1 Objective

- To find the coefficient of thermal expansion for copper, steel and aluminum from given data, and perform an error analysis to understand the precision of the experiment.

2 Introduction

Most materials expand when heated through a temperature range that does not produce a phase change. The added heat increases the average amplitude of vibration of the atoms in the material which increases the average separation between the atoms.

If an object has length L at some initial temperature T_i is heated to temperature T_f, the increase in length $\Delta L = L_f - L_i$ is characteristic of the composition of the object. The coefficient of linear expansion α is given by:

$$\alpha = \frac{\Delta L}{L \Delta T} \tag{1}$$

In this lab we will use data gathered by students in a previous term to calculate α and do an error analysis to investigate the precision of the lab and see whether the data agrees with the accepted values of α for copper, steel, and aluminum.

3 Experimental Procedure

This is an explanation of the experimental procedure followed in previous terms. You will not actually perform these steps. However, you need to understand what was done so that you can properly analyze the data and draw conclusions.

The basic idea of the experiment is to heat a metal tube by running steam into it, indirectly measure the change in its temperature, and also measure the change in its length.

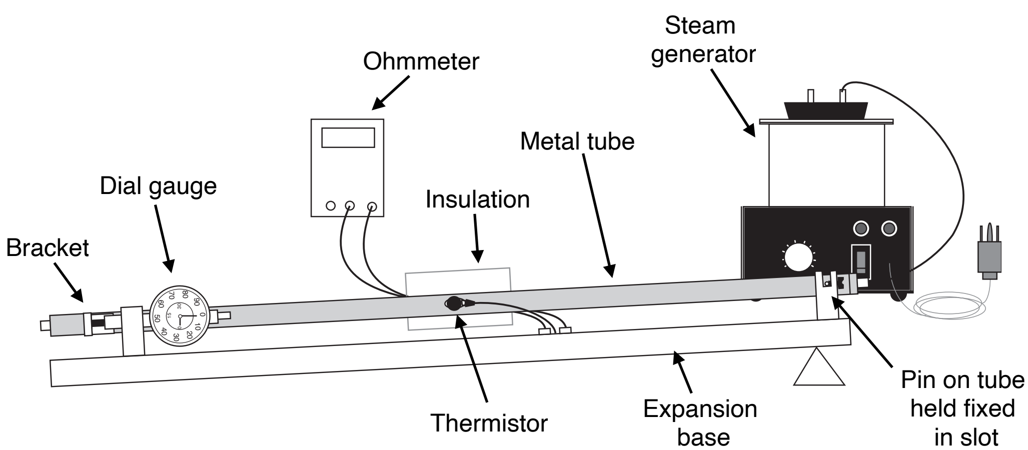

Figure 1: Schematic of the apparatus for the experiment.

1. The length of the copper tube at room temperature, L, was measured with a meterstick. Care was taken to measure just the length of the part of the rod whose expansion would be measured. The L was taken to be the distance from the pin in one end of the rod, which was held fixed in place by the apparatus, to the bracket attached at the far end of the rod. The end of the rod with the bracket could move horizontally to allow for the expansion, which was measured with a dial gauge.
2. Water was added to the steam generator and heated to a boil.
3. The copper rod was fit into in expansion base as shown in Figure 1. The stainless steel pin on the tube fit into the slot that fixed it in place, and the bracket at the other end fit against the spring arm of the dial gauge.
4. A device called a thermistor, which is a resister whose resistance depends on temperature more sensitively than a normal resistor, was attached to the side of the tube, making good contact with it and a foam insulator is put over it.
5. An ohmmeter was used to measure the resistance of the thermistor at room temperature, R_i.
6. The vent of the steam generator was connected to the inside of the tube using black flexible rubber tubing. The end of the expansion base that held the tube where it was connected to the steam generator was propped up so that condensation inside the tube ran down and out the other end, where it was collected in a small cup.
7. On the dial gauge, each increment is equivalent to 0.01 mm of tube expansion.
8. The value on the ohmmeter, R, and the value on the dial gauge were observed as the tube warmed. When the thermistor resistance (ohmmeter reading) stabilized, R_{hot} and the reading on the dial gauge, ΔL, were recorded.
9. This procedure was repeated for steel and aluminum.

4 Data Analysis

Using the conversion for the thermistor resistance, find the temperature of the rod initially and finally. You will need to interpolate in order to give your values of the temperature to a precision of 0.1 °C. The uncertainty stated by Pasco for the thermistor is ±0.2 °C.
Calculate α for each of the rods and the absolute uncertainty using the partial derivative method.

5 Conclusions

1. Are your values within uncertainty of the accepted values? Which ones are or are not?

$$\begin{aligned} \alpha_{\text{Cu}} &= 17.6 \times 10^{-6}\,(^\circ\text{C})^{-1} \\ \alpha_{\text{steel}} &= 11.3\text{---}13.5 \times 10^{-6}\,(^\circ\text{C})^{-1} \quad \text{(varying compositions)} \\ \alpha_{\text{Al}} &= 23.4 \times 10^{-6}\,(^\circ\text{C})^{-1} \end{aligned}$$

2. Do these results support the idea that solids expand slightly when heated, in a way that can be modeled as the fractional expansion ($^{\Delta L}/_{L}$) is directly proportional to the temperature change?
3. What input uncertainty was the largest contributor to the absolute uncertainty of α?
4. Think through the experimental procedure. Can you think any errors that could have occurred in the experiment would not have been accounted for in your error analysis and could have affected your results? If so, describe them.

THERMISTOR CONVERSION TABLE:
Temperature versus Resistance

Res. (Ω)	Temp. (°C)	Res. (Ω)	Temp. (°C)	Res. (Ω)	Temp. (°C)	Res. (Ω)	Temp. (°C)
351,020	0	95,447	26	30,976	52	11,625	78
332,640	1	91,126	27	29,756	53	11,223	79
315,320	2	87,022	28	28,590	54	10,837	80
298,990	3	83,124	29	27,475	55	10,467	81
283,600	4	79,422	30	26,409	56	10,110	82
269,080	5	75,903	31	25,390	57	9,767.2	83
255,380	6	72,560	32	24,415	58	9,437.7	84
242,460	7	69,380	33	23,483	59	9,120.8	85
230,260	8	66,356	34	22,590	60	8,816.0	86
218,730	9	63,480	35	21,736	61	8,522.7	87
207,850	10	60,743	36	20,919	62	8,240.6	88
197,560	11	58,138	37	20,136	63	7,969.1	89
187,840	12	55,658	38	19,386	64	7,707.7	90
178,650	13	53,297	39	18,668	65	7,456.2	91
169,950	14	51,048	40	17,980	66	7,214.0	92
161,730	15	48,905	41	17,321	67	6,980.6	93
153,950	16	46,863	42	16,689	68	6,755.9	94
146,580	17	44,917	43	16,083	69	6,539.4	95
139,610	18	43,062	44	15,502	70	6,330.8	96
133,000	19	41,292	45	14,945	71	6,129.8	97
126,740	20	39,605	46	14,410	72	5,936.1	98
120,810	21	37,995	47	13,897	73	5,749.3	99
115,190	22	36,458	48	13,405	74	5,569.3	100
109,850	23	34,991	49	12,932	75		
104,800	24	33,591	50	12,479	76		
100,000	25	32,253	51	12,043	77		