Thermal Expansion

Apparatus: thermal expansion apparatus, digital multimeters, banana cables, steam generators and cables, note: Styrofoam cups should be included in thermal expansion apparatus

Goal: Determine thermal expansion coefficients of various metals.

Before reading further: Fill the steam generator tank with water and turn it on. It takes 5-10 minutes to heat up. You can keep reading while the water warms up.

DO NOT CONNECT THE STEAM GENERATOR TO THE METAL TUBE YET!
You need to take a measurement BEFORE heating the tube. Read the instructions while the water warms up.
WATCH OUT! The metal reservoir of the steam generator will be hot all day. Don't burn yourself.
WATCH OUT! Keep a close eye on the water level between trials. If the water level gets too low you will have bad data AND the metal gets even hotter (and more dangerous).

The figure at right shows an overview of the apparatus set-up.
Important to notice:

1) Notice the right end of the metal tube is connected to the steam generator by metal tubing. We often tell students to place a wood block under this end of the tube to force condensation to drain out of the tube.
2) With a wood block placed under the *right* end of the metal tube, you should also place something under the left end of the tube to collect the drained condensation.

3) Look on the apparatus for a spring collar.
   The spring collar looks like the *left* object in the figure at right.
   Use the spring collar to secure the thermistor to the *middle* of the rod.
   The thermistor looks a lot like the *right* object in the figure at right.
   After the thermistor is secured to the middle of the rod, use the foam insulation to cover the thermistor. This improves the accuracy of temperature measurements.

4) Our apparatus uses an analog micrometer instead of the digital micrometer.
   The analog micrometer looks similar to the figure at right.

   Learn how to read the micrometer (the dial) before taking measurements.
   Slowly (gently) cause the micrometer measurement to change by pushing on it slightly with your hand. Each tick on the outer edge corresponds to 0.01 mm. This means pushing the gauge 1 mm causes the indicator to rotate one full revolution (100 tick marks).

   Look for a knurled knob on the outer casing of the micrometer dial and ensure it is slightly loose.
   Turn the outer casing of the micrometer to align the zero point on the scale with the long indicator needle.
   Later, when the rod expands, the indicator arrow will change from this initial value.
   The final reading on the micrometer minus this initial reading gives CHANGE in length.

5) To use the thermistor, it must be connected to a device which measures electrical resistance. We use a Digital Multimeter (DMM).

Every DMM looks a little bit different so read this part carefully.
Your DMM might be a mirror image of the one shown at right.

One cable must connect to the OHMs terminal (Ω).
The other cable must connect to the common terminal (COM).
The dial settings used will vary during the experiment.
You want to try any of the settings which have an Ω on them.
Each time you take a measurement, try all the settings to maximize sig figs.
If the DMM screen says OL you are "over limit".
Try a less sensitive setting (higher number of Ω setting).

6) The resistance in Ω corresponds to temperatures using the chart shown below.
Notice: as temperature increases the resistance *decreases*!
This occurs because the thermistor uses a semi-conductor (not a metal).
Typically resistance increases with temperature for metals but the opposite is true for semi-conductors!

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		

Procedure:

1. Ensure the thermistor is securely coupled to the middle of the metal rod using the spring collar.
2. Ensure the foam insulation covers the thermistor.
3. Ensure the C-clamps on the metal rod are secured in the grooves.
4. Verify water in the steam generator is boiling.
5. While the metal tube is at room temperature, rotate the rim of the micrometer housing to align 0 with the micrometer's indicator needle.
6. Connect the DMM to the thermistor.
7. Use the DMM resistance value to record the initial temperature of the metal tube.
   Note: it is unlikely the resistance value on the DMM matches a value on the chart.
   Use interpolation to estimate the temperature *to one decimal place*!
   The manual states the thermistor has a precision of ± 0.2 ℃.
8. *Now* connect the rubber tube from the steam generator to the metal tube.
9. *Ensure condensation is able to drain out of the tube!*
10. Eventually the indicator needle will stop rotating.
    When it stops rotating, record the change in length AND the final temperature.
    Assume the precision of the micrometer needle is ± 0.01 mm.
11. Once you have data, check if the steam generator needs more water.
    Keep the steam generator more than 1/3 full.
    If you have to top it off, wait for it to reach boiling before resuming data collection.
12. Collect data for all of the different metal tubes available to you.
13. Turn off the steam generator once you have recorded data on all metal tubes available to you!
14. Measure the length L_0 of one of the metal tubes (preferably one which is cool to the touch).
    WATCH OUT! The length which matters is the length of metal tube between the C-clamps!!!
    Estimate the precision of your measurement based on the measurement tool you used!
15. Use the values of $L_0, \Delta T,$ & ΔL to determine the linear expansion coefficient for each type of metal.
16. Use propagation of error formulas (last page of Lab Manual Appendices) to estimate the precision of your measurements of the linear expansion coefficients. Remember to round error calculations to one digit. Exception: round to 2 digits if the first digit is 1. Watch out for the precision of ΔT & ΔL! They each used two measurements so the precision must be doubled! By this I mean $\delta\Delta T = 2\delta T_f$ and $\delta\Delta L = 2\delta L_f$.
17. The rods we have are probably aluminum, brass, copper, or steel. You'll need to look up the accepted values of these expansion coefficients to compare your experiments with theory.
18. Compare the experimentally measured values of the expansion coefficients to the accepted values using a percent difference. Remember to round error calculations to one digit. Exception: round to 2 digits if the first digit is 1.
19. Tabulate your final results in a clear and concise manner.
    Use your precision calculations (step 16, propagation of errors) to set the sig figs on your final answers.
    Show all your work in a calculations section in your submitted work.
    Include the algebraic formula, a step with numbers plugged in (and no work done), the unrounded final answers, and the rounded final answer with units. This helps me follow along during grading.

Conclusions

1) Did you notice any systematic errors in measuring the expansion coefficients? A systematic error would cause all of the % differences to be negative or all of the % differences to be positive. If yes, speculate as to while the % differences are all skewed positive or negative.

   Hint: we typically use

$$\% \, diff = \frac{exp - th}{th} \times 100\%$$

   If the percent differences are all positive, the experimental values are always larger than expected.
   If the percent differences are all negative, the experimental values are always smaller than expected.

2) Determine the volume expansion coefficients for each type of material.
   Tabulate your results with units and briefly explain how you determine these results.

3) Suppose you did an experiment on a tube of length 30.0 cm.
   The initial resistance reading was 126.7 kΩ and the final resistance reading was 6.98 kΩ.
   You notice the dial rotated *backwards* by 0.25 mm.
   What does this imply about the sign of the linear expansion coefficient?
   Are there any materials in the real world which have this type of linear expansion coefficient?
   Name one such material and the applicable temperature range.
   Hint: web search. You drink one such material every day…but please note the temperature range.

Submission Checklist:

Introduction

- Use no more than two sentences to state the linear expansion equation in standard form.
- Present tense is ok.
- Define variables in the standard way without including units.

Data table

- a handwritten table is probably fastest since there are only 3 or 4 rows of data with 3 or 4 columns

Calculations

- algebraic formula, one line with numbers plugged in with no work done, unrounded answer, rounded answer with units
- propagation of error calculations

Conclusion questions

- use a numbered list
- answer questions in full sentences
- answer in a manner which makes clear what question was asked (so you don't have to write out the questions)
- double space