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THERMOELECTRIC EFFECT AND THERMAL CONDUCTIVITY

By

TAN WEI LIANG

December 2023

First Year Laboratory Report

THERMOELECTRIC EFFECT AND THERMAL CONDUCTIVITY

ABSTRACT

The title of this experiment is THERMOELECTRIC EFFECT AND THERMAL CONDUCTIVITY. These experiments explore the thermoelectric effect and thermal conductivity through experiments using various materials. The thermoelectric investigation focused on determining the electromotive force (EMF) in copper-iron (Cu/Fe) thermocouples at different temperatures within 0-100 °C, yielding insights into the Seebeck effect and the associated phenomena of neutral and inversion temperatures by use a thermocouple as a thermometer within 0-400 °C. Concurrently, thermal conductivity experiments were conducted on materials like Masonite, wood, Lexan, Rock, and Glass, using a PASCO apparatus. The study involves collecting data to establish correlation between the EMF and the temperature of various thermocouple types by measuring the thermal energy in conduction. By plotting graph of EMF against temperature (Figure 6), derived experimental values from the graph's gradient. For Cu/Cn thermocouple, found that Seebeck coefficients of (44.27 ± 0.81) μV°C⁻¹, with a discrepancy of 8.32% compared to the standard. For Cu/Fe thermocouple, the result was (-10.00 ± 0.00) μV°C⁻¹, showing a significant discrepancy of 28.01%. The Cn/Fe thermocouple combination yielded (-50.36 ± 1.56) μV°C⁻¹, with an 8.04% discrepancy. These results highlighted varying degrees of accuracy among different thermocouple types within this temperature range. Expanding the study to 0 to 400°C, used the Cu/Cn thermocouple as a thermometer and further investigated the characteristics of Cu/Fe thermocouple. Through multiple graphs (Figure 8, 10, and 11), identified neutral (T_n) and inverse temperatures (T_i). Figure 8, 10 and 11 all indicated T_n = 253°C and T_i = 506°C with a discrepancy of 11.23%. These finding demonstrated a noticeable but constant discrepancy from experimental and theoretical values across various graphing method. The thermal conductivity of various materials is calculated: Masonite [$(2.52 \pm 0.05) \times 10^{-4}\, Cal\, cm^{-1} s^{-1} °C^{-1}$, 122.72 % discrepancy]; wood [$(1.24 \pm 0.07) \times 10^{-4}\ Cal\ cm^{-1} s^{-1} °C^{-1}$, (39.91~62.49) % discrepancy], Lexan [$(4.38 \pm 0.06) \times 10^{-4} Cal\ cm^{-1} s^{-1} °C^{-1}$, 4.88 % discrepancy]; rock [$(3.47 \pm 0.12) \times 10^{-4} Cal\, cm^{-1} s^{-1} °C^{-1}$, 66.32 % discrepancy], and glass [$(2.39 \pm 0.07) \times 10^{-4} Cal\, cm^{-1} s^{-1} °C^{-1}$, (86.13~88.42) % discrepancy]. These findings showed considerable discrepancies from standard values, indicating potential major experimental errors. Overall, this experiment highlights the complexities in accurately measuring thermoelectric effects and thermal conductivity and underscores the importance of precision in experimental physics.

Acknowledgements

First and foremost, I express my deepest gratitude to *Dr. Mohd Marzaini Mohd Rashid*, our distinguished lecturer and examiner, for his invaluable guidance and unwavering support throughout our scientific exploration. I am truly thankful for his mentorship and the foundation he laid for our scientific understanding. I extend my sincere gratitude to my experiment partner, *Aina Imanina Binti Mohb Khozikin*. Her invaluable cooperation and dedication throughout both experiments were instrumental to the success of this project. I appreciate her commitment, expertise, and teamwork, which made these scientific endeavours both productive and enjoyable. I extend my sincere gratitude to the individuals whose invaluable contributions have played a pivotal role in the development and enhancement of this lab manual. Originally crafted by *T. S. T., K. W. K., L. B. S., L. S. H*., and *Emeritus Prof. Dr. Lim Koon Ong* in 1996, this manual stands as a testament to their dedication and expertise. Special acknowledgment is extended to *A. Prof. Quah Ching Kheng* and *I. M.,* whose efforts in translating the manual in 2009 have greatly contributed to its accessibility and reach. A heartfelt acknowledgment is also extended to *Dr. John Soo Yue Han* for his dedicated efforts in revising and standardizing the manual in 2021, elevating its clarity and educational significance. This collective endeavor has significantly enhanced our scientific learning journey, and I extend genuine gratitude to everyone mentioned for their noteworthy contributions.

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INTRODUCTION

This physics experiment delves into two fundamental aspects: the thermoelectric effect and thermal conductivity. These phenomena are integral to our understanding of energy conversion and heat transfer in the fields of physics and materials science. The objective of this study is to conduct an in-depth exploration of these concepts through a series of interconnected experiments.The first part of the experiment centres on the thermoelectric effect, with a specific focus on the Seebeck effect. Here, the generation of electromotive force (EMF) in thermocouples, when exposed to different temperature gradients, is closely examined. This aspect of the study is particularly relevant for its applications in energy harvesting and temperature sensing.The investigation then progresses by elevating the temperature differential from 0 to 400°C. In this stage, a Cu/Cn thermocouple is employed as a thermometer. This is complemented by a detailed examination of the characteristics of a Cu/Fe thermocouple, further enriching our understanding of thermoelectric phenomena. The final segment of the experiment shifts focus to thermal conductivity in various materials. Thermal conductivity is a critical element in many fields, including engineering and construction. By assessing these materials, the experiment not only links theoretical principles to practical findings but also sheds light on the real-world applications and limitations of these materials. Overall, this study aims to provide comprehensive insights into the thermoelectric effect and thermal conductivity, enhancing our practical and theoretical knowledge in these key areas of physics and material science.

THEORY

Thermocouples

Thermocouples are temperature sensors made from two different metals. A voltage is generated when these metals are brought together to form a *junction*, creating a temperature gradient between them. This phenomenon was discovered in 1822 by *Thomas Seebeck* (German physicist), where he took two different metals at different temperatures and made a series circuit by joining them together. He found that this circuit generated an electromotive force (EMF), and the larger the temperature differences between the metals, the higher the generated voltage. His discovery is known as the *Seebeck effect*, and it is the basis of all thermocouples.

The voltage produced in the Seebeck effect is proportional to the temperature difference between the two junctions at low temperatures. The proportionality constant α is known as the *Seebeck coefficient*, it can be found by finding the gradient when plotting the voltage against the temperature (thus has the units of V K^{-1}).

The Law of Intermediate Materials

The *law of intermediate materials* was originally known as the law of intermediate metals. This law states that the sum of all the EMF in a thermocouple circuit using two or more different metals is zero if the circuit is at the same temperature. This law is interpreted to mean that the addition of different metals to a circuit will not affect the voltage the circuit creates, provided they are at the same temperature as the junctions in the circuit. This means that a third metal (e.g. a copper wire) may be added to the circuit to allow measurements to be taken. This allows thermocouples to be used with digital multimeters, or be soldered to join the metals.

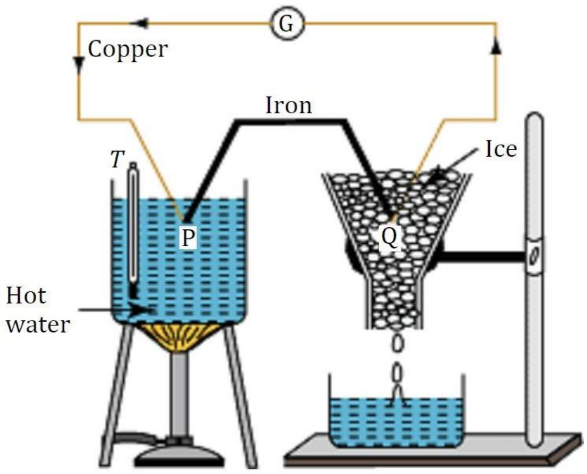


Figure 1: A setup of a Cu/Fe thermocouple.

Thermo EMF vs. Temperature

The thermo EMF in a thermocouple increases if the temperature of the *hot junction* is increased, while the *cold junction* (usually kept at 0 °C) is kept constant. Consider a copper-iron (Cu/Fe) thermocouple with the hot junction (P) placed in a hot water bath, while the cold junction (Q) kept in ice (**Figure 1**). A deflection in the galvanometer (G) measures the thermo EMF, while the thermometer measures the temperature T of the water bath.

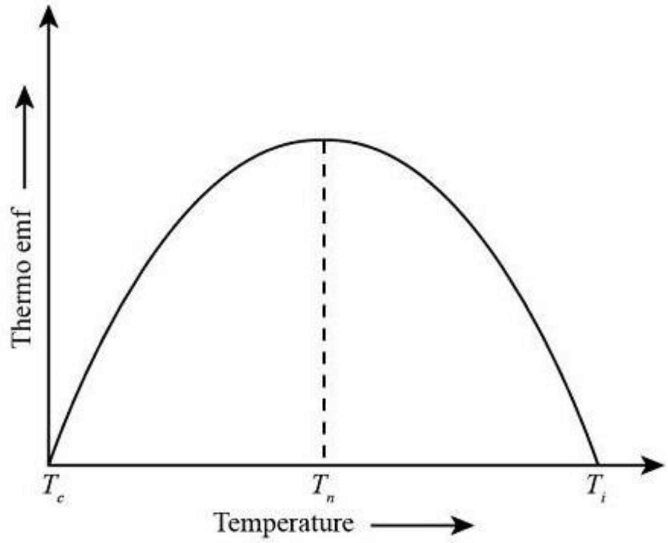


Figure 2: Graph of thermo EMF vs. temperature.

A graph of thermo EMF vs. the temperature in the hot junction is shown in **Figure 2**. From the graph, it can be seen that as the temperature of the hot junction increases (keeping the cold junction at a constant temperature of 0 °C), the thermo EMF increases to a maximum, corresponding to a temperature known as the *neutral temperature* (T_n). For a given thermocouple, T_n is fixed and independent of the temperature of the cold junction.

When the temperature is further increased beyond the neutral point, the thermo EMF decreases to zero, corresponding to a temperature known as the *inversion temperature* (T_i). Any further heating will result in the thermo EMF being reversed (having negative values), since the number densities and rates of diffusion of electrons in the two metals being reversed. T_n, T_i and the temperature at the cold junction (T_c) are related via the equation

$$T_n - T_c = T_i - T_n, \tag{1}$$

which gives $2T_n = T_i + T_c$. Unlike the neutral temperature, the inversion temperature depends on the temperature of the cold junction, in addition to the nature of the materials forming the thermocouple.

As seen from **Figure 2**, the graph of the thermo EMF vs. temperature of the hot junction is *parabolic* in nature, in contrast with the Seebeck relation at low temperatures, which is *linear*. Thus, a more accurate relationship between the thermo EMF (E) and the temperature of the hot junction (T) is

$$E = \alpha T + \frac{1}{2}\beta T^2, \tag{2}$$

where α is just the Seebeck coefficient as seen before. Together, α and β are collectively known as the *thermoelectric constants*.

Thermal Conductivity

Heat can be transferred from one place to another in three ways: *conduction*, *convection,* and *radiation*. Each method has its own experimental procedures to determine the *thermal conductivity* of a material. In this experiment, the thermal conductivities for solid materials commonly found in buildings are determined using PASCO's thermal conductivity apparatus.

Thermal conductivity is a characteristic of a material. *Heat* (Q) flows through a material if a temperature difference *(temperature gradient*, ΔT) exist in that material, given by

$$\Delta Q = kA\Delta T\frac{\Delta t}{h}, \tag{3}$$

where ΔQ is the *heat energy* conducted, A the *area* through the conduction takes place, Δt the *time* when the conduction occurs, h the *thickness* of the material, and k the *thermal conductivity* of the material. Rewriting **Equation 3** in terms of k, we get

$$k = \frac{h\Delta Q}{A\Delta T\Delta t}. \tag{4}$$

The value of k determines whether the material is a good *conductor* or *insulator*.

The characteristics of thermal conductivity explained above assumes a semi-static condition, i.e. the temperature gradient should be uniform or unchanged. If the temperature starts to change, the values of the parameters will also change, and this makes the process of determining the conductivity of a material very difficult. In this experiment, *temperature equilibrium* is necessary to eliminate uncertainties, but it is hard to achieve.

