Section: Monday / Tuesday (circle one)

Name: ______________________________

Partners: ______________________________

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Total: /35

PHYSICS 107 LAB #4: WIND INSTRUMENTS: WAVES IN AIR

Equipment: Thermometer, function generator, two banana plug wires, resonance tube with speaker, small cups (for bailing) cardboard resonance tube, Isopropyl & paper towels (cleaning resonator mouth), jug, speaker, large plastic measuring cup, ruler, meter stick, microphone, o'scope.

OBJECTIVES

1. To observe the phenomenon of resonance for sound waves in air.
2. To explore the conditions for resonance in a tube and a Helmholtz resonator.

READINGS

To prepare for this lab, you should read the following sections of the text: Sections 3.4, 11.3, and 12.1

OVERVIEW

Tube

A tube of resonating air is central to two families of instruments, brass and woodwinds; more generally, the resonance cavities of the stringed instruments play important roles in coloring their tones by selectively amplifying some frequencies over others. In this lab, we will study the relationship between the modes of air-filled resonators and the resonating cavities' dimensions.

The speed of a traveling wave is related to its frequency and wavelength by

$$v = f\lambda .$$

The speed depends on the medium in which the wave is traveling. The speed of sound in air depends most strongly on the temperature; factors such as changes in humidity (i.e., subtle changes in the air's composition) don't affect it as much. If the temperature is measured in Celsius, the theoretical value of the speed of sound in air is approximately

$$v = 344\,\tfrac{m}{s} + \left(0.6\,\tfrac{m}{s\,°C}\right)\left(T - 20°C\right).$$

Closed at one end

A standing wave is when the wave crests don't appear to travel along the medium (string, or air). Instead, points of no displacement (nodes) stay put and the crests (antinodes) oscillate between maximum and minimum. For sound waves in a pipe, a closed end will be a node of displacement (the air can't be pushed *through* the pipe's capped end.) and an open end will be an antinode. A wave "fits" these conditions only if (quite nearly) an odd integer number of *quarter*-wavelengths fit in the tube:

$$L = n\tfrac{\lambda}{4}\text{, where n = 1,3,5....}$$

When this condition for a standing wave is met, there will be a resonance and the amplitude of the wave will become large. For sound waves this means a louder sound.

Open at both ends

Most wind instruments would qualify as being open at one end (the bell) and closed at the other (the mouth piece); however, there are a couple of exceptions – some organ pipes and the flute are open at *both* ends. For these, the air is *extra free* to move at both ends – making these displacement anti-nodes. A wave "fits" these conditions only if (quite nearly) an integer number of *half*-wavelengths fit in the tube:

$$L = n\tfrac{\lambda}{2}\text{, where n = 1,2,3,....}$$

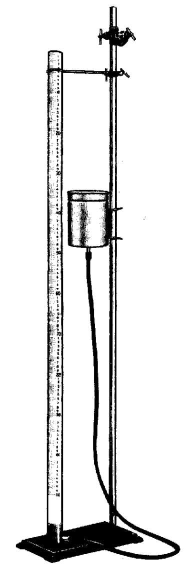
When this condition for a standing wave is met, there will be a resonance and the amplitude of the wave will become large. For sound waves this means a louder sound.

Helmholtz Resonator

A typical example of a Helmholtz Resonator is a jug or soda pop bottle. As you're quite familiar, blowing across its top produces a characteristic tone, indicating that the air in the bottle prefers to oscillate, or resonates, at a particular frequency. A qualitative mechanical analogy is that the air in the bottle's neck is like a mass sitting on the spring / cushion of the air in the bottle's volume. Blowing across the moth of the bottle produces a complicated disturbance in the air pressure at the mouth which sets the 'mass' bouncing. For the bottle, the natural frequency is $f_{Helmholtz} = \varepsilon \frac{v}{2\pi}\sqrt{\frac{a}{Vl}}$ where v is the speed of sound in air, a is the area of the mouth (πr^2), l is the length of the neck, and V is main volume (excluding the neck) of the bottle. The exact shape of the bottle affects the parameter ε, a 'form factor', it is typically in the range of 0.5 to 1 which speaks to how much air above and below the neck should be considered part of the 'mass' that bounces on the 'air spring.'

Experiment: Speed of Sound in Tube Closed at one End

With a speaker playing a constant frequency (f) mounted at the top of a column of air, you will vary the column's length and identify the lengths for which the column resonates (the sound gets louder). From this you will determine the wavelength corresponding to frequency of sound, which will be used find the wave speed.



