PHYS 2425
Engineering Physics I

EXPERIMENT 9

MEASUREMENT OF ATMOSPHERIC PRESSURE USING AN INVERTED TUBE WATER BAROMETER

OBJECTIVE

The objective of this experiment is to measure the pressure of the atmosphere by compressing a known volume of air with a water column. A tube containing air is inverted in another tube containing water. As the inner tube is lowered into the water, the water level rises thus compressing the air column and the various levels shown in figure (1) are measured allowing us to relate the changes in the volume of the air to the pressure on the air column.

APPARATUS

Inverted tube water barometer and a supply of water.

THEORY

The air captured in the tube can be considered an ideal gas. The ideal gas law states that

$$PV = nRT \tag{1}$$

where P is the absolute pressure, V is the volume, n is the number of moles of air, R is the universal gas constant and T is the absolute temperature. Since the amount of air is constant and the temperature can be assumed constant for the duration of the experiment, the above equation can be written as

$$P_1V_1 = P_2V_2 \tag{2}$$

relating the pressure and the volume of the air at two levels of compression. Take the first level to be where the inner tube makes contact with the water surface, the air pressure at this point being equal to the atmospheric pressure and the volume of the air is $V_1 = AL$ where A is the cross sectional area of the air column and L is its length. The second level is where the water has risen in the inner tube an amount $(y_m - y_b)$-(see figure 1). At this point the volume of the air column is $V_2 = A[L - (y_m - y_b)]$ and the ideal gas law becomes

$$P_{\text{atmosphere}}AL = P_2A[L - (y_m - y_b)]. \tag{3}$$

The pressure P_2 can also be related to the atmospheric pressure by

$$P_2 = P_{\text{atmosphere}} + \rho_{\text{water}}g(y_s - y_m). \tag{4}$$

In this equation ρ_{water} is the density of water and $(y_s - y_m)$ is the difference between the levels of the water columns outside and inside the inner tube. Combining the last two equations gives

$$\rho_{\text{water}}g(y_s - y_m)[L - (y_m - y_b)] = P_{\text{atmosphere}}(y_m - y_b). \tag{5}$$

This equation suggests that the atmospheric pressure can be measured by measuring the various levels indicated in figure (1) and plotting the left hand side of eq. (5) as a function of the quantity $(y_m - y_b)$. The slope of the straight line graph is the atmospheric pressure. Now give the left hand side of equation (5) the symbol Z and rewrite the equation as

$$Z = P_{\text{atmosphere}}(y_m - y_b). \tag{6}$$

EXPERIMENTAL PROCEDURE

1. Measure the length, L, of the inner tube which will contain the trapped air sample. Measure up to but not including the stopper.
2. Fill the outer tube with water up to an appropriate level. Around $45.0\,\mathrm{cm}$ high from the bottom will work best. It is suggested that you tape a meter stick by the side of the tube and use it to measure the water level for the entire experiment. It allows you to get more consistent measurements.
3. Lower the inner tube until the opening makes contact with the water surface. Let this be your first data point. Read the levels and record them in your data table. Note that the three levels are the same.
4. Now lower the tube below the water surface, read all the levels and record them in your data table. It is suggested that you lower the tube around $7\,\mathrm{cm}$ and read the levels to the nearest millimeter. It is very important to the success of this experiment that the levels be read very carefully.
5. Repeat the above step by lowering the tube in the water and recording the levels until the inner tube is near the bottom of the water. This should give you either 6 or 7 data points.
6. Measure the density of tap water by filling a graduated cylinder with a certain volume of water (about $100\,\mathrm{cm}^3$). Measure the mass of the water and find the density by dividing the mass by the volume. Record the density in $\mathrm{kg/m}^3$.
7. Read the barometer hanging on the wall of the lab to get the actual atmospheric pressure.

ANALYSIS

1. Complete the calculations indicated in the data table. In your lab report show a sample of these calculations.
2. Plot the quantity Z on the vertical axis and the quantity $(y_m - y_b)$ on the horizontal axis. Draw the best straight line fit for the data (do not connect the points). Calculate the slope of the line and give its units. The slope of the line represents the atmospheric pressure which is the result of this experiment. Record it in the results table.

3. Calculate the percent difference between the measured atmospheric pressure and the actual atmospheric pressure read from the lab barometer.

$$\% \text{ difference} = \frac{|P_{\text{measured}} - P_{\text{actual}}|}{\left(\dfrac{P_{\text{measured}} + P_{\text{actual}}}{2}\right)} \times 100 \tag{7}$$

4. Write a conclusion summarizing your results. Comment on the success of this experiment. Is your result within 10% of the actual atmospheric pressure? What do you think are the two most important sources of error in this experiment?

Experiment (9) Data Table
Length of Inner Tube in (m), $L =$
Density of Water in $(\mathrm{kg/m^3})$, $\rho_{\text{water}} =$
Actual Atmospheric Pressure in $(\mathrm{N/m^2})$, $P_{\text{actual}} =$

Experiment (9) Data Table

y_b (m)	y_m (m)	y_s (m)	$(y_m - y_b)$ (m)	$L - (y_m - y_b)$ (m)	$(y_s - y_m)$ (m)	Z (N/m)

Experiment (9) Results Table
Measured Atmospheric Pressure in $(\mathrm{N/m^2})$, $P_{\text{atmosphere}} =$
% difference =