TEXAS TECH UNIVERSITY
Department of Mechanical Engineering

ME 4251: Thermal Fluids Laboratory

Experiment 4

One Dimensional Linear Heat Conduction

Prepared by: Group B2 Section 510

I certify my work.

AF Travis Gardner

Submitted to:

Instructor: Abrar Navid

Date of Experiment: March 20, 2026

Date of Submission: April 3, 2026

Abstract

An experiment was conducted to demonstrate steady-state, one-dimensional linear heat conduction and to quantify thermal contact resistance across metallic junctions. A 16 W electrical heat load was applied axially through a 25 mm diameter segmented brass conduction stack, with a continuous water cooling loop extracting heat at the base. Steady-state axial temperature gradients were recorded using eight evenly spaced type-K thermocouples under two distinct conditions: bare metal-to-metal contact and a thermally pasted interface. The thermal conductivity of the brass specimen was experimentally determined to average 124.6 W/m·K, aligning with standard literature values. Under dry conditions, significant contact resistance was observed, characterized by discrete interfacial temperature drops of 11.74 °C and 19.40 °C, yielding contact conductances of 2,776 W/m^2·K and 1,680 W/m^2·K, respectively. The application of thermal paste significantly enhanced interfacial heat transfer, decreasing the respective temperature drops to 0.91 °C and 1.53 °C, and correspondingly increasing the contact conductances to 35,819 W/m^2·K and 21,304 W/m^2·K. Consequently, the maximum system temperature under a constant power load was reduced from 76.10 °C to 53.12 °C, validating Fourier's Law and demonstrating the critical role of interstitial materials in thermal management.

Table of Contents

List of Symbols

Symbol	**Definition**	**Units**
A	Cross-sectional area of the brass specimen	m^2
D	Diameter of the brass cylinders	m
h_c	Thermal contact conductance	W/m^2·K
k	Coefficient of thermal conductivity	W/m·K
Q	Axial heat transfer rate (electrical power load)	W
T	Temperature	°C
x	Axial position along the conduction stack	m

Greek & Other Symbols

$\Delta T_{interface}$	Discrete temperature drop across a physical junction	°C
$\frac{dT}{dx}$	Axial temperature gradient	°C/m

1 Introduction

Heat conduction is a fundamental energy transport mechanism driven by temperature gradients within solid mediums. In engineering applications, controlling this heat transfer is critical; for instance, building walls are generally designed to limit heat conduction to maintain comfortable indoor temperatures at a low energy cost. Conversely, in electronic packaging, components such as a computer CPU and heat-sink assembly are generally designed to conduct heat easily so that the CPU operating temperature can be maintained as low as possible.

The primary objective of this investigation was to operate an experimental apparatus in steady state to demonstrate Fourier's Law of Conduction in a one-dimensional system and to determine the coefficient of thermal conductivity of a brass specimen. Additionally, the experiment aimed to investigate the phenomenon of thermal contact resistance across physical material interfaces, comparing heat transfer performance with and without the application of thermal paste. Finally, the collected data was analyzed to identify any evidence of deviation from the idealized one-dimensional steady state linear heat conduction model.

The experimental apparatus consisted of a segmented brass conduction stack, composed of three segments, each 25 mm in diameter. The upper end of the stack was heated by an electric resistance heater, while the lower end was cooled by a continuous stream of water. To monitor the thermal gradient, eight type-K thermocouples were embedded at 15 mm intervals along the conduction stack. To enforce one-dimensional heat flow and minimize radial heat losses, the brass conduction stack was housed within a thick thermoplastic casing.

To mathematically model the heat transfer through the segmented brass specimen, the system was assumed to operate under steady-state, one-dimensional linear heat conduction. Under ideal conditions, it was assumed that the entirety of the electrical power supplied by the heater traveled axially down the conduction stack without radial losses.

The heat flow rate through a solid medium is governed by Fourier's Law of Conduction, expressed in one dimension as:

$$Q = -kA\frac{dT}{dx}$$

where Q is the heat flow rate, k is the coefficient of thermal conductivity, A is the cross-sectional area, and $\frac{dT}{dx}$ is the temperature gradient.

