

11. MEASUREMENT OF THE ISOCHORIC COEFFICIENT OF THE THERMAL EXPANSION OF THE GAS. DETERMINATION THE UNIQUE POINT.

ASSIGNMENT

1. Measure the thermal dependence of the air for the isochoric process
2. Calculate the value of the isochoric coefficient of the thermal expansion
3. Determine the unique point temperature
4. Calculate the percentage error of measurement

THEORETICAL PART

Most gases at room temperature and atmospheric pressure behave as ideal gas. The ideal gas is defined as gas with low density (or low pressure - up to 10^5 Pa). The properties of such a gas can be described on a microscopic scale on which matter is treated as a collection of molecules. From the kinetic theory, gas molecules move about in a random fashion, colliding with the walls and with each other. The most important consequence of this theory is that it shows the equivalence between the kinetic energy of molecular motion and the internal energy of the system. In the simplest model of gas, each molecule is considered to be a hard sphere that collides elastically with other molecules or with container wall. The hard sphere-model assumes that the molecules do not interact with each other except during collision and they are not deformed by collisions. This description is adequate only for monatomic gases, where the energy is entirely translation kinetic energy. One must modify the theory for more complex molecules, such as O_2 or air, to include the internal energy associated with rotations and vibrations of the molecules. With this model of an ideal gas, we have arrived at an important result that relates the macroscopic quantity of pressure P and volume V with the microscopic quantity such an average molecular speed.

Equation of state for an ideal gas is given by

$$PV = nRT \quad (8.1)$$

where n is the number of moles, R is **the universal gas constant** and T is the temperature in Kelvin. We know that there are three processes during which the gas transfers from one state to another state: isobaric, isochoric and isothermal.

If the pressure of gas is a constant the process called **isobaric process**. The process that occurs at constant at constant volume is called an isochoric (isovolumetric) **an isochoric process**. The process during which the temperature is constant is called an **isothermal process**.

Let us take an interest in an isochoric process. From eq. (5.1) we have

$$P = P_0 \frac{T}{T_0} \quad (8.2)$$

where the temperatures T and T_0 are in Kelvin scale The Celsius temperature t is shifted from the Kelvin temperature, T , by

$$T = T_0 + t \quad (8.3)$$

where $T_0 = 273,15$ K is the thermodynamics temperature of **the ice-point (or freezing point)**.

Therefore, the eq. (8.2) transformers into form we have

$$P = P_0 \left(1 + \frac{t}{T_0} \right) \quad (8.4)$$

If we denote the reverse of temperature T_0 as

$$\gamma = \frac{1}{T_0} = \frac{1}{273,15} \text{ K}^{-1} \quad (8.5)$$

we have

$$P = P_0 (1 + \gamma t) \quad (8.6)$$

The eq. (5.5) called the law of Gay-Lussac. The coefficient γ is called **the coefficient of thermal expansion.**

Now we are going to show how the ice point T_0 can be determined. Such a device is called **the gas thermometer**. One version of the constant-volume gas thermometer is shown in Fig. 8.1. In a gas thermometer, the temperature readings are nearly independent of the substance used in the thermometer. The physical property in this device is the pressure variation with the temperature of a fixed volume of gas. This device consists of the tube of the shape of U filled by the liquid especially with the mercury. This manometer is called **U – manometer**. As the gas in the bulb is heated, its pressure increases and the high of the mercury column in manometer connected to the bulb increases too. When the gas is cooled, its pressure decreases, so the column high decreases. The volume of the gas in the bulb is kept constant by rising or lowering the column on the right such the mercury level on the left remains constant. Thus, we can define temperature in terms of the concept of pressure. If the variation of temperature t with pressure is assumed to be linear, then

$$t = aP + b \quad (8.7)$$

where a, b are constants. These constants can be determined from two fixed points, such as the ice and steam points. One of the fixed-point temperatures normally chosen is that of a mixture of water and ice at atmospheric pressure that defines the zero degree of Celsius temperature scale. Another fixed point is the temperature of a mixture of water and water vapour in equilibrium at atmospheric pressure. This one defines 100C.

Now suppose that temperature is measured with variation gas thermometers, containing different gases. Experiments show that the thermometer readings are nearly independent of the type of gas used, so long as the gas pressure is low and temperature is well above the liquefaction point. The agreement among thermometers using various gases improves as the pressure is reduced. This agreement at all gas thermometers at low pressure and height temperature implies that the intercept b in eq. (8.6) is the same for all gases. This fact is illustrated in Fig. (8.2), where is shown the pressure versus temperature for dilute gases.

