LAB NO 1
MEASURE THE COEFFICIENT OF THERMAL EXPANSION

C 3205 LAB

Lab 1: Thermal Expansion of Steel

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Purpose: To measure the Linear Coefficient of Thermal Expansion of steel.

Theory:

Linear coefficient of thermal expansion (α_ℓ): The fractional change in length divided by the change in temper'-

$$\frac{\ell_f - \ell_o}{\ell_o} = \alpha_\ell (T_f - T_o) \quad \text{or} \quad \Delta \ell = \alpha_\ell \times \ell_o \times \Delta\theta$$

where ℓ_o is the initial length.
ℓ_f is the final length.
T_o is the initial temparature.
T_f is the final temperature.
α_ℓ is the linear coefficient of thermal expansion.
$\Delta \ell$ is the change in length.
$\Delta\theta$ is the change in temperature

Fig 1: Steel Tube

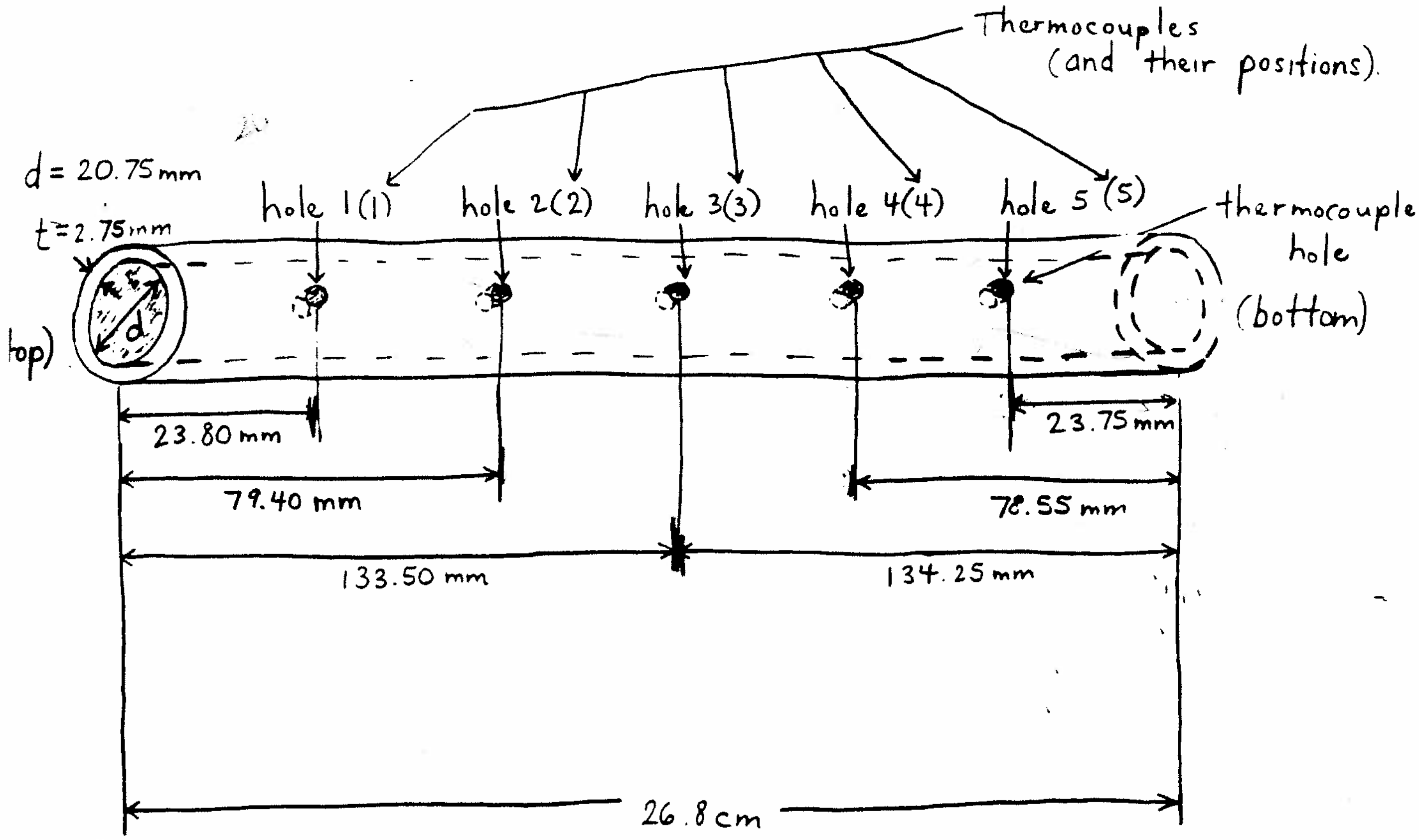
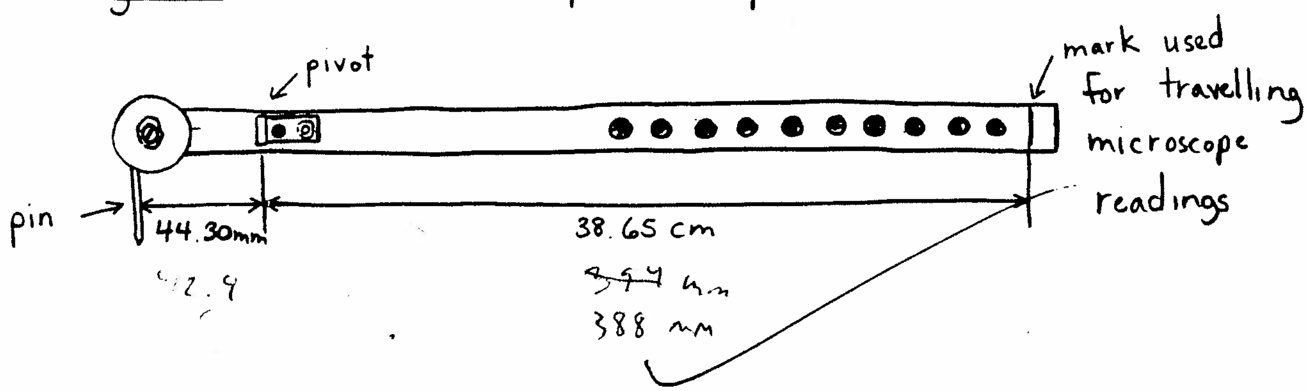