To determine the thermal conductivity of the brass segments, the theoretical equation was rearranged to solve for k using the experimentally derived temperature gradients:

$$k = -\frac{Q}{A\frac{dT}{dx}}$$

The temperature gradient, $\frac{dT}{dx}$, is interpreted from the slopes of linear curve fits applied to the discrete temperature measurements within each segment.

When two discrete sections of a given material are in physical contact, they will not conduct heat as well as a continuous block of the same material. Surface imperfections prevent perfect mating, leaving interstitial spaces that restrict heat flow and cause contact resistance. This contact resistance causes a discrete temperature drop, $\Delta T_{interface}$, across the junction. By adapting Fourier's Law for a discrete interface, the heat transfer rate was expressed using contact conductance, h_c:

$$Q = h_c A \Delta T_{interface}$$

The contact conductance for each interface was evaluated experimentally using the relation:

$$h_c = \frac{Q}{A \Delta T_{interface}}$$

Contact resistance is simply the inverse of this calculated contact conductance.

2 Methods

The experimental apparatus utilized to investigate one-dimensional steady linear heat conduction consisted of a segmented brass conduction stack. To enforce one-dimensional heat flow and minimize radial heat losses to the ambient environment, the three individual brass segments were encased in a rigid, low-conductivity white thermoplastic housing. The test section was comprised of a top and bottom brass cylinder, each with a height of 37.5 mm, and a central brass cylinder with a height of 30 mm. All three cylinders possessed a uniform diameter of 25 mm. The physical arrangement of these components, including the interfaces and securing clamp, is illustrated in Figure 1.

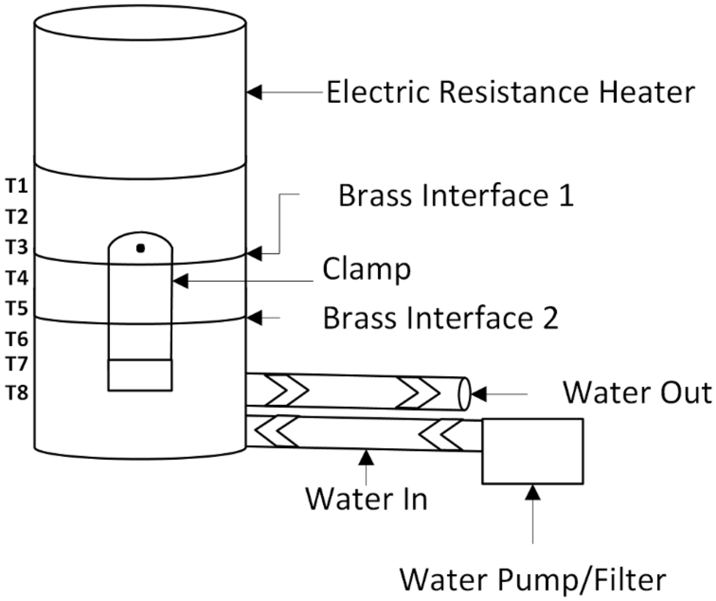

Figure 1: Schematic of the segmented brass conduction stack, illustrating the location of the electric resistance heater, cooling loop, physical interfaces, and the eight embedded thermocouples (T1-T8).

To establish the required temperature gradient across the specimen, heat was generated at the top of the first brass cylinder by an Armfield HT11X inbuilt electrical resistance heater, set to deliver a constant thermal power of 16 W. Conversely, the base of the lowest cylinder was maintained at a constant, lower temperature by an Armfield HT10X cooling loop, which continuously circulated water through the bottom section to a drain. To capture the axial temperature profile, eight K-type thermocouples (designated T1 through T8) were embedded along the central axis of the conduction stack. These sensors were spaced evenly at 15 mm intervals and connected to the Armfield HT11X Data Acquisition (DAQ) control system. The specifications and performance attributes of the experimental equipment are detailed in Table 1.