When the pressure versus temperature curve is extrapolated to very low temperature, one finds that the pressure is zero when the temperature is $t_0 = -273,15C$. This temperature corresponds to the constant b in eq. (8.6).

If we take $b = 0$ in eq.6 and call P_0 the pressure at the double point temperature then we see that $a = 273,15 / P_0$. Therefore, the temperature at the measured gas pressure p for a constant volume gas thermometer is defined to be

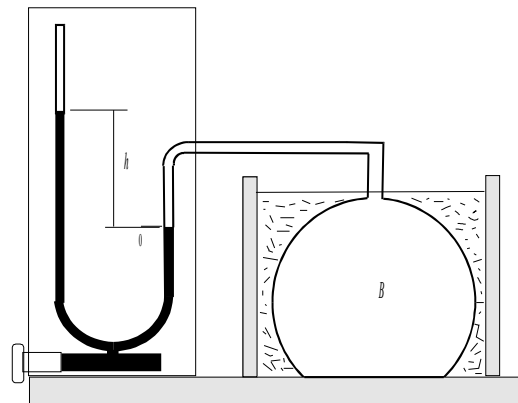
$$T = \left(\frac{273,16}{P_0} \right) P \quad (8.8)$$

The temperature read with a constant-volume gas versus pressure P_0 at the steam point of water for various gases is shown in Fig. 8.2.

Note: that as the pressure is reduced, the steam-point temperature of water approaches a common value of 273,15 K. The data for He are nearly independent of pressure, which suggests it behaves like an ideal gas over this range. At the temperature 0K all random motion cease and this is the physical significance of the lowest possible temperature

The first significance step in the direction of achieving absolute zero was taken in 1870 at the liquefied oxygen, at about 44,27 K and with nitrogen at 42,15 K. Each of these advances provided low-temperature physicists with a new liquid coolant that could be used to liquefy other gases. In 1908 the Dutch physicist H.K.Kammerling Onnes liquefied the helium at about 1,49 K. Today, when the temperature of less that a degree above absolute zero is achievable, this trend continues.

THE METHOD - PRACTICAL PART.



One of the methods of measuring the value of isobaric coefficient of the thermal expansion is represented in Fig.8.3.

Bulb *B* that is filled by the air is immersed in water. The bulb is connected with a U-manometer. The moving the mercury reservoir can change the height of the mercury level. The mercury level in the right side of U-tube must be having a constant value. The temperature of the water increases by the burner and the thermometer measures it. Fig. 8.3 gives the pressure of the air in bulb

$$P = b + \rho g(h_2 - h_1)$$

Fig.8.3
(8.9)

where *b* is the atmospheric pressure of the air *P* is the density of mercury and $h = (h_2 - h_1)$ is the difference between the levels of U-manometer

MEASUREMENT

APPARATUS: bulb *B* filled by the air, mercury manometer with reservoir of mercury, thermometer, beaker, burner, barometer

Move the mercury of the reservoir that the mercury of the right side U-tube manometer reaches the fixed mark (high h_1). Measure the start temperature and height h_2 in the left side of the manometer. Increase the temperature of the water step-by-step about 5 °C. If the gas is in thermal equilibrium put a mercury level in manometer into position h_1 and read the high h_2 on the left side of U-tube. Measure the temperature *t*. Repeat the measurements a few times for various temperatures of the gas in interval up to 100C. Read all measured values into Tab.8.1. Measure the atmospheric pressure *b* on the scale of barometer.

CALCULATION

Using eq.8.9 calculate the pressure of the air each pair of measuring value h_2 and temperature t . Using the computer draw the graph of P versus t with the linear regression. Eq.8.6 gives

$$P = P_0 + P_0 \gamma t \quad (8.10)$$

This equation is the equation of linear in generally form

$$y = b + ax \quad (8.11)$$

Comparing eq.8.10 to eq.8.11 gives

$$b = P_0$$

$$a = P_0 \gamma$$

These equations determine the values of the starting pressure P_0 and the isochoric coefficient of thermal expansion of the gas. Determine the unique point of the temperature T_0 by the extrapolating of the linear dependence of the pressure versus temperature to the pressure equals zero. Calculate the relative error

$$\frac{\Delta y}{y_t} \cdot 100 \% \quad (8.12)$$

where $y_t = \frac{1}{273,15} \text{ K}^{-1}$, $\Delta y = y_m - y_t$, y_m is the measured value of the air.

Discuss the source of error in your measurement.