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CLEMENT AND DESORMES' EXPERIMENT

OBJECT: To measure the ratio of the specific heats of air at constant pressure and constant volume according to the method of Clement and Desormes.

METHOD: A mass of dry air under a small pressure is enclosed in a large vessel having a gas tight valve. The valve is opened for an instant permitting the pressure to "become atmospheric" and causing the temperature to be reduced. After the valve is closed, the gas warms up to room temperature and the pressure increases. From a knowledge of the initial and final pressures, the ratio of the specific heats is obtained.

THEORY: Consider a mass of gas enclosed in a vessel at a pressure p_1 which is slightly greater than atmospheric

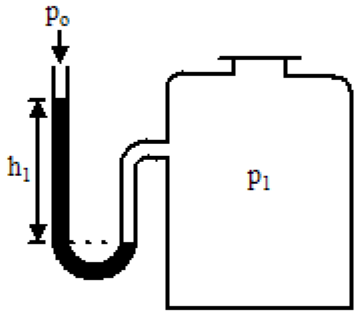

Fig. 1. Pressure p_1 of gas in vessel measured in terms of difference in heights of manometer column.

pressure p_o (Fig. 1). The pressure p_1 is measured by the difference in the heights h_1 of the two columns of a manometer containing a liquid of density d grams per cubic centimeter so that

$$p_1 = p_o + h_1 dg \tag{1}$$

where both p_1 and p_o are measured in dynes per square centimeter. The initial temperature of the gas is t°C, i.e., the temperature of the laboratory. Suppose that by momentarily opening a valve the gas is allowed to attain atmospheric pressure p_o. The change in pressure takes place so rapidly that there is no transfer of heat to or from external sources and the expansion is said to be purely adiabatic. The compressed gas in the vessel has to do some work in forcing some of the gas out of the vessel during the expansion. Consequently immediately after closing the valve the temperature of the gas remaining in the vessel is below room temperature. If the gas is now allowed to warm up to room temperature, the pressure increases to some value p_2 given by

$$p_2 = p_o + h_2 dg \tag{2}$$

where h_2 is the difference in the heights of the manometer columns.

Let V_1, V_0, and V_2 denote the initial, intermediate and final volumes of *unit mass* of the gas in the vessel, so that in each case the same mass of gas is considered. If the expansion from the initial state, pressure p_1 volume V_1, to the intermediate state, pressure p_o volume V_0, is adiabatic, the pressure and volumes are related by the equation

$$p_1 V_1^{\gamma} = p_o V_o^{\gamma} \tag{3}$$

where γ is the ratio of the specific heats of the gas at constant pressure and constant volume respectively. Since the gas in the initial and final states is at the same temperature, the relation between the pressures and volumes is given by Boyle's law, or

$$p_1 V_1 = p_2 V_2 \tag{4}$$

Now $V_2 = V_o$ since there is the same mass of gas in the vessel in the intermediate and final states. To find the relationship existing between γ and the various pressures it is necessary to eliminate the various volumes V_0, V_1, V_2 in Eqs. (3) and (4).

From Eq. (4), raising both sides of the equation to the same power γ, it follows that

$$\left(\frac{V_1}{V_2}\right)^{\gamma} = \left(\frac{p_2}{p_1}\right)^{\gamma} \tag{5}$$

From Eq. (3) and the fact that $V_2 = V_o$

$$\left(\frac{V_1}{V_2}\right)^{\gamma} = \frac{p_o}{p_1} \tag{6}$$

Thus

$$\left(\frac{p_2}{p_1}\right)^{\gamma} = \frac{p_o}{p_1} \tag{7}$$

or

$$\gamma = \frac{\log(p_o/p_1)}{\log(p_2/p_1)} \tag{8}$$

If the various pressures do not differ greatly from atmospheric, then the expression for γ may be further simplified. Substituting the expressions for p_o and P_2 from Eqs. (1) and (2) in Eq. (7), it follows that

$$\left[\frac{p_1-(h_1-h_2)dg}{p_1}\right]^{\gamma} = \frac{p_1-h_1dg}{p_1} \qquad (9)$$

or

$$\left[1-(h_1-h_2)\frac{dg}{p_1}\right]^{\gamma} = 1-h_1\frac{dg}{p_1} \qquad (10)$$

