Physics 180D **Experiment #1**

OBJECTIVE:

To study the acoustic normal modes of air-filled cavities of rectangular and cylindrical geometry.

Using speakers driven by a variable oscillator, the resonant frequencies of the acoustic eigenmodes can be measured. When these are compared to the theory discussed in class, an inherent error in frequency of a few parts in a thousand can and should be achieved. Using a movable microphone, a map of the amplitude of the eigenmode's pressure oscillations can be made as a function of each coordinate.

BEFORE COMING TO THE LAB TO TAKE DATA:

VERY IMPORTANT: Do not waste your lab time on a calculator!!! You will need to know the approximate frequencies of the eigenmodes to make efficient use of and accurate measurements during your lab time. Before coming to the first lab session you need to:

A) Measure the three internal dimensions of the rectangular enclosure and the radius and height of the cylindrical enclosure using the slide micrometer provided. Average a few readings to insure accuracy. Estimate uncertainties in your measurements

B) Using the crude estimate of 345 m/s for the speed of sound in air and your measured dimensions of the rectangular enclosure, calculate the theoretical frequencies of all 33 modes whose frequencies are less than that of the (4,0,0) mode. Use the convention that the indices n_x, n_y, n_z, refer to the longest, middle, and shortest dimensions of the enclosure. Tabulate according to increasing frequency.

C) Similarly calculate the frequencies of all 17 modes of the cylindrical enclosure, with frequencies below that of the (4,2,0) mode with the convention of index order being m,n,n_z.

THE LAB:

The speed of sound varies from day to day!

To make accurate comparisons between theory and experiment you must measure some properties of the air you are resonating. If you take data on different days, you must do the following on each day:

Measure: temperature
Barometric pressure
relative humidity

Note all units and estimate uncertainties in all measurements!!

RECTANGULAR ENCLOSURE:

A) Mode Selection
With both the speaker and the microphone in corners, set the waveform generator to sweep from 500 Hz to 5 kHz over 2 seconds, at its maximum amplitude of 10 V. Start the FFT analysis, and average for several minutes until the spectrum no longer changes appreciably. Before stopping the FFT save this data to a file (after stopping the data is no longer available). Now move the microphone to the slot halfway down z but still at the corner. Predict which modes will still have a significant response, and check your prediction by comparing the FFT spectrum at this position with the first spectrum. Repeat this again with the microphone moved to the slot at the center of the box.

B) Speed of Sound
From the FFT data, determine the resonant frequencies of all the modes up to (4,0,0). For each peak estimate the uncertainty in determining the resonant frequency. Be careful: at least a couple of the modes nearly overlap in frequency, and to separate them you will need to use the mode selection technique from part A) above to isolate each mode and ensure an accurate measurement of the mode frequencies.

C) Eigenmode Pressure Maps

Measure the pressure amplitude along the x, y, and z axes of the box for two different modes, manually tuning the waveform generator to drive the modes on resonance. The oscilloscope can measure rms voltages. Neither mode should contain any zeros in its set of indices. Do not use any degenerate modes! Make voltage measurements every 0.5 cm along the entire length of each axis by moving the box, or by adjusting the position of a tube attached to the microphone.

CYLINDRICAL ENCLOSURE:

A) Speed of Sound

Measure the frequencies of all of the modes up to (4,2,0), again using "mode selection" as needed.

B) Eigenmode Pressure Maps

Measure the pressure amplitude as a function of radius and angle for two modes with neither m or n equal to zero. Again be sure to not use a mode degenerate with any other. With the microphone at the outer wall, record the voltage every 5 degrees around the full circumference. With the microphone on the same diameter as the speaker, record the voltage amplitude every 0.5 cm from the center of the cylinder to the outer wall. Remember that the radius equals zero at the center of the cylinder.

WRITE UP:

A) Discuss mode elimination, comparing the spectra you took.

B) Calculate the speed of sound using the properties of the air you measured. Use the following:

$$c = \sqrt{\frac{\gamma RT}{M_w}}$$

where $\gamma = C_p / C_v$, R is the gas constant, T is temperature (K) and M_w is the molecular weight of air.

