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INVESTIGATION: Specific Heat Capacity and name of Unknown Metals.

Research question: What are the specific heat capacities[$Jkg^{-1}°C^{-1}$] and identities of two unknown metals?

The heating and cooling of matter are a universal phenomenon in everyday life. This qualitative characteristic of matter is closely related to a physical property---Specific heat capacity. According to its definition, specific heat capacity is the amount of energy[J] required to raise 1 kilogram of matter by one degree celsius or kelvin. Every matter has its own specific heat capacity that can be used to determine the name of the matter.

In this experiment, we are measuring the specific heat capacities of two unknown metals, and determining the name of the metals by comparing the experimentally obtained values with the values found on the internet. To obtain the specific heat capacities of the metals, we use the following thermodynamic equation:

$$Q = cm\Delta T$$

in which Q represents the amount of heat[J], c stands for the specific heat capacity[$Jkg^{-1}°C^{-1}$], m represents the mass[kg] and ΔT stands for the change in temperature[k]. In this experiment, we are putting the two metals at room temperature in hot water and detecting the temperature change of the system using a calorimeter.

Three fundamental thermodynamic theories in this experiment are the zeroth, the second law of thermodynamics and the law of conservation of energy. The zeroth law of thermodynamics is the law of thermal equilibrium (Chad, 2022), which states that The macroscopic physical properties of a heat equilibrium system, such as pressure and temperature, do not change with time. In other words, the relatively hotter water and colder metal would finally reach the same temperature after achieving thermal equilibrium. The second law of thermodynamics by Rudolf Clausius describes that an object with a higher temperature can spontaneously transfer its heat to an object with a lower temperature (Chad, 2022). In this case, the heat in hot water will be transferred to the relatively colder metals, causing their temperatures to rise. Moreover, according to the law of conservation of energy, the heat lost by the water should equal the heat gained by the metals. Thus, we came up with this modified equation to obtain the value of c_{metal}, which is the specific capacity of the metal:

$$c_{water}m_{water}\Delta T_{water} = c_{metal}m_{metal}\Delta T_{metal}$$

For this experiment, when the hot water is poured into the calorimeter, it is necessary to consider the heat absorbed by the container as well. Thus, the above equation will be revised into:

$$c_{water}m_{water}\Delta T_{water} - c_{container}m_{container}\Delta T_{container} = c_{metal}m_{metal}\Delta T_{metal}$$

in which $c_{container}$ will be calculated by simply adding water into the empty container.
Then, to determine the specific heat capacity of the metals, we will measure 100 ml of distilled water in the beaker. Using the density formula m=v, the mass of water [kg] is also obtained. Then, we measure the mass [kg] of the two metals separately using an electronic balance and their initial temperatures [°C] using 1 Pasco© Temperature Probe. After recording the values to

facilitate final calculations, we heat the distilled water in the beaker to 80-degree celsius and transfer the water into the calorimeter. When the calorimeter starts reading, we put the metal into the calorimeter and wait until the system's temperature stabilizes to let the heat transfer process occur. After the system temperature stabilizes, we record the final temperature of the water and the metal[°C], which should be the same according to the zeroth law of thermodynamics introduced previously. Finally, we apply the equation with all the experimentally obtained values and obtain the heat capacities of the metals.

Variables:

Name of the variable	Property of the variable	Reason to control	How it will be controlled/achieved
Type of the metals and specific heat capacity of metals $[Jkg^{-1}°C^{-1}]$	Independent variable	Not controlled variable	The two different metals will be distinguished in the way that a dot will be painted on metal 1. In this way, the two metals will be very distinctive
Change in temperature of the metals, container and water $[°C]$	Dependent variable	Not controlled variable	If the type of metal changes, the temperature of water will drop in a different amount than the metals used in the experiment. In this case, the final temperatures would be different and the change in temperature would be different.
Heat capacity of water	Controlled variable	If the heat capacities of water are different in this experiment, then the change in temperature is not measured in conditions exactly the same.	The heat capacity of water will be controlled by using the distilled water from the same source throughout the entire experiment.
Mass of metals and container[kg]	Controlled variable	The masses of two metals and the container are crucial in terms of calculating the heat capacities of the two metals.	It will be controlled by using the same metal chips for three trials and the same container as well.
Mass of the water	Controlled variable	Even though the mass of the water does not need to be controlled to be the same for each trial, it is controlled so that it is easy to make comparisons to previous trials to determine whether this trial should be an outlier.	The water mass will be controlled by weighing 100 ml of water every time using the graduated cylinder carefully each time.

