Research Question

How does the initial temperature of 200 ml water (˚C ± 0.1: 30, 35, 40, 45, 50) affect the temperature change (K ± 0.2) of a 6.30 g zinc sheet in a closed system?

Introduction

In the 19th century, with the establishment and development of industrial civilization, especially the birth of the steam engine, calorimetry has made great progress. After years of experimental research, people accurately determined the equivalent amount of thermal work and gradually recognized the conversion and conservation of energy of different natures (such as thermal energy, mechanical energy, electrical energy, etc.) between the most fundamental law of the natural world of material movement, which became one of the greatest scientific advances of mankind in the 19th century. Calorimetry is defined as a field of thermochemistry that measures the amount of heat involved in a physical or chemical reaction. From today's point of view, calorimetry is based on "heat" or "thermal mass", which is not in line with the viewpoint of molecular dynamics theory and lacks scientific content. However, this does not detract from the historical contribution of calorimetry. To date, calorimetry has been widely used in physics, aerospace, mechanical engineering, and various thermal and refrigeration engineering.

In the field of thermodynamics, the first law of thermodynamics energy conservation states that energy can neither be created nor destroyed, it can only transfer from one form of energy to another, which standardized the findings of previous generations. In relation to the conservation of energy, the specific heat capacity (c) of a substance is the amount of energy needed to raise (or lower) the temperature of 1g of the substance by 1°C. Its determination is important for the study of the relationship between macroscopic physical phenomena and microscopic structure of substances and can be identified via observing the conduction of thermal energy in a closed system.

Based on the theoretical support, the purpose of this experiment is to measure the specific heat capacity of a solid (zinc sheet) by comparing the change in internal energy between constant amount of zinc block and water. While the temperature of the zinc sheet is lower than the water temperature, a decrease in the energy of water is equal to an increase in the energy of zinc, hence the equation $\Delta Q_{\text{water}}=\Delta Q_{\text{zinc}}$ can be established. As heat energy is calculated by $Q=mc\Delta T$ for energy transfer without phase change, physical quantities of mass, initial temperature, and final temperature of water and zinc have to be measured. When a metal sheet to be tested (let its specific heat capacity be c) of mass m and temperature T_z is put into water inside a calorimeter, let the mass of the water be m_w and the specific heat capacity be c_w. Let the temperature of water before metal sheet is thrown into the water be T_w and the temperature of its mixture after the metal is placed into the water is noted as T_e. Then the following relationship will exist between T_z and ΔT_w, without taking into account the exchange of heat between the calorimeter and the outside world:

$$m_z c_z \Delta T_z = m_w c_w \Delta T_w$$

$$m c_z (T_e - T_e) = m_w c_w (T_e - T_w)$$

$$\frac{\Delta T_w}{\Delta T_z} = \frac{(T_e - T_w)}{(T_e - T_z)} = \frac{m_z c_z}{m_w c_w}$$

Therefore, as shown in the equation, the temperature change of zinc sheet may have a proportional relationship with the temperature change of water since the ratio of ΔT_z to ΔT_w is constant when the mass of zinc and the mass of water are unchanged. Also, obtaining a value for this ratio is the first step in calculating the specific heat capacity of zinc, the final coefficient to be calculated.

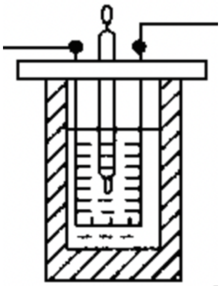


Figure 1. Thermal insulation cup

In addition, heat exchange between the system and the outside world is inevitable in thermal experiments. Thus, efforts are made to create a thermodynamically isolated system as shown in Figure 1, while making corrections for other heat absorption and dissipation during the experiment and trying to improve the accuracy of the experiment. As a result, the calorimeter with an outer cylinder made of insulating material and an inner cylinder made of insulating material is selected. The mouth of the outer cylinder is covered with a plastic wood cover, and the central hole of the cover is used to insert a thermometer. This closed structure reduces convection and heat conduction and the smooth inner cylinder wall decreases heat radiation, thus lessening the heat exchange between the liquid in the cylinder and the surrounding environment.

Hypothesis

From the derived formula, it could be hypothesized that as the initial temperature (˚C) of water increases, the temperature change (K) of zinc sheet will increase. When plotting the temperature change of water against the temperature change of zinc sheet in Kelvin, a linear line with a positive gradient is expected.