A. The apparatus you will use is pictured to the right. Slide the metal reservoir as high up as it will go. Slowly fill the reservoir until the glass tube is nearly full (within about 10 cm). Be sure that there are no kinks in the rubber tubing. The water level in the glass tube can be adjusted by raising or lowering the supply tank.

B. Position the speaker over the glass tube and connect it to the function generator. Make sure the function generator is set to produce a sinusoidal wave. Set the frequency to about 650 and turn the speaker on at a <u>low</u> volume (0.05 Volts should do.)

f = ______________________

C. Keeping the frequency constant, *slowly* lower the water level until the first resonance is reached and the sound becomes much louder. Determine the position of the resonance by slightly raising and lowering the water level until you are sure that the sound is at maximum intensity. Enter this into the table on the next page. **Warning**: the speaker does not produce a pure tone, so you may hear fainter and higher pitched resonances – you should ignore these.

D. Repeat the above procedure for the entire length of the glass tube and enter the results in the first column of the table below. Be careful to increase the length of the air column so that you don't miss a resonance! (Note: Make sure the reservoir does not overflow. At some point, you'll need to remove some water from it.)

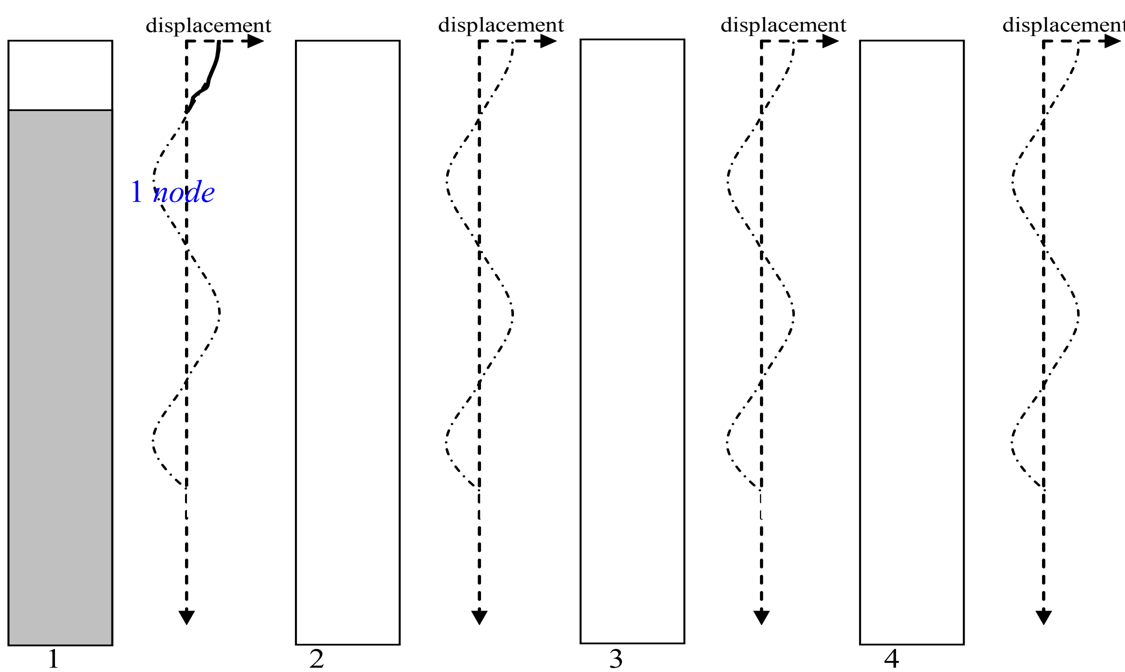
/4 pts

	Length of air column (m)	Fraction of wavelengths in column*	Wavelength (m)
shortest		= __1_ λ/4	
		= ____ λ/4	
		= ____ λ/4	
longest		= ____ λ/4	

*See the sketches you're to produce below.

E. Sketch the water level and trace over the appropriate length of the dashed standing waves for the displacement of the air for each of the resonances. (The first one is done for you.) In the table above, enter the number of wavelengths or fractions of wavelengths are in each standing wave. (The first one is done for you.)

/6 pts



F. Take the average of all of your measurements for the wavelength.

/1 pt

λ_{avg} = ________m____

You'll compare your measured wavelength with that expected, given the frequency and the expected speed of sound in air.

G. Measure the temperature of the room in Celsius (the instructor should have a thermometer out that's measuring this.)

/1 pt

T_C = ________ °C

Question: Based on the equation given on page 1, what's the theoretically expected speed of sound?

