T4a: Thermal Expansion

Introduction:

When having problems opening a glass jar with a metal lid because it is too tight, a good solution would be running hot water over the lid. Why would hot water help you to open the jar?. Most materials expand somewhat when heated through a temperature range that does not produce change in phase. The added heat increases the average amplitude of vibration of the atoms in the material, which increases the average separation between atoms. Since the metal expands more than the glass when heated, the lid will loosen easily.

The focus of this experiment is on learning how different materials are affected by changes of temperature. The intrinsic characteristic of materials that determine its capability to expand in one dimension under heat exposure is called "coefficient of linear expansion". On this experiment, a thermal expansion apparatus will be used to measure the coefficient of linear expansion for brass, copper and aluminum.

Apparatus:

- Thermal expansion apparatus.
- Steam generator
- Temperature sensor
- Meter stick
- Glass cup
- Computer with Pasco Capstone Software
- Heat resistant gloves

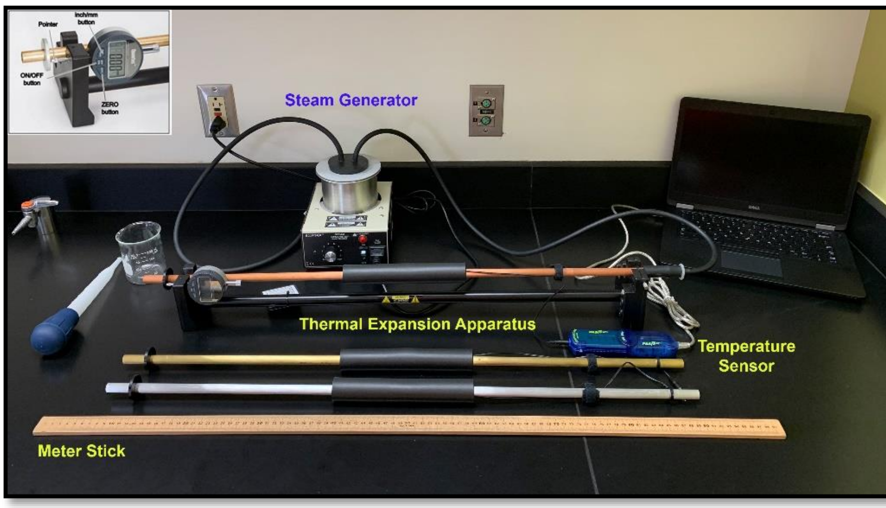

Figure 1. Experimental Setup

Theoretical Background:

Most materials expand when heated and contract when cooled. The increase in any one dimension of a solid is called ***linear expansion***.

If a rod of length L_0 and initial temperature T_0 undergoes a temperature change of a reasonably small magnitude of ΔT, the change in length, ΔL, is generally proportional to L_0 and ΔT. Stated mathematically:

$$\Delta L = \alpha L_0 \Delta T \qquad (1)$$

Here α is called the coefficient of linear expansion for the material with common units of $1/°\mathrm{C} = (°\mathrm{C})^{-1}$. Then, solving equation 1, the coefficient of linear expansion will be given by:

$$\alpha = \frac{\Delta L}{L_0 \Delta T} \qquad (2)$$

Different materials with the same initial length expand and contract by different amounts as the temperature changes, so the value α depends on the nature of the material. For materials that are not isotropic, such as an asymmetric crystal for example, α can have a different value depending on the axis along which the expansion is measured. The coefficient α 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. In this experiment, you will measure α for aluminum, brass, and copper. These metals are isotropic, that means α needs only be measured along one direction. Also, within the limits of this experiment, α does not vary with temperature.

The materials and corresponding values of the coefficient of linear expansion, reported by the manufacturer, for the metal tubes used on this experiment can be found in Table 1.

Table 1. Accepted values for the coefficient of thermal expansion, α.

Material	**α** ($°\boldsymbol{C^{-1}}$)	**Composition (%)**
Aluminum (6061-T6)	$2.36 * 10^{-5}$	Al (95.8 - 98.6), Mg (0.80 - 1.2), Fe (<0.70), Si (0.40 - 0.80)
Brass (C270)	$2.03 * 10^{-5}$	Brass (63 - 68.5), Zn (31.3 - 37), Pb (0.1), Fe (0.07)
Copper (C122)	$1.70 * 10^{-5}$	Cu (99.9), P (0.02 nominal)

Procedures:

<u>WARNING! HIGH TEMPERATURE</u>

The metal tube gets hot during the experiment. Steam can cause burns. Do not touch the metal tube during operation.