Table 1: Experimental Equipment Specifications

Name	**Manufacturer / Model**	**Range**	**Resolution**
Heater	Armfield / HT11X	0–60 W	±0.1°C
Cooling Loop	Armfield / HT10X	0–1.5 L/min	±0.1 L/min
Thermocouples	Armfield / HT11X	0–133°C	±0.1°C
DAQ System	Armfield / HT11X	±27 V	16 bit
Brass Cylinders	TTU shop / Custom	$D = 25$ mm $h = 30$ mm, 37.5 mm	±0.025 mm
Thermal Paste	Bymugo / HY880-TU10A	-30°C–280°C	> 5.15 W/m·K

The experimental procedure was initiated by activating both the electrical resistance heater and the water cooling loop. The system was then allowed a stabilization period of approximately 20 minutes to achieve a steady-state thermal condition. Once steady state was reached, the Armfield HT11X control software was utilized to record instantaneous temperature readings from all eight thermocouples. To ensure a reliable representation of the steady-state profile, a total of 10 samples were collected over a 5-minute interval and averaged. Following the collection of this baseline dry-contact data, the electrical heater was deactivated while the cooling loop remained active until the temperature at all thermocouple junctions fell below 40°C. The stack was then carefully disassembled, and a designated thermal paste (Bymugo HY880-TU10A) was applied between the brass interfaces. The stack was reassembled and clamped, ensuring interstitial air gaps were minimized. The heater was subsequently reactivated to the 16 W setting, and the 20-minute stabilization period was repeated. A second set of temperature data was then gathered using the identical 5-minute, 10-sample methodology to evaluate the impact of the thermal paste on interfacial contact resistance.

3 Results and Discussion

The temperature profiles recorded along the segmented brass conduction stack are presented in Figure 2 for the dry contact case and Figure 3 for the case utilizing thermal paste. A summary of the calculated thermal properties, derived using the corrected cross-sectional area of 490.9 mm^2, is provided in Table 2.

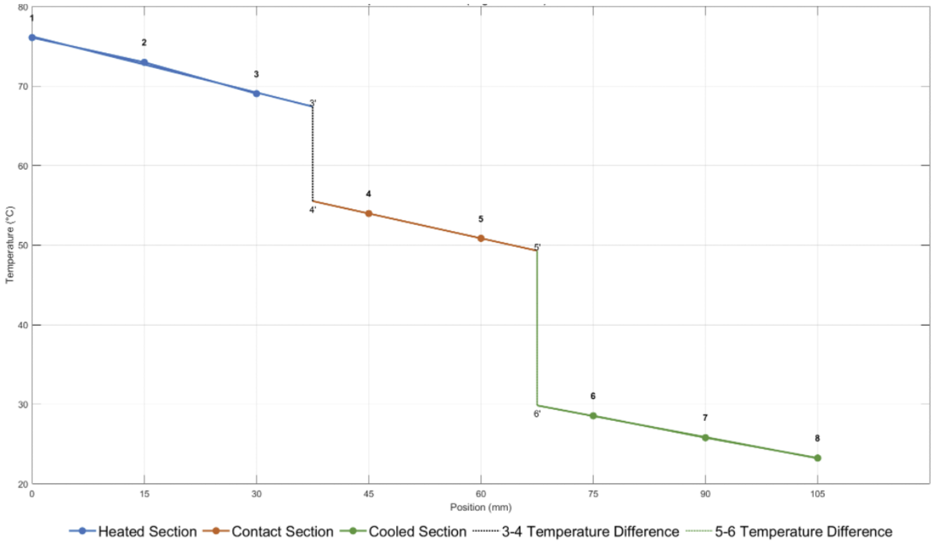

Figure 2: Temperature versus position for the segmented brass conduction stack without thermal paste, demonstrating significant temperature discontinuities at the physical interfaces.