However, the technique used to determine the thermal conductivity in this experiment is simple. A material shaped as a plate is placed between a vapor container fixed at temperature 100 °C, and a block of ice at 0 °C. Thus, the steady temperature at 100 °C can be used as a temperature in equilibrium state.

The amount of heat drained is measured by through the amount of water melted from the ice. The rate at which the ice melts is 1 g per 80 cal (*calories*) of heat absorbed. This is the *latent heat of fusion* for ice. Therefore, the value of k (in units of cal cm^{-1} s^{-1} $°C^{-1}$) can be determined using the equation above, rewritten as

$$k = \frac{\text{mass of melted ice} \times 80\ \text{cal g}^{-1} \times \text{material thickness}}{\text{ice area} \times \Delta T\Delta t} \tag{5}$$

where distances are measured in cm, mass in g, and time in s. The standard values of k for some materials are listed in **Table 1** below.

Material	$\mathbf{10^{-4}}$ **cal cm^{-1} s^{-1} °C^{-1}**	**W m^{-1} K^{-1}**
Masonite	1.13	0.047
Pine wood	$2.06 - 3.30$	$0.11 - 0.14$
Lexan	4.60	0.19
Rock slab	10.30	0.43
Glass	$17.20 - 20.60$	$0.72 - 0.86$

Table 1: Thermal conductivity for some material

EXPERIMENTAL METHODOLOGY

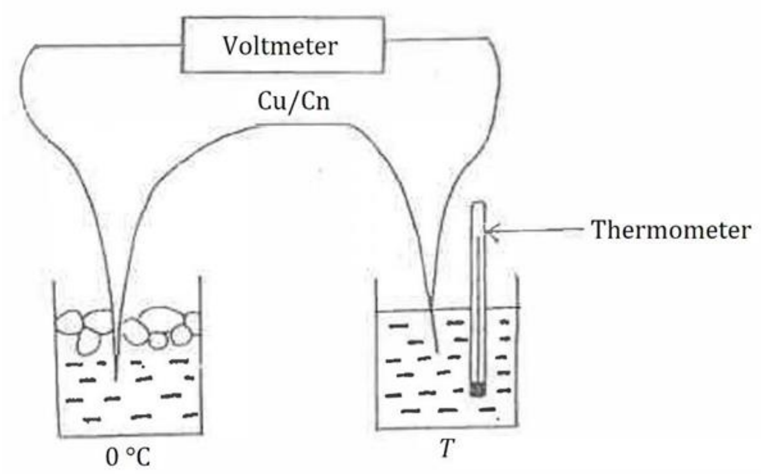


Figure 3: EMF measurement of a Cu/Cn thermocouple.

In PART A， this experimental study the characteristics of thermocouples at low temperatures were investigated, focusing on Cu/Cn, Cu/Fe, and Cn/Fe thermocouples. The circuit configuration illustrated in Figure 3 was employed for the measurements, using a Cu/Cn thermocouple as the initial subject.

The experimental procedure commenced by setting the cold junction's temperature in the beaker and maintained to 0 °C. The temperature of the hot junction was systematically increased from 0 °C to 100 °C in 10 °C increments, achieved either by adding ice or activating a heater. At each temperature step, the electromotive force (EMF) of the Cu/Cn thermocouple was measured and recorded in Table 2. Notably, the connection of the hot junction to the positive or negative terminal of the digital multimeter was observed and documented for each measurement.

This process was then replicated for the Cu/Fe and Cn/Fe thermocouples, following the same steps of temperature variation and EMF measurement. The sign convention for the EMF was established, considering the potential of the hot junction as positive when compared to the potential of the cold junction and negative in the opposite case.

After data collection, the analysis phase began. A graph was plotted, depicting EMF against temperature for all three thermocouples on the same graph paper. The sign of the EMF for each thermocouple was clearly indicated on the graph. Seebeck coefficients (α) for each thermocouple were calculated from the graphs, incorporating their respective uncertainties.

The experimental results were then compared with standard values for the Seebeck coefficients ($\alpha_{\mathrm{Cu/Cn}}$ = 40.87 µV °C^{-1}, $\alpha_{\mathrm{Cu/Fe}}$ = -13.89 µV °C^{-1}, and $\alpha_{\mathrm{Cn/Fe}}$ = -54.76 µV °C^{-1}), and the percentage discrepancy were determined. This step aimed to assess the accuracy and reliability of the experimental data in relation to established theoretical values.

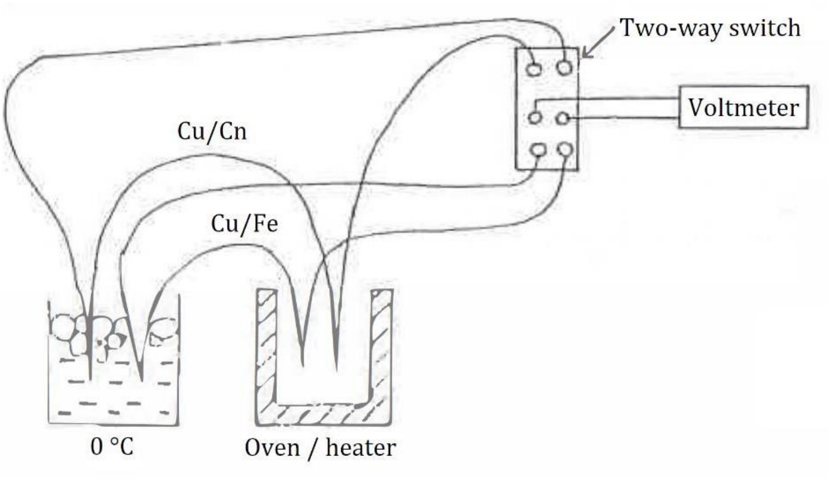


Figure 4: EMF measurement for the Cu/Fe thermocouple at temperatures up to 400 °C. The Cu/Cn thermocouple is used as a thermometer.

In PART B experiment, the characteristics of the Cu/Fe thermocouple were investigated over a temperature range of 0–400 °C, utilizing the Cu/Cn thermocouple as a thermometer. The circuit configuration depicted in Figure 4 was implemented, ensuring the cold junction remained at a constant 0 °C.

The measurement process involved rapidly recording the temperature and electromotive force (EMF) readings for the Cu/Cn and Cu/Fe thermocouples as the temperature increases at a rate of 5 °C per minute. This was achieved by promptly switching the two-way switch and recording the respective values. The average EMF for the Cu/Cn readings used to determine the corresponding temperature from a pre-established lookup table (Table A1 in the Appendix). The procedure was repeated until the Cu/Cn thermocouple's EMF reached ~21 mV (~400 °C).

To analyse the collected data, a graph of Cu/Fe thermocouple EMF (E) against temperature (T) was plotted. From this graph, the neutral temperature (T_n) and inversion temperature (T_i) for the Cu/Fe thermocouple were determined. Percentage discrepancies between experimental values and standard values (T_n = 285 °C and T_i = 570 °C) were calculated and compared. Additionally, the derivative of EMF with respect to temperature (dE/dT) was computed for each point on the Cu/Fe thermocouple EMF vs. temperature graph, assuming dE/dT is approximately equal to the change in EMF over a small temperature range ($\Delta E/\Delta T$). These values were recorded in Table 4, assuming $dE/dT \approx \Delta E/\Delta T$. A graph of dE/dT against T was plotted, and the values of Seebeck coefficients (α and β) and neutral temperature (T_n) were determined. Subsequently, calculated E/t from graph of Cu/Fe thermocouple EMF (E) against temperature (T) for selected temperatures at roughly 25 °C intervals and tabulated these in Table 5.

Further analysis involved plotting a graph of E/T against T. From this graph, the values of α, β, and T_n were identified. The experiment then sought to verify if $T_i = 2T_n$ and if the equation $E = \alpha T + \frac{1}{2}\beta T^2$ adequately explained the thermoelectric effects of the Cu/Fe thermocouple within the 0–400 °C temperature range.

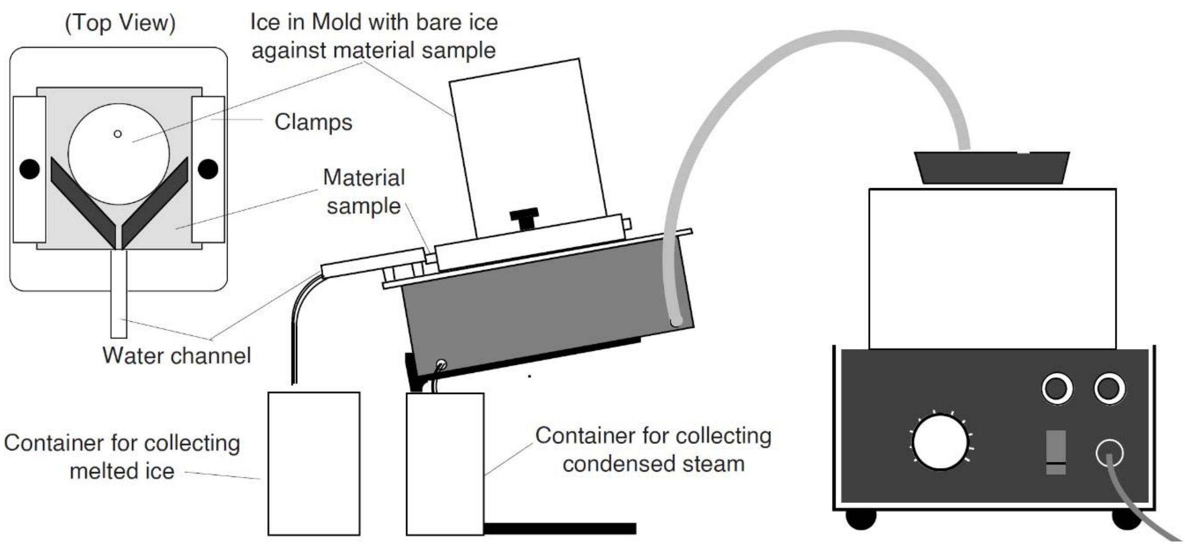


Figure 5: Experimental setup for **Part C**.

In PART C this thermal conductivity experiment, the methodology involved a systematic series of steps designed to measure and analyse the heat transfer properties of different solid materials. The experimental setup, as illustrated in Figure 5, required careful execution to ensure accurate and reliable results.

The procedure commenced with the freezing of water in a plastic cup, which was then slightly washed to loosen the ice inside the cup. The Masonite (wood fibre board), serving as the sample material, was placed onto the steam chamber and rubber layer was applied to create a seal, preventing water leakage, and its thickness (h) was measured and recorded in Table 6. The diameter of the ice block (d_1) was measured without removing it from the cup and then place it onto the Masonite ensuring ice is direct contact with sample.

Data collection involved placed ice block directly on the Masonite and allowed it to sit for 1-2 minutes until the melting process started. It was crucial not to collect data before this point. we first determined the mass of the container for collecting water from the melting ice. We then recorded the time taken to collect a specified amount of water (t_a), approximately 10 minutes) and weighed the container with the collected water. By subtracting the mass of the empty container, we obtained the mass of the collected water (m_{ws}). Subsequently, the steam chamber was switched on and allowed to stabilize in temperature. The container used for collecting water from the melted ice was then emptied. This step was repeated to obtain readings using steam from the steam chamber. We measured and recorded the weight of the water (m_w) and the time taken (t, 5-10 minutes). The diameter of the ice block was measured again as (d_2).

