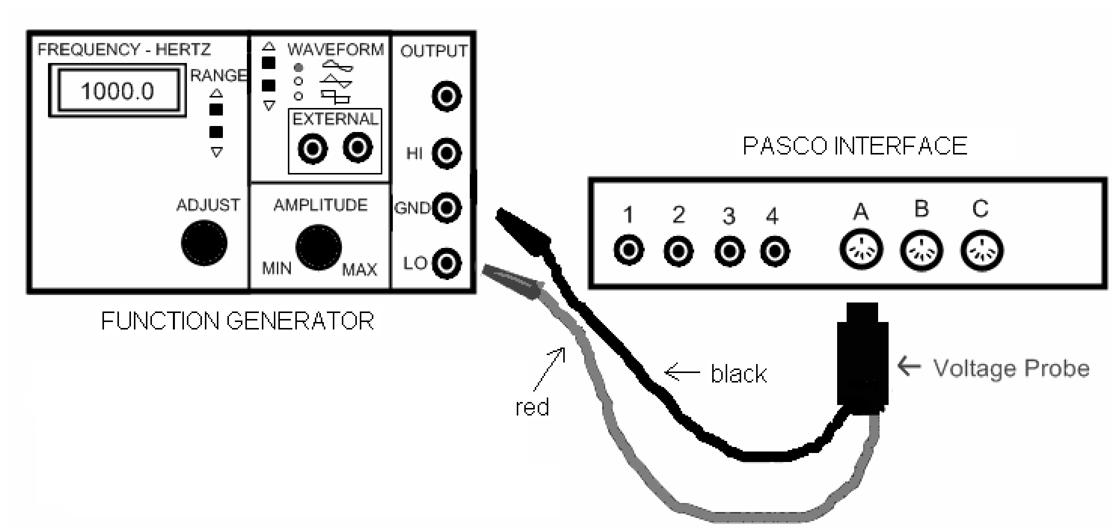

Figure 8. Connect cables from the PASCO function generator to the interface.

ACTIVITY 2-1. OPERATION OF FUNCTION GENERATOR AND OSCILLOSCOPE MODE OF *DATA STUDIO*

We first examine the output of the function generator by using the oscilloscope mode of *Data Studio*.

1. Set up the experiment as shown in the diagram in Fig.8. The function generator is turned on by a switch on the rear of the unit. Connect the voltage probe into channel A of the PASCO 750 interface. Connect the red banana plug of the other end to the LO Ω output of the function generator. Connect the black banana plug to the GND output of the function generator.

2. Look at the Waveform setting on the function generator. The light indicating the sine curve should be lit. If it is not, push the buttons above and below the up and down arrows to choose the sine curve. Set the frequency to 1000 Hz by turning the ADJUST knob (bottom left). You may need to adjust the Range buttons to obtain 1000.0 Hz. Note that by using the Range buttons, you can obtain an output accurate to 0.1 Hz.

3. Start *Data Studio* if not already started and open the experiment file titled **L12.A2-1.Wave Properties**. You will see *Data Studio* in the oscilloscope mode.

4. Click on the Start icon, and you might see data. If not, do not despair, because you probably need to make several adjustments. Everyone should pay attention to this procedure! The x-axis is the time scale, and the horizontal grid represents a time range. Look at the bottom of the screen and click the left or right arrows by the "ms/div" indicator and set this to 0.5 ms/div. The y-axis represents the voltage output of the function generator. Look at the Amplitude area on the function generator and turn the knob to about the 9:00 (on the clock) position. You may or may not be seeing a sine curve on the computer monitor by now. You still need to set the y-axis setting of the oscilloscope. Look at the top right area on the monitor and you will observe a box indicating voltage A with a "V/div" range and up and down arrows. This represents the volts/grid line on the vertical scale. Click the up or down arrows until you have 0.5 V/div.