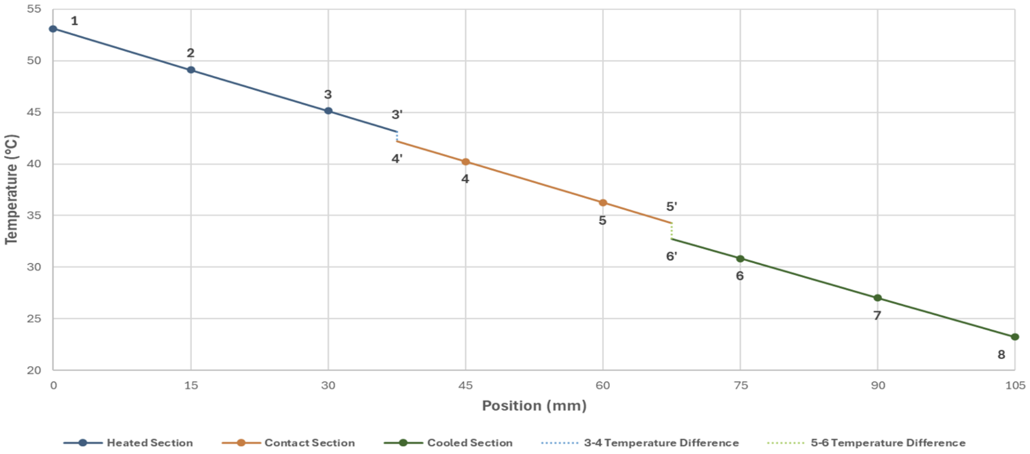

Figure 3: Temperature versus position for the segmented brass conduction stack with thermal paste applied, demonstrating reduced interfacial temperature drops and a lower overall system temperature.

Table 2: Summary of Calculated Thermal Properties

Description	**Symbol**	**Without Paste**	**With Paste**
Average Thermal Conductivity	k_{avg}	159.8 W/m·K	124.6 W/m·K
Interface 1 Temp Drop	$\Delta T_{3'-4'}$	11.74 °C	0.91 °C
Interface 2 Temp Drop	$\Delta T_{5'-6'}$	19.40 °C	1.53 °C
Contact Conductance 1	h_{c1}	2,776 W/m^2·K	35,819 W/m^2·K
Contact Conductance 2	h_{c2}	1,680 W/m^2·K	21,304 W/m^2·K
Maximum System Temp	T_{max}	76.10 °C	53.12 °C

As shown in the plotted figures, the temperature profiles within each of the three continuous brass segments exhibit a highly linear relationship with position. According to Fourier's Law of Conduction, a constant steady-state heat transfer rate through a material with a uniform cross-sectional area and constant thermal conductivity will produce a constant temperature gradient. The observed linearity within the solid segments confirms this theoretical one-dimensional steady-state behavior.

Using the linear curve fits from the thermally pasted trial, the average thermal conductivity of the brass specimen was calculated to be 124.6 W/m·K. This value exhibits excellent agreement with standard literature values for brass, which typically range between 109 and 125 W/m·K, validating the accuracy of the experimental apparatus and Fourier's Law. In the dry contact case, the calculated thermal conductivity appeared artificially high (159.8 W/m·K). This discrepancy arises because the un-pasted stack runs at much higher overall temperatures, increasing the radial heat losses to the ambient environment. Consequently, the actual axial heat transfer rate (Q) passing through the brass is less than the 16 W supplied by the heater. Utilizing the full 16 W in the calculation overestimates the true thermal conductivity.

The phenomenon of thermal contact resistance is clearly evidenced by the data collected at the physical interfaces. In the dry contact scenario, massive temperature discontinuities were observed, measuring 11.74 °C at the first interface and 19.40 °C at the second. Because microscopic surface roughness prevents perfect metal-to-metal mating, insulating air gaps form at the junction and heavily restrict heat flow. When thermal paste was applied, these temperature drops plummeted to 0.91 °C and 1.53 °C, respectively. The paste displaced the insulating voids with a higher-conductivity medium, increasing the contact conductance at the first junction from 2,776 W/m^2·K to nearly 36,000 W/m^2·K, allowing heat to flow seamlessly between the brass segments.