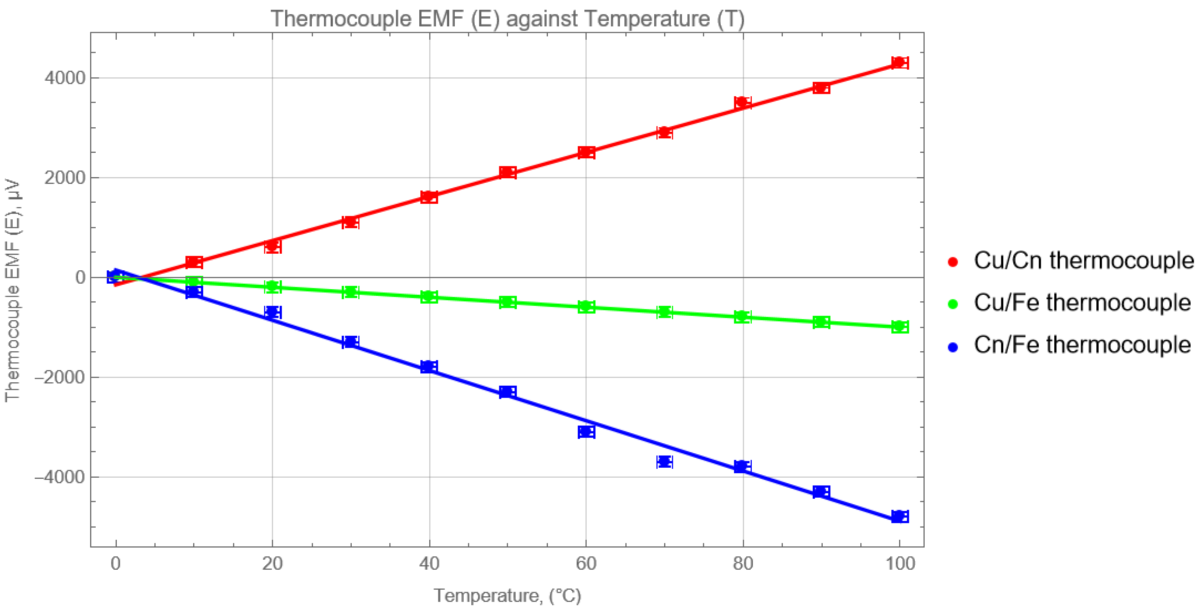
The experiment was repeated with different materials: wood, Lexan, rock, and glass, replacing Masonite each time. For analysis, the average diameter (d_{avg}) of the ice block was calculated from d_1 and d_2. This average diameter was used to determine the area (A) where heat transfer occurred between the ice and the vapor container. The rates of ice melting (R_a = m_{wa}/t_a) and after (R = m_w/t) are calculated, which are the rates of ice melting before and after the steam is used. Finally, the net rate of ice melting (R_o) was calculated as $R_o = R - R_a$, followed by the calculation of the thermal conductivity (k) of each sample in $Calcm^{-1}s^{-1}{}^{\circ}C^{-1}$, using the formula $k = \frac{R_o h \times 80\ cal\ g^{-1}}{A \Delta T}$, taking ΔT as the boiling point of water at 1 atmospheric pressure.

DATA ANALYSYS

Part A

Cu/Cn		Cu/Fe		Cn/Fe	
Voltage: + / –		**Voltage**: + / –		**Voltage**: + / –	
Temperature (°C)	**EMF (μV)**	**Temperature (°C)**	**EMF (μV)**	**Temperature (°C)**	**EMF (μV)**
0	0	0	0	0	0
10.0	300	10.0	-100	10.0	-300
20.0	600	20.0	-200	20.0	-700
30.0	1100	30.0	-300	30.0	-1300
40.0	1600	40.0	-400	40.0	-1800
50.0	2100	50.0	-500	50.0	-2300
60.0	2500	60.0	-600	60.0	-3100
70.0	2900	70.0	-700	70.0	-3700
80.0	3500	80.0	-800	80.0	-3800
90.0	3800	90.0	-900	90.0	-4300
100.0	4300	100.0	-1000	100.0	-4800

Table 2: EMF of Cu/Cn, Cu/Fe and Cn/Fe thermocouples as a function of temperature.



Cu/Cn thermocouple: $y = 44.2727\,x - 150.$, Uncertainty in Slope: 0.808018

Cu/Fe thermocouple: $y = -10.\,x - 1.24345\times10^{-13}$, Uncertainty in Slope: 7.45651×10^{-16}

Cn/Fe thermocouple: $y = 145.455 - 50.3636\,x$, Uncertainty in Slope: 1.55818

Figure 6: Graph of Thermocouple EMF (E) against Temperature (T).

[Display by Mathematica: Appendix 2]

Based on the Results of Mathematica Programing,

For Cu/Cn thermocouple,

The experimental value of Seebeck coefficients, $\alpha_{\mathrm{Cu/Cn}}$ = (44.27 ± 0.81) μV °C^{-1}

The standard value of Seebeck coefficients, $\alpha_{\mathrm{Cu/Cn}}$ = 40.87 μV °C^{-1},

The percentage discrepancies between the experimental and standard value

$=\left|\frac{44.27-40.87}{40.87}\right| \times 100\ \%$

= 8.32 %

For Cu/Fe thermocouple,

The experimental value of Seebeck coefficients, $\alpha_{\mathrm{Cu/Fe}}$ = (-10.00 ± 0.00) μV °C^{-1}

The standard value of Seebeck coefficients, $\alpha_{\mathrm{Cu/Fe}}$ = -13.89 μV °C^{-1}

The percentage discrepancies between the experimental and standard value

$=\left|\frac{(-10.00)-(-13.89)}{-13.89}\right| \times 100\ \%$

= 28.01 %

For Cn/Fe thermocouple,

The experimental value of Seebeck coefficients, $\alpha_{\mathrm{Cn/Fe}}$ = (-50.36 ± 1.56) μV °C^{-1}

The standard value of Seebeck coefficients, $\alpha_{\mathrm{Cn/Fe}}$ = -54.76 μV°C^{-1}

The percentage discrepancies between the experimental and standard value

$=\left|\frac{(-50.36)-(-54.76)}{-54.76}\right| \times 100\ \%$

= 8.04 %

For the theoretical value;

By using the Law of Intermediate Metals;

For the thermocouple of Cu/Cn, $\alpha_{\mathrm{Cu/Cn}} = \alpha_{\mathrm{Cu/Fe}} + \alpha_{\mathrm{Fe/Cn}}$

= -10.0 + (50.36)

= 40.36 μV°C^{-1}

For the thermocouple of Cu/Fe, $\alpha_{\mathrm{Cu/Fe}} = \alpha_{\mathrm{Cu/Cn}} + \alpha_{\mathrm{Cn/Fe}}$

= 44.27 + (-50.36)

= -6.09 μV°C^{-1}

For the thermocouple of Cn/Fe, $\alpha_{\mathrm{Cn/Fe}} = \alpha_{\mathrm{Cn/Cu}} + \alpha_{\mathrm{Cu/Fe}}$

= -44.27 + (-10.0)

= -54.27 μV°C⁻¹

Seebeck coefficients of Thermocouple	Experimental Value (μV°C^{-1})	Theoretical Value (μV°C^{-1})	Standard Value (μV°C^{-1})	Percentage of discrepancy (%)
$\alpha_{\mathrm{Cu/Cn}}$	(44.27 ± 0.81)	40.36	40.87	8.31
$\alpha_{\mathrm{Cu/Fe}}$	(-10.00 ± 0.00)	-6.09	-13.89	28.01
$\alpha_{\mathrm{Cn/Fe}}$	(-50.36 ± 1.56)	-54.27	-54.76	8.04

Table 3: Seebeck coefficients of Thermocouple of various thermocouples.

Part B

EMF of Cu/Cn, $E_{Cu/Cn}$ (μV)	Corresponding Temperature (T, °C)	EMF of Cu/Fe, E (μV)
1400	35	-300
2400	58	-500
3400	81	-700
4400	103	-900
5400	124	-1000
6400	144	-1100
7400	164	-1200
8400	183	-1300
9400	202	-1300
10400	221	-1400
11400	239	-1400
12400	257	-1400
13400	275	-1400
14400	292	-1400
15400	309	-1400
16400	326	-1300
17400	343	-1300
18400	360	-1200
19400	376	-1100
20400	392	-1000
21400	400	-900

Table 4: EMF (E) of the Cu/Fe thermocouple as a function of temperature (T).

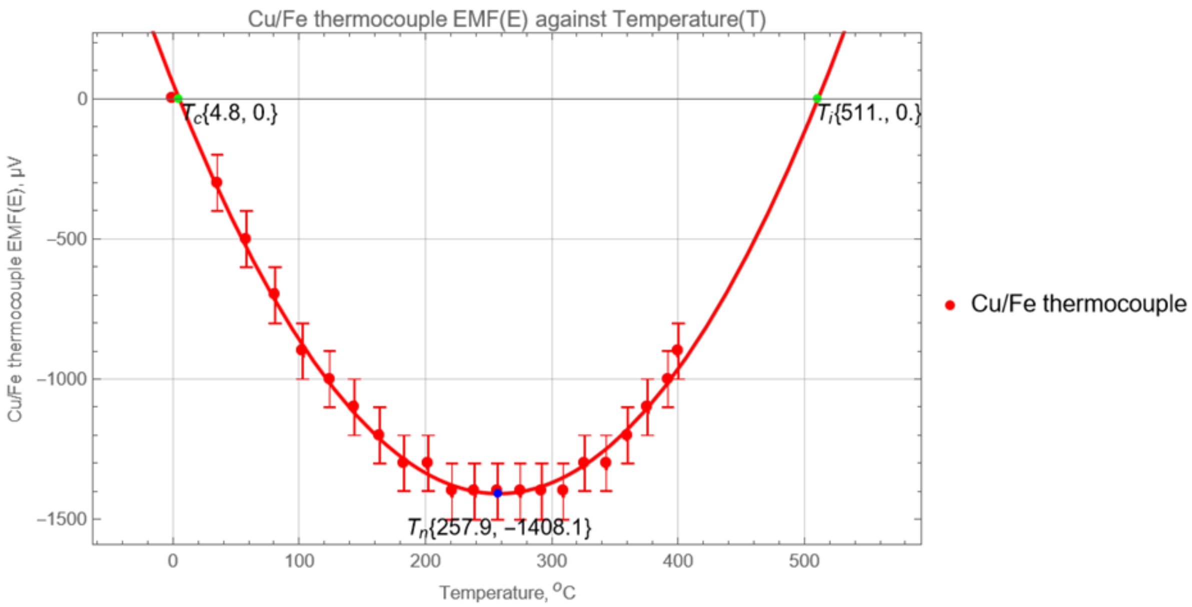


Figure 7: Original Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple.

[Display by Mathematica: Appendix 3]

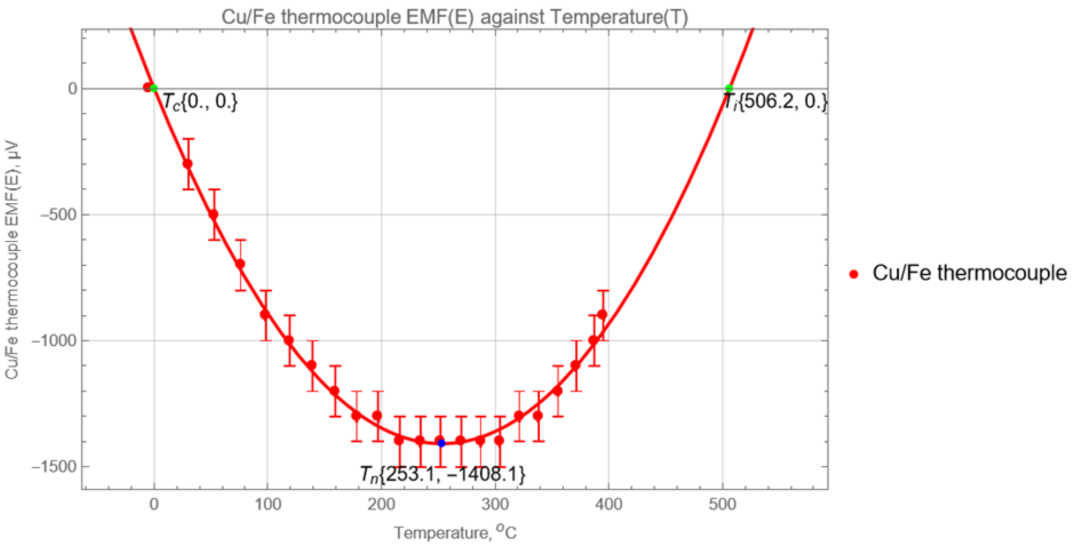


Figure 8: Shifted Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple.

[Display by Mathematica: Appendix 4]

To align with the theoretical principles, the graph depicting the relationship between Thermocouple EMF (E) and Temperature (T) for a Cu/Fe thermocouple has been adjusted. This modification ensures that the graph reflects the theory accurately, which states that the Critical temperature, T_c should be zero when the Thermocouple EMF (E) is also zero. The revised graph provides a clearer and more accurate representation of the theoretical relationship between these variables.