Materials:

- 1× Pasco© Temperature Probe with Air Link with a range of -40-135°C
- 1× Calorimeter with Stirring Rod (attached)
- 1×Pair of Tongs
- 1×Stirring Rod
- 1×Glass Beaker (500 mL)
- 1× Heating Plate
- 1× Digital Scale
- 3×Safety goggles
- Distilled Water(unlimited)
- 2×Unknown Metals
- 1×Surface Temperature Probe
- 1×Heat Proof Gloves
- 6×Plastic Gloves
- 1×Computer

Safety precautions:

Apparatus	Possible Hazard	Precautions
Water and Beaker	After heating the water in the beaker with a hot plate, water might spill when being transferred into the calorimeter. The container wall of the beaker can be hot as well. It can cause burning of the skin.	Wear the heat proof gloves and use a pair of tongs to transfer the water into the calorimeter. Make sure to keep a distance from the apparatus when transferring the water.
The metals	The edges of the metals are very sharp. It might cut fingers if not careful.	Try not to touch and hold the edge of the metal slices. Wear the gloves when holding and dropping the metal slices to avoid cutting.
Calorimeter	After the experiments, the container wall of the calorimeter can still be very hot. It might potentially burn hands.	Use the tongs to hold the calorimeter and pour the hot water down the sink after the experiments.

Procedure

(Designed by student)

1. Put on safety goggles, gloves and make sure the working space is clear and clean. Complete all other required preparations.
2. Measure the mass[kg] of metal 1 (with dot) by placing the unknown metal on a digital scale.

3. Record the mass[kg] of metal 1 on the computer
4. Measure the initial temperature[°C] of metal 1 (with dot) using a surface temperature probe
5. Record the temperature[°C] of the metal on the computer
6. Measure 100 ml of distilled water with a beaker. Use the volume-density formula($m = \rho v$) to determine the mass of distilled water.
7. Record the value of distilled water mass[kg] on the computer.
8. Use the heating plate to heat the water in the beaker to 80 degree celsius, stir the water with the stirring rod to make sure the water is heated evenly in the beaker. Monitor the temperature by immerging the detecting rod of the calorimeter in the middle of the solution.
9. Turn on the calorimeter and pour the water into the calorimeter carefully using a pair of tongs when it reaches 80 degree celsius.
10. When the reading of the calorimeter rises to the temperature of the water(80 degree celsius), put the first metal in the water and wait until it reaches a constant temperature/stabilizes .
11. Record the final temperatures for the water. This should also be the final temperature of the metal.
12. Repeat steps 1-11 for metal 2 three times
13. Repeat steps 1-11 for the container three times.
14. Apply all the experimentally measured value into the equation for final calculations $c_{water} m_{water} \Delta T_{water} - c_{container} m_{container} \Delta T_{container} = c_{metal} m_{metal} \Delta T_{metal}$
15. Rearrange the equations to get the specific heat capacities of two metals respectively.

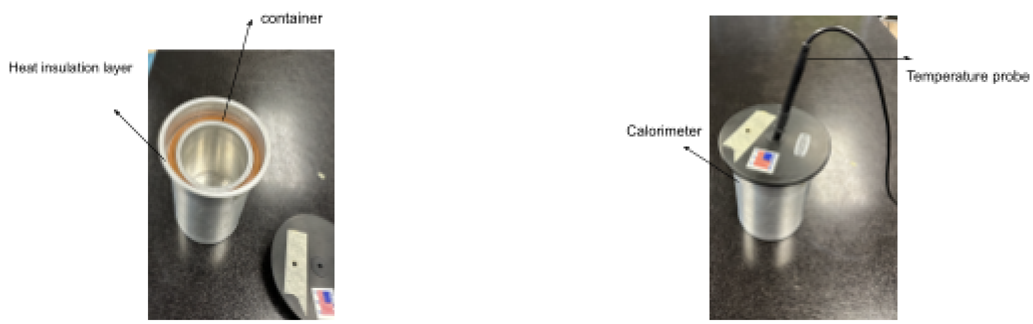

Figure 1: The calorimeter used in the experiment and its crucial parts.

