

## LAB 12 THERMAL EXPANSION

**Caution: This lab involves the use of water vapor/steam. Be very careful – use gloves when handling the steam lines, water beakers, or hot metal rods.**

### Goals:

- Measure the change in length of rods (of different materials) due to a temperature change

### Thermal Expansion theory:

When the temperature of an object is raised, the internal energy of the object is raised. This implies a larger degree of kinetic motion of the molecules of the object - resulting in an increase in the separation distance between them. When an object is cooled, the reverse happens, with the "size" of the object decreasing. Over a reasonable range, this effect is a linear one, and each material has a specific fixed *coefficient of thermal expansion*. Depending on whether the length, the area, or the volume is the dimension that is expanding or contracting, we can use the following formulas to describe the change in the dimension of the object undergoing a temperature change:

$$\text{Length : } L_F = L_0 + L_0\alpha\Delta T \quad \Delta L = L_F - L_0 \quad \text{so, } \Delta L = L_0\alpha\Delta T$$

$$\text{Area : } A_F = A_0 + A_0\sigma\Delta T \quad \Delta A = A_F - A_0 \quad \text{so, } \Delta A = A_0\sigma\Delta T$$

$$\text{Volume : } V_F = V_0 + V_0\beta\Delta T \quad \Delta V = V_F - V_0 \quad \text{so, } \Delta V = V_0\beta\Delta T$$

We will heat several metal rods using steam from a water boiler. We can measure the changes in temperature and in length of the rods, and from that verify the linear expansion formulas above.

### Part 1 Initial Preparation

It would be very helpful to look at the online help page for this lab.

1. Boiling water. Fill the glass flask (the boiler) with water and seal the top tightly. Place the free end of the hose connected to the boiler in a cup (so it is safely out of the way). Place the boiler on the hot plate. Make sure the hot plate is plugged in, and then turn it on. (Make sure the flask is clamped to the pole using the three-fingered clamps so that it doesn't tip over!) (See help page picture.)

2. Length of rod. There will be an assortment of "rods" connected to the thermal apparatus. Select two such rods and measure their lengths with a meter stick in units of millimeters (**You do not measure the whole length of the rod**, refer to the online help page for the specific dimension that you should measure as the length). Estimate the uncertainty ( $\delta L$ ) of the measurement (remember that the precision of the ruler is 1/10th the smallest division, but if the "ends" of the measurement are not clearly defined, your uncertainty would be higher). Record these initial lengths on the Question/Data sheet. {It is strongly recommended that one of the rods you select be aluminum.}

3. Connecting the thermal apparatus to the steam line. The online help page shows the way the apparatus is connected to the steam line. The steam line connects on the end opposite to the dial end. The dial end is open to the air. Make sure there is a small glass beaker to collect any condensation from the open end.

4. Apparatus not room temp? If the apparatus was used recently (a previous lab session), it might still be warm. Be careful until you are sure – and use the gloves if necessary.

5. Connecting the multimeter. This apparatus has a thermocouple inside, and we can measure the resistance with an external multimeter. There is a conversion graph to convert the resistance measurement to the temperature. Connect the multimeter (acting as an Ohmmeter, ask your instructor for how to set it as an Ohmmeter) to the apparatus as shown in the online help pages. Make sure the thin wire from the apparatus is connected to the middle of the rod.

6. "Anchoring" the metal rod. See the online help page for images/text concerning how to seat the rod in the apparatus. Once in place, you can turn the dial to zero by rotating the outside of the dial.

7. Recording original temperature. The initial temperature of the metal rod is the room temperature. Take a reading on the multimeter, consult the calibration curve, and estimate the starting temperature (and estimate the uncertainty in the measurement). Record this information on the Data/Question sheet.

8. Steam lines and cup to catch condensation. In the next section, you can connect the steam line to the upper nozzle and place the glass beaker under the end nozzle to catch the condensation that might come out from the tube. **Tilt the steam apparatus so that the steam exit end is lower.** By doing so, you can prevent water condensation building up in the rod, which can significantly slow down the experiment.

## Part 2 Heating Metal Rod with Steam

1. Proper setup for the apparatus. When the steam is going through the system, there has to be a good flow, otherwise water will collect, and block the steam, thus not ensuring a uniform temperature for the metal rod. Also, be careful of the water vapor that is coming out the open end – make sure there is nothing (or no one) in the path that can be damaged.

2. Connecting the steam. Carefully connect the steam hose to the connector on the expansion apparatus. (Fold a sheet of paper towel into several layers to help hold the high temperature hose). Make sure that you see water vapor coming out the other end (that is, make sure there is a good air flow through the apparatus). This will begin the heating process of the metal rod. [Important - there cannot be any "low" points in the path from the glass flask nozzle down to the connector on the expansion apparatus - if there are low points, the water could condense, and the steam won't get to the apparatus! Arrange the hose to provide only a downward path to the top connection nozzle of the apparatus.]