Based on the graph,

The neutral temperature, T_n= 253 °C

The inverse temperature, T_i= 506 °C

The standard value of neutral temperature, T_n= 285 °C

The standard value of inverse temperature, T_i= 570 °C

The percentage discrepancies between the experimental and standard value of T_n

$$=\left|\frac{253-285}{285}\right| \times 100\,\%$$

= 11.23 %

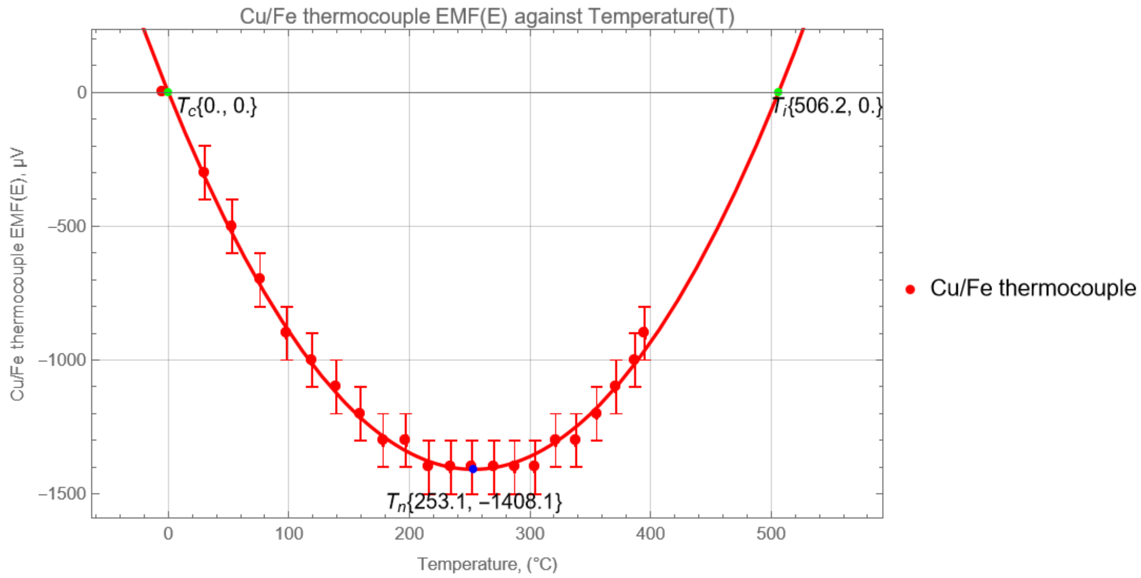
The percentage discrepancies between the experimental and standard value of T_i

$$=\left|\frac{506-570}{570}\right| \times 100\,\%$$

= 11.23 %

Results obtained from Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple				
Thermocouple	Neutral temperature, T_n (°C)	Percentage of discrepancy of T_n(%)	Inverse temperature, T_i (°C)	Percentage of discrepancy of T_i (%)
$\alpha_{Cu/Fe}$	253	11.23	506	11.23

Table 5: Results obtained from Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple

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Points on Curve:
Point at x = 25  : {25, -264.012}
Point at x = 50  : {50, -501.046}
Point at x = 75  : {75, -710.596}
Point at x = 100 : {100, -892.663}
Point at x = 125 : {125, -1047.25}
Point at x = 150 : {150, -1174.34}
Point at x = 175 : {175, -1273.96}
Point at x = 200 : {200, -1346.09}
Point at x = 225 : {225, -1390.74}
Point at x = 250 : {250, -1407.9}
Point at x = 275 : {275, -1397.58}
Point at x = 300 : {300, -1359.78}
Point at x = 325 : {325, -1294.49}
Point at x = 350 : {350, -1201.71}
Point at x = 375 : {375, -1081.46}
Point at x = 400 : {400, -933.719}
Point at x = 425 : {425, -758.496}
Gradients at Specific Points:
Gradient at x = 25  : -10.031
Gradient at x = 50  : -8.93168
Gradient at x = 75  : -7.83233
Gradient at x = 100 : -6.73298
Gradient at x = 125 : -5.63362
Gradient at x = 150 : -4.53427
Gradient at x = 175 : -3.43492
Gradient at x = 200 : -2.33556
Gradient at x = 225 : -1.23621
Gradient at x = 250 : -0.136856
Gradient at x = 275 : 0.962498
Gradient at x = 300 : 2.06185
Gradient at x = 325 : 3.1612
Gradient at x = 350 : 4.26056
Gradient at x = 375 : 5.35991
Gradient at x = 400 : 6.45927
```

Figure 9: Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple with coordinates of points on curve and gradient of the points on the curve.

[Display by Mathematica: Appendix 5]

Using Mathematica's functional code, the coordinates of points on the curve are determined, and the gradient at these points is calculated.

Temperature, T (°C)	ΔT (°C)	ΔE (μV)			$\frac{dE}{dT} \approx \frac{\Delta E}{\Delta T}$ (μV °C^{-1})	
		$E\ (T + 25)$	$E\ (T - 25)$	ΔE	$\frac{d\,E}{d\,T}$	$\frac{\Delta E}{\Delta T}$
25	50	-501	0	-501	-10.03	-10.02
50	50	-711	-264	-447	-8.93	-8.94
75	50	-893	-501	-392	-7.83	-7.84
100	50	-1047	-711	-336	-6.73	-6.72
125	50	-1174	-893	-281	-5.63	-5.62
150	50	-1274	-1047	-227	-4.53	-4.54
175	50	-1346	-1174	-172	-3.43	-3.44
200	50	-1391	-1274	-117	-2.34	-2.34
225	50	-1408	-1346	-62	-1.24	-1.24
250	50	-1398	-1391	-7	-0.14	-0.14
275	50	-1360	-1408	48	0.96	0.96
300	50	-1294	-1398	104	2.06	2.08
325	50	-1202	-1360	158	3.16	3.16
350	50	-1081	-1294	213	4.26	4.26
375	50	-934	-1202	268	5.36	5.36
400	50	-759	-1081	322	6.46	6.44

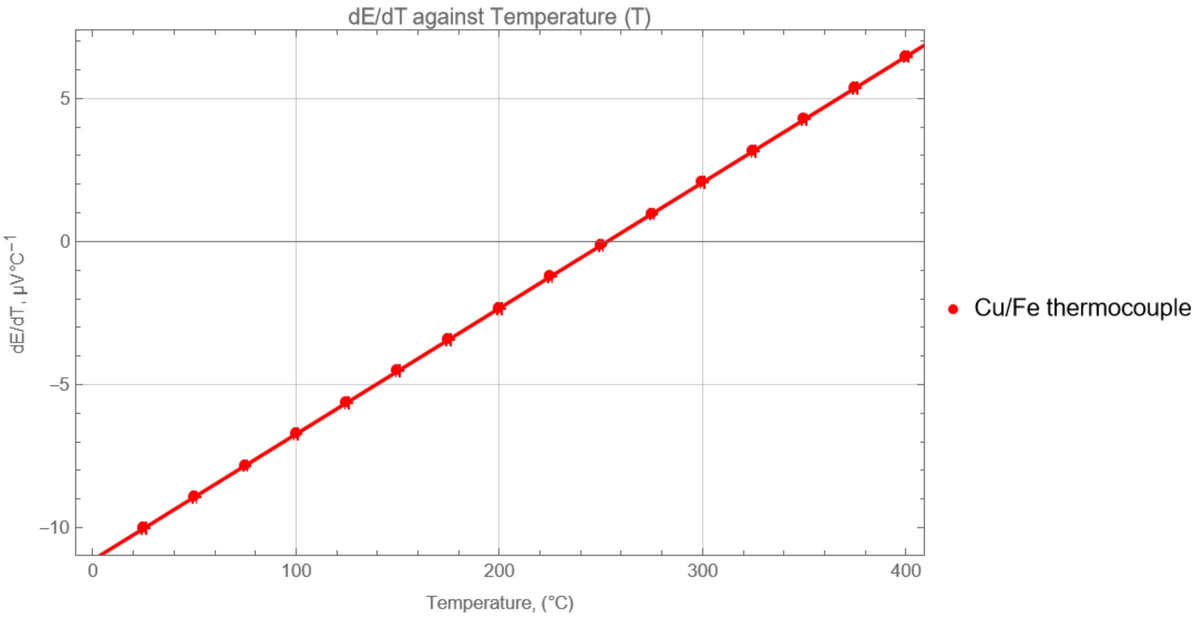
Table 6: dE/dT as a function of T.

$\frac{d\,E}{d\,T}$	$\frac{\Delta E}{\Delta T}$	Percentage of discrepancy between $\frac{d\,E}{d\,T}$ and $\frac{\Delta E}{\Delta T}$
-10.03	-10.02	0.10
-8.93	-8.94	0.11
-7.83	-7.84	0.13
-6.73	-6.72	0.15
-5.63	-5.62	0.18
-4.53	-4.54	0.22
-3.43	-3.44	0.29
-2.34	-2.34	0.00
-1.24	-1.24	0.00
-0.14	-0.14	0.00
0.96	0.96	0.00
2.06	2.08	0.97
3.16	3.16	0.00
4.26	4.26	0.00
5.36	5.36	0.00
6.46	6.44	0.31

Table 7: Percentage of discrepancy between $\frac{d\,E}{d\,T}$ and $\frac{\Delta E}{\Delta T}$

[Calculated by Excel: Appendix 6]

Based on the percentage of discrepancy between $\frac{d\,E}{d\,T}$ and $\frac{\Delta E}{\Delta T}$ of all the certain points are smaller than 0.5%, It can sufficiently make an assumption that the $\frac{d\,E}{d\,T}$ is approximate to $\frac{\Delta E}{\Delta T}$ ($\frac{d\,E}{d\,T} \approx \frac{\Delta E}{\Delta T}$).



Cu/Fe thermocouple: $y = 0.0439629\,x - 11.1278$, Uncertainty in Slope: 5.85287×10^{-6}

Figure 10: Graph of dE/dT against Temperature (T) of Cu/Fe thermocouple.

[Display by Mathematica: Appendix 7]

Given that the equation $E = \alpha T + \frac{1}{2}\beta T^2$

$\frac{dE}{dT} = \frac{d}{dT}(\alpha T + \frac{1}{2}\beta T^2)$

$\frac{dE}{dT} = \alpha + \beta T$

$\frac{dE}{dT} = \beta T + \alpha$

Since the graph is a linear graph with the general linear equation,

Y = mX + C

By comparing,

Gradient, m = β

Y-intercept, C= α

The value of gradient obtained by using the programing with Mathematica is

Gradient, m = 0.0439659

β= 0.044 μV°C^{-1}

The value of Y-intercept obtained by using the programing with Mathematica is

Y-intercept, C = -11.1278

α = -11.13μV°C^{-1}

The neutral temperature, T_n occurred when $\frac{dE}{dT} = 0$,

$\beta T_n + \alpha = 0$

$0.044 T_n - 11.13 = 0$

$T_n = \frac{11.13}{0.044}$

$T_n =$ 253 °C

The inverse temperature, T_i ,
$T_i = 2T_n$
$T_i = 2(253)$
$T_i = 506$ °C

The percentage discrepancies between the experimental and standard value of T_n
$= \left|\frac{253-285}{285}\right| \times 100\ \%$
= 11.23 %

The percentage discrepancies between the experimental and standard value of T_i
$= \left|\frac{506-570}{570}\right| \times 100\ \%$
= 11.23 %

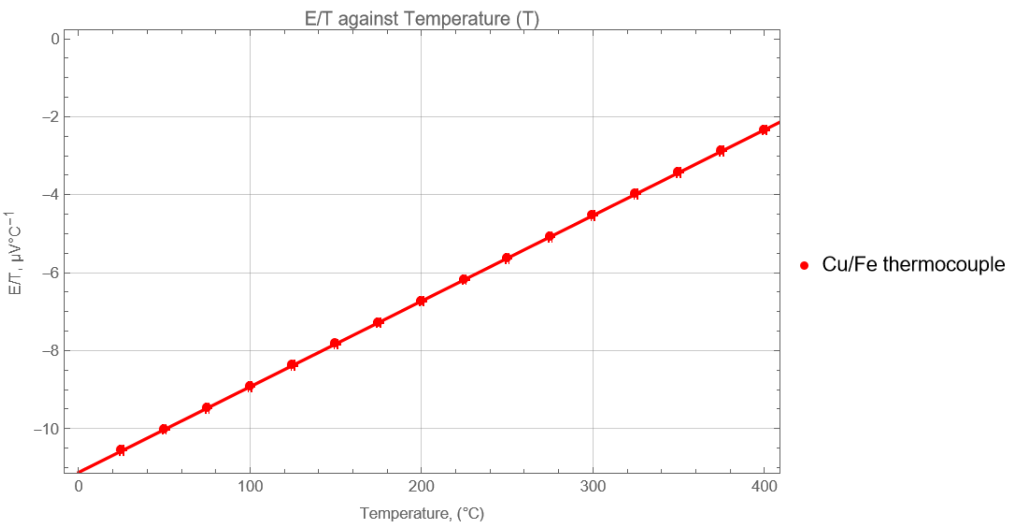
Results obtained from Graph of dE/dT against Temperature (T) of Cu/Fe thermocouple				
Thermocouple	Neutral temperature, T_n (°C)	Percentage of discrepancy of T_n(%)	Inverse temperature, T_i (°C)	Percentage of discrepancy of T_i (%)
$\alpha_{Cu/Fe}$	253	11.23	506	11.23

Table 8: Results obtained from Graph of dE/dT against Temperature (T) of Cu/Fe thermocouple.

Temperature, T (°C)	**EMF, E (μV)**	**E/T (μV °C^{-1})**
25	-264	-10.56
50	-501	-10.02
75	-711	-9.48
100	-893	-8.93
125	-1047	-8.38
150	-1174	-7.83
175	-1274	-7.28
200	-1346	-6.73
225	-1391	-6.18
250	-1408	-5.63
275	-1398	-5.08
300	-1360	-4.53
325	-1294	-3.98
350	-1202	-3.43
375	-1081	-2.88
400	-934	-2.34

Table 9: Values of E/T for their corresponding temperatures T.

[Calculated by Excel: Appendix 8]



Cu/Fe thermocouple: $y = 0.0219659\,x - 11.1215$, Uncertainty in Slope: 0.0000104944

Figure 11: Graph of E/T against Temperature (T) of Cu/Fe thermocouple.

[Display by Mathematica: Appendix 9]

Given that the equation $E = \alpha T + \frac{1}{2}\beta T^2$

$E = T(\alpha + \frac{1}{2}\beta T)$

$\frac{E}{T} = \alpha + \frac{1}{2}\beta T$

$\frac{E}{T} = \frac{1}{2}\beta T + \alpha$

Since the graph is a linear graph with the general linear equation,

Y = mX + C

By comparing,

Gradient, m = $\frac{1}{2}\beta$

Y-intercept, C= α

The value of gradient obtained by using the programing with Mathematica is
Gradient, m = 0.0219659

$\frac{1}{2}\beta$= 0.0219659

β= 2× 0.0219659

β= 0.044 μV°C⁻¹

The value of Y-intercept obtained by using the programing with Mathematica is
Y-intercept, C = -11.1215

α = -11.12 μV°C⁻¹

The inverse temperature, T_i occurred when $\frac{E}{T}$ = 0,

$E = \alpha T + \frac{1}{2}\beta T^2$

$E = T(\alpha + \frac{1}{2}\beta T)$

$\frac{E}{T} = \alpha + \frac{1}{2}\beta T$

$\alpha + \frac{1}{2}\beta T_i = 0$

$\frac{1}{2} \times 2 \times 0.0219659 \times T_i - 11.12 = 0$

$T_i = 11.12 \div 0.0219659$

$T_i = 506$

T_i= 506 °C

The neutral temperature, T_n ,

$T_n = \frac{1}{2} T_i$

$T_n = \frac{1}{2} \times 506$

T_n = 253 °C

The percentage discrepancies between the experimental and standard value of T_n

$= \left|\frac{253-285}{285}\right| \times 100\ \%$

= 11.23 %

The percentage discrepancies between the experimental and standard value of T_i

$= \left|\frac{506-570}{570}\right| \times 100\ \%$

= 11.23 %

Results obtained from Graph of E/T against Temperature (T) of Cu/Fe thermocouple				
Thermocouple	Neutral temperature, T_n (°C)	Percentage of discrepancy of T_n(%)	Inverse temperature, T_i (°C)	Percentage of discrepancy of T_i (%)
$\alpha_{Cu/Fe}$	253	11.23	506	11.23

Table 10: Results obtained from Graph of E/T against Temperature (T) of Cu/Fe thermocouple.

Thermocouple	Neutral temperature, T_n (°C)	Percentage of discrepancy of T_n(%)	Inverse temperature, T_i (°C)	Percentage of discrepancy of T_i (%)
Results obtained from Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple				
$\alpha_{Cu/Fe}$	253	11.23	506	11.23
Results obtained from Graph of dE/dT against Temperature (T) of Cu/Fe thermocouple				
$\alpha_{Cu/Fe}$	253	11.23	506	11.23
Results obtained from Graph of E/T against Temperature (T) of Cu/Fe thermocouple				
$\alpha_{Cu/Fe}$	253	11.23	506	11.23

Table 11: Results of Neutral and Inverse temperature with Percentage of discrepancy obtained from various graphing methods.

Part C

Material	$\boldsymbol{h}$ ($\pm$0.001cm)	$\boldsymbol{d_1}$ ($\pm$0.001cm)	$\boldsymbol{d_2}$ ($\pm$0.001cm)	$\boldsymbol{t_a}$ ($\pm$0.01s)	$\boldsymbol{m_a}$ ($\pm$0.1 g)	$\boldsymbol{t}$ ($\pm$0.01s)
Masonite	0.850	9.058	6.086	600.00	19.0	600.00
Wood	0.750	6.400	5.600	600.00	14.7	600.00
Lexan	0.550	6.065	5.400	600.25	21.3	600.15
Rock	1.280	6.830	5.120	600.00	21.0	600.00
Grass	0.700	6.180	5.200	600.00	20.1	600.00
Material	$\boldsymbol{m_W}$ ($\pm$0.1 g)	$\boldsymbol{d_{avg}}$ (cm)	$\boldsymbol{A}$ (cm^2)	$\boldsymbol{R_a}$(gs^{-1})	$\boldsymbol{R}$(gs^{-1})	$\boldsymbol{R_O}$(gs^{-1})
Masonite	29.0	7.5720	45.03095	0.031666667	0.048333333	0.016666667
Wood	18.2	6.0000	28.27433	0.024500000	0.030333333	0.005833333
Lexan	36.7	5.7325	25.80941	0.035485214	0.061151379	0.025666164
Rock	26.7	5.9750	28.03921	0.035000000	0.044500000	0.009500000
Grass	26.6	5.6900	25.42813	0.033500000	0.044333333	0.010833333

Table 12: Data for Part C.

The experimental thermal conductivity, k of each sample in $Cal\ cm^{-1}s^{-1}{}^{\circ}C^{-1}$, using the formula:

$$k = \frac{R_o h \times 80\ cal\ g^{-1}}{A \Delta T}$$

taking ΔT as the boiling point of water at 1 atmospheric pressure.

Material	experimental thermal conductivity, k ($\times\ 10^{-4} Cal\ cm^{-1}s^{-1}{}^{\circ}C^{-1}$)	Standard thermal conductivity, k_o ($\times\ 10^{-4}\ Cal\ cm^{-1}s^{-1}{}^{\circ}C^{-1}$)		Percentage of discrepancy of experimental and standard thermal conductivity (%)	
Masonite	2.52$\pm$0.05	1.13		122.72	
Wood	1.24$\pm$0.07	2.06	3.30	39.91	62.49
Lexan	4.38$\pm$0.06	4.60		4.88	
Rock	3.47$\pm$0.12	10.30		66.32	
Grass	2.39$\pm$0.07	17.20	20.60	86.13	88.42

Table 13: Results of experimental thermal conductivity, k and Percentage of discrepancy of different material.

All the calculations for obtained the results of experimental thermal conductivity, uncertainty, and percentage of discrepancy of experimental and standard thermal conductivity is conducted by using Excel.

[Calculated by Excel: Appendix 10]

$$d_{\text{avg}} = \frac{d_1 + d_2}{2}$$
$$\Delta d_{\text{avg}} = \sqrt{\left(\frac{1}{2}\Delta d_1\right)^2 + \left(\frac{1}{2}\Delta d_2\right)^2}$$

$$A = \pi \left(\frac{d_{\text{avg}}}{2}\right)^2 = \frac{\pi}{4} d_{\text{avg}}^2$$
$$\left(\frac{\Delta A}{A}\right)^2 = \left(2\frac{\Delta d_{\text{avg}}}{d_{\text{avg}}}\right)^2$$
$$\Delta A = A\sqrt{\left(2\frac{\Delta d_{\text{avg}}}{d_{\text{avg}}}\right)^2} = 2A\frac{\Delta d_{\text{avg}}}{d_{\text{avg}}}$$

$$R_a = \frac{m_a}{t_a}$$
$$\left(\frac{\Delta R_a}{R_a}\right)^2 = \left(\frac{\Delta m_a}{m_a}\right)^2 + \left(\frac{\Delta t_a}{t_a}\right)^2$$
$$\Delta R_a = R_a\sqrt{\left(\frac{\Delta m_a}{m_a}\right)^2 + \left(\frac{\Delta t_a}{t_a}\right)^2}$$

$$R = \frac{m_w}{t}$$
$$\left(\frac{\Delta R}{R}\right)^2 = \left(\frac{\Delta m_w}{m_w}\right)^2 + \left(\frac{\Delta t}{t}\right)^2$$
$$\Delta R = R\sqrt{\left(\frac{\Delta m_w}{m_w}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}$$

$$R_0 = R - R_a$$
$$\Delta R_0 = \Delta R + \Delta R_a$$

$$k = \frac{R_0 h \times 80\,\text{cal g}^{-1}}{A\Delta T}$$
$$\left(\frac{\Delta k}{k}\right)^2 = \left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 + \left(\frac{\Delta A}{A}\right)^2$$
$$\Delta k = k\sqrt{\left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 + \left(\frac{\Delta A}{A}\right)^2}$$

Figure 12: Derivations of the formula used to find the uncertainty of experimental thermal conductivity, k (Written by Latex).

[Display by Latex: Appendix 11]

DISCUSSION AND CONCLUSION

DISCUSSION

In our PART A experiment, we derived the experimental values for each thermocouple from the slope of Graph of Thermocouple EMF (E) against Temperature (T) [Figure 6]. We determined the experimental Seebeck coefficient, $\alpha_{Cu/Cn}$ for Copper/Constantan (Cu/Cn) thermocouple as (44.27 ± 0.81) μV°C⁻¹, with a discrepancy of 8.32% from the standard value. However, for Copper/Iron (Cu/Fe) thermocouple, the experimental $\alpha_{Cu/Fe}$ was (-10.00 ± 0.00) μV°C⁻¹, deviating significantly by 28.01% from the expected standard. Similarly, the Constantan/Iron (Cn/Fe) thermocouple showed an experimental $\alpha_{Cn/Fe}$ of (-50.36 ± 1.56) μV°C⁻¹, with an 8.04% discrepancy.

These results indicate that while the discrepancies for Cu/Cn and Cn/Fe thermocouples are within an acceptable 10% range of discrepancy, the error margin for Cu/Fe exceeds this limit, pointing to significant experimental errors. Discrepancies in the Seebeck coefficient could be due to inaccurate temperature measurements, non-ideal thermocouple behavior, or electromagnetic interference. The purity and condition of the metals used in the thermocouples might not be consistent. Possible sources of these errors also include non-uniform water temperature during heating, a result of insufficient stirring or uneven heat distribution. Additionally, the placement of the thermometer might have contributed to the errors; if placed too low, it could have touched the container's bottom, affecting the readings.

To mitigate such errors in future experiments, it is crucial to use thermocouples made from high-purity metals and ensure consistent manufacturing processes. During the experiment ensure uniform water temperature by constant stirring during the heating process and to position the thermometer correctly, avoiding contact with the container bottom. Additionally, to minimize heat loss and prevent parallax errors, it would be advisable to conduct the experiment in a controlled environment, such as turning off fans and carefully reading the thermometer.

Another, PART B experiment yielded three identical sets of values, each derived from a different graph. From the Graphs of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple, dE/dT against Temperature (T) of Cu/Fe thermocouple and E/T against Temperature (T) of Cu/Fe thermocouple, we determined the neutral temperature, T_i and inverse temperature, T_n to be 253 ºC and 506 ºC, with the percentage discrepancy of 11.23%.

The values for the neutral temperature across different graphs showed consistency. However, the presence of experimental errors that affected the outcomes cannot be overlooked. Rapid temperature changes could lead to non-equilibrium states, affecting the EMF readings. For instance, the equipment used, such as the multimeter, may have had sensitivity issues or not been functioning optimally. Additionally, the irregular shape of the rock used to maintain the temperature might have caused the thermocouples to displace from the heater. Another potential source of error could be the floating of the cold end in ice water as the ice melted.

To improve the accuracy of future experiments, several corrective measures should be implemented. Slow down the rate of temperature change to allow the system to reach equilibrium at each step. Ensuring the hot junction is in direct contact with the heater and maintaining the cold end at a steady 0ºC by regularly adding ice are crucial steps. Also, taking voltmeter readings promptly and switching off any fans to reduce air movement will help in minimizing errors and achieving more reliable results.

In PART C experiment, we measured the thermal conductivity (k) of various materials:

Masonite: k_{Masonite} = [(2.52 $\pm$ 0.05)$\times$ $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 122.72 % discrepancy];

Wood: k_{Wood} = [(1.24$\pm$0.07)$\times$ $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, (39.91~62.49) % discrepancy];

Lexan: k_{Lexan} = [(4.38$\pm$0.06)$\times$ $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 4.88 % discrepancy];

Rock: k_{Rock} = [(3.47$\pm$0.12)$\times$ $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 66.32 % discrepancy];

Glass: k_{Glass} = [(2.39$\pm$0.07)$\times$ $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, (86.13~88.42) % discrepancy].

These large discrepancies suggest the presence of major experimental errors.

One notable source of error was the inconsistency in the ice block's diameter, as it did not melt uniformly. This irregular melting affected the accuracy of diameter measurements taken at various points. It's crucial to ensure consistent measurement points and to handle the Vernier calliper delicately to avoid marking or scratching the ice, as these marks could deepen with melting and skew results.

Furthermore, the melting of ice throughout the experiment necessitated rapid post-experiment measurements to minimize errors due to changing diameters. Another issue was potential leakage between the sample and the container's surface.

To mitigate these errors in future experiments, several precautionary steps are recommended. First, ensuring all equipment and apparatus are in optimal condition is paramount. Any equipment with known zero errors should be either recorded for correction or replaced. Multiple measurements should be taken to calculate an average, enhancing accuracy. Environmental factors, such as air movement or humidity, should be controlled by turning off fans. Careful reading techniques must be employed to avoid parallax errors. Finally, ensuring the water channel is dry before starting a new experiment will help in obtaining more accurate results.

CONCLUSION

From this experiment, concluded that Seebeck coefficient of thermocouples :

$\alpha_{\mathrm{Cu/Cn}} = (44.27 \pm 0.81)$ μV°C^{-1}, with an 8.32% discrepancy;

$\alpha_{\mathrm{Cu/Fe}} = (-10.00 \pm 0.00)$ μV°C^{-1}, with an 28.01% discrepancy;

$\alpha_{\mathrm{Cn/Fe}} = (-50.36 \pm 1.56)$ μV°C^{-1}, with an 8.04% discrepancy.

Through multiple graphs indicated T_n = 253°C and T_i = 506°C with a discrepancy of 11.23% for Cu/Fe thermocouple. The thermal conductivity, k of various materials:

Masonite: k_{Masonite} = [(2.52 ± 0.05)× $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 122.72 % discrepancy];

Wood: k_{Wood} = [(1.24±0.07)× $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, (39.91~62.49) % discrepancy];

Lexan: k_{Lexan} = [(4.38±0.06)× $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 4.88 % discrepancy];

Rock: k_{Rock} = [(3.47±0.12)× $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, 66.32 % discrepancy];

Glass: k_{Glass} = [(2.39±0.07)× $10^{-4} Cal\ cm^{-1} s^{-1} {}^{\circ}C^{-1}$, (86.13~88.42) % discrepancy].

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APPENDICES

Appendix 1:

Table A1: Thermoelectric voltage (mV) for Cu/Cn thermocouple hot junction at temperature 0–400 °C, reference junction at 0 °C.

Temperature (°C)	0	1	2	3	4	5	6	7	8	9
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352
10	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749
20	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155
30	1.196	1.238	1.279	1.320	1.362	1.403	1.445	1.486	1.528	1.570
40	1.612	1.654	1.696	1.738	1.780	1.823	1.865	1.908	1.950	1.993
50	2.036	2.079	2.122	2.165	2.208	2.251	2.294	2.338	2.381	2.425
60	2.468	2.512	2.556	2.600	2.643	2.687	2.732	2.776	2.820	2.864
70	2.909	2.953	2.998	3.043	3.087	3.132	3.177	3.222	3.267	3.312
80	3.358	3.403	3.448	3.494	3.539	3.585	3.631	3.677	3.722	3.768
90	3.814	3.860	3.907	3.953	3.999	4.046	4.092	4.138	4.185	4.232
100	4.279	4.325	4.372	4.419	4.466	4.513	4.561	4.608	4.655	4.702
110	4.750	4.798	4.845	4.893	4.941	4.988	5.036	5.084	5.132	5.180
120	5.228	5.277	5.325	5.373	5.422	5.470	5.519	5.567	5.616	5.665
130	5.714	5.763	5.812	5.861	5.910	5.959	6.008	6.057	6.107	6.156
140	6.206	6.255	6.305	6.355	6.404	6.454	6.504	6.554	6.604	6.654
150	6.704	6.754	6.805	6.855	6.905	6.956	7.006	7.057	7.107	7.158
160	7.209	7.260	7.310	7.361	7.412	7.463	7.515	7.566	7.617	7.668
170	7.720	7.771	7.823	7.874	7.926	7.977	8.029	8.081	8.133	8.185
180	8.237	8.289	8.341	8.393	8.445	8.497	8.550	8.602	8.654	8.707
190	8.759	8.812	8.865	8.917	8.970	9.023	9.076	9.129	9.182	9.235
200	9.288	9.341	9.395	9.448	9.501	9.555	9.608	9.662	9.715	9.769
210	9.822	9.876	9.930	9.984	10.038	10.092	10.146	10.200	10.254	10.308
220	10.362	10.417	10.471	10.525	10.580	10.634	10.689	10.743	10.798	10.853
230	10.907	10.962	11.017	11.072	11.127	11.182	11.237	11.292	11.347	11.403
240	11.458	11.513	11.569	11.624	11.680	11.735	11.791	11.846	11.902	11.958
250	12.013	12.069	12.125	12.181	12.237	12.292	12.349	12.405	12.461	12.518
260	12.574	12.630	12.687	12.743	12.799	12.856	12.912	12.969	13.026	13.082
270	13.139	13.196	13.253	13.310	13.366	13.423	13.480	13.537	13.595	13.652
280	13.709	13.766	13.823	13.881	13.938	13.995	14.053	14.110	14.168	14.226
290	14.283	14.341	14.399	14.456	14.514	14.572	14.630	14.688	14.746	14.804
300	14.862	14.920	14.978	15.036	15.095	15.153	15.211	15.270	15.328	15.386
310	15.445	15.503	15.562	15.621	15.679	15.738	15.797	15.856	15.914	15.973
320	16.032	16.091	16.150	16.209	16.268	16.327	16.387	16.446	16.505	16.564
330	16.624	16.683	16.742	16.802	16.861	16.921	16.980	17.040	17.100	17.159
340	17.219	17.279	17.339	17.399	17.458	17.518	17.578	17.638	17.698	17.759
350	17.819	17.879	17.939	17.999	18.060	18.120	18.180	18.241	18.301	18.362
360	18.422	18.483	18.543	18.604	18.665	18.725	18.786	18.847	18.908	18.969
370	19.030	19.091	19.152	19.213	19.274	19.335	19.396	19.457	19.518	19.579
380	19.641	19.702	19.763	19.825	20.886	20.947	20.009	20.070	20.132	20.193
390	20.255	20.317	20.378	20.440	20.502	20.563	20.625	20.687	20.748	20.810
400	20.872									

Appendix 2:

Figure 6: Graph of Thermocouple EMF (E) against Temperature (T).