5. If you don't see the sine curve, there is one last setting that needs to be done. Oscilloscopes have a trigger level that only allows signals above a certain level to be observed. You will see this trigger level on the left side of the monitor data region. It will probably be a small red arrow. Set the computer mouse arrow to be on top of this trigger level indicator (you should then see the small hand icon). Move the trigger up and down vertically using the mouse, and you should see the beginning of the sine curve start and stop at the particular level. The heavy horizontal grid line is zero voltage, so notice that you can even trigger the sine curve on a negative voltage. By moving the trigger level too far negative or too far positive notice that the signal goes away. That is because your signal is not large enough. You can make the signal reappear by increasing the Amplitude on the function generator! Do this. The trigger level can be very useful sometimes to help clean up signals. Sometimes we forget and leave the trigger level too high, and we cannot see our data.

Question 2-1: With the oscilloscope settings as described in steps 4 and 5, answer the following:

Full time width of horizontal scope view: ________ s

Maximum positive voltage on vertical scale: _________ V

HINT: We want you to use the scale settings on the x- and y-axes to determine this. You can check your results by using the Smart Tool.

ACTIVITY 2-2. WAVE PROPERTIES

We will use the same settings as the previous activity to examine the wave properties.

1. The function generator frequency should still be set at 1000.0 Hz.
2. For this frequency calculate the period expected.

   Period T ____________________ s

3. Determine the period of the waveform using the oscilloscope data. The easiest method is to use the Smart Tool to determine the total time for multiple cycles (periods); then divide the total time by the number of periods to obtain the period for one cycle.

   Number of time periods ____________ Total time ________________ s

   Period _________ s

Question 2-2: Compare your experimental results for the period with the calculated one from the function generator. Explain any discrepancies in the results.

Question 2-3: Change the frequency setting on the function generator to 500 Hz while observing the output with the oscilloscope. Describe what happens. Does this make sense?

INVESTIGATION 3: SOUND

In this investigation we will examine sound waves traveling down the plastic tube and examine interference effects. We will use the function generator to drive a speaker placed at one end of the plastic tube.

In addition to the material used for the previous Investigation we will need to add the following:

- 90 cm clear plastic tube
- two mounting stands for tube
- microphone with battery power amplifier
- long brass rod
- speaker
- 3-m tape
- wall mounted thermometer in room
- black and red wires to connect speaker

ACTIVITY 3-1. STANDING WAVES IN A CLOSED TUBE

1. The experiment may or may not be set-up when you enter the laboratory, with proper cable connections between the apparatus, oscilloscope and function generator. We will check this in steps 4-6 below. (See Fig. 9.) NOTE: The microphone is a pressure transducer.
2. We want to study standing waves in a closed tube, so we want the plastic tube set up like that described in the introduction. The end with the speaker should have the spacer inserted so there is a space of 3 mm between the plastic piece holding the speaker and the end of the plastic tube. This is the open end. The other end of the plastic tube should have the insert placed in the tube set precisely at the 80.0 cm mark (this is the value of L, the length of the tube) . This is the closed end. One end of the tube (with the 3 mm opening) is open. When one end of the tube is open and the other end is closed, we call it a closed tube. When both ends of the tube are open, we call it an open tube.
3. Open experiment file **L12.A3-1 Standing Waves** in *Data Studio*. This file will look just like the previous one, but the y-axis sensitivity has been increased by a factor of 100 because of the smaller signal coming from the microphone.
4. The black and red wires should be connected between the speaker input on one end of the plastic tube to the GND and LO Ω output of the function generator. It is okay to simply insert the banana plugs into the ones already there. The sound should be clearly audible, but not loud. Note also that many function generators become more efficient at higher frequencies, so you may need to reduce the amplitude as you raise the frequency.
5. Insert the microphone through the small end cap of the sound tube (speaker end). Insert the brass rod through the same hole and tape the microphone onto the end of the brass rod such that the microphone itself is 1-2 cm past the end of the rod. Use masking tape to attach the microphone wire tightly to the brass rod in a few places along the length of the brass rod. Hopefully you will find it in this situation, but you may have to repair it. The microphone is slid back and forth into the 90-cm long plastic tube. Note there is a switch on the microphone wire to turn the microphone amplifier on and off. It should be found in the off position in order to save special, expensive batteries. If you find it on, please tell the TA so we can deduct points from the previous students doing the experiment at this table! Make sure you turn the microphone amplifier off at the end of the lab. You can now turn on the microphone. The other end of the wire for the microphone should be connected to the BNC adapter that is connected to Channel B of the ANALOG CHANNEL INPUT on the PASCO interface.

