10. MEASUREMENT OF THE LINEAR EXPANSION OF METALS DUE TO TEMPERATURE. DETERMINATION OF THE COEFFICIENT OF EXPANSION

ASSIGNMENT

1. Measure the linear expansion of metal rod
2. Determine the coefficient of linear expansion
3. Analyse the errors in experiment

THEORETICAL PART

We know that the matter expands on being heated and contracts on being cooled. The amount of expansion and contraction is greatest in gases, may be neglected in liquids and is least in solids.

The phenomena of thermal expansion in liquids and gases can be explained by the kinetic-molecular theory of the matter. According to the theory, the kinetic energy of the molecules of a matter increases with increasing temperature. As molecules acquire greater energy, they move with greater speed and collide with one another violently. The result is that the average distance between them becomes greater. Then the actual volume of the material increases with increasing temperature.

In solids, which consist of atoms held together by elastic forces we can use a mechanical model of these forces by imagining that the atoms are connected by a set of shift springs as is shown in Fig.9.1

Fig.9.1

The interaction forces are taken to be elastic. At ordinary temperatures, the atoms vibrate about their equilibrium positions with amplitude of about 10^{-11} m and the frequency of 10^{13} Hz. The average spacing between the atoms is of order to 10^{-10} m. As the temperature of solids increases, the atoms vibrate with large amplitudes and the average separation between them increases. It means that the solids expand with increasing temperature. If the expansion of a solid is small compared with its initial dimension, then the dimension is approximately linear function of temperature.

Let us suppose the linear dimension of a solid rod along some direction is l_0 at some temperature T_0. The length increases by an amount Δl for change in temperature ΔT. Experiments show that the change in Δl is proportional to the temperature difference ΔT as

$$\Delta l = \alpha l_0 \Delta T \qquad (9.1)$$

where the constant of proportionality α is called **the coefficient of linear expansion** of the material Rearranging eq.9.1 gives the definition of coefficient of linear expansion in form.

$$\alpha = \frac{1}{l_0} \frac{\Delta l}{\Delta T} \qquad (9.2)$$

The unit of the coefficient α is K^{-1}. Generally, the coefficient of expansion is the linear function of the temperature given by expression

$$\alpha = \alpha_1 + \alpha_2 t \tag{9.3}$$

where α_1 is of the order 10^{-5} K^{-1}

α_2 is of order 10^{-8} K^{-1}

Usually this temperature variation is negligible over the temperature range of about 100C. The coefficient of linear expansion for materials near room temperature is of order $(10^{-5} - 10^{-6})$ K^{-1}.

THE METHOD-PRACTICAL PART

There are many methods of measurement of linear coefficient of expansion. We shall measure this coefficient using the device that is called **Edelmann's dilatometer**. The apparatus is shown in Fig.9.2

Fig.9.2

The Edelmann dilatometer consists of the metal rod that is immersed into oil. The oil is used as medium to heat the rod. The rod is supported between two points. Because the elongation of the metal rod due to the change in the temperature is very small we shall measure this one by the optical method. Therefore, one end is connected with the micrometric screw and the second end is supported with a small vertical mirror. The mirror reflects light from the small spot of light of the light source and hence is incident on the screen containing the scale. By changing the length of rod the spot of light changes its position on the scale. The change in position of the spot is proportional to the elongation of the rod. We must, of course, determine **the constant of the optical lever** it means the relation between the change in position of the spot and the elongation of the rod. The constant of the device is measured with the micrometric screw and is calculated from the expression

$$k = \frac{a}{\Delta d} \tag{9.4}$$

where a is one revolution of micrometric screw which response to the length of 0.65mm

$\Delta d = d - d_0$ is the change of position of the spot due to one revolution of the screw

then the elongation of the rod dl due to the change in temperature of ΔT may be express

$$dl = kdx \tag{9.5}$$

Inserting eq.9.5 into eq.9.2 gives the expression for determination the measured value of the linear coefficient of expansion in form

$$\alpha = \frac{1}{l_0} k \frac{\Delta x}{\Delta T} \tag{9.6}$$

where k is the value of the constant of the device

$\Delta x = x - x_0$ is the change in position of the spot due to increase of the temperature.

$\Delta T = T - T_0$ is the corresponding change in the temperature

MEASUREMENT

APPARATUS: Edelmann's apparatus, source of the light, two thermometers

Measure the constant of proportionality *k* of the optical lever a few times. Read the temperatures t_1 and t_2 of the rod by two thermometers. Carefully read the position y_0 of the spot at room temperature. Heat the oil about 5 ^{0}C. If the rod is in equilibrium temperature state read the position of the spot *x* and the temperatures t_1 and t_2 . Repeat several times for various temperatures. Record all values in the Tab.9.1

CALCULATION

Calculate the constant *k* of device for each value of *a*. Compute the average value of *k*. *Using* eq.9.6 calculate the coefficient of linear expansion α . From the data of measurement compute the average linear coefficient of expansion of copper rod**.** Calculate the percentage error of the measurement of coefficient of linear expansion as

$$\frac{\Delta \alpha}{\alpha_t} \cdot 100\%$$

where $\Delta \alpha = \alpha_m - \alpha_t$

α_m is the experimental value of linear coefficient of expansion, α_t is the table value. This value for the copper rod at the room temperature is $1.7 \times 10^{-5} \text{K}^{-1}$.
Discuss the significant source of errors in this experiment