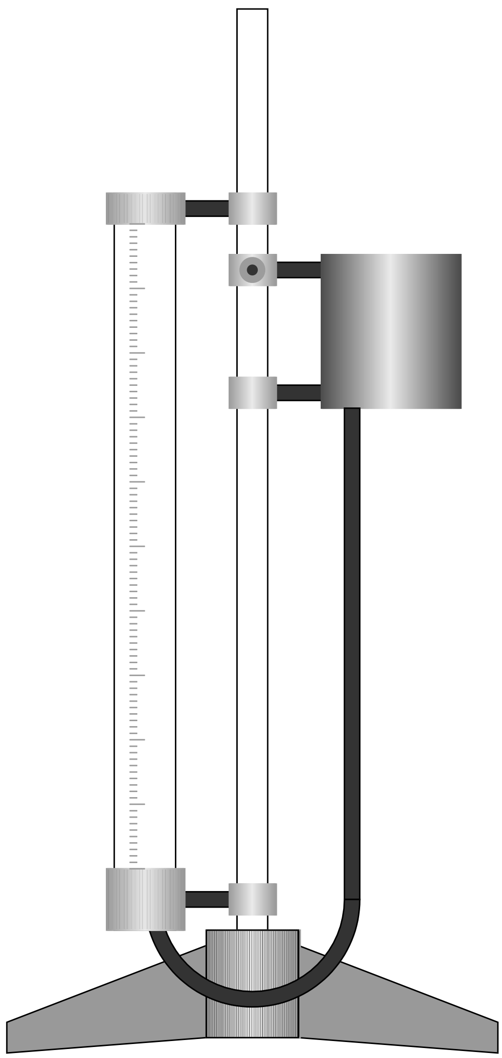
20 Sound waves in air columns

The purpose of the lab is to study longitudinal sound waves created in an air column of variable length.

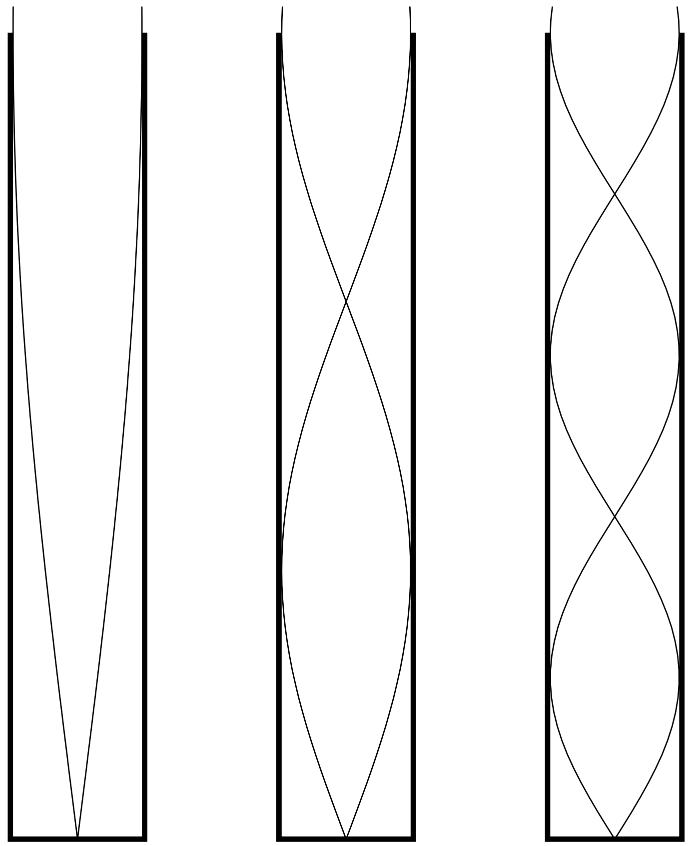
The apparatus is a modified Kundts tube with a movable water reservoir, and a tuning fork.

An air column with a movable closed end is made when a tube is filled with water, and we can adjust the water level by raising and lowering a water reservoir connected to the tube. There will be a sound wave node at the point where water meets air, and as we have seen in class an **anti-node just outside of the tube** at the open end.



The wavelengths of standing waves in a cylindrical pipe of length L that is open at one end are

$$\lambda = 4L, \qquad \lambda = \frac{4L}{3}, \qquad \lambda = \frac{4L}{5}$$



and in general for n_q quarter-waves in the waveform

$$\lambda = \frac{4L}{n_q}$$

The frequency of the vibrations in each case can be found from

$$f = \frac{c}{\lambda}$$

where c is the speed of sound in air (if the tube is filled with air).
Since the wavelength of the sound standing wave is determined by the length of the pipe and the resonance conditions, we can use the above equation to determine the speed of sound if the frequency is known.

