Name____________________
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Velocity of Sound in Air

Purpose:

To measure the velocity of sound in air using the resonance produced in an air column of variable length.

Introduction:

A tuning fork acts as a source of sound when it is set into vibration. The vibration of the fork causes periodic changes in the density of the surrounding air which propagate outward at a velocity given by

$$v = \sqrt{\frac{l\ P}{r}}, \qquad (1)$$

where P is the pressure of the undisturbed gas, and λ is the ratio of the specific heat at constant pressure to the specific heat at constant volume (1.403 for air) and ρ is the density of air. Using the Ideal Gas Law, $PM/\rho = RT$, this equation can be rewritten as,

$$v = \sqrt{\frac{l\ RT}{M}}, \qquad (2)$$

where R is the universal gas constant, M is the molecular weight of air, and T is the absolute (Kelvin) temperature. Therefore, the velocity of sound in air depends only on the temperature; if we measured the velocity at two **different** temperatures we should find,

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}. \qquad (3)$$

The sound waves generated in air are longitudinal waves (the air molecules vibrate in a direction parallel to the propagation of the waves), in contrast to the waves on a plucked string. For either the longitudinal or transverse was the velocity, v, is related to the frequency of vibration, f, and the wavelength, λ, through,

$$v = f\ l. \qquad (4)$$

In this experiment we will be given f, measure λ, and thus find v.

To measure the wavelength of sound we will use the phenomenon of resonance in closed tubes. The closed tube, similar to an organ pipe, is called the resonator. For certain lengths of the pipe the sound emitted by the tuning fork is strongly amplified. This occurs when one of the pressure maxima in the wave travels down the pipe, is reflected, and returns to the fork just when the fork is producing another maximum. This gives the fork more material to "push against," increasing the transfer of energy from the fork to the air and thus increasing the intensity of the sound wave.

How long will the resonator be? The closed end must be at a position of minimal vibration amplitude (node), while the tuning fork end must be at a maximum. As there are two nodes per wavelength the minimum resonator length is $\lambda/4$. Further resonances will occur for each $\lambda/2$ extension of the tube.

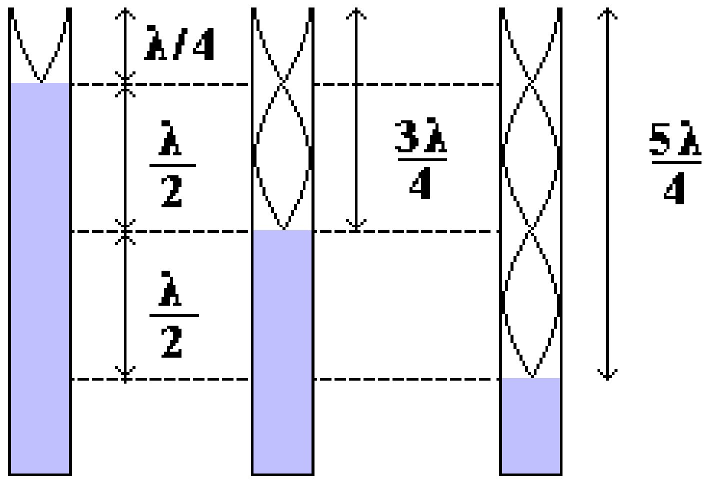

Figure 1: Resonant Pipes

Since the mouth of the organ pipe is somewhat different from the remainder of the pipe it is not too surprising that the position of the shortest resonance point might not quite be $\lambda/4$. It is safer to measure the separations between the longer resonance lengths. From this measurement of wavelength the velocity of sound in air can be found. Since the density of air varies with temperature it is easier to compare the measured value of v with an accepted value by applying the law of expansion of gases to obtain

$$v_o = v_T\,(1 - aT), \tag{5}$$

where v_{oi} is the velocity at 0ºC (332 m/s), T is the temperature of the air in the resonance tube in degrees Celsius and $a = 1.83 \times 10^{-3}$ / ºC.

Experiment:

The apparatus to be used for this experiment is the resonance tube shown in Figure 2 (next page). A plastic tube is mounted vertically next to a meter stick. The lower end of the tube is connected through a flexible tube to a reservoir. The elevation of this reservoir can be adjusted along the supporting rod; as this elevation is adjusted, the length of the water column in the plastic tube will vary. If the vibrating tuning fork is held above the tube, the length of the air in the column in the tube can be adjusted until a reinforcement of the sound is heard. At that point the length of the column will be:

$$L = l\ /4, 3l\ /4, 5l\ /4, \ldots \tag{6}$$

According to Equation (6) the difference between successive resonance positions will be $\lambda/2$. Start with the water level near the top of the tube. Strike the tuning fork gently with a soft rubber hammer (never use a hard object; this will damage the tuning fork).

Slowly lower the water level while listening for the pronounced increase in loudness indicating resonance. Once you have determined the approximate position, make several trials, running the water level upwards and then downwards, until you have determined the position to within a millimeter or two. Note this position on the scale.

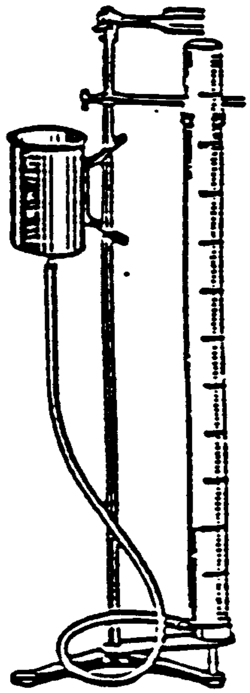

Figure 2: Resonance Tube of variable length

Now, lower the water surface and , in a similar way, find successive resonance points, continuing all the way to the bottom of the tube.

By subtraction, find the distance between successive points, take the average and use this average value to find λ. Be sure to include uncertainties in your measurements so that you will be able to find the uncertainty in λ.

Use this value of λ and the frequency stamped on the tuning fork to find the velocity of sound in air at the ambient temperature [Equation(4)]. Correct this value of v_T to 0^oC using Equation (5) and compare this result for v_o with the published value of *332 m/s*. Do your experimental uncertainties account for the derivation of your value of v_o from the published value?

Repeat this experiment with a tuning fork of a different frequency. Do your values of v_o agree with each other? With the published value? Do your estimates of the uncertainty now seem reasonable, or did you over- (or under-) estimate these uncertainties?

Questions:

Q1: Derive Equation (5) starting from Equation (3) and using the fact that *T(in oC) = T(in K) + 273K*. You will also have to use the fact that, for the temperatures encountered in the lab, *T(in oC)* << 273.

Q2: Would you expect your experimental measurements of λ to be more precise if you used a tuning fork with large f or small f? Explain.

Q3: If the length of your resonance tube is *1 m*, what is the lowest frequency f for which this experiment can be performed?

Q4: Suppose that, at a given temperature, the barometric pressure P changes, what will be the effect on the velocity of sound? Explain.

Q5: Suppose the absolute temperature in the lab increased by 10%. (Let's hope not!) What will be the percent change in v?

Q6: Suppose the Celsius temperature increased by 10%. (We could live with this!) What will be the percent change in v?

Q7: List some systematic factors which might influence the outcome of this experiment.