CAUTION!
YOU CAN DAMAGE THE SPEAKER BY OVERDRIVING IT.
RAISE THE AMPLITUDE ON THE FUNCTION GENERATOR CAUTIOUSLY.

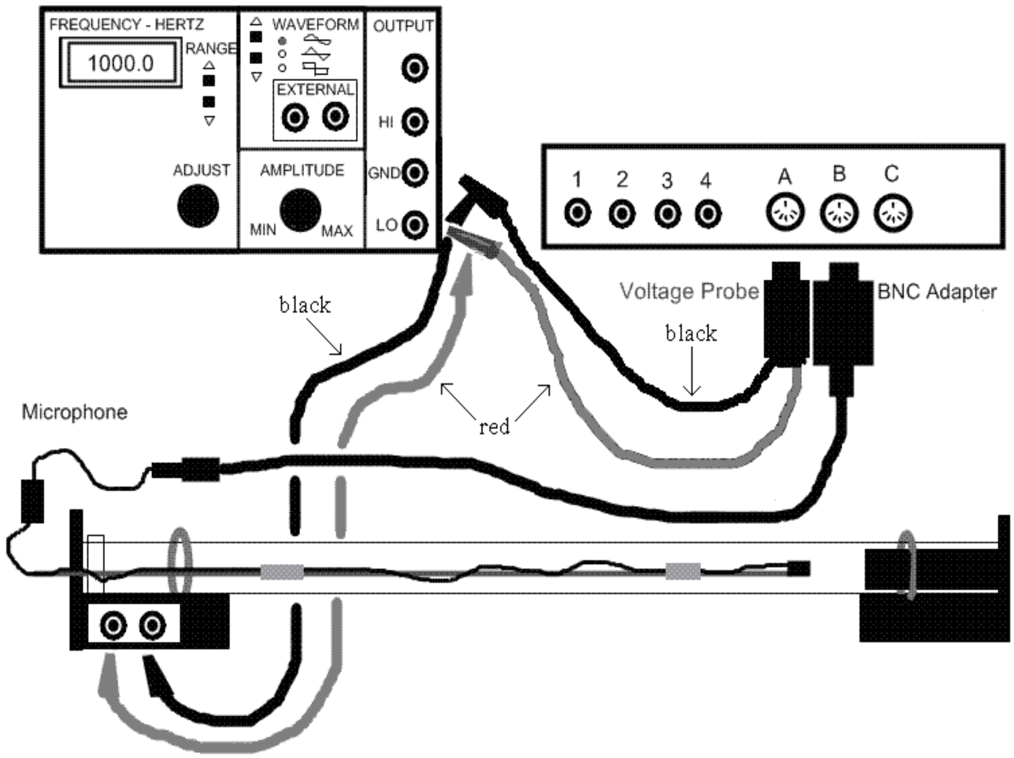

Figure 9. Setup for sound tube, oscillator, and microphone

6. Set the frequency of the function generator to about 900 Hz and the AMPLITUDE knob to about 9 o'clock. Start *Data Studio* and you should see sine waves. This represents the traveling sound waves moving back and forth in the plastic tube. The waves leave the speaker, travel down the tube, reflect from the closed end, and then interfere with the incoming sound waves. We will look for the places where the traveling waves interfere to make them appear to be standing or stationary waves as described previously. If you don't see a signal, check that the triggering level in *Data Studio* is not too high. You might also move the microphone (on the brass rod) back and forth and note that the signal level goes up and down. We will be examining the maximum signal levels in this experiment. You should leave the microphone near the closed end of the tub.