1. Take the rubber lid off from the Steam Generator. Fill the one-liter tank approximately 1/2 to 3/4 full of water using the auxiliary cup and place the rubber stopper over the top. Two long plastic tubes should be attached to the rubber stopper with one blocked with a tubing clamp. Place the free plastic tube inside of a separate flask while not using it and place the flask near to the right side of the apparatus. **<u>Do not connect the plastic tubing to the metal tubes yet! You will do it later when you get approved by a lab assistant.</u>**
2. Turn ON the Steam Generator and set the dial from LOW to HIGH. It will take between 10 to 15 minutes to bring the water from room temperature to boiling.
3. While the Steam Generator heats up the water, measure the length L of the three metal tubes at room temperature with the provided meter stick. Measure from the inner edge of the larger circular disk on one end to the inner edge of the smaller circular disk at the other end. Make sure the meter stick is straight when measuring the rod. Record the lengths on Data Table 1.
4. Mount the aluminum tube in the apparatus frame as shown in Figure 2, with the larger disk to your left and the smaller disk to your right. The larger disk of the rod presses against the tip of the spring arm of the dial indicator, while the smaller disk fits into a slot on the right side of the apparatus.

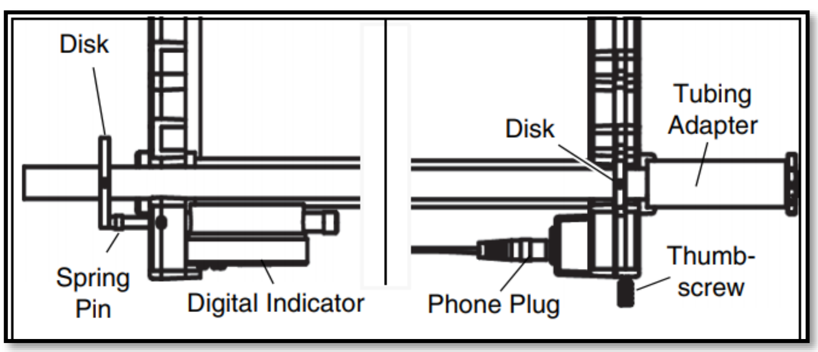

Figure 2.

5. Turn the aluminum metal tube so that the thermistor lug under the foam insulation is on top. Connect the phone plug into the phone jack of the temperature sensor.
6. Tighten up the thumb-screw in the right end of the apparatus frame against the tube to lock it.
7. Make sure that the foam insulator is centered over the thermistor lug.
8. Connect the PASCO Thermal Sensor to the computer.

9. Turn ON the computer and open the T4a experiment software. The file is located in the experiments folder.
10. Press the ON/OFF button on the digital indicator to turn it on. Press the ZERO button to set the initial digital reading to zero.
11. Press the record button in the computer software to begin recording the temperature of the aluminum rod. Leave the record button on.
12. **Verify with a lab assistant that your set up is correct before you continue to next steps**.
13. Wear disposable gloves and the heat resistant gloves on top.
14. Once the free plastic tubing inside the separate flask begins pouring water vapor, ***carefully take it out of the flask and stick it on the aluminum rod*****.**
15. Once the steam starts flowing through the tube, you will be able to observe the temperature change in the computer and the digital indicator will reflect the length that the metal tube has expanded. Once the final temperature stabilizes and the value displayed in the digital indicator doesn't change, stop the data collection and record the change in length, ΔL, on Data Table 1.
16. Using the protecting gloves remove the plastic tubing from the right side of the metal tube and place it back to the auxiliary glass.
17. Disconnect the phone plug from the temperature sensor. Untighten the thumb-screw that is holding the aluminum tube to the apparatus frame and carefully remove it. **Be careful** to not burn yourself; the tube might contain hot water vapor inside. Place the hot tub in the sink.
18. Ask a lab assistant for instructions using the Pasco Capstone software and find the beginning and ending temperature. Record your values on Data Table 1.
19. Repeat steps 4 to 18 with the other metal tubes.
20. Turn of the steam generator.
21. Calculate the change of temperature for all metal rods.
22. Calculate the experimental coefficients of thermal expansion α.
23. Compare your calculated values of α with the theoretical values registered on Table 1 and calculate the percentage errors.
24. Answer the questions.

Experiment T4a: Thermal Expansion

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor____

Experiment Start Date____

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: T4a: Thermal Expansion

NAME: ______________________________ DATE: __________________

Tube Material	**Initial Length (m)**	**Initial Temperature (°C)**	**Final Temperature (°C)**	**Change of Temperature**	**Change of length (m)**	**Thermal expansion Coefficient**	**Percent Error**
Aluminum							
Brass							
Copper							

Questions:

1) Which of the three materials has the largest coefficient of thermal expansion?

2) Why do you think civil engineers leave gaps between segments in a bridge or in a concrete wall?