These results directly illustrate principles critical to engineering design. In electronics packaging, minimizing contact resistance is vital. For a CPU generating a fixed thermal power, heat must be rejected rapidly to prevent failure. The experimental data physically demonstrates this: under the same 16 W power input, the maximum temperature of the heated section in the dry case reached 76.10 °C. The application of thermal paste lowered the maximum system temperature to 53.12 °C, demonstrating a clear operational benefit for protecting sensitive components. Conversely, in building design, maximizing thermal resistance is the primary goal. To maintain comfortable indoor temperatures against extreme outdoor conditions, building envelopes intentionally utilize materials with low thermal conductivity and sealed air spaces (such as double-pane windows) to exploit the exact insulating properties of air gaps that were shown to be detrimental in the brass stack.

Finally, while the data generally aligns with idealized one-dimensional conduction, clear deviations from the purely adiabatic model are present. In both cases, the magnitudes of the temperature gradients (the curve fit slopes) sequentially decreased from the heated section down to the cooled section. According to Fourier's Law, a decreasing gradient magnitude implies that the axial heat transfer rate (Q) is diminishing along the stack, definitively proving that minor radial heat losses occurred through the thermoplastic casing. Furthermore, the temperature drop across the second interface was consistently larger than the drop across the first interface in both experimental runs. Assuming identical surface finishes on the brass segments, this localized discrepancy suggests a non-uniform contact pressure along the stack, potentially caused by unequal mechanical loading from the clamping mechanism.

4 Conclusion

From the experimental investigation of one-dimensional steady linear heat conduction, the following principal conclusions were drawn:

1. The highly linear temperature gradients observed within the continuous segments of the brass conduction stack successfully demonstrated the validity of Fourier's Law of Conduction. When evaluated under well-conductive conditions and with properly corrected geometric parameters, the experimentally determined thermal conductivity of the brass specimen exhibited excellent agreement with established literature values.

2. Significant thermal contact resistance is inherently present at the physical junctions of bare solid materials due to microscopic interfacial air gaps, which severely restrict heat flow.

3. The application of thermal paste effectively mitigates interfacial contact resistance by displacing insulating air voids with a higher-conductivity medium. This dramatically increases contact conductance, allowing for much more efficient heat transfer and significantly lowering the overall temperature of the heated components.

4. The principles of contact resistance govern practical engineering thermal management; minimizing this resistance is critical for heat dissipation in electronics packaging, whereas maximizing it is a foundational strategy for the thermal insulation of building envelopes.

5. The physical system exhibited distinct deviations from the idealized one-dimensional adiabatic conduction model. Evidence of radial heat loss to the ambient environment was observed—which artificially inflated the apparent thermal conductivity during the high-temperature dry run—alongside indications of non-uniform contact pressure at the physical interfaces.

5 References

1 Incropera, F. P., DeWitt, D. P., Bergman, T. L., & Lavine, A. S. (2007). *Fundamentals of Heat and Mass Transfer* (6th ed.). John Wiley & Sons.

2 Texas Tech University ME 4251 Faculty. (2026). *One-dimensional Steady Linear Heat Conduction Lab Handout.*

3 Texas Tech University ME 4251 Faculty. (2021). *Handbook for Thermal Fluids Lab.*

Appendices

Appendix A: Experimental Data

Table 3: Averaged Steady-State Data for Segmented Brass Stack

Thermocouple Position	**Without Paste (°C)**	**With Paste (°C)**
T_1 ($x = 0$ mm)	76.10	53.00
T_2 ($x = 15$ mm)	73.00	49.38
T_3 ($x = 30$ mm)	69.05	44.97
T_4 ($x = 45$ mm)	53.99	40.22
T_5 ($x = 60$ mm)	50.87	36.24
T_6 ($x = 75$ mm)	28.57	30.87
T_7 ($x = 90$ mm)	25.81	26.90
T_8 ($x = 105$ mm)	23.25	23.22
System Parameters		
Heater Power (Q)	16.0 W	16.0 W
Cooling Flow Rate	1.65 L/min	1.61 L/min

Appendix B: Sample Calculations

The following sample calculations demonstrate the data reduction process utilizing the data collected during the **With Paste** experimental trial.