7. In the pre-lab assignment you calculated several things. Let's examine some of those results. Go to the wall thermometer and write down the room temperature.

   Temperature ______________________

Use Equation (5) in Appendix 1 to calculate the speed of sound at this temperature just like you did for the pre-lab.

Speed of sound (theoretical) ____________________

Write down the fundamental frequency (determined in the pre-lab assignment) that you expect for this experimental setup (which is the same as given you for the pre-lab).

Expected fundamental frequency _________________

We find that this fundamental frequency is not quite correct because of edge and other effects, but we do not have sufficient time to study these effects. We want to take measurements for the ninth and fifth harmonic frequencies for the closed tube. Use Equation (20) to calculate these expected frequencies. Remember that we only obtain odd harmonics for the closed tube.

Expected 9th harmonic frequency _________________

Expected 5th harmonic frequency _________________

8. Set the function generator frequency to the expected 9th harmonic frequency. The microphone should be about 10 cm from the closed end. Move the microphone back and forth a few centimeters until you obtain a relative maximum signal on the oscilloscope.

9. Now that we have the position of a presume antinode, let's adjust the frequency, because we mentioned previously that the calculation for the fundamental frequency is not precise. The expected 9th harmonic frequency will not be quite correct. We find the actual frequency is a little lower than expected. Slowly decrease the frequency until you find the maximum signal on the oscilloscope (and the loudest sound). Write down this frequency:

Maximum 9th harmonic frequency *f* __________________

Question 3-1: Put an X everywhere in the resonance sound tube outlined above where you expect to see a pressure node or antinode.

10. Note how many standing wave maxima you should expect in this case as you move the microphone down the tube. You should have determined this in the pre-lab assignment. Write down the positions of the standing wave maxima as you move the microphone towards the speaker. You may not need all the spaces below.

Standing wave maxima __________________ cm

Standing wave maxima __________________ cm

Standing wave maxima __________________ cm

Standing wave maxima __________________ cm

Standing wave maxima __________________ cm

Standing wave maxima __________________ cm

Question 3-2: Did the number of standing maxima that you just found agree with the number you predicted in Question 3-1 above? If not, explain the difference.

11. Use the data in the previous step to determine the wavelength λ. Show your work.

Value of wavelength ________________

12. Now determine the speed of sound, because you know both the frequency and wavelength.

Experimental speed of sound _______________

Question 3-3: Compare the experimental speed of sound you just found with the theoretical one you found earlier in step 7. Discuss how well they agree. Discuss possible errors if they are not within 5%.

ACTIVITY 3-2. STANDING WAVES IN OPEN TUBE

Now we want to examine standing waves for the open tube. According to the discussion in the Introduction, we should hear all the harmonic frequencies. We will only examine one of the harmonics in this activity.

1. We continue to use the same apparatus and experiment file.

2. On the end of the tube opposite the speaker, remove the bracket with attached plug that closed the tube for the previous activity. Lay the bracket with plug on its side to support the end of the tube. We now have an open pipe. Note that the length *L* of the tube is now 90 cm. You calculated the fundamental frequency for the open tube in the pre-lab assignment. Write it down here.

   Calculated fundamental frequency (open tube) ________________

Question 3-4: We should find pressure standing wave maxima at positions where we have pressure antinodes (or displacement nodes). Should we have maxima at the ends of the tubes? Explain.