Fig. 2: Beam (with pin and pivot)



41.32mm

Apparatus:

- steel tube (see fig. 1)
- meter stick
- Vernier calipers
- insulation box (with insulation)
- electrically heated cartridge
- K (chromel-alumel) thermocouples (1-5)
- thermocouple switch box
- travelling microscope
- copper pillar (water)
- microscope
- beam (with pin and pivot) (see fig. 2)
- Voltage supply

Procedure:

1. Measured the locations of the thermocouple holes using the meter stick and calipers and noted where each thermocouple was located (i.e. which holes they were placed in).

2. Measured the lengths from the pin to the pivot and from the pivot to the mark on the beam using the meter stick and calipers.

3. Placed the steel tube in the insulation box and then placed the heated cartridge in the steel tube. Filled the remaining area in the insulation box with vermiculite insulation and

placed the lid on the box.

see fig. 3) 4. Placed the beam on the beam support by resting the pivot on it, such that the pin touched the top edge of the steel tube (that was above the lid on the insulation box).

5. Adjusted the travelling microscope to line up the mark on the beam with the cross hairs on the lens of the microscope. Recorded the intial reading on the microscope before applying heat.

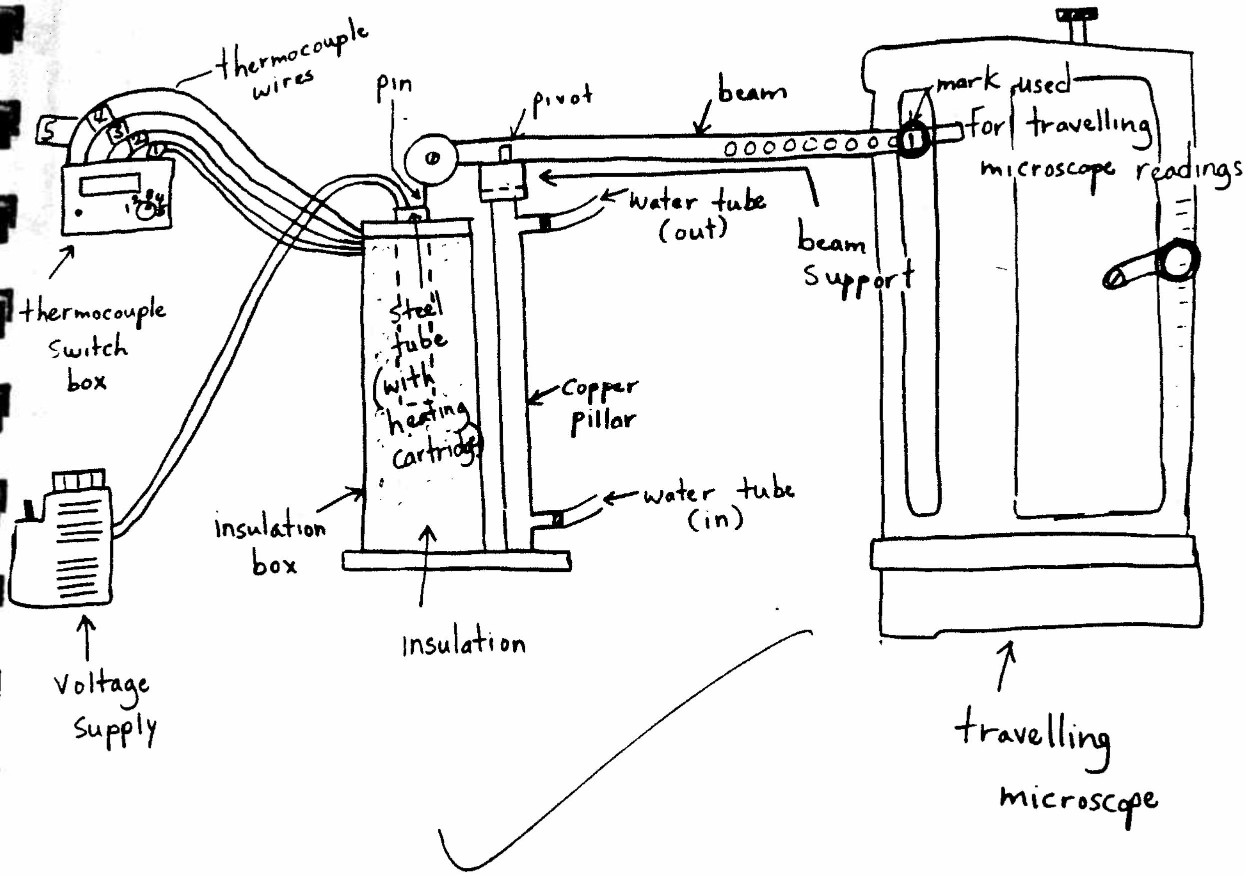
6. Recorded the initial readings on the thermocouple switch box for each thermocouple before applying heat.