Methodology

Independent Variable: The initial temperature of water (˚C ± 0.1: 30, 35, 40, 45, 50)

This is a range of values that can be measured directly in a school laboratory. Via heater and LabQuest, the temperature of a liquid can be raised and recorded in order to achieve the expected values and a constant interval between values. Manipulating the temperature of the water in the insulated cup through laboratory equipment is an effective method, which also maintains high accuracy and convenience.

Dependent Variable: The temperature change of zinc block (K ± 0.2)

The temperature change of a zinc sheet can be calculated from measurable quantities of initial and final temperature by using a sensor and LabQuest. The value of initial and final temperature (K) of the metal from without water to adding water will be measured as two raw dependent variables and will be used to calculate the processed dependent variable through the formula, $\Delta T = T_f - T_i$.

Control Variables:

Table 1 below lists the controlled variables in the experiment.

Controlled Variables	Method to control	Reason to control
Mass of zinc sheet	Use an electric balance to measure a zinc sheet of 6.30g and keep the mass constant by applying the same piece of metal.	The mass of zinc sheet will affect its total capacity of heat as $Q=mc\Delta T$, which further decreases the accuracy of the temperature variation.
Volume of water	Use a measuring cylinder with a maximum capacity of 250 ml and control the volume of water to maintain 200 ml. To properly read the value, the line of sight must be level with the center of the curve of the meniscus.	The volume of water should be constant since the it is related to the mass of water from the equation $\rho=m/V$. The variation of mass may change the result of the temperature change between matters.
Room temperature	Maintain a constant temperature of the surroundings to minimize temperature fluctuation between trials. Close doors and windows and complete the experiment within a similar time frame.	The temperature of the environment has an impact on its change in internal energy, which will affect the accuracy of the initial temperature change.
Purity of zinc	The same 6.30 g zinc sheet is used to keep the purity constant.	The purity of the metal block will affect its mass as $m=\rho V$, which further increases the precision of the calculation of specific heat capacity.

Table 1. Control variables

Material List (See in Figure 2a):

Table 2 below shows the materials used in the experiment.

Material	Quantity	Uncertainty
Zinc sheet	6.30g	/
Water	200 ml	/
Measuring cylinder (250 ml)	1	± 25 ml
LabQuest	2	± 0.1˚C
Heat sensor	2	/
Laboratory hot plate	1	± 0.1˚C
Thermal insulation cup	1	/
Electric balance	1	± 0.01g
Stainless steel basin	1	/

Table 2. Apparatus list

Figure 2 below shows the equipment and materials used in the experiment.

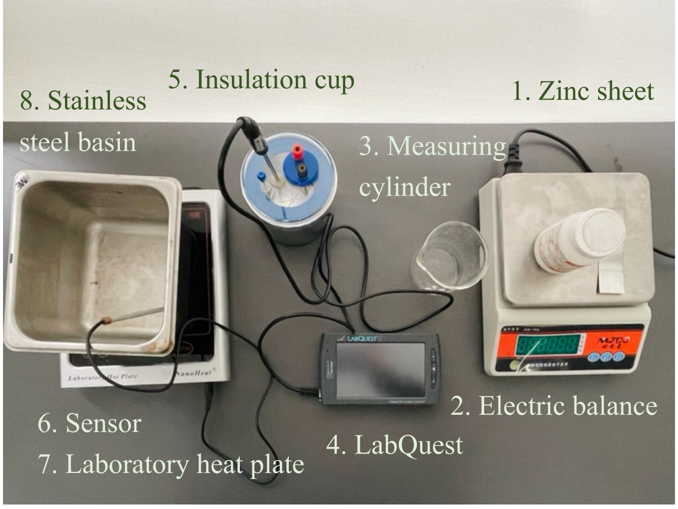


Figure 2. Material list

Procedure:

1. Record the mass of the zinc sheet using an electronic balance and the initial temperature with a thermal sensor. Record the value.
2. Place the zinc sheet into the thermal insulation cup.
3. Measure 200ml water with a measuring cylinder and heat water to 30 ˚C using a water heater.
4. Pour water into the thermal insulation cup.
5. Monitor the change in temperature with LabQuest and record the value of temperature when the water and zinc sheet achieve equilibrium.
6. Repeat steps 1-5 four times.
7. Repeat steps 1-6, increasing the initial temperature of water by increments of 5.0 ˚C, stopping at 50˚C.
8. The setup of the lab is shown in Figure 3 below.