```
(*Define the datasets*)
t1 = {{0, 0}, {10, 300}, {20, 600}, {30, 1100}, {40, 1600}, {50,
   2100}, {60, 2500}, {70, 2900}, {80, 3500}, {90, 3800}, {100,
   4300}};
t2 = {{0,
   0}, {10, -100}, {20, -200}, {30, -300}, {40, -400}, {50, -500}, \
{60, -600}, {70, -700}, {80, -800}, {90, -900}, {100, -1000}};
t3 = {{0,
   0}, {10, -300}, {20, -700}, {30, -1300}, {40, -1800}, {50, \
-2300}, {60, -3100}, {70, -3700}, {80, -3800}, {90, -4300}, {100, \
-4800}};

t1error = {
  {Around[0, 1], Around[0, 100]},
  {Around[10, 1], Around[300, 100]},
  {Around[20, 1], Around[600, 100]},
  {Around[30, 1], Around[1100, 100]},
  {Around[40, 1], Around[1600, 100]},
  {Around[50, 1], Around[2100, 100]},
  {Around[60, 1], Around[2500, 100]},
  {Around[70, 1], Around[2900, 100]},
  {Around[80, 1], Around[3500, 100]},
  {Around[90, 1], Around[3800, 100]},
  {Around[100, 1], Around[4300, 100]}};
t2error = {
  {Around[0, 1], Around[0, 100]},
  {Around[10, 1], Around[-100, 100]},
  {Around[20, 1], Around[-200, 100]},
  {Around[30, 1], Around[-300, 100]},
  {Around[40, 1], Around[-400, 100]},
  {Around[50, 1], Around[-500, 100]},
  {Around[60, 1], Around[-600, 100]},
```

```
  {Around[70, 1], Around[-700, 100]},
  {Around[80, 1], Around[-800, 100]},
  {Around[90, 1], Around[-900, 100]},
  {Around[100, 1], Around[-1000, 100]}};
t3error = {
  {Around[0, 1], Around[0, 100]},
  {Around[10, 1], Around[-300, 100]},
  {Around[20, 1], Around[-700, 100]},
  {Around[30, 1], Around[-1300, 100]},
  {Around[40, 1], Around[-1800, 100]},
  {Around[50, 1], Around[-2300, 100]},
  {Around[60, 1], Around[-3100, 100]},
  {Around[70, 1], Around[-3700, 100]},
  {Around[80, 1], Around[-3800, 100]},
  {Around[90, 1], Around[-4300, 100]},
  {Around[100, 1], Around[-4800, 100]}};

(*Fit linear models to the data*)
fitt1 = LinearModelFit[t1, x, x];
fitt2 = LinearModelFit[t2, x, x];
fitt3 = LinearModelFit[t3, x, x];

(*Extracting uncertainties in the slope of each fit*)
uncertainty1 = fitt1["ParameterTableEntries"][[2, 2]];
uncertainty2 = fitt2["ParameterTableEntries"][[2, 2]];
uncertainty3 = fitt3["ParameterTableEntries"][[2, 2]];

(*Extract equations as strings*)
eq1 = ToString[TraditionalForm[y == fitt1["BestFit"]]];
eq2 = ToString[TraditionalForm[y == fitt2["BestFit"]]];
eq3 = ToString[TraditionalForm[y == fitt3["BestFit"]]];

(*Existing code for plotting*)Column[{combinedPlot =
  Show[ListPlot[{t1error, t2error, t3error},
```

```
   PlotStyle -> {Red, Green, Blue},
   PlotLegends -> {"Cu/Cn thermocouple", "Cu/Fe thermocouple",
     "Cn/Fe thermocouple"}],
  Plot[{fitt1[x], fitt2[x], fitt3[x]}, {x, 0, 100},
   PlotStyle -> {Red, Green, Blue}], Frame -> True,
  FrameLabel -> {"Temperature, (°C)", "Thermocouple EMF (E), µV"},
  GridLines -> Automatic,
  PlotLabel -> "Thermocouple EMF (E) against Temperature (T)",
  ImageSize -> 500];
(*Displaying the results*)
Column[{combinedPlot,
  Row[{"Cu/Cn thermocouple: ", eq1, ", Uncertainty in Slope: ",
    uncertainty1}],
  Row[{"Cu/Fe thermocouple: ", eq2, ", Uncertainty in Slope: ",
    uncertainty2}],
  Row[{"Cn/Fe thermocouple: ", eq3, ", Uncertainty in Slope: ",
    uncertainty3}]}]
 }
]
```

Appendix 3:

Figure 7: Original Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple

```
(*graph before shifted*)
(*Data and Error Definitions*)
t1 = {{0,
   0}, {35, -300}, {58, -500}, {81, -700}, {103, -900}, {124, \
-1000}, {144, -1100}, {164, -1200}, {183, -1300}, {202, -1300}, {221, \
-1400}, {239, -1400}, {257, -1400}, {275, -1400}, {292, -1400}, {309, \
-1400}, {326, -1300}, {343, -1300}, {360, -1200}, {376, -1100}, {392, \
-1000}, {400, -900}};