3. Choose one of the harmonics from *n* = 3 to 6. List your choice below and determine the expected frequency for this harmonic.

   chosen harmonic: _______ calculated harmonic frequency____________ Hz

4. You will now perform a procedure similar to what you did in the two previous activities. Move the microphone to a position where you might expect a maximum. Set the frequency to the calculated harmonic frequency. Adjust the frequency a little to find a maximum (it should be a little lower than your calculation). Then move the microphone back and forth a few cm to find the local maximum. Now move the microphone to the far end of the tube and move it to

determine all the standing wave maxima for this harmonic. Write the postions you found for the maxima below. (If the distances are greater than 80 cm (on the tape), simply estimate and move on. Don't use this result in any calculation)..

Experimental harmonic frequency ________________ Hz

Standing wave maxima _________________ cm

Standing wave maxima _________________ cm

Standing wave maxima _________________ cm

Standing wave maxima _________________ cm

Standing wave maxima _________________ cm

Standing wave maxima _________________ cm

5. Now determine the wavelength of the standing wave and the speed of sound.

Value of wavelength _______________

Experimental speed of sound ______________

Question 3-5: Compare your experimental speed of sound with the one you calculated previously. How good is the agreement? Discuss. How might you improve the experimental value?

TURN OFF THE MICROPHONE AND FUNCTION GENERATOR.

APPENDIX 1: SPEED OF LONGITUDINAL WAVES

The propagation speed of longitudinal waves depends upon the mechanical properties of the medium. The calculation is beyond the scope of this course. Here we just quote the result:

$$\text{speed} = v = \sqrt{\frac{B}{\rho}} \tag{1}$$

where ρ is the density of the medium and *B* is known as the bulk modulus defined by

$$B = -\frac{\text{Pressure Change}}{\text{Fractional Volume Change}} = -\frac{\Delta P}{\Delta V/V}. \tag{2}$$

One now must know the equation of state for the medium in order to calculate the value of *B*. In this experiment, you will be using air at a pressure of 1 atmosphere (1 atm = 101.3 kPa) and at room temperature. At these conditions air will be very well described by the ideal gas law, $PV = nRT$. It should be realized that the pressure variations that constitute sound waves are very small. A very loud sound corresponds to a pressure change of about 10 Pa (10^{-4} atm) and a quiet sound has a gauge pressure change of less than 0.002 Pa.

If the temperature of the gas remains constant during the passage of the sound wave then *PV* = constant. However, when the gas is compressed, the temperature actually rises and when it expands the temperature decreases. This describes an adiabatic process where no heat enters or exits the system. In an adiabatic process for an ideal gas, $PV^{\gamma} = \text{constant}$, and we obtain a different result for *B*. The constant γ is the ratio of the specific heat at constant pressure to that at constant volume. For a diatomic gas such as air, $\gamma = 1.4$. (For monatomic gases such as helium, $\gamma = 1.67$). Thermal conductivities of gases are very small, and it turns out that for ordinary sound frequencies, from 20 to 20,000 Hz, propagation of sound is very nearly *adiabatic*.

Using the adiabatic bulk modulus B_{ad}, derived from the assumption that PV^{γ} = constant, we determine the speed of sound for an ideal gas to be

$$v = \sqrt{\frac{\gamma P}{\rho}}. \tag{3}$$

We can obtain a useful alternative form by using the ideal gas law to determine the density ρ of an ideal gas. Remember that *n* is the number of moles, *M* is the molecule mass per mole, and the total mass is $m_t = nM$). Then

$$\rho = \frac{m_t}{V} = \frac{nM}{nRT / P} = \frac{PM}{RT}, \tag{4}$$

Where P is the pressure, R is the gas constant, and T is the absolute temperature. If we insert the density ρ from Eq. (4) into Eq. (3), we find the speed for an ideal gas to be

$$v = \sqrt{\frac{\gamma RT}{M}}. \tag{5}$$

For any particular gas, γ, R, and M are constants, and the wave speed is proportional to the square root of the absolute temperature. Air consists of 78% N_2 and 21% 0_2, with a mean molecular mass of $M = 28.8\times10^{-3}$ kg/mole. Recall that $R = 8.3145$ J/(mole K), and at a room temperature of 20°C, T = 293 K.