7. Turned on the voltage supply and adjusted the voltage to supply 50 V.

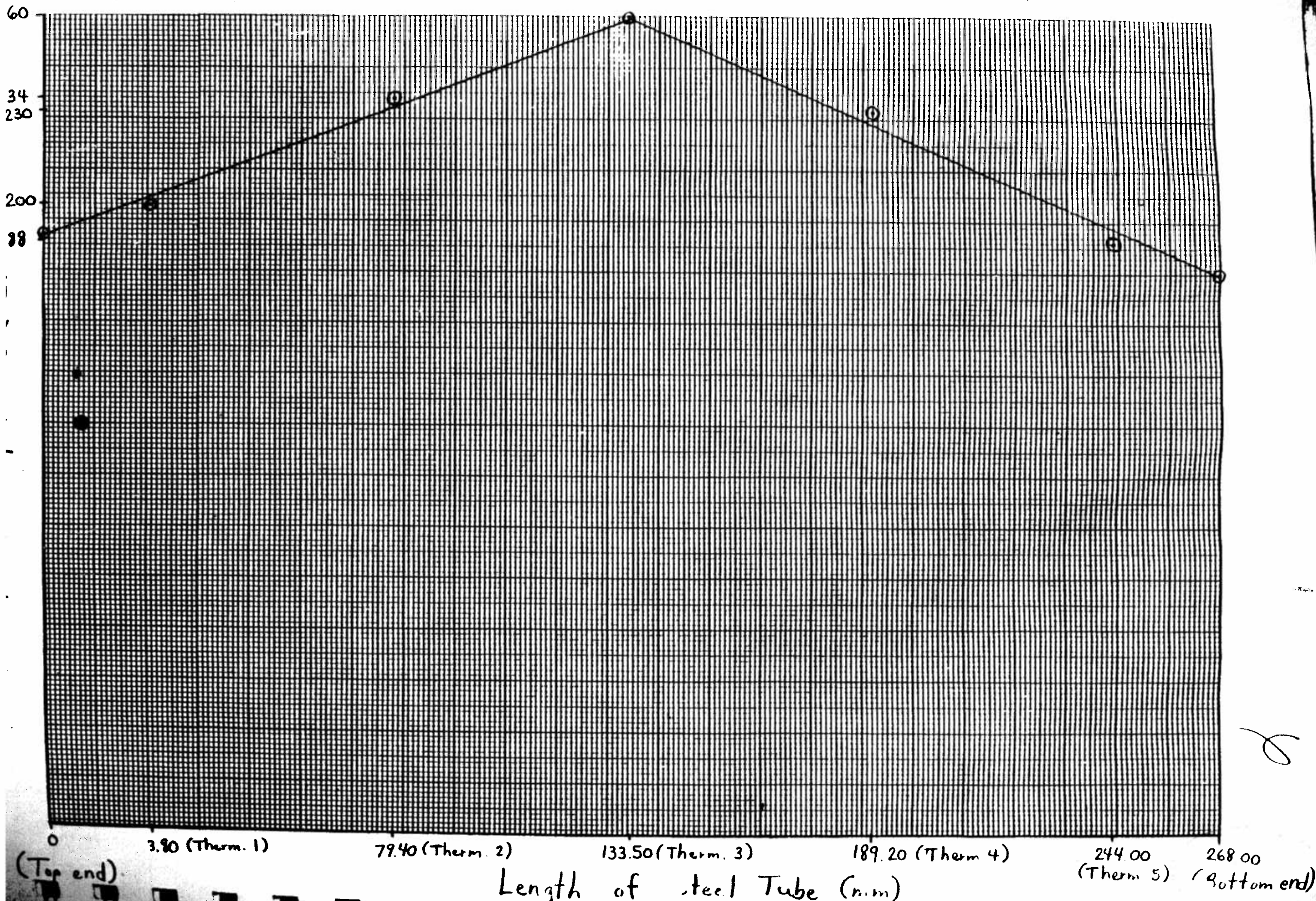
8. Waited for the thermocouple temperatures to stabilize (approximately 1 hour later) and recorded final readings for each thermocouple. 41.5

9. Measured final location of mark on the beam using the travelling microscope.

Fig. 3: Experimental Set-up



Final Temperature Along the Length of the Steel Tube



Results:

Table 1 Measurements and Readings

Reading	Thermocouple (°C) 1	2	3	4	5	Travelling Microscope (cm)
Initial, T_0	25	23	23	22	22	14.780
Final, T_f	200	234	260	230	188	14.170 61
$\Delta\theta_i$	175	211	237	208	166	

