LAB 10 THERMAL EXPANSION(TPL2)

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:

Length : $L_F = L_0 + L_0\alpha\Delta T \qquad \Delta L = L_F - L_0 \qquad$ so, $\Delta L = L_0\alpha\Delta T$

Area : $A_F = A_0 + A_0\sigma\Delta T \qquad \Delta A = A_F - A_0 \qquad$ so, $\Delta A = A_0\sigma\Delta T$

Volume : $V_F = V_0 + V_0\beta\Delta T \qquad \Delta V = V_F - V_0 \qquad$ so, $\Delta V = V_0\beta\Delta T$

We will heat several metal rods using steam from a water boiler. We can measure the change in temperature and the change 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. 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 (see the online help page for the specific dimension that you should measure as the length). Record these initial lengths on the Data/Question 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 "cup" to collect any condensation from the open end.
It is a good idea to elevate (1.0cm) the steam line end of the apparatus.

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) 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 initial 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. 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 Styrofoam cup under the lower nozzle to catch the condensation that might come out from the tube.

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 and the apparatus should be raised (1.0cm) at the steam entry end.]

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.) Now put the rubber stopper tightly in the top of the flask (boiler).

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). **Wait until you see steam and water coming out of the open end of the tube.**

1. Final temperature. Take a reading from the multimeter, calibrate that to the temperature. Copy those values to the Data/Question sheet. If the final temperature reading from this method is less than 100^{o}C use 100^{o}C for the final temperature – the temperature of a mixture of steam and water.)

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. Record on the Data/Question sheets. (Remember- One full revolution on the dial represents a ΔL = 1mm so each division is 0.01mm.) Remember, the dial reads backwards.

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. Then repeat the above steps.

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, (There will be water in the tube.) 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. Record this number 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. Record these calculations on the Data/Question sheet and answer any questions.

Part 5 Completion of the heating of the Second rod

1. Final temperature and change in length. When the multimeter has stabilized, record the final resistance reading on the Data/Question sheet and if 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. Again, wait until steam and water comes out of the open end of the tube and if the multimeter reading corresponds to a temperature less than 100^{o}C, record the final temperature to be 100^{o}C.

2. Caution. Using the gloves, take apart the apparatus and store it where indicated by the lab instructor. (Remember, the tube will have water in it.)

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. Record these calculations on the Data/Question sheet.

4. Calculate the %error. Using the measured coefficients of thermal expansion, α_{meas}, for each rod and the given values, α_{given}, calculate the %errors for each rod. Record on the Data/Question sheet and answer any questions.

Given Coefficients of Thermal expansion (α_{given})

Aluminum	2.3 x10^{-5} 1/C^{o}	Steel	1.1 x10^{-5} 1/C^{o}
Nickel	1.1 x10^{-5} 1/C^{o} to 1.4 x10^{-5} 1/^{o}C	Brass	1.9 x10^{-5} 1/C^{o}
Copper	1.7 x10^{-5} 1/C^{o}		

DATA/QUESTION SHEET FOR LAB 10 THERMAL EXPANSION

Part 1 – Initial Preparations

2. Length of rods

Rod #1 material ________________ Original Length, L_o = _______________mm
coefficient of thermal expansion, α_{given}= ___________ 1/C^o (from table on previous page)

Rod # 2 material ________________ Original length, L_o = _______________mm
coefficient of thermal expansion, α_{given} = ___________ 1/C^o (from table on previous page)

7. Initial temperature (Rod #1)
Initial RESISTANCE measurement = ____________Ω
Initial temperature, T_i, = ___________ ^{o}C

Part 3 – Preliminary Calculations

1. Final Temperature.

Final RESISTANCE measurement = ___________Ω
Final temperature, T_f = __________ ^{o}C (If this is not 100^{o}C, record 100^{o}C)

2. Final change in length
Final change in length; ΔL = _________mm (From the dial indicator)

Part 4 – Switching Metal Rods

3. Initial temperature (Rod #2)
Initial RESISTANCE measurement = ____________Ω
Initial temperature, T_i, = ___________ ^{o}C

5. Calculate the coefficient of thermal expansion. (For ROD #1)
Using the final change in length, ΔL, and the final change in temperature, ΔT, we can calculate The coefficient of thermal expansion, α_{meas}, and compare it to the given value, α_{given}. We can also calculate the uncertainty in that calculation.

$T_f - T_i = \Delta T$ = _______C^o, ΔL = ________mm (Part 3.2), L_o = _________mm(Part 1.2)

$$\alpha_{meas} = \frac{\Delta L}{L_o \Delta T} = \underline{\qquad\qquad} \ {}^{1}/_{C^o}$$

Part 5 – Completion of the Heating of the Second Rod

1. Final Temperature and change in length.

Final RESISTANCE measurement = ___________Ω
Final temperature, T_f = __________ ^{o}C (If this is not 100^{o}C, record 100^{o}C)
Final change in length; ΔL = _________mm (From the dial indicator)

3. Calculate the coefficient of thermal expansion. (For ROD #2)

Using the final change in length, ΔL, and the final change in temperature, ΔT, we can calculate The coefficient of thermal expansion, α_{meas}, and compare it to the given value, α_{given}. We can also calculate the uncertainty in that calculation.

$T_f - T_i = \Delta T$ = ________C^o, ΔL = __________mm(Part 5.1), L_o = ________mm(Part 1.2)

$$\alpha_{meas} = \frac{\Delta L}{L_o \Delta T} = \_\_\_\_\_\_\_\_\_\_\_\_ {}^{1}/_{C^o}$$

4. Calculate the % error between α_{meas} and α_{given}.

$$\%\ error = \frac{|\alpha_{given} - \alpha_{meas}|}{\alpha_{given}} * 100$$

(This is different from the % difference we have been dealing with because we now have a value, α_{given}, that is generally accepted.)

% error for ROD #1.

% error = __________ (rod #1)

% error for ROD # 2

% error = ____________ (rod #2)

Questions a) Discuss the agreement between the measured and given coefficient of expansion.

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b) 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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