We must correct the speed of sound by including the effects of water vapor in the air. If h is the humidity, then the fraction of the air that is water ,X, equals:

$$X = h \ * (\text{saturated vapor pressure}/\text{barometric pressure})$$

The saturated vapor pressure can be found in the CRC Handbook of Chemistry and Physics.

To find the molecular weight we use the approximation that dry air is 78% nitrogen (M_N= 28), 21% oxygen (M_O= 32), and 1% argon (M_{Ar}= 40). Including the fraction of air that is water (M= 18) we find for molecular weight:

$$M_w = (X*18) + \{(1-X)*[(0.78*28)+(0.21*32)+(0.01*40)]\}$$

Similarly we can find the heat capacity of wet air if we assume nitrogen and oxygen to be ideal diatomic gases:

$$C_v = (X*C_v(H_2O)) + ((1-X)*(5*\frac{R}{2}))$$
$$C_p \ = \ C_v \ + \ R$$

The specific heat of superheated steam $C_v(H_2O)$ can be found in the CRC Handbook.

C) For each enclosure, calculate the speed of sound using your measured frequencies and make a plot of speed vs. frequency, including error bars for the uncertainty of the speed. Include your thermodynamic result from above on this plot.

D) Make graphs of your pressure amplitude (microphone voltage) data, with each dimension of each mode on a separate graph. Explain why the theory curves on these plots should be the absolute value of the pressure amplitude functions derived in lecture. Tables of Bessel functions can be found in Abramowitz and Stegun, or are easily generated by computer software such as Igor.

E) Present error analysis as discussed in class.

F) Draw a thoughtful conclusion! What problems were encountered during the measurement, and how did this affect the results? How could the experiment be improved? What has been learned, and are there any practical consequences?

FOR SUCCESS:

1) NUMBERS!!! Tables of the measured quantities (ie mode frequencies and their uncertainties) and of the final calculated outputs (ie speed of sound and its uncertainty) should be included in the report. Give titles to all tables, and label all columns of data including their units and uncertainties. There is no need to present tables full of intermediate steps. Instead show sample calculations of how one data point was analyzed with the theory to get the final result. Present results with the **correct number of significant figures** and the **correct units**.

2) Title all graphs, label their axes, and include error bars. Discuss the agreement between the theory and the results. Plot your data as individual points and include a normalized theoretical curve on each graph. It is generally better not to connect data points with lines between them (the default plotting method of Excel!).

3) A really good lab report always contains something extra, not required or presented in class. Discuss possibilities with the instructor or TA.

REFERENCES:

FUNDAMENTALS OF ACOUSTICS
Kinsler, Frey, Coppens and Sanders

VIBRATION AND SOUND
P.M. Morse

CRC HANDBOOK OF CHEMISTRY AND PHYSICS
Robert C. Weast, ed.

THERMODYNAMICS AND AN INTRODUCTION TO THERMOSTATISTICS
Herbert B. Callen

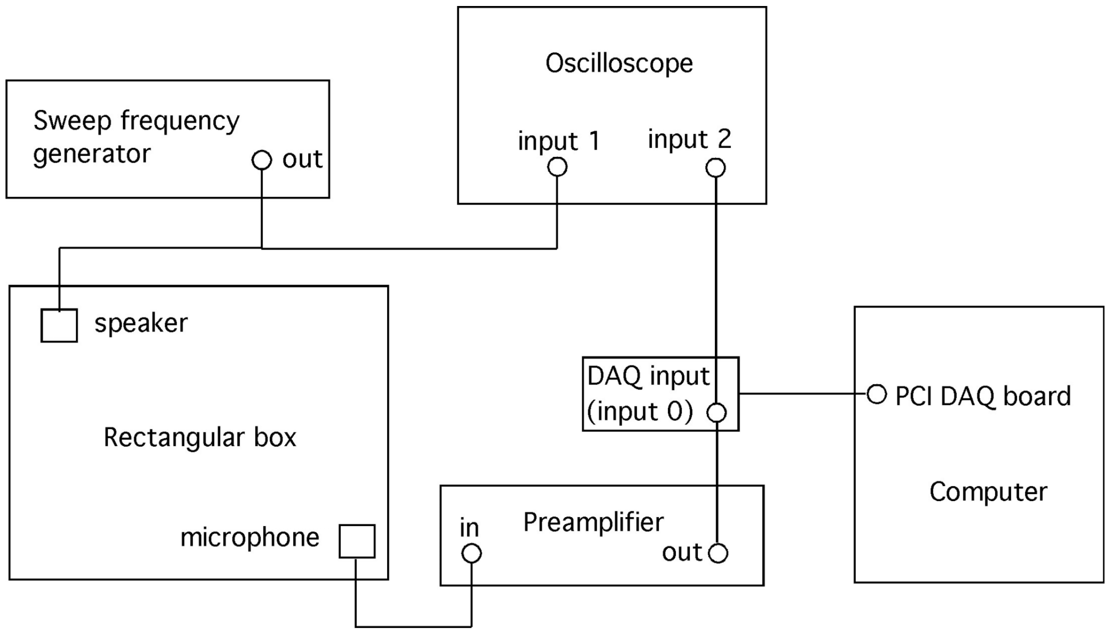
HANDBOOK OF MATHEMATICAL FUNCTIONS
M. Abromowitz & I. Stegun