Table 2 : Uncertainties

Parameters	(mm) Δl	$\Delta(\Delta l)$ (mm)	ΔT (°C)
Instrument	$\pm$ 0.5	$\pm$ 0.005	$\pm$ 0.5
Object	$\pm$ 0.5	$\pm$ 0.005	—
Use	$\pm$ 0.5	$\pm$ 0.01	—
Total	$\pm$ 0.5	$\pm$ 0.01	$\pm$ 0.5

13.17
x 2.25

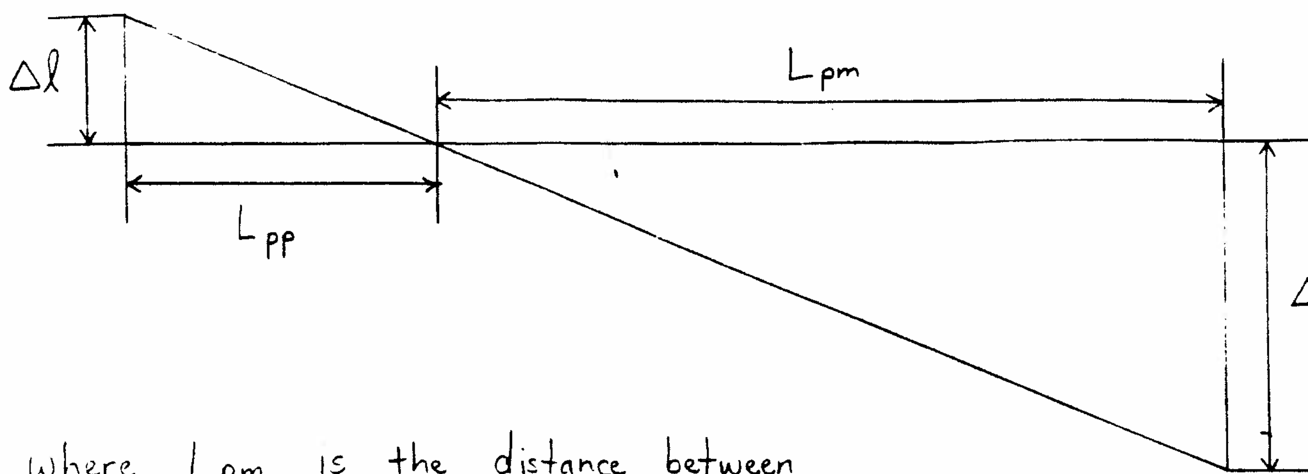
Calculations:

Sample calculations:

$\Delta\theta$ for thermocouples

eg. Thermocouple 1 : $\Delta\theta = T_f - T_0 = 200\,°C - 25\,°C = 175\,°C$

Fig. 4: Lever Ratio (exaggerated scale)



where L_{pm} is the distance between pivot and mark used for travelling microscope readings, on the beam.

L_{pp} is the distance between pivot and pin, on the beam.

ΔTM is the difference between the initial and final travelling microscope readings.

Δl is the change in length of the steel tube.

$$\frac{\Delta l}{L_{pp}} = \frac{\Delta TM}{L_{pm}} \Rightarrow \Delta l = \left(\frac{L_{pp}}{L_{pm}}\right)\Delta TM$$

$$\Delta l = \left(\frac{44.30\text{ mm}}{386.5\text{ mm}}\right)(14.780\text{ cm} - 14.170\text{ cm})$$

$$\Delta l = 0.0699\text{ cm} = 0.699\text{ mm}$$

Sample calculations: **$\Delta\theta$ for ends of steel tube**

On the assumption that the initial temperatures at the top and bottom ends of the steel tube are the same as the temperature of the thermocouple closest to each end,

$$\Delta\theta_{Top} = T_f\ (\text{from graph}) - T_o\ (\text{Therm. } 1)$$

$$= 190.125\,°C - 25\,°C$$

$$= 165.125\,°C$$

$$\Delta\theta_{Bottom} = T_f\ (\text{From graph}) - T_o\ (\text{Therm. } 5)$$

$$= 178.75\,°C - 22\,°C$$

$$= 156.75\,°C$$

Table 3: Average $\Delta\theta$ values.