If $(h_1 - h_2)dg/p_1$ is so small compared to unity that its square may be neglected, the left-hand member of Eq. (10) may be replaced by the first two terms in the binomial expansion of this expression. Eq. (10) then becomes

$$1-\gamma(h_1-h_2)dg/p_1 = 1-h_1dg/p_1 \qquad (11)$$

Hence

$$\gamma = \frac{h_1}{h_1-h_2} \qquad (12)$$

APPARATUS: The apparatus consists essentially of a large Pyrex flask the top of which is ground plane, a cover plate of

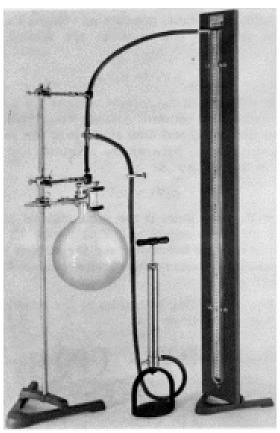

Fig. 2. Apparatus for determining the ratio of specific heats of air.

metal also ground plane and provided with a hose nipple, a manometer with light oil or xylol as the indicating liquid, a three-way or T-connecting tube and a small pressure pump with rubber tubing for making the connections (Fig. 2). A small amount of some drying agent such as Dessigel S is needed in the flask to eliminate any water vapor present in the atmosphere. Stopcock grease and a small rod in a clamp with a rubber stopper on one end are required to ensure an airtight seal between the top of the flask and the plate. The pressure pump shown in Fig. 2 may be replaced by the rubber pressure bulb shown in Fig. 3. A large stand and clamps for holding the flask and a pinchcock for preventing any air leak through the pump are required.

PROCEDURE: Place a small amount of drying agent in the flask and mount the apparatus as shown in Fig. 2. Place a liberal supply of stopcock grease over the ground portion of the top of the vessel and slide the plate over the ground part several times so that the grease is evenly distributed. Mount the small rod so that the rubber stopper on its end presses firmly down on the plate. Pump a small amount of air into the flask and cut off the connection to the pump with the pinchcock. The difference in level of the liquid in the manometer arms should be of the order of 15cm. Allow the air in the flask to come to room temperature and be sure that no air is escaping. If air is escaping, regrease the ground top

Fig. 3. Rubber pressure bulb which may be used in place of pump shown in Fig. 2.

of the flask and again adjust the rod and rubber stopper on top of the plate.

After making sure there is no leak, read the manometer arms and determine h_1. The flask is now opened momentarily to the atmosphere by raising the arm and rubber stopper, sliding the metal plate sidewise for about half a second and then sliding it back. The opening to the flask should be as large as possible and the operation performed as quickly and carefully as possible. Replace the rod and rubber stopper so that the plate is pressed against the ground glass top. After a short time the temperature of the gas rises to room temperature and the pressure stops rising. Record the difference in the height h_2 of the two arms of the manometer. If the pressure of the air begins to fall as shown by the manometer, it means there is a leak in the apparatus and the experiment must be repeated.

From the heights h_1 and h_2 and Eq. (12) calculate the value of γ. If the pressure p_1 has greatly exceeded atmospheric, then it is necessary to use Eq. (8) and the suitable data.

QUESTIONS: 1. Draw a rough graph typical of the relationship between pressure and volume for the case of a gas compressed (a) isothermally; (b) adiabatically. Which of the two graphs is steeper? Give the reasons for the difference in slopes.

2. If during the course of the experiment the atmospheric pressure should change, would it be legitimate to use Eq. (12) to calculate γ?

3. If the air in the flask contained water vapor, would the value of γ for this damp air be greater or less than the value of γ for dry air?

4. Why is it necessary that the flask be opened only momentarily to the atmosphere?

5. If C_p and C_v are the thermal capacities per gram molecule of a gas at constant pressure and constant volume respectively, what does their difference C_p - C_v represent? Give the derivation and explanation of the equation given for C_p - C_v.