Extrema points of Bessel functions of order *m* , counted by *n* .

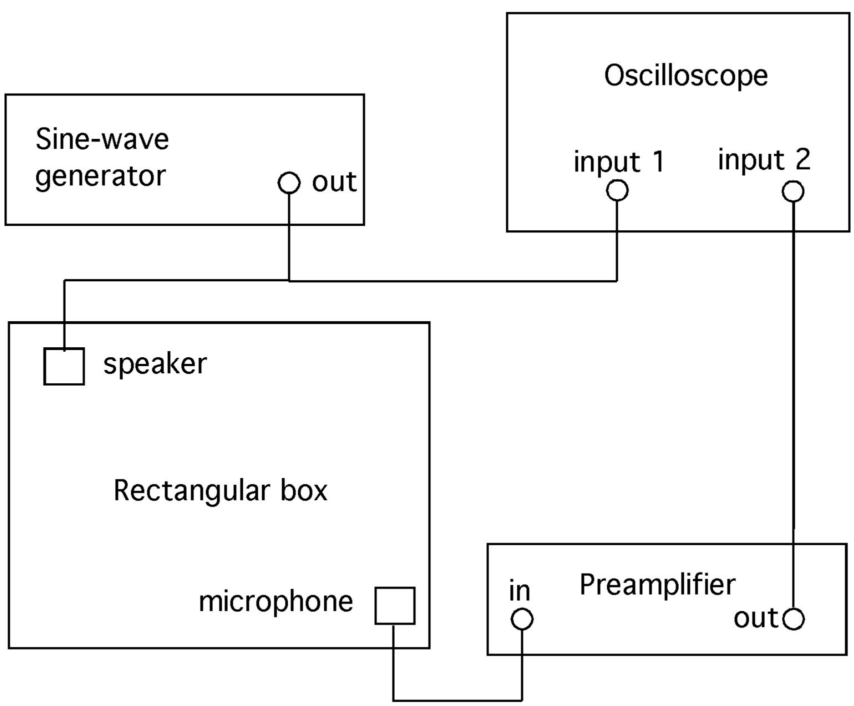
$$\frac{dJ_m}{dx} = 0 \quad \text{at} \quad x = j'_{mn}$$

Values are ±0.0001

	n=1	2	3	4	5	6
m=0	0.0000	3.8317	7.0156	10.1735	13.3237	16.4706
1	1.8412	5.3314	8.5363	11.7060	14.8636	18.0155
2	3.0542	6.7061	9.9695	13.1704	16.3475	19.5129
3	4.2012	8.0152	11.3459	14.5858	17.7887	20.9725
4	5.3176	9.2824	12.6819	15.9641	19.1960	22.4010
5	6.4156	10.5199	13.9872	17.3128	20.5755	23.8036
6	7.5013	11.7349	15.2682	18.6374	21.9317	25.1839
7	8.5778	12.9324	16.5294	19.9419	23.2681	26.5450
8	9.6474	14.1155	17.7740	21.2291	24.5872	27.8893
9	10.7114	15.2867	19.0046	22.5014	25.8913	29.2186
10	11.7709	16.4479	20.2230	23.7607	27.1820	30.5345



FFT measurement set-up



Mode mapping set-up