CENCO Physics Selective Experiments In Physics

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EXPANSION OF GASES

OBJECT: To investigate the relationship between the pressure and temperature of a constant volume of gas.

METHOD: A mass of dry air is trapped above a column of mercury in a closed tube immersed in water. The closed tube forms one arm of a mercury manometer. The pressure upon the confined air, and hence its volume, can be regulated by means of a plunger in a mercury reservoir. The value of the pressure is obtained from the difference between the mercury levels in the open and closed arms of the manometer. The temperature of the water bath is altered and a series of observations is made upon the pressure of the confined gas, its volume being maintained constant.

THEORY: When the temperature of a solid or a liquid is raised its volume is increased, the volume increase depending directly upon the original volume, the increase in temperature, and a physical property of the substance called the *volume coefficient of expansion*. Representing the initial volume by V_o and the final volume by V, the change in volume may be written

$$V - V_o = aV_o t \qquad (1)$$

where a is the volume coefficient of expansion and t is the increment in temperature. Solving Eq. (1) for a

$$a = \frac{V - V_0}{V_0 t} \qquad (2)$$

Eq. (2) is a mathematical statement of the definition of the volume coefficient of expansion a.

Since $\frac{V - V_0}{V_0}$ is the fractional change in volume, the volume coefficient of expansion may be defined as the fractional change in volume per degree change in temperature, the original volume being measured at zero degrees centigrade.

The expansion of a gas is a somewhat more complicated problem than the expansion of solids and liquids because it involves a third factor, namely, pressure. It becomes necessary, therefore, in the case of a gas, to define a volume coefficient and a pressure coefficient. The volume coefficient of expansion of a gas is defined as the fractional change in volume per degree change in temperature, the pressure remaining constant and the initial volume being measured at 0° C. Mathematically expressed,

$$a = \frac{V - V_0}{V_0 t} \quad \text{(P constant)} \qquad (3)$$

Similarly the pressure coefficient is defined as the fractional change in pressure per degree centigrade, volume remaining constant and the initial pressure being measured at 0˚C. Thus

$$\beta = \frac{P - P_o}{P_o t} \quad \text{(V constant)} \qquad (4)$$

where β is the pressure coefficient, and P and P_o are, respectively, the final and initial values of the pressure. While the necessity for two coefficients of expansion appears to complicate the problem, certain relationships discovered by Charles, Gay-Lussac and others greatly simplify the situation. The first of these far-reaching discoveries was that within a wide range of temperatures the volume coefficient has approximately the same value for all gases. The same is found to be true of the pressure coefficient. More over, it was discovered that, to a close approximation, the volume coefficient is equal to the pressure coefficient. The fact that the volume coefficient is approximately constant for all gases is known as Charles' law. As a consequence of this relationship it is convenient to define a temperature scale, called the *absolute scale*, such that at zero on this scale a gas would occupy no volume. (Volume here refers to the space occupied by a gas by virtue of the motion of its molecules, the size of the molecules themselves being considered negligible.)

The average value of a is found to be 0.00367 or approximately 1/273 per degree centigrade. Thus, for every degree (centigrade) change in temperature a gas undergoes a change of volume equal to 1/273 of its volume at 0°C. Consequently, a given mass of gas would have to be cooled to -273°C in order to reduce its volume to zero. This temperature is called *absolute zero*. Thus, the absolute temperature T is related to the centigrade temperature t as follows

$$T = t + 273 \qquad (5)$$

A similar argument with regard to pressure changes shows that at zero on the absolute scale a gas would exert no pressure. Absolute zero may be defined, therefore, as the temperature to which a permanent gas would have to be cooled in order that it occupy zero volume and exert no pressure, i.e., in order that all molecular activity should cease. Charles' law may now be restated as follows: *The volume of a given mass of gas is directly proportional to its absolute temperature, pressure remaining constant*. Thus

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \qquad \text{(P constant)} \qquad (6)$$

Similarly,

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \qquad \text{(V constant)} \qquad (7)$$

It is the object of this experiment to investigate the relationships expressed by Eq. (7).

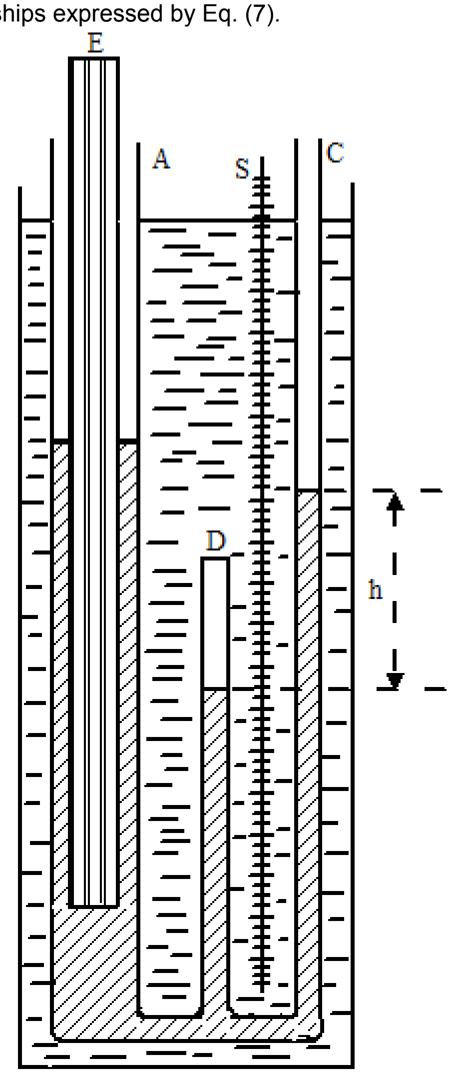

Fig. 1. Diagram of Gas Laws Apparatus.