(*Define the error bar*)
t1error = {{Around[0, 0], Around[0, 0]},
  {Around[35, 0.5], Around[-300, 100]},
  {Around[58, 0.5], Around[-500, 100]},
  {Around[81, 0.5], Around[-700, 100]},
  {Around[103, 0.5], Around[-900, 100]},
  {Around[124, 0.5], Around[-1000, 100]},
  {Around[144, 0.5], Around[-1100, 100]},
  {Around[164, 0.5], Around[-1200, 100]},
  {Around[183, 0.5], Around[-1300, 100]},
  {Around[202, 0.5], Around[-1300, 100]},
  {Around[221, 0.5], Around[-1400, 100]},
  {Around[239, 0.5], Around[-1400, 100]},
  {Around[257, 0.5], Around[-1400, 100]},
  {Around[275, 0.5], Around[-1400, 100]},
  {Around[292, 0.5], Around[-1400, 100]},
  {Around[309, 0.5], Around[-1400, 100]},
  {Around[326, 0.5], Around[-1300, 100]},
  {Around[343, 0.5], Around[-1300, 100]},
  {Around[360, 0.5], Around[-1200, 100]},
  {Around[376, 0.5], Around[-1100, 100]},
  {Around[392, 0.5], Around[-1000, 100]},
```

```
  {Around[400, 0.5], Around[-900, 100]}};



(*Curve Fitting*)
x1 = t1[[All, 1]];
y1 = t1[[All, 2]];
fit1 = Fit[Transpose[{x1, y1}], {1, x, x^2}, x];

(*Finding Intersection Points with Y=0 Line*)
solutions = NSolve[fit1 == 0, x];
intersectionPoints = {#, 0} & /@ (x /. solutions);

(*Finding the Minimum Point*)
minX = x /. Last[FindMinimum[fit1, {x, 0}]];
minY = fit1 /. x -> minX;
minPoint = {minX, minY};

(*Labeling Function*)
labelPoint[pt_, label_, offset_] :=
 Text[Style[label <> ToString[Round[pt, 0.1]], Black, 12], pt + offset]

(*Plotting*)
Show[ListPlot[{t1}, PlotStyle -> {Red}],
 ListPlot[{t1error}, PlotStyle -> {Red},
  PlotLegends -> {"Cu/Fe thermocouple"}],
 Plot[{fit1}, {x, -100, 700}, PlotStyle -> {Red}],
 Graphics[{Blue, PointSize[0.01], Point[minPoint],
   labelPoint[minPoint,
    "\!\(\*SubscriptBox[\(T\), \(n\)]\)", {0, -120}]}],
 Graphics[{Green, PointSize[0.01], Point[intersectionPoints],
   labelPoint[intersectionPoints[[1]],
    "\!\(\*SubscriptBox[\(T\), \(c\)]\)", {40, -50}],
   labelPoint[intersectionPoints[[2]],
    "\!\(\*SubscriptBox[\(T\), \(i\)]\)", {40, -50}]}], Frame -> True,
```

```
 FrameLabel -> {"Temperature,\!\(\*SuperscriptBox[\(\\\ \), \
\(o\)]\)C", "Cu/Fe thermocouple EMF(E), μV"}, GridLines -> Automatic,
 PlotLabel -> "Cu/Fe thermocouple EMF(E) against Temperature(T)",
 ImageSize -> 500, PlotRange -> {{-50, 580}, {200, -1500}}]
```

Appendix 4:

Figure 8: Shifted Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple.

```
(*graph after shif*)

(*Data and Error Definitions with Shift*)

t1 = {{0 - 4.8,
  0}, {35 - 4.8, -300}, {58 - 4.8, -500}, {81 - 4.8, -700}, {103 -
   4.8, -900}, {124 - 4.8, -1000}, {144 - 4.8, -1100}, {164 -
   4.8, -1200}, {183 - 4.8, -1300}, {202 - 4.8, -1300}, {221 -
   4.8, -1400}, {239 - 4.8, -1400}, {257 - 4.8, -1400}, {275 -
   4.8, -1400}, {292 - 4.8, -1400}, {309 - 4.8, -1400}, {326 -
   4.8, -1300}, {343 - 4.8, -1300}, {360 - 4.8, -1200}, {376 -
   4.8, -1100}, {392 - 4.8, -1000}, {400 - 4.8, -900}};


(*Adjust t1error by Subtracting 4.8 from Each x-value*)

t1error = {{Around[0 - 4.8, 0], Around[0, 0]}, {Around[35 - 4.8, 0.5],
   Around[-300, 100]}, {Around[58 - 4.8, 0.5],
   Around[-500, 100]}, {Around[81 - 4.8, 0.5],
   Around[-700, 100]}, {Around[103 - 4.8, 0.5],
   Around[-900, 100]}, {Around[124 - 4.8, 0.5],
   Around[-1000, 100]}, {Around[144 - 4.8, 0.5],
   Around[-1100, 100]}, {Around[164 - 4.8, 0.5],
   Around[-1200, 100]}, {Around[183 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[202 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[221 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[239 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[257 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[275 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[292 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[309 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[326 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[343 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[360 - 4.8, 0.5],
   Around[-1200, 100]}, {Around[376 - 4.8, 0.5],
   Around[-1100, 100]}, {Around[392 - 4.8, 0.5],
   Around[-1000, 100]}, {Around[400 - 4.8, 0.5], Around[-900, 100]}};


(*Curve Fitting*)
```

```
x1 = t1[[All, 1]];
y1 = t1[[All, 2]];
fit1 = Fit[Transpose[{x1, y1}], {1, x, x^2}, x];

(*Finding Intersection Points with Y=0 Line*)
solutions = NSolve[fit1 == 0, x];
intersectionPoints = {#, 0} & /@ (x /. solutions);

(*Finding the Minimum Point*)
minX = x /. Last[FindMinimum[fit1, {x, 0}]];
minY = fit1 /. x -> minX;
minPoint = {minX, minY};

(*Labeling Function*)
labelPoint[pt_, label_, offset_] :=
 Text[Style[label <> ToString[Round[pt, 0.1]], Black, 12], pt + offset]

(*Plotting*)
Show[ListPlot[{t1}, PlotStyle -> {Red}],
 ListPlot[{t1error}, PlotStyle -> {Red},
  PlotLegends -> {"Cu/Fe thermocouple"}],
 Plot[{fit1}, {x, -100, 700}, PlotStyle -> {Red}],
 Graphics[{Blue, PointSize[0.01], Point[minPoint],
   labelPoint[minPoint,
    "\!\(\*SubscriptBox[\(T\), \(n\)]\)", {0, -120}]}],
 Graphics[{Green, PointSize[0.01], Point[intersectionPoints],
   labelPoint[intersectionPoints[[1]],
    "\!\(\*SubscriptBox[\(T\), \(c\)]\)", {40, -50}],
   labelPoint[intersectionPoints[[2]],
    "\!\(\*SubscriptBox[\(T\), \(i\)]\)", {40, -50}]}], Frame -> True,
  FrameLabel -> {"Temperature,\!\(\*SuperscriptBox[\(\\\ \), \
\(o\)]\)C", "Cu/Fe thermocouple EMF(E), μV"}, GridLines -> Automatic,
 PlotLabel -> "Cu/Fe thermocouple EMF(E) against Temperature(T)",
 ImageSize -> 500, PlotRange -> {{-50, 580}, {200, -1500}}]
```

Appendix 5:

Figure 9: Graph of Thermocouple EMF (E) against Temperature (T) of Cu/Fe thermocouple with coordinates of points on curve and gradient of the points on the curve

```
(*Data and Error Definitions with Shift*)
t1 = {{0 - 4.8,
   0}, {35 - 4.8, -300}, {58 - 4.8, -500}, {81 - 4.8, -700}, {103 -
    4.8, -900}, {124 - 4.8, -1000}, {144 - 4.8, -1100}, {164 -
    4.8, -1200}, {183 - 4.8, -1300}, {202 - 4.8, -1300}, {221 -
    4.8, -1400}, {239 - 4.8, -1400}, {257 - 4.8, -1400}, {275 -
    4.8, -1400}, {292 - 4.8, -1400}, {309 - 4.8, -1400}, {326 -
    4.8, -1300}, {343 - 4.8, -1300}, {360 - 4.8, -1200}, {376 -
    4.8, -1100}, {392 - 4.8, -1000}, {400 - 4.8, -900}};

(*Adjust t1error by Subtracting 4.8 from Each x-value*)
t1error = {{Around[0 - 4.8, 0], Around[0, 0]}, {Around[35 - 4.8, 0.5],
    Around[-300, 100]}, {Around[58 - 4.8, 0.5],
   Around[-500, 100]}, {Around[81 - 4.8, 0.5],
   Around[-700, 100]}, {Around[103 - 4.8, 0.5],
   Around[-900, 100]}, {Around[124 - 4.8, 0.5],
   Around[-1000, 100]}, {Around[144 - 4.8, 0.5],
   Around[-1100, 100]}, {Around[164 - 4.8, 0.5],
   Around[-1200, 100]}, {Around[183 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[202 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[221 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[239 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[257 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[275 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[292 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[309 - 4.8, 0.5],
   Around[-1400, 100]}, {Around[326 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[343 - 4.8, 0.5],
   Around[-1300, 100]}, {Around[360 - 4.8, 0.5],
   Around[-1200, 100]}, {Around[376 - 4.8, 0.5],
   Around[-1100, 100]}, {Around[392 - 4.8, 0.5],
   Around[-1000, 100]}, {Around[400 - 4.8, 0.5], Around[-900, 100]}};
```

```
(*Curve Fitting*)
x1 = t1[[All, 1]];
y1 = t1[[All, 2]];
fit1 = Fit[Transpose[{x1, y1}], {1, x, x^2}, x];

(*Finding the Derivative*)
derivative = D[fit1, x];

(*Define a list of specific x values where you want to find the \
gradient*)
specificXValues = {25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275,
   300, 325, 350, 375, 400};  (*Replace with your desired x values*)

(*Calculating the Gradient at the Specific Points*)
gradientAtSpecificPoints =
  Table[{xVal, derivative /. x -> xVal}, {xVal, specificXValues}];

(*Finding Intersection Points with Y=0 Line*)
solutions = NSolve[fit1 == 0, x];
intersectionPoints = {#, 0} & /@ (x /. solutions);

(*Finding the Minimum Point*)
minX = x /. Last[FindMinimum[fit1, {x, 0}]];
minY = fit1 /. x -> minX;
minPoint = {minX, minY};

(*Labeling Function*)
labelPoint[pt_, label_, offset_] :=
 Text[Style[label <> ToString[Round[pt, 0.1]], Black, 12], pt + offset]

(*Evaluate the fitted curve at specific x-values*)
xValuesToList = {25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275,
   300, 325, 350, 375, 400, 425}; (*example x-values*)
pointsOnCurve = {#, fit1 /. x -> #} & /@ xValuesToList;

(*Creating a list of coordinates*)
coordinateList =
  Table[{"Point at x = ", xValuesToList[[i]], ": ",
    pointsOnCurve[[i]]}, {i, 1, Length[pointsOnCurve]}];
```

```
(*Plotting*)
plot = Show[ListPlot[{t1}, PlotStyle -> {Red}],
  ListPlot[{t1error}, PlotStyle -> {Red},
   PlotLegends -> {"Cu/Fe thermocouple"}],
  Plot[{fit1}, {x, -100, 700}, PlotStyle -> {Red}],
  Graphics[{Blue, PointSize[0.01], Point[minPoint],
    labelPoint[minPoint,
     "\!\(\*SubscriptBox[\(T\), \(n\)]\)", {0, -120}]}],
  Graphics[{Green, PointSize[0.01], Point[intersectionPoints],
    labelPoint[intersectionPoints[[1]],
     "\!\(\*SubscriptBox[\(T\), \(c\)]\)", {40, -50}],
    labelPoint[intersectionPoints[[2]],
     "\!\(\*SubscriptBox[\(T\), \(i\)]\)", {40, -50}]}],
  Frame -> True,
  FrameLabel -> {"Temperature, (°C)",
    "Cu/Fe thermocouple EMF(E), µV"}, GridLines -> Automatic,
  PlotLabel -> "Cu/Fe thermocouple EMF(E) against Temperature(T)",
  ImageSize -> 500, PlotRange -> {{-50, 580}, {200, -1500}}];