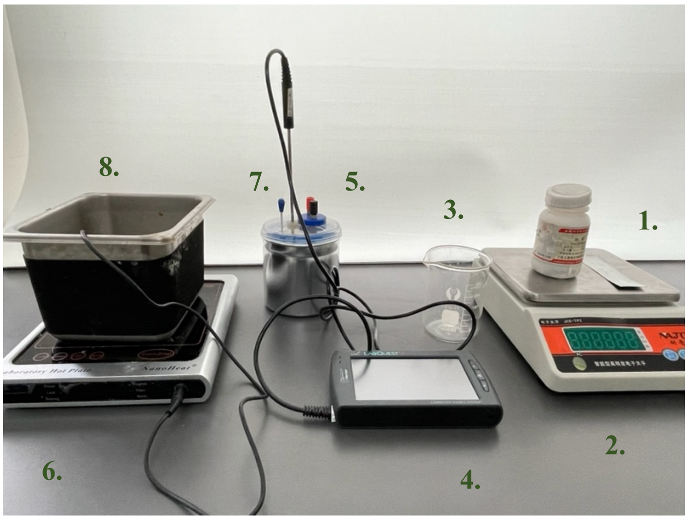


Figure 3. Experiment setting

Safety, Environmental and Ethical Issues:

Apart from this, as electricity is used to heat water, the experimenter should not heat the water too high or touch the appliance with water to protect the safety of themselves.

Raw Data

Qualitative Data – What is observed when the zinc sheet is placed into the water

Once the zinc flakes were placed in the insulated cup of water, the higher water temperature could be seen through the transparent lid since water vapor gradually adhered to the cover. As the initial temperature of the water increases, the water vapor that evaporates from the water attached to the surroundings increases.

Quantitative Data – Table 3 below shows the raw data table.

	The temperature of zinc sheet (˚C ± 0.1)									
The initial temperature of water (˚C ± 0.1)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
30.0	23.5	28.6	23.7	28.8	23.8	28.8	22.7	28.0	22.8	28.0
35.0	23.3	32.5	23.3	32.2	23.4	32.7	23.2	32.2	23.3	32.5
40.0	20.5	35.7	20.5	35.3	20.6	35.8	20.5	35.6	20.5	35.9
45.0	20.9	39.4	20.8	39.6	20.8	39.4	21.0	39.5	20.8	39.7
50.0	22.0	43.5	22.3	43.8	22.2	43.7	22.3	43.4	22.1	43.2

Table 3. Raw data: the initial temperature of water with respect to the final temperature of zinc sheet to reach thermal equilibrium with water

Sample Calculation

In my investigation, the change in temperature of zinc sheet is defined as the final temperature (equilibrium) of the system subtracted the initial temperature of zinc sheet.

$$\frac{\Delta T_{\mathrm{z}}}{\Delta T_{\mathrm{w}}} = \frac{(T_{\mathrm{e}} - T_{\mathrm{z}})}{(T_{\mathrm{w}} - T_{\mathrm{e}})} = \frac{m_{\mathrm{w}} c_{\mathrm{w}}}{m_{\mathrm{z}} c_{\mathrm{z}}}$$

A sample calculation based on water’s initial temperature of 30.0 ˚C is given below:

$$\Delta T_{\mathrm{z}_1} = T_f - T_i = 5.1\mathrm{K}, \quad \Delta T_{\mathrm{z}_2} = 5.1\mathrm{K}, \quad \Delta T_{\mathrm{z}_3} = 5.1\mathrm{K}, \quad \Delta T_{\mathrm{z}_4} = 5.3\mathrm{K}, \quad \Delta T_{\mathrm{z}_5} = 5.2\mathrm{K}$$

$$T_{\mathrm{ave}} = \frac{5.1 + 5.1 + 5.1 + 5.3 + 5.2}{5} = 5.2\mathrm{K}$$

$$T_{\mathrm{unc}} = \frac{\Delta T_{max} - \Delta T_{min}}{2} = \frac{5.3 - 5.1}{2} = 0.1\mathrm{K}$$

