Theory

When a solid rod is heated, its atoms vibrate more intensely and tend to occupy slightly more space, causing the rod to expand. This phenomenon is known as thermal expansion. For most solids, particularly metals, the change in length is proportional to the initial length and to the temperature change.

The relationship describing linear thermal expansion is:

$$\Delta l = \alpha l \Delta T$$

where:

- Δl is the change in length of the rod.
- α is the coefficient of linear expansion.
- l is the initial length of the rod.
- ΔT is the temperature change.

The proportionality constant, α , quantifies how much the material expands per degree of temperature increase per unit length. By measuring the change in length as the temperature increases and knowing the initial length, the coefficient of expansion can be determined. The coefficient of expansion is calculated using:

$$\alpha = \frac{\Delta l}{l \Delta T}$$

The behavior is linear within moderate temperature ranges, and different metals have different coefficients reflecting their atomic structure and bonding strength. This property is critical in engineering, where thermal expansion can affect material performance and structural integrity.

Experimental Procedure

The brass tube was measured for its initial length at room temperature, then secured in the PASCO Thermal Expansion Apparatus with sensors for temperature and displacement attached. The steam generator was used to steadily heat the tube while the PASCO interface recorded changes in length and temperature (Figure 1). Data collection continued as the rod was heated to around $90^{\circ}C$ and then allowed to cool. The resulting displacement versus temperature data was analyzed to determine the thermal expansion coefficient using the linear fit method (Figure 2).

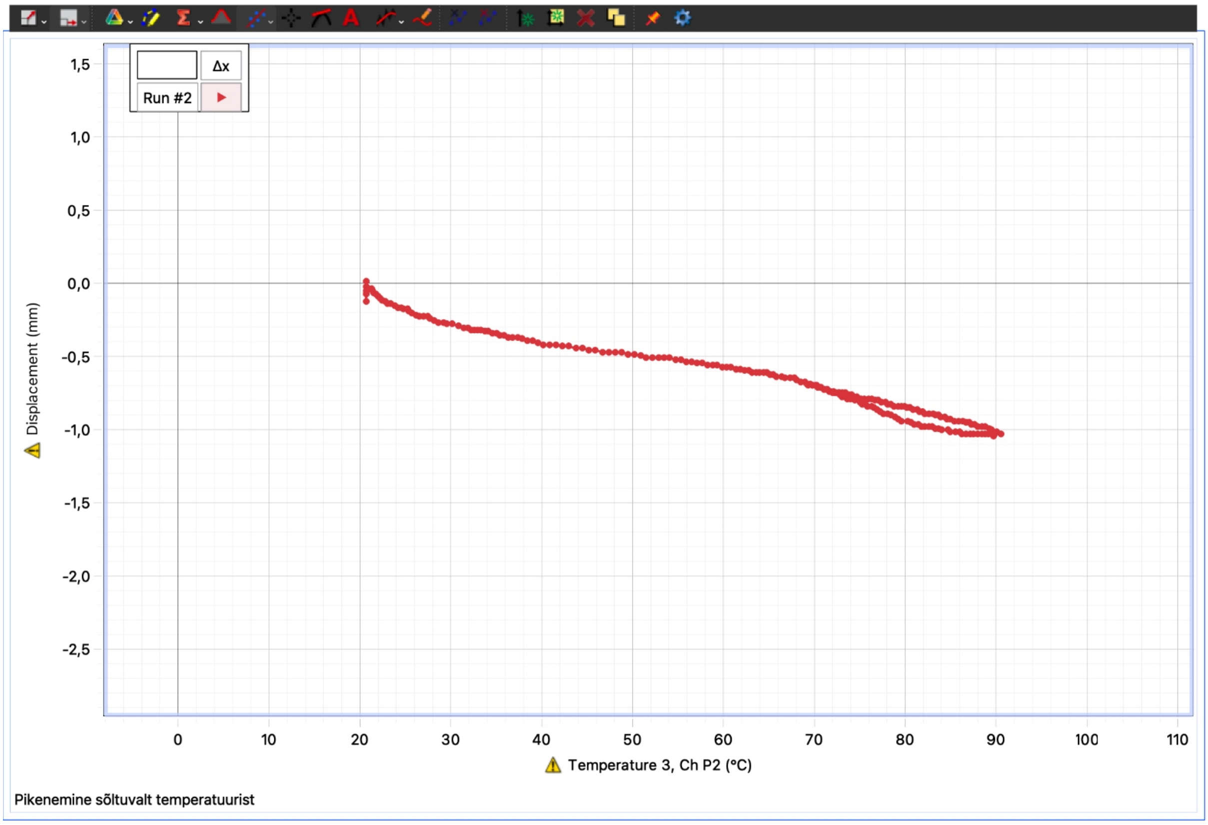

Figure 1: Relation between temperature and displacement.