/2 pts

v = ____________________________ m/s

Question: Now, since $v = f\lambda$, given the frequency you used (recorded on page 3), what wavelength would you theoretically expect the sound waves to have?

/2 pts

λ_{th} = _______________________ m

Question: Finally, how does your average experimental measurement of the wavelength compare with that theoretical value (% difference)? Show your work. If they differ by much more than 10% find and fix your mistake.

/2 pts

$$\% \text{ difference} = \left(\frac{\lambda_{\text{avg}} - \lambda_{\text{theory}}}{\lambda_{\text{theory}}}\right) \cdot 100\% =$$

Experiment: Speed of Sound in Tube Open at Both Ends

You'll explore the relation between tube length and resonance frequency for a tube that's open on both ends.

A. **Setup**. You'll use most of the same apparatus as before, but rather than a glass tube with water that can be raised or lowered, a pair of nested cardboard tubs that can be lengthened or shrunk like a telescope. Swing the microphone away from the glass tube so you can hold the cardboard one below it.

B. You'll fill in the table below.

a. For each frequency, dial in the frequency, then hold the tube beneath the speaker and adjust its length until it resonates (the sound becomes appreciably louder), measure the length of the tube.

b. At resonance, the tube should be holding half a wavelength; actually, the sound wave extends about 2cm beyond each open end, so to calculate the wavelength by adding 4cm and then multiplying by two.

c. Given that the wave speed is 344m/s for sound in air, calculate the wavelength you'd *expect* for sound of this frequency.

d. Compare – find the percent difference.

/3 pts

frequency f (Hz)	Length L (m)	Wavelength measured (m) $(L + 0.04)*2$	Wavelength expected (m) $\frac{344\ m/s}{f}$	Percent difference
525				
500				
475				

Question: How do the expected wavelengths compare with those you've determined by assuming that half a wavelength fits in the open tube (within 10%)?

/1 pt

Experiment: Helmholtz Resonator form factor

You'll experimentally determine a jug's Helmholtz resonance frequency, from that and the predicted equation for it, you'll determine the 'form factor,' ε, then you'll test your value with a half-filled jug.

1. **Determine a Helmholtz resonator's resonance frequency by ear**. Blow across the mouth of a Helmholtz resonator and simultaneously drive a speaker with a function generator and dial its frequency until it matches pitch with the resonator. Note: *like a piano tuner, you should hear the slow pulsing of 'beats' when you get close – the slower they are, the closer the two frequencies match.*

/1 pt

f_{ear} = ______________________Hz

2. **Determine the frequency directly.** Let's see how good a job you did by ear – use the microphone connected to the o'scope to measure the frequency.
   a. **Setup.** As usual, this should already have been done by your instructor, but worth glancing over to make sure.
      i. Microphone plugged into channel 1 of the o'scope
      ii. Channel 1's scale set to 5.0 mV per division and the time scale set to 5.0 ms.
      iii. O'scope set to read out Channel 1's frequency (left side of the screen)
      iv. Acquire – set to average over four 'snapshots' before displaying.
   b. Recall, you can freeze the o'scope by pushing the "run/stop" button in the upper right corner, and the frequency measurement should be displayed at the right side of the screen.

/1 pt

$f_{o'scope}$ = ____________________ Hz

Question: How close were you? What's the percent difference between the frequency you determined by listening for beats and the frequency that the o'scope reports? (should be within 10%)

/1 pt

3. **Determine the 'form factor' for your resonator.** Use the ruler to measure the length of your resonator's neck and the radius of its mouth and determine its area

l = __________________ m

r = __________________ m

/2 pts

a = π r^2 = _______________ m^2

   a. Determine the resonator's volume (by determining the volume of water it holds)

      Poor water in up to the base of the neck, then poor the water into a measuring cup. Note: 1 Liter = 0.001 m^3.

/1 pt

V = ________________ m^3

b. Use your measured values and the speed of sound (page 5) to solve $f = \varepsilon \frac{v}{2\pi}\sqrt{\frac{a}{Vl}}$ for the form factor, ε. (remember, *v* is the speed of sound, *V* is the volume.)

/2 pts

ε = ____________________

4. **Test your value.** If you got it right, then changing the effective volume of the resonator should change its resonance frequency in a predictable way. So, change the effective volume of your resonator by roughly a factor of 2 by adding water. Predict and measure the new frequency (again, by blowing across and tuning a function generator until you hear beats).

/1 pt

V_{new} = ____________________________ m^3

/2 pts

$f_{predicted}$ = _______________________ Hz

/1 pt

$f_{measured}$ = _______________________ Hz

Question: How do these compare; that is, what's their percent difference?

/1 pt