3. Double-check the dial indicator. During the handling above, the dial may have moved slightly. As soon as you connect the steam line, reset the dial indicator on the apparatus to zero. This will now allow us to measure the change in length due to the increase in temperature. Tap the dial to make sure that it is not sticking. (Watch the dial as the rod heats to see if the needle goes all the way around.)

## Part 3 Preliminary Calculations

We are now going to wait for the temperature to stabilize near 100 degrees and the dial reading to stop changing (indicating that the maximum change in length of the rod has been reached). We took the initial temperature with the multimeter, and we will take the final temperature the same way. We can watch the multimeter to see when it starts to stabilize (when the dial on the apparatus stops changing, and the multimeter is pretty stable, the rod is heated up and expanded as far as it will go).

1. Final temperature. Take a reading from the multimeter, calibrate that to the temperature, and estimate the uncertainty ( $\delta T_{\text{final}}$ ) of the measurement. Copy those values to the Data/Question sheet.

2. Final change in length. When the “thermometer” has stabilized, and the dial reading (indicating the change in length) has stopped changing, the system has reached the final temperature, and we can measure the final length change. Again, tap the dial indicator to make sure that it is not sticking before making the reading. Estimate the uncertainty ( $\delta(\Delta L)$ ) in the change in length. Record on the Data/Question sheets. (Remember- One full revolution on the dial represents a  $\Delta L = 1\text{mm}$ .)

We will make the calculations using these numbers after we start the process with the next rod.

#### **Part 4 Switching metal rods – Heating second rod**

Once the final length change has been made, we can switch rods. But the system is very hot at the moment; we need to take care with it.

1. Use caution when handling the system. Use the gloves to handle the heated rods, and be careful of the steam/water vapor hoses.
2. Switch rods. Take the first rod out of the apparatus after it is cooled enough to handle, and insert the next rod. Make sure you don't use someone else's recent metal rod – pick a room temperature metal rod. Follow the directions from Part 1 and Part 2 on how to properly set up the equipment.
3. Recording initial temperature. Using the multimeter and the calibration chart, record the initial temperature. Estimate the uncertainty ( $\delta T_{\text{initial}}$ ) of the measurement. Record these numbers on the Data/Question sheet.
4. Reconnect steam line. Reconnect the steam line (making sure there is good downward-only air flow through the system). Reset the dial reading to zero (tapping to relieve sticking). Begin the heating process. We are again looking for the “thermometer” to stabilize, and for the rod length to stop changing. During that time, we can do some calculations and answer some questions.
5. Calculate the coefficient of thermal expansion (for Rod #1). While we are waiting for the second rod to expand, we can finish the calculations on the first rod. Using the final change in length, and the final temperature change, we can calculate the coefficient of thermal expansion and compare it to the given value. We can also calculate the uncertainty in that calculation. Record these calculations on the Data/Question sheet.

Questions Answer the questions for this section on the Data/Question sheet.

#### **Part 5 Completion of the heating of the Second rod**

1. Final temperature and change in length. When the multimeter has stabilized, and the dial reading (indicating the change in length) has stopped changing, the system has reached the final temperature, and we can measure the final length change. Again, tap the dial indicator to make sure that it is not sticking before making the reading. Estimate the uncertainty ( $\delta(\Delta L)$ ) in the change in length.
2. Caution. Using the gloves, take apart the apparatus and store it where indicated by the lab instructor.
3. Calculate the coefficient of thermal expansion (for Rod #2). Using the final change in length, and the final temperature change, we can calculate the coefficient of thermal expansion and compare it to the

given value. We can also calculate the uncertainty in that calculation. Record these calculations on the Data/Question sheet.

## DATA/QUESTION SHEET FOR LAB 12 THERMAL EXPANSION

Rod # 1 material = \_\_\_\_\_ Original length = \_\_\_\_\_  $\pm$  \_\_\_\_\_ mm  
 coefficient of thermal expansion =  $\alpha$  = \_\_\_\_\_ 1/C (from table on next page)

Rod # 2 material = \_\_\_\_\_ Original length = \_\_\_\_\_  $\pm$  \_\_\_\_\_ mm  
 coefficient of thermal expansion =  $\alpha$  = \_\_\_\_\_ 1/C (from table on next page)

### **Rod #1 :**

#### Recording initial temperature (ROD 1).

Initial RESISTANCE measurement = \_\_\_\_\_  $\pm$  \_\_\_\_\_  $\Omega$

Initial temperature of the rod = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C

#### Final temperature.

Final RESISTANCE measurement = \_\_\_\_\_  $\pm$  \_\_\_\_\_  $\Omega$

Final temperature of the rod = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C

#### Final change in length.

final change in length measurement -  $\Delta L$  = \_\_\_\_\_  $\pm$  \_\_\_\_\_ mm

Calculate the coefficient of thermal expansion. Using the final change in length, and the final temperature change, we can calculate the coefficient of thermal expansion and compare it to the given value. We can also calculate the uncertainty in that calculation. (See equations on next page.)