Results and Analysis:

Results:

Raw Data Table:

Table 1: Raw data of the water volume[ml], water mass[kg], mass of metal one[kg], mass of container[kg], initial temperature of the metal one, water and container[°C] and the final temperature of all the objects[°C] and their respective uncertainties.

	Water volume[ml] (±0.1ml)	Water mass [kg] (±0.00001kg)	Mass of metal1[kg] (±0.00001kg)	Container mass[kg] (±0.00001kg)	Initial temperature of metal1[°C] (±0.1°C)	Initial temperature of water[°C] (±0.1°C)	Initial temperature of container[°C] (±0.1°C)	Final temperature of all[°C] (±0.1°C)
Trial 1	100.0	0.0997	0.0026	0.056	22.8	80.0	23.8	69.9
Trial 2	100.0	0.0997	0.00261	0.056	22.8	80.0	23.6	70.1
Trial 3	100.0	0.0997	0.00262	0.056	22.9	80.0	23.7	69.8

Table 2: The water volume[ml], water mass[kg], mass of metal 2[kg], mass of container[kg], initial temperature of the metal 2, water and container[°C] and the final temperature of all the objects[°C] and their respective uncertainties.

	Water volume[ml] (±0.1ml)	Water mass[kg] (±0.00001 kg)	Mass of metal 2[kg] (±0.00001kg)	Container mass 2[kg] (±0.00001kg)	Initial temperature of metal 2[°C] (±0.1°C)	Initial temperature of water[°C] (±0.1°C)	Initial temperature of container[°C] (±0.1°C)	Final temperature of all[°C] (±0.1°C)
Trial 1	100.0	0.0997	0.005	0.056	23.9	80.0	23.5	69.5
Trial 2	100.0	0.0997	0.005	0.056	23.8	80.0	22.4	69.9
Trial 3	100.0	0.0997	0.005	0.056	23.9	80.0	23.9	69.6

Table 3: The water volume[ml], water mass[kg], mass of container[kg], initial temperature of the water and container[°C] and the final temperature of water and container[°C] and their respective uncertainties.

	Water volume[ml] (±0.1ml)	Water mass [kg] (±0.00001kg)	Container mass[kg] (±0.00001 kg)	Initial temperature of metal[°C] (±0.1°C)	Initial temperature of water[°C] (±0.1°C)	Initial temperature of container[°C] (±0.1°C)	Final temperature of both[°C] (±0.1°C)	Heat capacity of water $[Jkg^{-1}°C^{-1}]$	Heat capacity of container $[Jkg^{-1}°C^{-1}]$
Trial 1	100.0	0.0997	0.0557	23.9	80.0	21.7	70.0	4184	1551
Trial 2	100.0	0.0997	0.0557	23.8	80.0	21.8	69.0	4184	1745
Trial 3	100.0	0.0997	0.0557	23.9	80.0	22.0	69.7	4184	1617
Average									1638

processed Data Table:

Table 4: water mass[kg], mass of metal 1[kg], mass of container[kg], temperature change metal 1[°C], temperature change of container[°C], temperature change of water[°C], heat capacity of water, container and metal[$Jkg^{-1}°C^{-1}$] and their respective uncertainties.

Water mass [kg] (±0.00001kg)	Mass of metal 1 [kg] (±0.00001kg)	Temperature change of water[°C] (±0.2°C)	Temperature change of metal 1[°C] (±0.2°C)	Temperature change of container[°C] (±0.2°C)	Container mass [kg] (±0.00001 kg)	Heat capacity of water[$Jkg^{-1}°C^{-1}$]	Heat capacity of container[$Jkg^{-1}°C^{-1}$]	Heat capacity of metal1[$Jkg^{-1}°C^{-1}$]
0.0997	0.0026	10.1	47.1	46.1	0.054	4184	1638	1113
0.0997	0.00261	9.9	47.3	46.5	0.053	4184	1638	758
0.0997	0.00262	10.2	46.9	46.1	0.055	4184	1638	834
Average								902

Table 5: water mass[kg], mass of metal 2[kg], mass of container[kg], temperature change metal 2[°C], temperature change of container[°C], temperature change of water[°C], heat capacity of water, container and metal 2[$Jkg^{-1}°C^{-1}$], and their respective uncertainties.