Average $\Delta\theta$ for each portion along the steel tube length					
Top - 1 (°C)	1 - 2 (°C)	2 - 3 (°C)	3 - 4 (°C)	4 - 5 (°C)	5 - Bottom (°C)
$\left(\frac{\Delta\theta_{Top} + \Delta\theta_1}{2}\right)$ = 170.06	$\left(\frac{\Delta\theta_1 + \Delta\theta_2}{2}\right)$ = 193.00	$\left(\frac{\Delta\theta_2 + \Delta\theta_3}{2}\right)$ = 224.00	$\left(\frac{\Delta\theta_3 + \Delta\theta_4}{2}\right)$ = 222.50	$\left(\frac{\Delta\theta_4 + \Delta\theta_5}{2}\right)$ = 187.00	$\left(\frac{\Delta\theta_5 + \Delta\theta_{Bottom}}{2}\right)$ = 161.38

Calculation of α_ℓ :

$$\Delta \ell = \alpha_\ell \left[\sum_{i=1}^{6} (\ell \times \Delta\theta) \right]$$

$$\Delta \ell = \alpha_\ell \left[(\ell_{(Top-1)} \times \Delta\theta_{(Top-1)}) + (\ell_{(1-2)} \times \Delta\theta_{(1-2)}) + (\ell_{(2-3)} \times \Delta\theta_{(2-3)}) + (\ell_{(3-4)} \times \Delta\theta_{(3-4)}) + (\ell_{(4-5)} \times \Delta\theta_{(4-5)}) + (\ell_{(5-Bottom)} \times \Delta\theta_{(5-Bottom)}) \right]$$

$$0.699\ mm = \alpha_\ell \left[((23.80\ mm)(170.06\ °C)) + ((55.60\ mm)(193.00\ °C)) + ((54.10\ mm)(224.00\ °C)) + ((55.70\ mm)(222.50\ °C)) + ((54.80\ mm)(187.00\ °C)) + ((24.00\ mm)(161.38\ °C)) \right]$$

$$\alpha_\ell = 1.31 \times 10^{-5}\ (C°)^{-1}$$

Error calculations:

$$\frac{\Delta\alpha_\ell}{\alpha_\ell} = \frac{\Delta(\Delta\ell)}{\Delta\ell} + \frac{\Delta\ell}{\ell} = \frac{(0.01\ mm)}{(0.699\ mm)} + \frac{(0.5\ mm)}{(268\ mm)}$$

$$\frac{\Delta\alpha_\ell}{\alpha_\ell} = 0.016$$

$$\Delta\alpha_\ell = 0.016\,(\alpha_\ell) = 0.016\,(1.31 \times 10^{-5}\ (°C)^{-1})$$

$$\Delta\alpha_\ell = \pm 2.1 \times 10^{-7}\ (°C)^{-1}$$

Discussion of Uncertainties:

Instrument Uncertainties:

The instrument errors are uncertainties caused by limitations in the calibration of the instruments used in this experiment. The vernier calipers and the meter stick created errors of ± 0.5 mm in the initial measurements of the steel tube and beam. The travelling microscope created an error of ± 0.005 mm and the thermocouples and the switch box created an error of ± 0.5°C.

Object Uncertainties:

The beam and steel tube may not have had uniform or constant dimensions, thus creating errors in their measurements.

Use Uncertainties:

Judgement of measurement values by the human eye created errors when using the meter stick, Vernier calipers, etc. for this experiment.

Conclusions:

When the steel tube was heated above room temperature to approximately 260°C, the temperature at the middle of the tube was consistent with this value, whereas, the temperature at the ends of the tube were much less due to heat loss.

The linear coefficient of thermal expansion for the steel tube was found to be $1.31 \times 10^{-5} \pm 2.1 \times 10^{-7} (°C)^{-1}$.