Coefficients of Linear Expansion

Purpose:
To determine the coefficient of linear expansion of glass, aluminum and brass samples.

Equipment:
- Linear Expansion Apparatus
- Linear Expansion Samples
- Steam Generator
- Hot Plate
- Micrometer Caliper
- Gloves or Oven Mitts

Theory:
Most materials, when heated, will expand. This expansion is not a function of the heat (energy) added to the material, but of its change in temperature. While this expansion takes place in three dimensions, it will be enough for us to consider expansion in only one dimension, along the length of a thin metal or glass tube.

Consider a tube of initial length \( L_0 \). When heated from its initial temperature, \( T_0 \), to a final temperature, \( T_f \), the tube expands to a new length, \( L_f \). The change in length, \( \Delta L = L_f - L_0 \), of the tube is found to be proportional to the initial length of the tube, \( L_0 \), and the change in temperature of the tube, \( \Delta T = T_f - T_0 \):

\[
\Delta L = \alpha L_0 \Delta T \quad \text{Eq. 1}
\]

where \( \alpha \) is a constant called the “linear coefficient of thermal expansion.”

Experiment:
1. Use the barometer in room 1824 to determine the atmospheric pressure. This is a sensitive (and expensive) piece of equipment, so be sure that your instructor or Richard Solomon has shown you how to use it.

2. Fill a steam generator with water and close the top with a cap or rubber stopper. Place the steam generator on a hot plate and turn the heat to medium-high or high. NOTE: Take care that the nozzle outlets of the steam generator are not aimed directly at any person in close proximity! Steam burns are very painful!
3. With a micrometer caliper, measure the diameter of the pointer axle in five different places. Calculate and record the average and deviation of the five readings ($d \pm \delta$).

4. Set the support on a flat surface and place the groove of the expansion tube firmly on the knife-edge of the support. Place the axle of the indicating dial mechanism 75cm from the support, and allow the other end of the expansion tube to rest across the axle. Measure and record the exact distance between the axle and the support $L_0$.

5. Make sure that the pointer doesn’t rub against the face of the scale.

6. Attach one rubber hose to each end of the expansion tube. Support the hoses with clamps so that the expansion tube doesn’t move when you’re connecting the hose to the steam generator, or from the discharge of waste-water. Put a beaker under the end of the “discharge tube” to catch the water.

7. Let the tube reach room temperature. Record the temperature. Adjust one side of the double pointer to read exactly $0^\circ$.

8. Attach the hose to a steam generator and let steam pass through the expansion tube until the tube stops elongating. Record the number of degrees indicated by the pointer at this time.

9. Repeat the experiment with a tube of a different material. CAUTION: The tubes may be hot! Wear gloves or oven mitts!

Analysis:
1. Using the barometric information you gathered, calculate the temperature of the steam. A conversion chart from the Handbook of Chemistry and Physics may be useful.

2. Calculate the circumference of the axle.

3. Determine the change in length of each tube, $\Delta L$.

4. Determine the change in temperature of the tube, $\Delta T$.

5. Using equation (1), find the linear expansion coefficient, $\alpha$, for each material. Compare with the value obtained from the Handbook of Chemistry and Physics. Does it lie within the error of your calculated value? (What are the sources of error in your calculated value?)
Summary Questions

Question 1: Setup Measurements
(a) Measure the axel in 5 places. Record data in a table.
(b) Calculate average diameter
(c) Calculate std. From this calculate the (absolute) uncertainty in the diameter: \( unc = \frac{std}{\sqrt{5}} \)
(d) Calculate the % uncertainty.

Question 2: Pointer Calibration
Note if the pointer moves an angle of \( \theta \) (in radians), the rod has expanded a length of \( \Delta L = R \theta \), where “R” is the radius of the axel. More conveniently, we can express: \( \Delta L = Z \theta \) where the angle \( \theta \) is measured in degrees, and \( Z=(\text{diameter in mm})/(2 \times 57.3^\circ) \) is the calibration of the expansion meter in mm of expansion per degree deviation.
(a) Calculate \( Z \)
(b) What is the percent uncertainty in \( Z \)? (Hint: it will be the same as the percent uncertainty in the diameter).

Question 3 Barometer
(a) What is the (uncorrected) barometer reading in mb? (millibars)
(b) What is the temperature at the barometer?
(c) What is the temperature correction for the barometer in mb? [Note, the barometer is made of mercury, so with an increase in temperature the mercury column expands even though the pressure is unchanged]
(d) What then is the corrected barometer reading in mb?
[Note, we ignored the gravity correction for which we should subtract 0.70 mb approximately]

Question 4 Boiling Point of Water
(a) Convert mb to torr (Note 760 torr = 1013.25 mb).
(b) Lookup the boiling point correction for water in the Handbook of Chemistry & Physics. What is the boiling point of water at today’s pressure?

Question 5 Initial Temperature
(a) What is the room temperature
(b) Are the rods initially at room temperature, or are the hotter or colder? [Is it possible to measure the temperature of the rods accurately?]

Question 6 Exit Steam Temperature
It is suspected that the actual temperature of the hot rod might be closer in value to that of the exiting steam, rather than the temperature of boiling water.
(a) If possible, measure the temperature of the boiling water.
(b) Measure the temperature of the exiting steam (for each rod, at end of experiment)
(c) Comment: which do you think is a better measure of the hot rod?

Data & Calculations Table (Sample)

<table>
<thead>
<tr>
<th>Composition</th>
<th>L (mm)</th>
<th>Pointer Deviation (Degrees)</th>
<th>( \Delta L ) (mm)</th>
<th>Initial Temp °C</th>
<th>Exit Steam Temp °C</th>
<th>( \Delta T ) (°C)</th>
<th>Measured Coefficient ( \alpha )</th>
<th>Known Value ( \alpha )</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bronze</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
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</tbody>
</table>

Question 7: Compare your measured values of coefficient of thermal expansion with known values.
Some sample data and calculations

<table>
<thead>
<tr>
<th>Composition</th>
<th>(L) (mm)</th>
<th>Deviation (Degrees)</th>
<th>Delta L (mm)</th>
<th>Delta T (degrees C)</th>
<th>(\alpha)</th>
<th>Known error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>750</td>
<td>60</td>
<td>1.24</td>
<td>74.5</td>
<td>2.22E-05</td>
<td>2.40E-05, -8%</td>
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<tr>
<td>Bronze</td>
<td>745</td>
<td>10</td>
<td>0.21</td>
<td>65</td>
<td>4.27E-06</td>
<td>1.70E-05, -75%</td>
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<tr>
<td>Glass</td>
<td>750</td>
<td>6</td>
<td>0.12</td>
<td>79</td>
<td>2.09E-06</td>
<td>4.00E-06, -48%</td>
</tr>
</tbody>
</table>

Axel d 2.368 mm
Z Factor 0.020663 mm/deg