Water mass [kg] (±0.00001kg)	Mass of metal 2 [kg] (±0.00001kg)	Temperature change of water[°C] (±0.2°C)	Temperature change of metal 2[°C] (±0.2°C)	Temperature change of container[°C] (±0.2°C)	Container mass [kg] (±0.00001kg)	Heat capacity of water[$Jkg^{-1}°C^{-1}$]	Heat capacity of container[$Jkg^{-1}°C^{-1}$]	Heat capacity of metal2[$Jkg^{-1}°C^{-1}$]
0.0997	0.005	10.5	45.6	48.3	0.054	4184	1638	476
0.0997	0.0051	10.1	46.1	47.2	0.053	4184	1638	495
0.0997	0.0049	10.4	45.7	47.7	0.055	4184	1638	187
Average								386

Table 6: The experimentally obtained heat capacities of two metals[$Jkg^{-1}°C^{-1}$], names of the most possible metals, heat capacities of most possible metals[$Jkg^{-1}°C^{-1}$] and the percent errors.

Metal	Experimentally obtained heat capacity	Name of the most possible metal	Heat capacity of most possible metal[$Jkg^{-1}°C^{-1}$]	Percent error
Metal 1	902	Aluminum	921	2.06
Metal 2	386	Zinc	377	2.45

Table 7: %uncertainties and uncertainties[$Jkg^{-1}°C^{-1}$] of metal 1, metal 2 and container respectively for three trials and their averages.

	%uncertainty of metal 1	uncertainties of metal 1 [$Jkg^{-1}°C^{-1}$]	%uncertainty of metal 2	uncertainties of metal 2 [$Jkg^{-1}°C^{-1}$]	%uncertainty of container	uncertainties of container [$Jkg^{-1}°C^{-1}$]
Trial 1	5	53	4	21	2	24
Trial 2	5	36	4	22	1	24
Trial 3	5	39	4	8	1	24
Average	5	43	4	17	1	24

Qualitative observation table:

Type of qualitative observation	Qualitative observations
Water	When the water in the beaker was being heated by the hot plate, there were bubbles rising from the bottom of the beaker to the surface
Steaming	During the heating process, there was water vapour coming out from the water sometime after the beaker was placed on the hot plate.
Temperature	Before the experiment, the distilled water was cold and the two metals were also relatively colder to skin temperature. After the experiment, the water was hot and the metal slices felt hot as well.

Sample calculations:

1. Temperature change[K] of metal one
   Data chosen for the sample calculation:

Initial temperature of metal1[°C]	Final temperature of all[°C]	Temperature change of metal 1[°C]
22.8	69.9	47.1
22.8	70.1	47.3
22.9	69.8	46.9

$Temperature\ change(\Delta T) of\ metal\ one\ = |Initial\ temperature\ -\ Final\ temperature|$

$\Delta T = T_{final} - T_{initial} = 69.9 - 22.8 = 47.1°C$

2. Mass of distilled water[kg]
   Data chosen for the sample calculation:
   $Mass\ of\ water(M_w) = volume\ of\ water \times density\ of\ water$

   $M_w = 0.0001kg \times 997\ kgm^3 = 0.0997\ kg$

3. Specific heat capacity of the container($c_{container}$)[$Jkg^{-1}K^{-1}$]
   Data chosen for the sample calculation:

Water mass[kg]	Container mass[kg]	Initial temperature of water[°C]	Initial temperature of container[°C]	Final temperature of both[°C]	Heat capacity of water [$Jkg^{-1}°C^{-1}$]	Heat capacity of container [$Jkg^{-1}°C^{-1}$]
0.0997	0.0557	80.0	21.7	70.0	4184	1551

$$c_{container} = \frac{c_{water} \times m_{water} \times \Delta T_{water}}{m_{container} \times \Delta T_{container}}$$

in which c_{water} and $c_{container}$ represents the specific heat capacity of water and container[$Jkg^{-1}°C^{-1}$]. m_{water} and $m_{container}$ stands for the mass of water and container[kg]. ΔT_{water} stands for the change in the temperature of water[°C], ΔT_{metal} stands for the change in the temperature of metal[°C].