1. Cross-Sectional Area (A)

The cross-sectional area of the brass cylinders was calculated using the measured diameter ($D = 25$ mm $= 0.025$ m):

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.025 \text{ m})^2}{4} = 4.909 \times 10^{-4} \text{ m}^2$$

2. Temperature Gradients ($\frac{dT}{dx}$)

The temperature gradient within each continuous brass segment was determined by extracting the slope from a linear curve fit of the temperature versus position data. For the "hot" section (thermocouples T_1, T_2, and T_3) in the pasted trial:

$$\frac{dT}{dx_{hot}} = -0.266 \frac{°\text{C}}{\text{mm}} = -266 \frac{°\text{C}}{\text{m}}$$

3. Thermal Conductivity (k)

The thermal conductivity of the brass specimen was determined by rearranging Fourier's Law of Conduction. Utilizing the 16 W electrical power input and the hot section temperature gradient calculated above:

$$k = -\frac{Q}{A \frac{dT}{dx}}$$

$$k = -\frac{16 \text{ W}}{(4.909 \times 10^{-4} \text{ m}^2)(-266 \frac{°\text{C}}{\text{m}})}$$

$$k = 122.5 \frac{\text{W}}{\text{m} \cdot \text{K}}$$

(Note: The average thermal conductivity of 124.6 W/m·K reported in the Results section is the mean of the conductivities calculated for all three individual brass segments).

4. Interfacial Temperature Drop ($\Delta T_{interface}$)

The discrete temperature drop across a physical junction was determined by evaluating the adjacent linear curve fits at the exact physical location of the interface. For the first interface ($x = 37.5$ mm), the extrapolated temperatures from the hot section ($T_{3'}$) and the middle section ($T_{4'}$) were:

$$\Delta T_{3'-4'} = T_{3'} - T_{4'}$$

$$\Delta T_{3'-4'} = 43.13°\text{C} - 42.22°\text{C} = 0.91°\text{C}$$

5. Thermal Contact Conductance (h_c)

The contact conductance at the first interface was calculated using the adapted Fourier's equation for discrete interfaces:

$$h_{c1} = \frac{Q}{A\Delta T_{3'-4'}}$$

$$h_{c1} = \frac{16 \text{ W}}{(4.909 \times 10^{-4} \text{ m}^2)(0.91°\text{C})}$$

$$h_{c1} = 35,819\frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

Appendix C: Lab Handout

One-dimensional Steady Linear Heat Conduction
2026 Spring

Heat conduction plays an important role in many engineered systems. The walls of a home are generally designed to limit heat conduction so that comfortable indoor temperatures can be maintained at low energy cost even in uncomfortable outdoor temperatures. In a computer, a CPU and heat-sink assembly is generally designed to conduct heat easily so that the CPU operating temperature can be maintained as low as possible.

Fourier's Law of Conduction is relevant in both cases. Today's lab is designed to demonstrate Fourier's Law of Conduction and to explore the related phenomenon of thermal contact resistance.

Objectives

1. To operate an experimental apparatus in steady state so that there is heat conduction through a brass test region where one end is heated by an electric resistance heater and the other is cooled by a continuous stream of water.

2. To collect data so that that the temperature profile can be plotted. The plot will be used to determine the coefficient of thermal conductivity of the material under test.

3. To investigate the phenomenon of contact resistance at two interfaces when thermal paste is present and when it is absent.

4. To consider out experimental procedure. Is there any evidence of deviation from our idealized model of heat conduction?

