EXPERIMENT T3

MEASURING THE COEFFICIENT OF THERMAL EXPANSION 
OF COPPER, STEEL AND ALUMINIUM

Objectives
- To understand the concepts of heat exchange and thermal equilibrium
- To measure the coefficient of thermal expansion of copper, steel and aluminium
- To calculate the coefficients of volume expansion of copper, steel and aluminium.

SAFETY WARNING
In this experiment you will work with steam, hot water, and hot metal bars. Be careful not to burn yourself when you touch an object. Do not open the steam generator, or touch the bars when they’re hot!

Background
Most materials expand somewhat when heated through a temperature range that does not produce melting or boiling. In a simple but useful atomic model of the material, the temperature rise causes an increase of the amplitude of vibration of the atoms in the material, which increases the average separation between the atoms, and the material expands as a result.

It turns out that, provided the change in temperature isn’t too big, the amount by which the material expands is directly proportional to the change in temperature. From the atomic model you can infer that the expansion should also be directly proportional to the size of the object. The constant of proportionality is called the coefficient of linear expansion (symbol: $\alpha$) and varies from material to material.

Not all materials expand to the same extent in different directions. Such materials are called anisotropic, i.e. not (an) the same (iso) in all directions (tropic). In an asymmetric crystal for example, $\alpha$ can have a different value depending on the axis along which the expansion is measured. $\alpha$ can also vary somewhat with temperature so that the degree of expansion depends not only on the magnitude of the temperature change, but on the absolute temperature as well.

Now answer questions A1-A3 on the answer sheet
Experiment
In this experiment, you will measure $\alpha$ for copper, aluminium, and steel. These metals are isotropic so that $\alpha$ need only be measured along one dimension. Also, within the limits of this experiment, $\alpha$ does not vary with temperature.

The thermal expansion apparatus is shown in Figure 1. It allows you to make reasonably accurate measurements of the coefficient of linear expansion for steel, copper, and aluminium in a straightforward manner. The length of the bar is measured at room temperature, and again when it has been heated up. By measuring the length at room temperature, the expansion, and the temperature difference, you can work out the value of $\alpha$.

To make the measurement, the tube is placed on the expansion base. The length of the tube is measured at room temperature; the expansion is measured with a built-in dial gauge. Steam from a steam generator (much like a kettle) is passed through the tube, and after a while the bar reaches a certain constant temperature. You can monitor the temperature using a thermistor attached to the centre of the tube. The resistance of the thermistor varies with temperature; the relationship between temperature and resistance is known beforehand. Thus by monitoring the resistance with a multimeter you can effectively monitor the temperature. Although the relationship between temperature and resistance is not linear, a linear approximation can be accurately used to interpolate between values listed in the table with an accuracy of approximately $\pm 0.2^\circ$C. If you wish to investigate the expansion of the metals at additional temperatures, hot or cold water can be passed through the tubes.

Experimental set-up

![Figure 1. Equipment set-up.](image-url)

The thermistor that measures the tube temperature is embedded in the thermistor lug. Once thermal equilibrium has been reached, the heat is highly uniform along the length of the tube. The foam insulator is used to inhibit heat loss through the thermistor lug so the lug temperature closely follows the tube temperature. The insulator does not have any appreciable effect on the local temperature of the tube itself.
Procedure
1. To find L, the length of the copper tube at room temperature, measure from the inner edge of the stainless steel pin on one end, to the inner edge of the angle bracket at the other end. Record your results as in Table A4.
2. Mount the copper tube in the expansion base as shown in Figure 2. The stainless steel pin on the tube fits into the slot on the mounting block and the bracket on the tube presses against the spring arm of the dial gauge.

![Figure 2. Mounting the tube.](image)

NOTE: Slide or push the tube to one side of the slide support. Drive the thumbscrew against the pin until the tube can no longer be moved. Use this as your reference point. Attach the thermistor lug to the middle of the copper tube. The lug should be aligned with the axis of the tube, as shown in Figure 2, so there is maximum contact between the lug and the tube.
3. Place the foam insulator over the thermistor lug as shown in Figure 3.
4. Plug the leads of the multimeter into the banana plug connectors labelled THERMISTOR in the centre of the expansion base and set the multimeter to measure resistance ($\Omega$).

![Figure 3. Thermistor lug.](image)

5. Measure and record $R_{rm}$, the resistance of the thermistor at room temperature. Record this value in the table A4.
6. Use tubing to attach your steam generator to the end of the copper tube. Attach it to the end farthest from the dial gauge.
7. Use a book or a block of wood to raise the end of the expansion base at which steam enters the tube - a few centimetres is sufficient. This will allow any water that condenses in the tube to drain out. Place a beaker under the other end of the tube to catch the draining water.
8. Turn the outer casing of the dial gauge to align the zero point on the scale with the long indicator needle. As the tube expands, the indicator needle will move in an anti-clockwise direction.

9. Ensure there is enough water in the steam generator before switching it on. Once switched on, do not remove the top. Turn on the steam generator. As steam begins to flow, watch the dial gauge and the multimeter. When the thermistor resistance stabilises, record the resistance ($R_{hot}$) as in Table A4. Also record the expansion of the tube length ($\Delta L$) as indicated by the displacement of the indicator on the dial gauge. (Each increment on the dial gauge is equivalent to 0.01 mm of tube expansion).

10. Repeat the experiment for the steel and aluminium tubes. Write down your results in table A4.

11. If time permits, repeat the experiment, replacing the steam with cold water running through the tube(s). Make sure the water is drained off properly! Complete

**Caution:** When changing tubes be careful not to pull the wires off the thermistor. *The thumbscrew must be completely removed* before the thermistor can be lifted off the threaded rod.

Now answer questions A4–A14 on the answer sheet
Mathematical notes

Equation 1 below defines the coefficient of linear expansion:

\[ \Delta L = \alpha L_0 \Delta T \]  

(1)

Appendix: Useful Data

Table 1. Coefficient of Thermal Expansion

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>( \alpha \times 10^{-6}/\text{oC} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>16.5</td>
</tr>
<tr>
<td>Steel</td>
<td>11.7</td>
</tr>
<tr>
<td>Aluminium</td>
<td>23</td>
</tr>
</tbody>
</table>