$$c_{container} = \frac{c_{water} \times m_{water} \times \Delta T_{water}}{m_{container} \times \Delta T_{container}} = \frac{4184[Jkg^{-1}°C^{-1}] \times 0.0997[kg] \times 10[°C]}{0.0557[kg] \times 48.3[°C]} \approx 1551[Jkg^{-1}°C^{-1}]$$

4. Average heat capacity of container
   Data chosen for the sample calculation:

Heat capacity of container [$Jkg^{-1}°C^{-1}$]	1551	1745	1617
Average			1638

$$Average\ c_{container} = \frac{c_{1\,container} + c_{2\,container} + c_{3\,container}}{3}$$

$$= \frac{1551[Jkg^{-1}°C^{-1}] + 1745[Jkg^{-1}°C^{-1}] + 1617[Jkg^{-1}°C^{-1}]}{3} \approx 1638[Jkg^{-1}°C^{-1}]$$

5. Specific heat capacity of the metals(c_m)[$Jkg^{-1}°C^{-1}$]
   Data chosen for the sample calculation:

Water mass [kg] (±0.00001kg)	Mass of metal 1 [kg] (±0.00001kg)	Temperature change of water[°C] (±0.2°C)	Temperature change of metal 1[°C] (±0.2°C)	Temperature change of container[°C] (±0.2°C)	Container mass [kg] (±0.00001 kg)	Heat capacity of water[$Jkg^{-1}°C^{-1}$]	Heat capacity of container [$Jkg^{-1}°C^{-1}$]	Heat capacity of metal1 [$Jkg^{-1}°C^{-1}$]
0.0997	0.0026	10.10	47.10	46.10	0.054	4184	1638	1113

$$c_m = \frac{c_{water} \times m_{water} \times \Delta T_{water} - c_{container} \times m_{container} \times \Delta T_{container}}{m_{metal} \times \Delta T_{metal}}$$

in which c_{water} and $c_{container}$ represents the specific heat capacity of water and container[$Jkg^{-1}°C^{-1}$]. m_{water} and $m_{container}$ stands for the mass of water and container[kg]. ΔT_{water}

stands for the change in the temperature of water[°C], m_{metal} stands for the mass of metal[kg]. ΔT_{metal} stands for the change in the temperature of metal[°C].

$$c_m = \frac{c_{water} \times m_{water} \times \Delta T_{water} - c_{container} \times m_{container} \times \Delta T_{container}}{m_{metal} \times \Delta T_{metal}}$$

$$= \frac{4184[Jkg^{-1}°C^{-1}] \times 0.0997[kg] \times 10.1[°C] - 1638[Jkg^{-1}°C^{-1}] \times 0.054[kg] \times 46.10[°C]}{0.0026[kg] \times 47.10[°C]} \approx 1113[Jkg^{-1}°C^{-1}]$$

6. Percent errors of heat capacities of two metals
   Data chosen for sample calculations:

Metal	Experimentally obtained heat capacity	Name of the most possible metal	Heat capacity of most possible metal[$Jkg^{-1}°C^{-1}$]	Percent error %
Metal 1	902	Aluminum	921	2.06

$$\%error = \left|\frac{Actual - theoretical}{theoretical}\right| \times 100\% = \left|\frac{902-921}{921}\right| \times 100\% \approx 2.06\%$$

7. Percent uncertainties of heat capacities of two metals and the container
   Data chosen for the sample calculation:

Water mass [kg] (±0.00001kg)	Mass of metal 1 [kg] (±0.00001kg)	Temperature change of water[°C] (±0.2°C)	Temperature change of metal 1[°C] (±0.2°C)	Temperature change of container[°C] (±0.2°C)	Container mass [kg] (±0.00001kg)	Heat capacity of water[$Jkg^{-1}°C^{-1}$]	Heat capacity of container [$Jkg^{-1}°C^{-1}$]	Heat capacity of metal1 [$Jkg^{-1}°C^{-1}$]	Water mass [kg] (±0.00001kg)
0.0997	0.0026	10.1	47.1	46.1	0.054	4184	1638	1113	5