As processing the independent variable, the initial temperature of water, into the temperature change of water makes the latter calculation more precise and convenient, this series of values is also being computed. A sample calculation based on water’s initial temperature of 30.0 ˚C is given below:

$$\Delta T_{w_1} = T_f - T_i = 1.4\text{K}, \quad \Delta T_{w_2} = 1.2\text{K}, \quad \Delta T_{w_3} = 1.1\text{K}, \quad \Delta T_{w_4} = 2.0\text{K}, \quad \Delta T_{w_5} = 2.0\text{K}$$

$$T_{\text{ave}} = \frac{1.4 + 1.2 + 1.1 + 2.0 + 2.0}{5} = 1.54\text{K}$$

$$T_{\text{unc}} = \frac{\Delta T_{max} - \Delta T_{min}}{2} = \frac{2.0 - 1.1}{2} = 0.5\text{K}$$

Processed Data

Table 4 below shows the calculated result the temperature change of zinc sheet.

	The temperature change of zinc sheet (K)						
The initial temperature of water (℃ ± 0.1)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average temperature change / K	Uncertainty of K
30.0	5.1	5.1	5.1	5.3	5.2	5.2	0.1
35.0	9.2	8.9	9.3	9.0	9.2	9.1	0.2
40.0	15.2	14.8	15.2	15.1	15.4	15.1	0.3
45.0	18.5	18.8	18.6	18.5	18.9	18.7	0.2
50.0	21.5	21.5	21.5	21.1	21.1	21.3	0.2

Table 4. Processed data of temperature change of zinc sheet

Table 5 below shows the calculated result of the temperature change of water.

	The temperature change of water (K)						
The initial temperature of water (℃ ± 0.1)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average temperature change / K	Uncertainty of K
30.0	1.4	1.2	1.1	2.0	2.0	1.5	0.5
35.0	2.5	2.8	2.3	2.8	2.5	2.6	0.3
40.0	4.3	4.7	4.2	4.4	4.1	4.3	0.3
45.0	5.6	5.4	5.6	5.5	5.3	5.5	0.2
50.0	6.5	6.2	6.3	6.6	6.8	6.5	0.3

Table 5. Processed data of temperature change of water

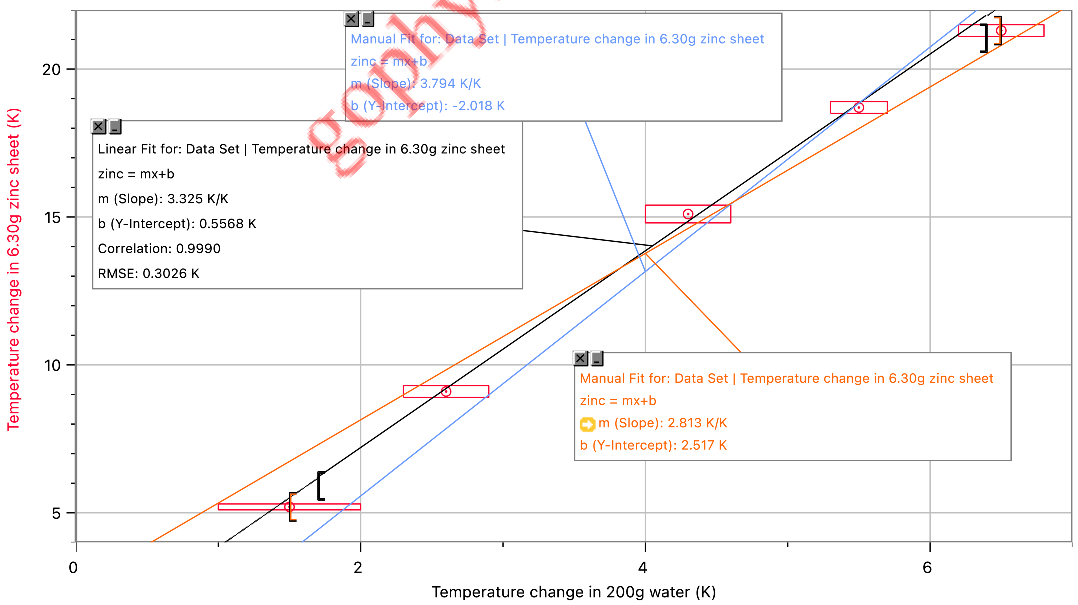
Following the procedure shows by sample calculation, the other values of processed data are summarized in Table 6.

