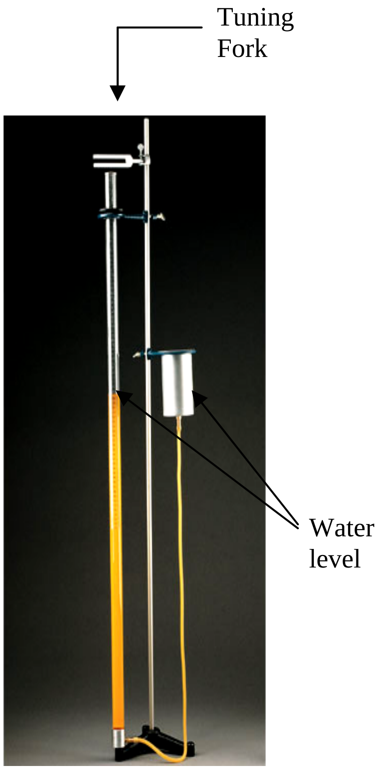
Resonant Air Column

Purpose: To measure the velocity of sound in air by determining the wavelength of resonant sound waves in an air column of variable length.

Equipment: Resonance air column apparatus, 1000, 2000, 4000 Hz tuning forks.

Introduction:



Resonance Apparatus

In this experiment, sound waves (compressional waves) will be generated by a vibrating tuning fork. The medium is air at room temperature enclosed in a glass tube, sealed at the lower end by a column of water (see figure).

When the tuning fork is set into vibration, a train of waves consisting of alternating compressions and rarefactions of the air is sent down the tube. This wave train is reflected at the water surface with a phase change of 180^o and passes back up the tube. At the open end of the tube, it is again reflected, but with no phase change in this case. The resultant waves in the tube are a combination of incident and reflected wave trains and may be very complex, just as in the case of transverse waves in a string. But just as in the case of the string, it is possible to produce standing waves when the proper relationship between frequency, wave speed and length of air column is achieved. The air column will then vibrate strongly in segments, with a frequency equal to the frequency of the tuning fork. This phenomenon occurs when the length of the air column is such that an odd multiple of quarter-waves "fits" the air column, since there must be a node at the lower end of the air column (at the surface of the water) and a loop or anti-node near the open end of the tube. Under these conditions, the air column resonates with the tuning fork and the intensity of sound from the system is considerably increased. You will listen for the increased sound as evidence that the air column is supporting a standing sound wave.

The length of the air column may be varied, by changing the level of the water in the tube. Thus the positions of the water surface at which resonance occurs may be determined. Analysis shows that the position of the anti-node at the open end of the tube is slightly above the top of the tube (about 0.6 times the radius of the tube). If the water level in the tube is lowered from the top of the tube, resonance will occur when the position of the water level corresponds with the position of the first node. This position is sharply defined and may be accurately determined.

As the water level is further lowered, a second resonance point may be found that corresponds to the second node. In some cases additional nodes may be found, depending upon the relation between the wavelength and the tube length. The inter-nodal distance is just a half wavelength.

Procedure:

1. From the selection of tuning forks available, find three frequencies that will provide wavelengths such that at least three or more nodes can be found in the glass tube. Each tuning fork, resonating in air, produces sound waves with a characteristic wavelength, λ,

   $$\lambda = \frac{v}{f} \qquad Eq.1$$

   where f is the frequency of the tuning fork (and the sound wave) and v is the speed of sound in air, which is approximately $v \approx 340\, {}^{m}\!/\!{}_{s}$ at standard conditions. Calculate and record the wavelength of the sound produced by your tuning fork using equation 1. For a tube open at only one end, resonance occurs when

   $$f = \frac{nv}{4L}, n = 1, 3, 5, \ldots \qquad Eq.2$$

   Solve equation 2 for L. Now use equation 1 to eliminate f, and write

   $$L = \frac{n\lambda}{4}, n = 1, 3, 5, \ldots \qquad Eq.3$$

   Equation 3 tells you that you should expect to hear the first resonance when the water surface is $L = \frac{\lambda}{4}$ below the top, open end of the tube. The next resonance will occur when the water surface is $L = \frac{3\lambda}{4}$ below the top end. Calculate and record all of the possible $L's$ for your resonance apparatus and your selected tuning fork.
2. Raise the water level in the glass tube until it is near the top of the tube. Start the tuning fork vibrating by striking it gently with a soft rubber hammer. Slowly lower the water level while listening for resonance to occur. The amplification of the sound at resonance is quite pronounced, even though the fork itself is emitting a scarcely audible sound. Once you have determined the approximate position of the resonance point, make several trials by running the water surface up and down. When the point of maximum intensity is located, mark its position with a rubber band on the tube. Then lower the water surface and, in a similar manner, locate and mark the next resonance point. Continue this process to the bottom of the tube. In each case make an estimate of the error involved in locating the resonance point.
3. Record the positions of the resonance points to the nearest millimeter and determine the distance between successive resonance points. This is the inter-nodal distance. Calculate the average inter-nodal distance, and from it, calculate the average wavelength for the standing sound waves produced by your tuning fork and the resonance apparatus.

4. Repeat steps 1 through 3 for the two other tuning forks selected.
5. Solve equation 1 for $\boldsymbol{v}$. Determine the velocity of sound in air at room temperature by using equation 1 with the rated frequency of the fork and the average wavelength you calculated in step 3. Compare this experimental value of $\boldsymbol{v}$ with the theoretical value given (in m/sec) by:

   $$\boldsymbol{v = 331.5 + 0.61T_c \qquad Eq.4}$$

   where $\boldsymbol{T_c}$ is the temperature of the air in ^{o}C.
6. Make a diagram showing an example of the standing waves set up in the air column. Be sure to include neat and organized tables for your calculated and measured data.