Uncertainty will be annotated as U

$$\%uncertainty: \left(\frac{U_{water\ mass}}{m_{water}} + \frac{U_{metal\ 1\ mass}}{m_{metal\ 1}} + \frac{U_{container\ mass}}{m_{container}} + \frac{U_{T\ water}}{T_{water}} + \frac{U_{T\ container}}{T_{container}} + \frac{U_{T\ metal\ 1}}{T_{metal\ 1}} + \frac{U_{c\ container}}{c_{container}}\right) \times 100\%$$

$$\%uncertainty: \left(\frac{0.00001}{0.0997} + \frac{0.00001}{0.0026} + \frac{0.00001}{0.054} + \frac{0.2}{10.1} + \frac{0.2}{46.1} + \frac{0.2}{47.1} + \frac{24}{1638}\right) \times 100\% \approx 5\%$$

8. Average of heat capacities for two metals and the container
   Data chosen for the sample calculation:

	%uncertainty of metal 1
Trial 1	5
Trial 2	5
Trial 3	5
Average	5

Average$= \frac{Trial\ 1 + Trial\ 2 + Trial\ 3}{3} = \frac{5+5+5}{3} = 5$

Conclusion:

Regarding the research question that explores the specific heat capacities and names of two unknown metals, after conducting the experiment by following the procedures listed above for metal 1 and metal 2 to the data collection, the specific heat capacity metal 1 is found to be 902$[Jkg^{-1}°C^{-1}]$, while that of metal 2 is found to be 386$[Jkg^{-1}°C^{-1}]$.
Firstly, by looking up the specific heat capacity table, it is determined that metal 1 is aluminum, with a theoretical heat capacity of 921$[Jkg^{-1}°C^{-1}]$ (Edge, n.d.). 921 is in the range of the metal 1 heat capacity uncertainty, which is 902±43$[Jkg^{-1}°C^{-1}]$. It suggests the measurement is precise. The percent error of the experimentally calculated heat capacity of metal 1 and aluminum is only 2.06%, which is very insignificant, suggesting the accuracy of this measurement.

Meanwhile, metal 2 is determined to be Zinc, with a theoretical specific heat capacity of 377$[Jkg^{-1}°C^{-1}]$ (Edge, n.d.). Same as metal 1, the theoretical specific heat capacity of metal 2 is also in the range of the metal 2 heat capacity uncertainty, which is 386±17$[Jkg^{-1}°C^{-1}]$. The percent error of this measurement is 2.45%, which is also very insignificant, suggesting the high accuracy of data.

By comparing the percent errors of other possible metals in the periodic table with the percent errors of aluminum and zinc, it is discovered that aluminum and zinc have the least percent errors. For metal 1, the second most probable metal would be magnesium, with a specific heat capacity of 1047$[Jkg^{-1}°C^{-1}]$ (Edge, n.d.). However, this value is outside the range 902±43$[Jkg^{-1}°C^{-1}]$. Thus, metal 1 is most possibly aluminum. For metal 2, the other most probable metals are yellow brass, with a specific heat capacity of 402; copper, with a specific heat capacity of 377; gallium, with a specific heat capacity of 368 (Edge, n.d.). However, metal would not be yellow brass or copper because of metal 2's grey colour; gallium would also be impossible because it is soft and silvery. Thus, metal 2 would most likely be zinc.

In conclusion, it is almost certain that metal 1 is aluminum, and metal 2 is Zinc. The discrepancies of the measurements can be due to methodological issues such as bad control in water evaporation, inconsiderations in the assumption that the temperature of the objects will all be equal and bad condition of heat isolation. The details of the methodological issues will be discussed later in the identification of errors.

Evaluation:

Firstly, the propagated percent uncertainties calculated for metal 1 and metal 2 are very insignificant, with the prior being 5% and the latter being 4%. These quantities suggest that the methodologies and data measurements of this experiment are relatively precise, since there is little variation in the data collection. In accordance with these uncertainties, the theoretical specific heat capacities of the two metals, aluminum and zinc, 921 and 377$[Jkg^{-1}°C^{-1}]$, are in the range of 902±5%$[Jkg^{-1}°C^{-1}]$ and 386±4% $[Jkg^{-1}°C^{-1}]$, suggesting the validity of the data.

Secondly, the percent errors in the experiments for two metals are also very insignificant. The percent error for metal 1 is 2.06% while the percent error for metal 2 is 2.45%. The low percent errors suggest the accuracy of the measurement. It means that the results for the three trials are valid for drawing the conclusion that the two metals are aluminum and zinc respectively.