(*Create a formatted grid for gradients*)
gradientList =
 Table[{"Gradient at x = ", xValuesToList[[i]], ": ",
   gradientAtSpecificPoints[[i, 2]]}, {i, 1,
   Length[gradientAtSpecificPoints]}];

(*Combine coordinateList and gradientList for display,formatted as a \
grid*)
combinedDisplay =
 Column[{plot, "Points on Curve:",
  Grid[coordinateList, Alignment -> Left, Frame -> False],
  "Gradients at Specific Points:",
  Grid[gradientList, Alignment -> Left,
   Frame -> False] (*Format as a grid with a frame for clarity*)}]
```

Appendix 6:

Temperature, T (°C)	ΔT (°C)	ΔE(μV)			$dEdT \approx \Delta E \Delta T$(μV °C−1)		Percentage of discrepancy
		$E(T+25)$	$E(T-25)$	ΔE	(d E)/(d T)	$\Delta E/\Delta T$	%
25	50	-501	0	-501	-10.03	-10.02	0.10
50	50	-711	-264	-447	-8.93	-8.94	-0.11
75	50	-893	-501	-392	-7.83	-7.84	-0.13
100	50	-1047	-711	-336	-6.73	-6.72	0.15
125	50	-1174	-893	-281	-5.63	-5.62	0.18
150	50	-1274	-1047	-227	-4.53	-4.54	-0.22
175	50	-1346	-1174	-172	-3.43	-3.44	-0.29
200	50	-1391	-1274	-117	-2.34	-2.34	0.00
225	50	-1408	-1346	-62	-1.24	-1.24	0.00
250	50	-1398	-1391	-7	-0.14	-0.14	0.00
275	50	-1360	-1408	48	0.96	0.96	0.00
300	50	-1294	-1398	104	2.06	2.08	-0.97
325	50	-1202	-1360	158	3.16	3.16	0.00
350	50	-1081	-1294	213	4.26	4.26	0.00
375	50	-934	-1202	268	5.36	5.36	0.00
400	50	-759	-1081	322	6.46	6.44	0.31

Appendix 7:

Figure 10: Graph of dE/dT against Temperature (T) of Cu/Fe thermocouple

```
(*Define the datasets*)
t1 = {{25, -10.03}, {50, -8.93}, {75, -7.83}, {100, -6.73}, {125, \
-5.63}, {150, -4.53}, {175, -3.43}, {200, -2.34}, {225, -1.24}, {250, \
-0.14}, {275, 0.96}, {300, 2.06}, {325, 3.16}, {350, 4.26}, {375,
   5.36}, {400, 6.46}};

t1error = {{Around[25, 1], Around[-10.03, 0.01]}, {Around[50, 1],
   Around[-8.93, 0.01]}, {Around[75, 1],
   Around[-7.83, 0.01]}, {Around[100, 1],
   Around[-6.73, 0.01]}, {Around[125, 1],
   Around[-5.63, 0.01]}, {Around[150, 1],
   Around[-4.53, 0.01]}, {Around[175, 1],
   Around[-3.43, 0.01]}, {Around[200, 1],
   Around[-2.34, 0.01]}, {Around[225, 1],
   Around[-1.24, 0.01]}, {Around[250, 1],
   Around[-0.14, 0.01]}, {Around[275, 1],
   Around[0.96, 0.01]}, {Around[300, 1],
   Around[2.06, 0.01]}, {Around[325, 1],
   Around[3.16, 0.01]}, {Around[350, 1],
   Around[4.26, 0.01]}, {Around[375, 1],
   Around[5.36, 0.01]}, {Around[400, 1], Around[6.46, 0.01]}};

(*Fit linear models to the data*)
fitt1 = LinearModelFit[t1, x, x];

(*Extracting uncertainties in the slope of each fit*)
uncertainty1 = fitt1["ParameterTableEntries"][[2, 2]];

(*Extract equations as strings*)
eq1 = ToString[TraditionalForm[y == fitt1["BestFit"]]];

(*Existing code for plotting*)Column[{combinedPlot =
  Show[ListPlot[{t1error}, PlotStyle -> {Red},
    PlotLegends -> {"Cu/Fe thermocouple"}],
   Plot[{fitt1[x]}, {x, 0, 420}, PlotStyle -> {Red}], Frame -> True,
   FrameLabel -> {"Temperature, (°C)",
```

```
    "dE/dT, \!\(\*SuperscriptBox[\(μV°C\), \(-1\)]\)"},
  GridLines -> Automatic,
  PlotLabel -> "dE/dT against Temperature (T)", ImageSize -> 500];
(*Displaying the results*)
Column[{combinedPlot,
  Row[{"Cu/Fe thermocouple: ", eq1, ", Uncertainty in Slope: ",
    uncertainty1}]}]
}
]
```

Appendix 8:

Temperature, $\boldsymbol{T}$ (°C)	EMF, $\boldsymbol{E}$ (μV)	$\boldsymbol{E/T}$ $(\mathbf{\mu V\ °C\ -1}$
25	-264	-10.56
50	-501	-10.02
75	-711	-9.48
100	-893	-8.93
125	-1047	-8.38
150	-1174	-7.83
175	-1274	-7.28
200	-1346	-6.73
225	-1391	-6.18
250	-1408	-5.63
275	-1398	-5.08
300	-1360	-4.53
325	-1294	-3.98
350	-1202	-3.43
375	-1081	-2.88
400	-934	-2.34

Appendix 9:

Figure 11: Graph of E/T against Temperature (T) of Cu/Fe thermocouple.

```
(*Define the datasets*)
t1 = {{25, -10.56}, {50, -10.02}, {75, -9.48}, {100, -8.93}, {125, \
-8.38}, {150, -7.83}, {175, -7.28}, {200, -6.73}, {225, -6.18}, {250, \
-5.63}, {275, -5.08}, {300, -4.53}, {325, -3.98}, {350, -3.43}, {375, \
-2.88}, {400, -2.34}};

t1error = {{Around[25, 1], Around[-10.56, 0.01]}, {Around[50, 1],
    Around[-10.02, 0.01]}, {Around[75, 1],
    Around[-9.48, 0.01]}, {Around[100, 1],
    Around[-8.93, 0.01]}, {Around[125, 1],
    Around[-8.38, 0.01]}, {Around[150, 1],
    Around[-7.83, 0.01]}, {Around[175, 1],
    Around[-7.28, 0.01]}, {Around[200, 1],
    Around[-6.73, 0.01]}, {Around[225, 1],
    Around[-6.18, 0.01]}, {Around[250, 1],
    Around[-5.63, 0.01]}, {Around[275, 1],
    Around[-5.08, 0.01]}, {Around[300, 1],
    Around[-4.53, 0.01]}, {Around[325, 1],
    Around[-3.98, 0.01]}, {Around[350, 1],
    Around[-3.43, 0.01]}, {Around[375, 1],
    Around[-2.88, 0.01]}, {Around[400, 1], Around[-2.34, 0.01]}};

(*Fit linear models to the data*)
fitt1 = LinearModelFit[t1, x, x];

(*Extracting uncertainties in the slope of each fit*)
uncertainty1 = fitt1["ParameterTableEntries"][[2, 2]];

(*Extract equations as strings*)
eq1 = ToString[TraditionalForm[y == fitt1["BestFit"]]];

(*Existing code for plotting*)Column[{combinedPlot =
   Show[ListPlot[{t1error}, PlotStyle -> {Red},
     PlotLegends -> {"Cu/Fe thermocouple"}],
    Plot[{fitt1[x]}, {x, 0, 420}, PlotStyle -> {Red}], Frame -> True,
    FrameLabel -> {"Temperature, (°C)",
```

```
    "E/T, \!\(\*SuperscriptBox[\(μV°C\), \(-1\)]\)"},
  GridLines -> Automatic,
  PlotLabel -> "E/T against Temperature (T)", ImageSize -> 500];
(*Displaying the results*)
Column[{combinedPlot,
  Row[{"Cu/Fe thermocouple: ", eq1, ", Uncertainty in Slope: ",
    uncertainty1}]}]
}
]
```

Appendix 10:

Material	h	$d1$	$d2$	ta	m_a	t	m_w	$davg$	$\Delta davg$	A	ΔA
Masonite	0.85	9.058	6.086	600	19	600	29	7.572	0.000707	45.03095	0.00841
Wood	0.75	6.4	5.6	600	14.7	600	18.2	6	0.000707	28.27433	0.006664
Lexan	0.55	6.065	5.4	600.25	21.3	600.15	36.7	5.7325	0.000707	25.80941	0.006367
Rock	1.28	6.83	5.12	600	21	600	26.7	5.975	0.000707	28.03921	0.006637
Grass	0.7	6.18	5.2	600	20.1	600	26.6	5.69	0.000707	25.42813	0.00632

Ra	ΔRa	R	ΔR	Ro	ΔRo
0.031667	0.000166668	0.048333333	0.000166669	0.016666667	0.000333336
0.0245	0.000166667	0.030333333	0.000166667	0.005833333	0.000333335
0.035485	0.000166598	0.061151379	0.000166628	0.025666164	0.000333226
0.035	0.000166668	0.0445	0.000166668	0.0095	0.000333336
0.0335	0.000166668	0.044333333	0.000166668	0.010833333	0.000333336

k	Δk	standard K		percentage of diecrapancy (%)	
2.52E-04	5.04E-06	1.13E-04		122.72	
1.24E-04	7.08E-06	2.06E-04	3.30E-04	-39.91	-62.49
4.38E-04	5.74E-06	4.60E-04		-4.88	
3.47E-04	1.22E-05	1.03E-03		-66.32	
2.39E-04	7.35E-06	1.72E-03	2.06E-03	-86.13	-88.42

Appendix 11:

Figure 12: Derivations of the formula used to find the uncertainty of experimental thermal conductivity, k (Written by Latex).

```
\documentclass[12pt]{article}
\usepackage{geometry}
\geometry{left=1in, right=1in, top=1in, bottom=1in}
\usepackage{amsmath} % For mathematical symbols and equations
\usepackage{ams symb}%For some mathrelationsymbol
\usepackage{siunitx}
\usepackage{mathrsfs} % Include the mathsymbol package
\usepackage{graphicx} % For including figures
\graphicspath{{./figure/}}
\DeclareGraphicsExtensions{.pdf,.jpeg,.png,.jpg}
\usepackage{lipsum} % For generating placeholder text (remove this in your actual document)
\usepackage{tasks}

\begin{document}
\begin{align*}
d_{\text{avg}} &= \frac{d_1 + d_2}{2} \\
\Delta d_{\text{avg}} &= \sqrt{\left(\frac{1}{2} \Delta d_1\right)^2 + \left(\frac{1}{2} \Delta
d_2\right)^2} \\
\\
A &= \pi \left(\frac{d_{\text{avg}}}{2}\right)^2 = \frac{\pi}{4} d_{\text{avg}}^2 \\
\left(\frac{\Delta A}{A}\right)^2 &= \left(2 \frac{\Delta d_{\text{avg}}}{d_{\text{avg}}}\right)^2 \\
\Delta A &= A \sqrt{\left(2 \frac{\Delta d_{\text{avg}}}{d_{\text{avg}}}\right)^2} = 2 A
\frac{\Delta d_{\text{avg}}}{d_{\text{avg}}} \\
\\
R_a &= \frac{m_a}{t_a} \\
\left(\frac{\Delta R_a}{R_a}\right)^2 &= \left(\frac{\Delta m_a}{m_a}\right)^2 + \left(\frac{\Delta
t_a}{t_a}\right)^2 \\
\Delta R_a &= R_a \sqrt{\left(\frac{\Delta m_a}{m_a}\right)^2 + \left(\frac{\Delta t_a}{t_a}\right)^2}
\\
\\
R &= \frac{m_w}{t} \\
\left(\frac{\Delta R}{R}\right)^2 &= \left(\frac{\Delta m_w}{m_w}\right)^2 + \left(\frac{\Delta
t}{t}\right)^2 \\
\Delta R &= R \sqrt{\left(\frac{\Delta m_w}{m_w}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}\\
\\
R_0 &= R - R_a \\
\Delta R_0 &= \Delta R + \Delta R_a \\
\\
k &= \frac{R_0 h \times 80 \, \text{cal g}^{-1}}{A \Delta T} \\
\left(\frac{\Delta k}{k}\right)^2 &= \left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta
h}{h}\right)^2 + \left(\frac{\Delta A}{A}\right)^2 \\
\Delta k &= k \sqrt{\left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 +
\left(\frac{\Delta A}{A}\right)^2}
\end{align*}

\end{document}
```