DETERMINATION OF COEFFICIENT OF LINEAR EXPANSION OF A METAL ROD

Objective. To experimentally determine the value of the coefficient of thermal expansion of a metal.

Pre-lab questions. Intermolecular forces, potential energy of molecules, thermal expansion of solids.

Theory. The overall thermal expansion of an object is a consequence of the change in the average separation between its constituent atoms or molecules. To understand this idea, consider how the atoms in a solid substance behave. These atoms are located at fixed equilibrium positions; if an atom is pulled away from its position, a restoring force pulls it back. We can imagine that the atoms are particles connected by springs to their neighbouring atoms (See Fig. 1) If an atom is pulled away from its equilibrium position, the distortion of the springs provides a restoring force. At ordinary temperatures, the atoms vibrate around their equilibrium positions with an amplitude (maximum distance from the centre of vibration) of about 10^{-11} m, with an average spacing between the atoms of about 10^{-10} m. As the temperature of the solid increases, the atoms vibrate with greater amplitudes and the average separation between them increases. Consequently, the solid as a whole expands. If the thermal expansion of an object is sufficiently small compared with the object's initial dimensions, then the change in any dimension is, to a good approximation, proportional to the first power of the temperature change.

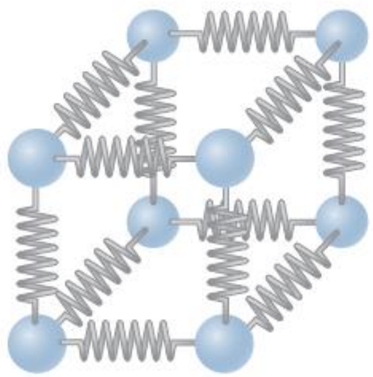

Fig. 1. A model of a portion of a solid. The atoms (spheres) are imagined as being attached to each other by springs, which represent the elastic nature of the interatomic forces. A solid consists of trillions of segments like this, with springs connecting all of them.

Suppose an object has an initial length L_0 along some direction at some temperature T_0. Then the length increases by ΔL for a change in temperature ΔT. So for small changes in temperature,

$$\Delta L = \alpha L_0 \Delta T \text{ or } L - L_0 = \alpha L_0 (T - T_0), \tag{1}$$

where L is the object's final length, T is its final temperature, and the proportionality constant a is called the **coefficient of linear expansion** for a given material and has units of K^{-1}.

In this work, the finite thermal expansion $\Delta L = L_1 - L_0$ which corresponds to finite temperature interval $t_1 - t_0$, will be calculated, therefore the average linear coefficient is expressed as following:

$$\alpha_v \cong \alpha = \frac{L_1 - L_0}{L_0 \left(t_1 - t_0\right)} = \frac{\Delta L}{L_0 \left(t_1 - t_0\right)}. \tag{2}$$

It is equal to relative expansion ($\Delta L / L_0$) when the temperature is raised by 1 degree. In this case using only two measures, the calculated average linear coefficient α_v is not reliable. The more reliable calculations can be made using experimental dependence of thermal expansion versus temperature change $\Delta L = f\left(t - t_0\right)$ (see Fig. 2). For the calculations the most linear part of the experimental line should be chosen. The relative

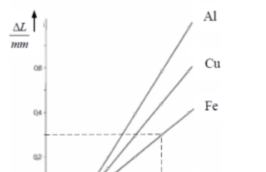

Fig. 2. Thermal expansion versus temperature change $\Delta L = f\left(t - t_0\right)$

limiting error of the coefficient of linear expansion is expressed as follows

$$\frac{\Delta\alpha}{\alpha_v} = \left|\frac{\Delta L_0}{L_0}\right| + \left|\frac{\Delta L}{L_1}\right| + \left|\frac{\Delta\left(t_1 - t_0\right)}{t_1 - t_0}\right| \tag{3}$$

Equipment. The equipment (Fig. 3) consists of: 1 – temperature indicator; 2 – temperature control knob; 3 – temperature probe; 4 – heated metal sample; 5 – expansion gauge

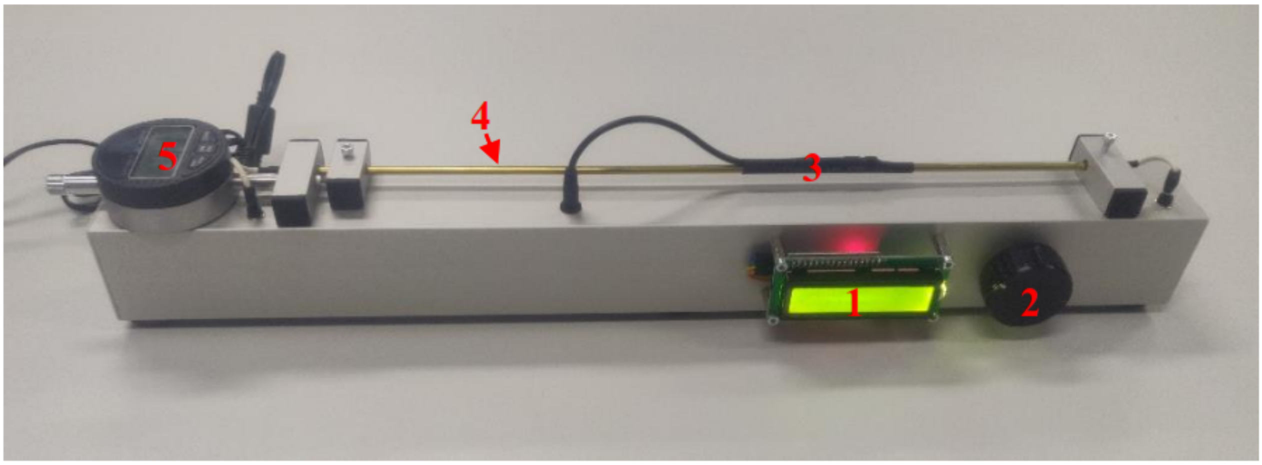

Fig. 3. Coefficient of linear expansion apparatus

Procedure:

1. Measure the length of the sample L_0 and the initial temperature t_0.
2. Set zero on the expansion gauge.
3. Change the temperature in 5 degree intervals (35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C) all over the temperature range up to 70 °C. After the new temperature value becomes stable - write down the value indicated by the expansion gauge n (n = ΔL) . To change the temperature, knob 2 is pressed in an the temperature value is entered by turning it. To set the new temperature value, press the knob twice.

L_0, mm	t_0, °C	t, °C	$t - t_0$, °C	ΔL, mm
362 ± 1				

4. After completing the measurements, set the thermostat control knob to zero and turn off the heating.

5. Plot the graph $\Delta L = f\left(t - t_0\right)$.

6. Choose the value $\left(t - t_0\right)$ and corresponding value ΔL from the linear part of the graph and calculate the average linear coefficient of thermal expansion α_v using the equation (2).