However, the existence of percent error and percent uncertainties suggests the existence of systematic or random errors in the methodologies, which will be specified below.
This section will identify three errors as sources of uncertainties in this experiment, including the significance of their impacts on the experiment results.

Firstly, it is assumed that after the temperature indicated in the calorimeter sensor stabilized, the metal, container and water will be at the same temperature. Although this is true in an ideal thermodynamic condition, it can take a long time to achieve thermal equilibrium. In this experiment, the temperature probe only tests the temperature of the water. Although the number in the temperature sensor stabilizes, it can be because the temperature of the metal is not low enough to have that much impact on the temperature of the system. This is a systematic error, and it means that the metal in the water can still be relatively colder than the temperature of the water tested. The influence on the experiment results can be significant. If the temperature of the metal is actually lower than expected, then the heat capacity of the metal tested will be smaller than the actual value.

Secondly, when heating the water with the hot plate, the open end of the beaker is not sealed. Then, the beaker's water can evaporate since bubbles are coming from the bottom of the beaker during the heating process. In this case, the previously measured 100ml of water can be lost because of evaporation, which causes the mass of the water examined to decrease. This is a systematic error, and the influence of water evaporation on the experiment results can be significant depending on how much water is lost. Suppose the mass of water in the calorimeter is less than theoretically used in the calculation. In that case, the experimentally tested heat capacity of the metals will be smaller than the actual value.

Finally, the heat lost by the system is not solely due to the thermal equilibrium caused by relatively colder metals and the container. Although there is an extra layer in the calorimeter to prevent the heat from escaping, the layer cannot entirely isolate the system, and the heat can still be lost through the top. This is also a systematic error, and in this case, if the heat lost is not solely due to the metal, then the experimentally obtained heat capacity of the metal would be larger than the actual.

Improvements:

To avoid the errors and uncertainties indicated above, the following improvements can be added to the procedures to ensure the accuracy of the measurements.

Firstly, to avoid the temperature of the metal and water not being the same, the temperature probe can be used again to determine the temperature of the metal and container after the experiment. In this case, the change in temperature of the metal will not be the final temperature of water minus the initial temperature of the metal. Instead, it would be the difference between the final and initial temperature of the metal itself. This way, the actual accurate temperature change of the metal can be determined.

Secondly, to avoid the evaporation of water that causes the heat capacity determined to be smaller, a glass board can be used to cover the top of the beaker during the heating process. In this way, the evaporated water can condense into water droplets and return to the beaker so that the water is not lost in the air.

Finally, to avoid the system's heat being lost to the outside, another heat isolation layer can be wrapped around the container as a second protection. To increase the heat isolation of the system, heat insulation materials can be used, such as asbestos. In this way, although it is not guaranteed that the container will be a 100% isolated system, the experiment conditions will still be ideal, improving the measurement accuracy.

Strengths and Weaknesses(Limitations)

Strengths:

All the equipment used in the experiment is universal in a high school lab. For example, the calorimeter, temperature probe and hot plate can be easily acquired. Thus, the experiment can be repeated easily.

This experiment's fundamental theories(Laws of thermodynamics) are well laid out. The equation for the final calculation is also scientifically proven.

Weaknesses(Limitation):

There are a lot of systematic errors that are hard to eliminate in this experiment, which causes the result to be wildly inaccurate. These systematic errors, such as poor heat insulation, cannot be removed in a high school lab environment.

The method of the experiment could be more optimum. For example, the assumption that the system, when conducting the measurement, will be in the state of thermal equilibrium is too ideal for the current lab condition. These assumptions can be ideally achieved in more advanced labs to reduce uncertainties and errors.

Thirdly and most importantly, apart from the three trials conducted in these experiments, no other methods are provided to test whether the two metals are aluminum and zinc. Since no information is provided about the metals, although three trials indicate that they are aluminum and zinc, it is not 100% certain. Theoretically, the measurements may be precise but not accurate, meaning that the wrong metals are always chosen.

Extensions:

An extension to this experiment can be finding the specific heat capacities of other metals. There can also be other methods to perform this experiment for comparison. For example, we can first put the metal in boiling water and transfer it into cold water to see the temperature change and thus detect its specific heat capacity. The comparison between the two experiments would be an exciting thing worth investigating.

Bibliography:

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