Student’s тame ____

Experiment № 9

DETERMINATION OF THERMAL EXPANSION COEFFICIENT FOR A SOLID

Objective: to determine experimentally the thermal expansion coefficients for different metals

1 EQUIPMENT

1. Heater.
2. Test-tube.
3. Micrometer indicator of expansion.
4. Metal rods.
5. Vernier caliper.
6. Thermometer.

2 THEORY

2.1 Majority of solids expand at increase of temperature and this phenomenonis known as a thermal expansion. Thermal expansion is explained by molecular theory, according to which the potential energy $U(x)$ of a particle in a matter (ion, atom, molecule), in the vicinity of equilibrium position, has a form

$$U(x) = ax^2 - bx^3 + \ldots, \quad (2.1)$$

where a, b,… are constants representing the peculiarities of a structure and an interaction of matter constituents, $x=R-R_0$ is a displacement of an ion from equilibrium condition. A typical plot for the dependence of ion interaction energy $U(R)$ on the inter-ionic distance, shown in figure 2.1. At absolute zero temperature the thermal motion is absent and a particle rests in its equilibrium position R_0, which corresponds to the minimum of potential energy U_{min}. At temperature $T_1>0$ the particle oscillates between extreme positions, denoted on the plot as points 1. The mean distance between ions corresponds to the very middle of this segment. The curve representing the ion’s potential energy is asymmetrical. In consequence of the asymmetry the mean distance between oscillating ions shifts to the right and reaches the value $R_1>R_0$. At temperature $T_2>T_1$ the energy of particle’s oscillations increase and the mean distance between particles is

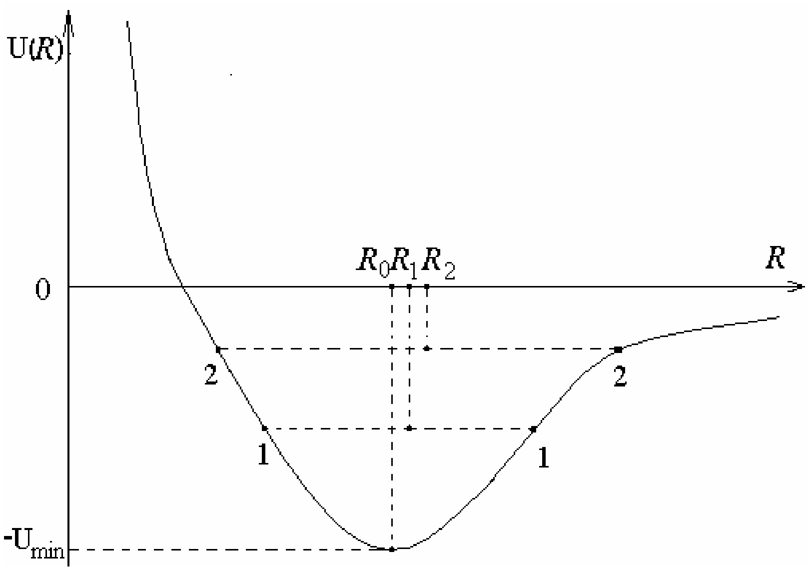

Figure 2.1

$R_2>R_1>R_0$. It is known that the mean displacement $<\Delta x>$ of ions at heating is proportional to temperature T. As a result of this increase of the mean distances, bodies expand at increase of temperature.

The resulting force acting on the particle from the other particles is

$$F_x = -\frac{\partial U(x)}{\partial x} = -2ax+3bx^2+ \dots \qquad (2.2)$$

is different from elastic forces, so the oscillations are not harmonic ones. At small displacements, one can take into account only the first term in right-hand-side in equation (2.2), and obtain, that F_x is quasi-elastic, and oscillations under the action of this force are harmonic ones (this is so only in case of extremely low temperatures).

2.2 At change of temperature of solids the dimensions of the bodies change. In broad temperature range the expansion is directly proportional to the temperature. Dependence of the body's length on temperature is determined by the formula

$$l = l_0(1+at), \qquad (2.3)$$

where l_0 is length of the body at 0°C, t is a temperature in Celsius, l is the length at the temperature t, a is called the linear coefficient of thermal expansion.