$\Delta T$  = final - initial temperatures = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C {in the form:  $\Delta T \pm \delta(\Delta T)$ }

$$\alpha = \frac{\Delta L}{L_0 \Delta T} = \text{_____} \pm \text{_____} \text{ 1/C} \quad \{\text{in the form: } \alpha \pm \delta(\alpha)\} \quad \% \text{ error} = \text{_____}$$

### **Rod #2 :**

#### Recording initial temperature (ROD 2).

Initial RESISTANCE measurement = \_\_\_\_\_  $\pm$  \_\_\_\_\_  $\Omega$

Initial temperature of the rod = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C

#### Final temperature.

Final RESISTANCE measurement = \_\_\_\_\_  $\pm$  \_\_\_\_\_  $\Omega$

Final temperature of the rod) = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C

#### Final change in length.

final change in length measurement -  $\Delta L$  = \_\_\_\_\_  $\pm$  \_\_\_\_\_ mm

#### Calculate the coefficient of thermal expansion.

$\Delta T$  = final - initial temperatures = \_\_\_\_\_  $\pm$  \_\_\_\_\_ C {in the form:  $\Delta T \pm \delta(\Delta T)$ }

$$\alpha = \frac{\Delta L}{L_0 \Delta T} = \text{_____} \pm \text{_____} \text{ 1/C} \quad \{\text{in the form: } \alpha \pm \delta(\alpha)\} \quad \% \text{ error} = \text{_____}$$

To calculate the uncertainties in the change in temperature and the coefficient of expansion, we can use the following formulas  $\Delta T$  = overall temperature change,  $\Delta L$  = dial reading (the change in length):

$$\delta(\Delta T) = \text{uncertainty in the change in temperature} = \sqrt{(\delta T_{\text{initial}})^2 + (\delta T_{\text{final}})^2}$$

$$\delta(\Delta L) = \text{uncertainty in the change in length (dial uncertainty!)}$$

$$\delta(\alpha) = \text{uncertainty in the coefficient} = (\alpha) \sqrt{\left(\frac{\delta(\Delta T)}{\Delta T}\right)^2 + \left(\frac{\delta L_{\text{initial}}}{L_{\text{initial}}}\right)^2 + \left(\frac{\delta(\Delta L)}{\Delta L}\right)^2}$$

$$\% \text{ error} = \frac{|\alpha_{\text{theory}} - \alpha_{\text{experimental}}|}{\alpha_{\text{theory}}} \times 100\%$$

Questions a) Discuss the agreement between the calculated and given coefficient of expansion, taking into account the calculated uncertainty in the coefficient.

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b) From the uncertainty of the data in each measurement, which would improve the accuracy of the coefficient of expansion more effectively, a more precise instrument than the meter stick for measuring the length of the rod or a better way to measure the expansion? (Remember, the smaller the percent uncertainty, the more accurate the measurement.) Explain with numbers.

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c) Conceptual question: When a mercury-in-glass thermometer is plunged into a hot water bath, the thermometer reading drops before it rises. Suggest a possible explanation. (Discuss with the lab group.)

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#### Coefficients of Thermal expansion ( $\alpha$ )

Aluminum	$23 \times 10^{-6} \text{ 1/C}$	Steel	$11 \times 10^{-6} \text{ 1/C}$
Copper	$17 \times 10^{-6} \text{ 1/C}$		

#### **How do I write up this lab? ... What is required for this lab report?**

Consult the Rubric for this experiment and the “Lab Report Instructions” document (both found on the Lab Schedule page).

Questions/Suggestions → Dr. Changgong Zhou [czhou@ltu.edu](mailto:czhou@ltu.edu)

*Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.*



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## Rubric - Lab 12 Thermal Expansion - 80 points

<b>Cover Page (R)</b>	Student Name	1
<b>5 Points</b>	Course-Section-Station	1
	Lab Title / Instructor's Name	1
	Date / Lab partner names	1
	HONOR CODE PLEDGE	1
<b>Introduction (R)</b>	Content/Grammar/Spelling	10
<b>10 Points</b>		
<b>Rod 1 – Calculations (D/Q)</b>	Calculations	15
<b>15 Points</b>		
<b>Rod 2 – Calculations (D/Q)</b>	Calculations	15
<b>15 Points</b>		
<b>Part 4 – Questions (D/Q)</b>	Questions	15
<b>15 Points</b>		
<b>Analysis <sup>(1)</sup> (R)</b>	Spelling/Grammar	10
<b>20 Points</b>	<b>Analyze the results of this experiment, including a discussion of the uncertainties of the coefficient, and the possible sources of error in the experimental procedure. (See “Lab Report Instructions” file for format details.)</b>	10

Also: points will be taken off for the following as appropriate:

- Report turned in late (5 points per school day)
- Any units missing (if not printed on data table) (1 pt each)
- Report not typed/stapled (5 pts)
- Decimal point and sig fig errors (1 pt each)
- Presentation (i.e. torn edges on papers (5 pts)
- Instructor's signature/stamp missing – 5 points**
- Data/Question sheets missing – 20 points**

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