Measuring the Coefficient of Linear Expansion
of Copper, Steel, and Aluminum

Introduction:

Measure the coefficient of linear expansion for steel, copper and aluminum.

Equipment:

Thermal expansion apparatus, three metal tubes; copper, aluminum, steel. foam insulator, thermoplastic tubing, steam generator, banana plug patch cords, voltmeter, meter stick, wooden block or wedge, beaker and water proof container.

Theory:

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

Suppose an object of length L undergoes a temperature change of magnitude ΔT. If ΔT is reasonably small, the change in length, ΔL, is generally proportional to L and ΔT. Stated mathematically:

$$\Delta L = \alpha L \Delta T$$

Where α is called the coefficient of linear expansion for 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. 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 copper, aluminum, and steel. These metals are isotropic so that α need only be measured along one dimension. Also, within the limits of this experiment, α does not vary with temperature.

Procedure:

1) Measure L, the length of the copper tube at room temperature. Measure from the inner edge of the stainless steel pin on one end, to the inner edge of the angle bracket at the other end (see Figure 1). Record your results in Table 1.

2) Mount the copper tube in the expansion base as shown in Figure 2. The stainless steel pin on the tube fits into the slot on the slotted mounting block and the bracket on the tube presses against the spring arm of the dial gauge.

> **Note:** Slide or push the tube to one side of the slide support. Drive the thumbscrew against the pin until the tube can no longer be moved. Use this as your reference point.

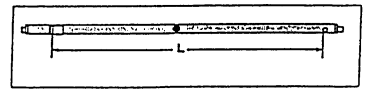

Figure 1 Measuring Tube Length

3) Use one of the provided thumbscrews to attach the thermistor lug to the threaded hole in the middle of the copper tube. The lug should be aligned with the

axis of the tube, as shown in Figure 2, so there is maximum contact between the lug and the tube.

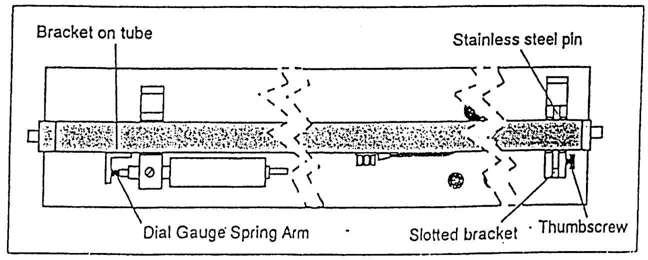

Figure 2 Equipment Setup (Top View)

4) Place the foam insulator over the thermistor lug.

5) Plug the leads of your ohmmeter into the banana plug connectors labeled THERMISTOR in the center of the expansion base.

6) Measure and record R_{rm} the resistance of the thermistor at room temperature. Record this value in the table.

7) Use tubing to attach your steam generator to the end of the copper tube. Attach it to the end farthest from the dial gauge.

8) Use a book or a block of wood to raise the end of the expansion base at which steam enters the tube, a few centimeters is sufficient. This will allow any water that condenses in the tube to drain out. Place a container under the other end of the tube to catch the draining water.

9) Turn the outer casing of the dial gauge to align the zero point on the scale with the long indicator needle. As the tube expands, the indicator needle will move in a counterclockwise direction.

10) Turn on the steam generator. As steam begins to flow, watch the dial gauge and the ohmmeter. When the thermistor resistance stabilizes, record the resistance (R_{hot}) in Table 1. Also record the expansion of the tube length (ΔL) as indicated by the displacement of the indicator on the dial gauge. (Each increment on the dial gauge is equivalent to 0.01 mm of tube expansion.) Note that ΔL is the difference between the dial gauge readings.

11) Repeat the experiment for the steel and aluminum tubes.

Data and Calculations:

TABLE 1 Data and Calculations

	DATA				CALCULATIONS		
	L (mm)	R_{rm} (Ω)	ΔL (mm)	R_{hot} (Ω)	T_{rm} (C)	T_{hot} (C)	ΔT (C)
Copper							
Steel							
Aluminum							

1) Use the Thermistor Conversion Table on the next page, or the one on the top of the expansion base, to convert your thermistor resistance measurements, R_{rm} and R_{hot}, into temperature measurements, T_{rm} and $T_{hot.}$ Record your results in the table.

2) Calculate $\Delta T = T_{hot} - T_{rm}$. Record the result in the table.

Using the equation $\Delta L = \alpha L \Delta T$, calculate α for copper, steel, and aluminum.

α_{Cu} = ____________

α_{steel} = ____________

α_{Al} = ____________

Questions:

1) What are the units of α, the thermal coefficient of linear expansion?

2) Most material expands when heated. What can you conclude about α for materials that contract when heated?

3) What is the accuracy of your measurement of α?

4) When an ordinary thermometer is placed in hot water the level temporally drops, the quickly rises…Why?

5) The golden gate bridge in SF is 4200 ft. long. Find the total expansion of the bridge for a temp change from -20C° to 40 C°. Use the coefficient of liner expansion for steel given above.

6) Compare these values with your experimental values. What is the percent discrepancy in each case? Is your experimental error consistently high or low?

$\alpha_{Cu} = 16 \times 10^{-6} \frac{1}{C^\circ}$ $\alpha_{Steel} = 11 \times 10^{-6} \frac{1}{C^\circ}$ $\alpha_{Al} = 23 \times 10^{-6} \frac{1}{C^\circ}$

Based on your answer to the first part of this question, speculate on the possible sources of error in your experiment. How might you improve the accuracy of the experiment?

7) From your result, derive the coefficients of volume expansion for copper, aluminum, and steel (i.e. $\Delta V = \alpha_{vol} V \Delta T$).

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		