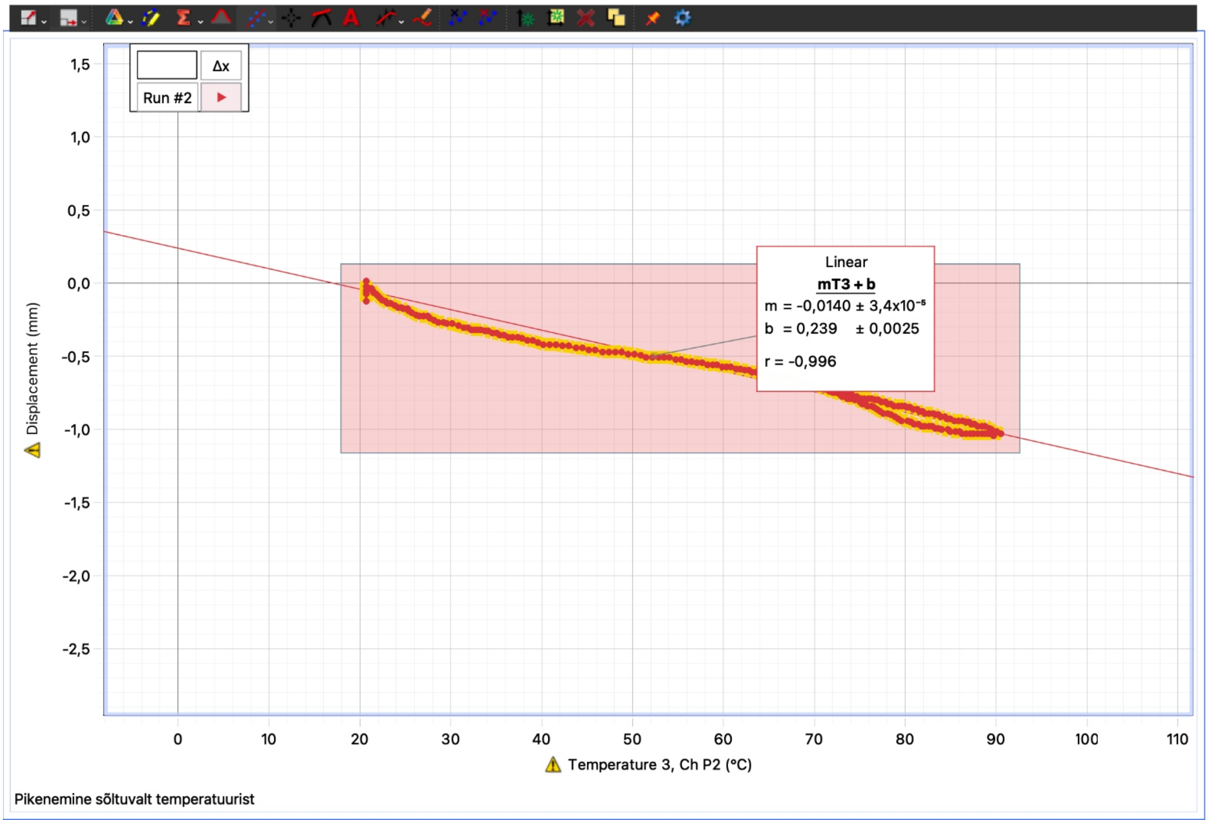

Figure 2: Slope analysis of the temperature/displacement graph.

Measurements and Formula Application

The initial length of the rod was measured as $l = 0.75m$. The linear fit of the displacement versus temperature graph yielded a slope$m = -0.0140mm/^{\circ}C$ with an uncertainty of $U_m = 3.4 \times 10^{-5} mm/^{\circ}C$.

Coefficient of Linear Expansion

The coefficient of linear expansion was calculated using:

$$\alpha = \frac{m}{l}$$

So, we have:

$$\alpha = \frac{-1.40 \times 10^{-5}}{0.75} = -1.87 \times 10^{-5} {}^{\circ}C^{-1}$$

Coefficient of Uncertainty

The uncertainty was calculated as:

$$U_a = \frac{U_m}{l}$$

Where u_m is converted to meters per degree:

$$U_a = \frac{3.4 \times 10^{-8}}{0.75} = 4.5 \times 10^{-8} {}^{\circ}C^{-1}$$