The initial temperature of water (˚C ± 0.1)	Average temperature change of zinc sheet/ K	Uncertainty of temperature change in zinc sheet/ K	Average temperature change of water/ K	Uncertainty of temperature change in water/ K
30.0	5.2	0.1	1.5	0.5
35.0	9.1	0.2	2.6	0.3
40.0	15.1	0.3	4.3	0.3
45.0	18.7	0.2	5.5	0.2
50.0	21.3	0.2	6.5	0.3

Table 6. Processed data: the temperature change in water with respect to the temperature change in zinc sheet

Data Analysis

The temperature change in the zinc sheet was graphed against the temperature change in water. The best fit line was obtained by the software used. The 2 worst fit lines were obtained by finding the steepest straight line and the gentlest straight line that intersects all error bars. Graph 1 below shows the graphing of one best fit line and two worst fit lines.



Graph 1. Temperature change in zinc sheet with respect to temperature change in water

The best-fit line reveals a relationship: $\Delta T_z = 3.325\text{K} \cdot \Delta T_w + 0.5568\text{K}$

The worst fit lines reveal a relationship: $\Delta T_z = 3.974\text{K} \cdot \Delta T_w - 2.018\text{K}$

$$\Delta T_z = 2.813\text{K} \cdot \Delta T_w + 2.517\text{K}$$

The uncertainty of the gradient is

$$\frac{3.974 - 2.813}{2} = 0.6\mathrm{K}$$

The uncertainty of the y-intercept is

$$\frac{|-2.018 - 2.517|}{2} = 2\mathrm{K}$$

Therefore, $\Delta T_\mathrm{z} = (3.3\mathrm{K} \pm 0.6\mathrm{K}) \cdot \Delta T_\mathrm{w} + (1\mathrm{K} \pm 2\mathrm{K})$

Hence by using this ratio relationship, the specific heat capacity of zinc can be calculated.

$$m_\mathrm{z} c_\mathrm{z} \Delta T_\mathrm{z} = m_\mathrm{w} c_\mathrm{w} \Delta T_\mathrm{w} \quad \Longrightarrow \quad c_\mathrm{z} = \frac{m_\mathrm{w} c_\mathrm{w} \Delta T_\mathrm{w}}{m_\mathrm{z} \Delta T_\mathrm{z}}$$

$$c_\mathrm{z} = 0.403 \times 10^3 \mathrm{J/(kg \cdot K)}$$

The uncertainty of the specific heat capacity of zinc is

$$\frac{\Delta c_\mathrm{z}}{c_\mathrm{z}} = \frac{\Delta m_\mathrm{w}}{m_\mathrm{w}} + \frac{\Delta\left(\frac{T_\mathrm{w}}{T_\mathrm{z}}\right)}{\frac{T_\mathrm{w}}{T_\mathrm{z}}} + \frac{\Delta m_\mathrm{z}}{m_\mathrm{z}} = \frac{25}{200} + \frac{0.6}{3.3} + \frac{0.01}{6.30} = 0.308$$

$$\Delta c_\mathrm{z} = 0.1 \times 10^3 \mathrm{J/(kg \cdot K)}$$

Therefore, the specific heat capacity of zinc is $(0.4 \pm 0.1) \times 10^3 \mathrm{J/(kg \cdot K)}$

Conclusion

This investigation aims to calculate the specific heat capacity of zinc element by performing the experiments and calculating the coefficient of the linear relationship between temperature change in water and temperature change in zinc sheet so that the ratio of these two variables can be determined. It was hypothesized that as the initial temperature (˚C) of water increases, the temperature change (K) of zinc sheet will increase, and a linear relationship will exist.

The processed experimental data was plotted and revealed a relationship as $\Delta T_\mathrm{z} = (3.3\mathrm{K} \pm 0.6\mathrm{K}) \cdot \Delta T_\mathrm{w} + (1\mathrm{K} \pm 2\mathrm{K})$ and it indicates that when the temperature of the zinc sheet changes by 1K, the temperature of water surrounded will change by 3.3K ± 0.6K. The calculation supports the hypothesis of a positive linear relationship between the temperature change in the system of zinc sheet and water. This is because the loss of thermal energy in water transfers to an increase of thermal energy on the zinc sheet due to the first law of thermal conservation. Based on the gradient of the linear equation, the value of the specific heat capacity of zinc was further calculated as $0.4 \times 10^3\ \mathrm{J/(kg \cdot ℃)} \pm 0.1 \times 10^3\ \mathrm{J/(kg \cdot ℃)}$.