APPARATUS: The gas laws apparatus represented diagrammatically in Fig. 1 and illustrated in Fig. 2 consists of three vertical tubes A, C and D connected together at their lower ends and encased in a cylindrical glass vessel filled with water. The tubes A and C are open at the top while the upper end of D is closed. The large tube A serves as a reservoir for mercury, and the mercury levels in the tubes C and D can be controlled by a wooden plunger E inserted in the reservoir. Mercury is poured into A, trapping some air in the closed tube D. The pressure on the confined air is measured by the difference in height *h* of the mercury columns in C and D, the levels being indicated by a scale S mounted beside the tubes. The pressure on the surface of the mercury in the open tube C is atmospheric and can be determined merely by reading a barometer. The pressure on the air confined in the closed tube D differs from atmospheric

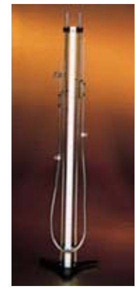
Fig. 2 Gas Laws Apparatus

pressure by an amount equal to the pressure exerted by the column of mercury *h* (Fig. 1); it is greater or less than atmospheric pressure depending upon whether the level in C is above or below that in D. Thus, if B represents the barometric reading expressed in centimeters of mercury, the pressure *P* of the confined air is

$$P = B \pm h \qquad (8)$$

The necessary auxiliary apparatus consists of a mercury barometer, a series of drying tubes, an aspirator pump, a thermometer, a stirring rod, a Bunsen burner and a steam generator.

PROCEDURE:

Experimental: *It is of utmost importance that the confined air be thoroughly dry*. A small amount of water vapor will vitiate the results of the experiment. In general, the apparatus will have been filled previously with dry air by the instructor, and *should not be refilled without his consent.* In case refilling becomes necessary, a convenient method of introducing dry air is illustrated in Fig. 3. A series of drying tubes containing calcium chloride, or other drying agent, is connected to the open tube C. The air is exhausted from the apparatus by means of an aspirator pump connected to the tube A. Close the pinchcock K and start the pump. After pumping a minute or two, open the pinchcock and permit air to be drawn in through the drying tubes. In this manner flush the apparatus with dry air two or three times before beginning the experiment.

A very effective method of drying the apparatus consists of enclosing it for several hours (without mercury) in a closed vessel containing the drying agent Dessigel S after which dry air is introduced by the method described above.

Read the laboratory barometer. Fill the water jacket to within 8 or 10 centimeters of the top with water at room temperature or a little below. Suspend the thermometer in the water bath beside the tube D. When the thermometer indicates steady temperature, take readings of the temperature and of the mercury levels in the tubes C and D. Record the data in Table I.

Raise the temperature of the bath by injecting a little steam and stir vigorously. When the temperature is constant,

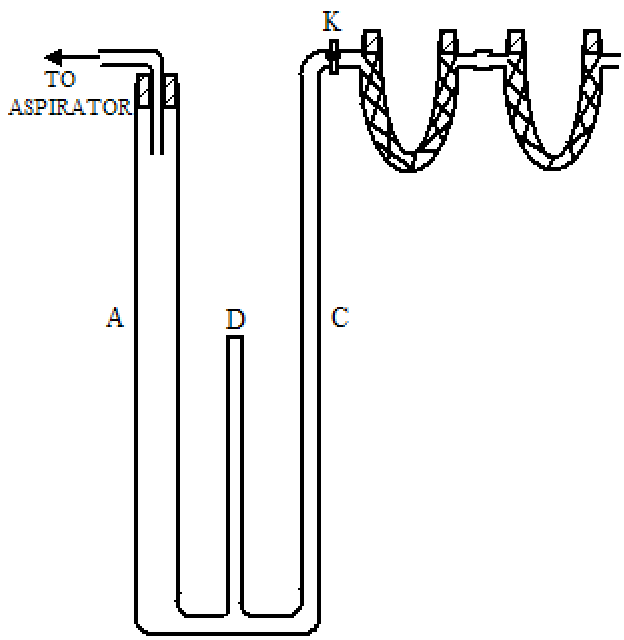

Fig. 3. Method of introducing dry air.

depress the plunger E until the mercury level in D is brought to its original position, and take another set of readings. Continue in this way until six observations have been made covering a temperature range up to about 80° C. Be sure to keep the volume constant by maintaining the mercury level in D at the same position. Two or three additional readings may be made as the apparatus cools down. At the end of the run, make a second reading of the barometer and record the average value of the barometric pressure over the duration of the experiment.

Interpretation of Data: Fill in Columns II, IV and V of the table. Plot a curve of pressure versus absolute temperature with P as the ordinate and T as the abscissa. Using Eq. (4) and the data from the lowest and highest temperature settings, compute a value of the pressure coefficient β.

QUESTIONS: 1. Does the form of the curve conform to the relationships expressed by Eq. (7)? Explain.

2. How would the experiment be affected by increasing the diameter of the tube C (Fig. 1)?

3. Describe a method of investigating the relationships expressed by Eq. (6) using this apparatus.

4. In the above computation of β is the error introduced by not measuring P_o at 0°C significant? Explain why.

5. Would the presence of water vapor in the confined air tend to make the experimental value of β too large or too small? Explain.

TABLE I

Constant level in D..			Barometric pressure...	
I	II	III	IV	V
Temperature t	Absolute Temperature T	Level in C	Pressure Difference h	Pressure P