Test Procedure

Study the equipment closely. Note the cord that delivers electrical power to the heater at the top of the conduction stack. Note the flow of water from the wall through the cooling loop at the bottom of the conduction stack and then out to the drain. Note the eight type K thermocouples spaced at 15 mm intervals along the conduction stack. Note that the brass conductor is not a continous element, but is composed of three segments, each 25 mm in diameter. There are interfaces at the midpoints between thermocouples 3 and 4 and between thermocouples 5 and 6. Note that the brass conduction stack is housed within a thick thermoplastic casing. Why? Control and data collection is performed through the Armbus software on the computer. The lab instructors will guide you in its use, but will insist that you operate the equipment.

Part A:

1. Open two water valves at the wall to provide a supply of water to the unit.

2. Turn on the software and open the Fourier Experiment.

3. Within the software, set the flow control to “manual” and move the slider to 100%. Confirm that water is flowing down the drain. The equipment could be damaged if heat is initiated without cooling.
4. Within the software, set the heater control to “manual” and adjust the slider so that a power of about 16 W is achieved.
5. It will take approximately twenty minutes to achieve a steady-state condition. Check out the various screens within the software. Particularly, notice that you can monitor the thermocouple temperatures as a function of time. This screen is a good way to assess if steady-state has been approached.
6. Once you are convinced that steady-state has been achieved (approximately), use the data collection feature to gather about 10 instantaneous data samples over about five minutes. You will average these readings to obtain the steady state data to be used in later calculations.
7. Save the data to file giving it a unique name and be sure to transfer it to your thumbdrive.
8. Within the software, turn the heater off, but leave the cooling water on. Wait. Monitor thermocouple temperatures until all are below $40°C$.

Part B:

1. Following the lab instructor’s directions. Carefully disassemble the conduction stack. Do not tug on thermocouple wires or drop anything. The parts are fragile.
2. Is there thermal paste at the interfaces?

   If so, use the microfiber cloth and rubbing alcohol to remove the paste. Try to prevent any paste from getting into the spaces between the brass and the housing. Gloves are provided to protect your hands.

   If not, apply a pea-sized dab of paste on each interface, smooth it uniformly with a gloved finger, and carefully reassemble the stack. Remember, the best conductance will arise with the minimum amount of paste sufficient to fill the interstitial spaces–so don’t use too much. Or too little.
3. Now repeat the steps of Part A.

You should now have two sets of data to work with. In both cased 16 W of heat should be delivered though a segmented brass conduction stack. In one case, there is no paste present at the interfaces. In the other case, there is paste at the interface.

Analysis Procedure

1. Make a graph for each case. Let thermocouple 1 be located at $x = 0\ mm$. Plot temperature versus position. Let discrete symbols mark the data locations. Perform linear curve fits within each segment (so there will be three separate curve fits). Plot the fits within segments as lines. The fits should be extrapolated past the data points right up to the interfaces.

2. How do you interpret the slopes of the curve fits? Use the slopes and whatever other necessary experimental information you have to calculate the coefficient of thermal conductivity for brass. Compare your results to values found in the literature.

3. Compare the graphs from your two cases. What did the thermal paste do? Calculate the coefficients of thermal conductance for four interfaces (two for the no paste case and two for the paste case).

4. Within the context of a computer CPU and heat-sink, explain the potential benefit of using thermal paste.

5. Comment on any evidence of a deviation from the idealized one-dimensional steady state linear heat conduction that you may see in your data. A detailed propagation of instrumental uncertainties into calculated results is not necessary in this experiment.

General Comment on Lab Reports

Remember that the purpose of the report is to document what you have done, providing enough information so that a future worker could reproduce your results without having to personally consult you. Your work should be self-contained and complete.

References

[1] Incropera, F. P., DeWitt, D. P., Bergman, T. L., & Lavine, A. S. (2007). *Fundamentals of Heat and Mass Transfer* (6th ed.). John Wiley & Sons.

[2] Texas Tech University ME 4251. (2026). *One-dimensional Steady Linear Heat Conduction Lab Handout*.

[3] Texas Tech University ME 4251. (2021). *Handbook for Thermal Fluids Lab*.