The calculated value of zinc's specific capacity has an absolute uncertainty of ± 0.1Jkg^{-1}°C^{-1}, and this is equivalent to a percentage uncertainty of $\frac{0.1}{0.4} \times 100\% = 25\%$, showing the value of the specific heat capacity is relatively unprecise and unreliable. However, considering the spread of points around the line of best fit, my results are also generally believed to be reliable. Besides appearance random errors, some systematic errors may occur since the line of the best-fit line does not go through the origin.

Although the uncertainty indicates that there are errors exist, the accuracy of the value of zinc's specific heat capacity is much better. The calculated value is nearly close to the standard number. When drawn to scale, the difference between two data points only differs by 0.01 units. When my result is compared to the accepted value, the experimental coefficient of the specific heat capacity of zinc is $0.403 \times 10^3\ \mathrm{J/(kg \cdot {}^\circ C)}$, while the theoretical coefficient for the material is $0.39 \times 10^3\ \mathrm{J/(kg \cdot {}^\circ C)}$. The percentage error can be calculated by using the formula

$$\text{Percentage error} = \left|\frac{\text{literature value} - \text{experimental value}}{\text{literature value}}\right| \times 100\%$$

Therefore, substituting the theoretical value and experimental value of the coefficient of specific heat capacity of zinc, the percentage error is

$$\text{Percentage error} = \left|\frac{390 - 403}{390}\right| = 3.3\% \text{ to 2 significant figures}$$

This percentage error has a small value that less than 10% which indicates a satisfactory accuracy.

Evaluation

Although the hypothesis is corroborated by the first law of thermal conversion, which states that energy cannot be created or destroyed but only transferred, the calculated value of specific heat capacity of zinc slightly differs from the theoretical value, with a value of 3.3% percentage error together with experimental uncertainties. The possible reasons for this discrepancy could be the weaknesses throughout the experiment. At the same time, there are some strengths which led to the success of this investigation. In the following session, the strengths and weaknesses of the investigation will be reflected and identified.

Table 7 below shows the strengths of this investigation, while Table 8 examined the limitations.

Strengths	Significance
Five trials per temperature and at least three concordant results are present in the data collection	As the experiment is repeated for multiple trials and the results are mostly concordant, the random errors can be reduced during the process, and the collected data will be more precise and closer together.
The laboratory heat plate is used to control the initial temperature of 200g water	Since the laboratory heat plate is an electronic equipment which can show the temperature of the heating liquid simultaneously with low uncertainty, the initial temperature of the water can be controlled readily and precisely, increasing the precision of the collected data and saving time in ensuring the temperature of water.

The form of zinc sheet used in the experiment	Compared to the alternative form zinc block, the same mass of zinc sheet has a larger surface area which benefits the measurement of its temperature change by using the sensor. This relatively reduced the influence of water temperature on the measurement of zinc temperature, increasing the accuracy of the calculated result.

Table 7. List of strengths in the investigation

Weaknesses/ Limitations	Consequences	Improvements
The heat loss from the system of water and zinc sheet to the environment	The heat loss makes the assumption of $m_z c_z \Delta T_z = m_w c_w \Delta T_w$ becomes unrealistic, adding an additional component to the equation hence reduced the accuracy of the value.	Although I used an insulated cup as the vessel to minimize the heat loss, the disparity still exists. Using equipment with a thicker layer of foam or insulated material could be a solution.
Insufficient sensitivity of temperature sensors as the temperature sensor I used is normally used for liquid temperature measurement	Using it on a solid would make the sensor less accurate in its temperature response which somewhat decreased the accuracy of the measured raw data.	Another type of equipment which does not require contact temperature measurement can be considered such as infrared thermometers. Using this kind of equipment may increase the accuracy of the collected data.
The heat loss during the process. Since I heat water greater than 200g together, I measure 200g only after the water temperature reaches the specified value.	The consumed time of measuring the mass of water and transferring it to an adiabatic container may result in heat loss, contributing to systematic error. Also, the difference between operation times leads to random errors.	Measure the mass of each heated water in advance to reduce the extra time consumed in the process. Speed up the process by quickly placing the water into the insulated cup along with the zinc flakes.

Table 8. List of weaknesses and limitations in the investigation

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