The linear coefficient of thermal expansion a may be defined as the relative change $\Delta l/l_1$ of the body's length at the 1 kelvin change of temperature.

$$a = \frac{\Delta l}{l_1 \Delta T} = \frac{\Delta l}{l_1 \Delta t}, \qquad (2.4)$$

here $\Delta l=l_2-l_1$ is the absolute change of the length at temperature change from the value t_1 to t_2 (l_1 and l_2 are values of body's length at temperatures t_1 and t_2, respectively), $\Delta T=\Delta t=t_2-t_1$ (note that 1˚C=1K). Actually, the temperature coefficient of thermal expansion also depends on temperature and, strictly speaking, the formula (2.4) is valid only for the mean value of the linear coefficient of thermal expansion in the temperature interval ΔT. 1 K^{-1} is the unit of coefficient of thermal expansion.

3 DESCRIPTION OF EXPERIMENTAL APPARATUS

The experimental apparatus for determination of the coefficient of thermal expansion includes the following parts (see fig. 3.1). The electric heater 1 is used to increase temperature of water in the test-tube 2. Metallic rod 5 is put in the water. In the holder 3 the micrometer indicator 4 is fixed. Using thermometer the initial temperature of water is measured. The initial length of the rod is measured with vernier caliper. After length of the rod is measured the rod is inserted into test-tube and indicator is put in contact with the upper end of the rod, the pointer is set to zero. The heater is on until the water start boiling. The absolute thermal expansion is read off the indicator. The final temperature is the boiling point (can be found from tables), corresponding to the value of air pressure in the laboratory.

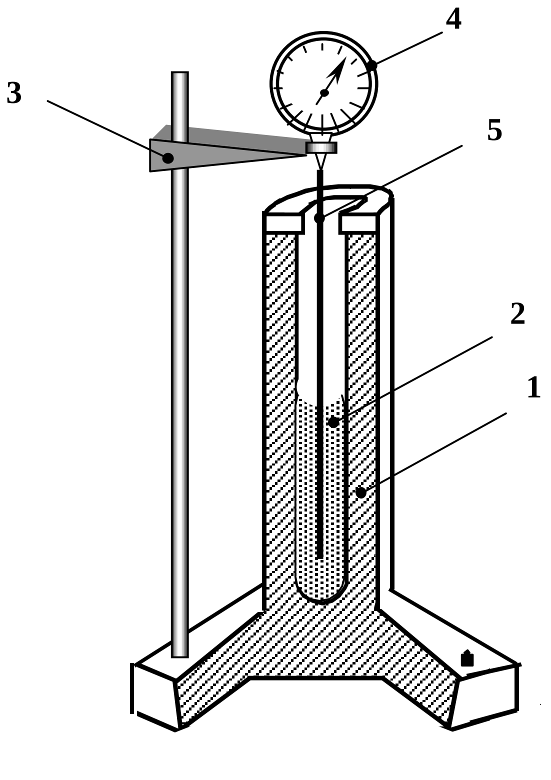

Figure 3.1

4 PROCEDURE AND ANALYSIS

4.1 Measure the initial length l_1 of the first rod with vernier caliper.
4.2 Fill 2/3 of the test-tube with water and find its temperature t_1 by thermometer.
4.3 Put the rod under investigation into the test-tube (the rounded end down). Put the test-tube into the electric heater.
4.4 Insert the micrometer indicator into holder and put indicator's spike in hollow on top of the rod. Fasten the indicator in the holder with screw.
4.5 Set the indicator pointer to zero point by turning a scale. Switch the heater on. Watch the motion of the pointer during the heating.
4.6 When the water in test-tube is boiling, the pointer stops. The final position of the pointer mark the total absolute expansion Δl of the rod. Turn the heater off.
4.7 Using table, determine the boiling point t_2 of water at the atmospheric pressure in the laboratory (determined from the laboratory barometer).
4.8 Calculate the value of linear coefficient of thermal expansion for material of the first rod using formula (2.4).
4.9 Repeat the experiment with other rods.
4.10 Estimate absolute and relative errors of the experiment.
4.11 Fill the table 4.1 with results of experiments and calculations.

Таблиця 4.1

	l_2-l_1, 10^{-3} m	$\Delta(l_2$-$l_1)$, 10^{-3} m	l_1, 10^{-3} m	Δl_1, 10^{-3} m	t_1, °C	Δt_1, °C	t_2, °C	Δt_2, °C	α, 10^{-6} K^{-1}	$\Delta\alpha$, 10^{-6} K^{-1}	ε, %
1											
2											
3											

4.12 Express results of the calculation in a form $a = a_m \pm \Delta a_m$ and specify the value of relative error ε.