20.1 Procedure

The apparatus consists of a glass tube that is open at one end and closed off by the water level to form an open ended air column above the waterline.
Standardized tuning forks will be used to excite resonances in the column. Strike a tuning fork and hold it near the mouth of the tube. Traveling waves will bounce back and forth within the air column in the tube, interfering with one another. Adjust the water level of the tube by raising or lowering the reservoir until the sound amplitude of the trapped waves reaches a maximum. Under these circumstances interference of the waves in the column

becomes constructive rather than destructive and we have a resonance condition.

Begin by finding the shortest length air column that gives a large amplitude standing wave for your tuning fork. This will be approximately a quarter wave.
Because of the fact that the anti-node is **outside** of the tube, we cannot use this measurement to get λ. First establish this particular resonance, and take note of the waterline. Now lower the waterline slowly and establish the value that gives you the **next** resonance condition. The new waterline level is the position of another node for the same frequency wave, and so the difference in the waterline marks for the two resonances equals a half-wavelength.

The frequency of the wave is that stamped on the fork. For several different tuning forks make at least two resonance condition measurements to determine the wavelength as described above, and compute the speed of sound from $c_{exp} = f_{fork}\lambda$ and compare it to the theoretical value;

$$c_{th} = 331\frac{m}{s} + 0.61\frac{m}{s\,C^o}T$$

Where T is the temperature in degree Celsius. Find the percent error of your average.

Summary of sound wave formulas

$$y(x,t) = A\sin[\tfrac{2\pi}{\lambda}(x - vt)] \quad y(x,t) = A\sin[kx - \omega t] \quad v_{sound} = c = \sqrt{\tfrac{\gamma P_{atm}}{\rho_{air}}}$$

$$P = P_0 - P_0\gamma\tfrac{dy(x,t)}{dx} \qquad I_0 = 1.0 \times 10^{-12}\,\tfrac{W}{m^2} \qquad \gamma = 1.4$$

$$\rho_{air} = 1.2\,\tfrac{kg}{m^3} \qquad P_{atm} = 1.01 \times 10^5\,\tfrac{N}{m^2} \qquad v_{air} = \tfrac{dy(x,t)}{dt}$$

$$\beta = 10\,dB\,log_{10}\,\tfrac{I}{I_0} \qquad I = \tfrac{1}{2}\rho_{air}\omega^2 A^2 c \qquad \omega = 2\pi f$$

$$I = \tfrac{1}{2}\rho_{air}v^2_{air,max}c \qquad I = I_0\,10^{\frac{\beta}{10}} \qquad c = \lambda f = \tfrac{\omega}{k}$$

20.2 Pre-lab questions

1. Consider a person speaking at a sound level of $40\,dB$, at frequency $f = 2000\,Hz$. Compute the maximum speed of air molecules in the sound wave.

2. For a pipe open at one end of length $L = 1.0\,m$ find the frequencies and wavelengths of the three lowest frequency resonances (standing waves).

3. For a pipe open at **both** ends of length $L = 1.0\,m$ find the frequencies and wavelengths of the three lowest frequency resonances (standing waves). Keep in mind there must be anti-nodes **near** the open ends.

20.3 Lab report

Sound waves in air columns

Experimenter 1 ____________________ **Experimenter 2** ____________________

Experimenter 3 ____________________ **Experimenter 4** ____________________

Ambient temperature T ____________________

Fork frequency f_{fork}**;**	
Resonance	Air Column length (cm)
First	
Second	
Third*	
Wavelength λ **(**m**);**	
c_{exp} (m/s)**;**	

Fork frequency f_{fork}**;**	
Resonance	Air Column length (cm)
First	
Second	
Third*	
Wavelength λ **(**m**);**	
c_{exp} (m/s)**;**	

Fork frequency f_{fork}**;**	
Resonance	Air Column length (cm)
First	
Second	
Third*	
Wavelength λ (m)**;**	
c_{exp} (m/s)**;**	

Computation of theoretical c_{th}

Final results		
$\bar{c}$	σ_c	$\frac{\lvert c_{exp}-c_{th}\rvert}{\lvert c_{exp}+c_{th}\rvert} \times 200\%$