A Tall Cold Drink of Water

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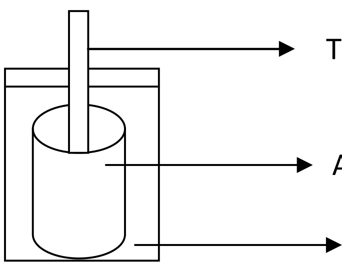
INTRODUCTION

The objective of this experiment was to use calorimetry in the design of a drink container that can cool 100cm^3 (100mL) of water by 5°C in 5 minutes. It was expected that this temperature change not be exceeded. Calorimetry is a technique that uses a calorimeter to measure the change in thermal or heat energy (enthalpy change) in a system undergoing change, in this case a chemical change. There are many different types of calorimeters but the type of calorimeter used in this experiment is a simple container made of Styrofoam with a nested aluminum can. It is assumed that the calorimeter is perfect without heat exchange between the calorimeter and its surroundings. In brief, the system setup is shown below in Figure 1. The process involves dissolving a chemical substance in water contained in the Styrofoam container with the aluminum can submerged in the solution. The can will contain the drinkable water and will not come in contact with any chemicals. If the chemical change is endothermic, energy will be extracted from the aluminum can, the drinkable water contained in the aluminum can, and the water in which the chemical is dissolved.

Figure 1. System Setup.



The department did some research and suggested two chemicals for this purpose: Ammonium Chloride (NH_4Cl) and Ammonium Nitrate (NH_4NO_3). There are a few factors to consider before deciding on which of the two chemicals to use if any. The chemical of choice should be endothermic when dissolved in water. Endothermic reactions absorb energy while exothermic reactions release energy. The type of reaction is determined from the enthalpy change of dissolution. Enthalpy of dissolution is the thermal energy change at constant pressure when one mole of an ionic compound dissolves completely in water. This is not known directly and will be determined from the lattice energy and enthalpy of hydration of NH_4Cl and NH_4NO_3. Lattice energy is the thermal energy change when one mole of an ionic compound is vaporized to form gaseous ions or when one mole of an ionic compound is formed from its gaseous ions. Enthalpy of hydration of gaseous ions is the thermal energy change when one mole of gaseous ions is hydrated in water to form one mole of aqueous ions under standard conditions. The enthalpy change of dissolution can be calculated from the lattice energy and enthalpy of hydration because of Hess's Law which states that the enthalpy change of an overall reaction is the sum of the multiple enthalpy changes of the intermediate reactions. This means that the enthalpy of dissolution is the sum of the lattice energy and enthalpy of hydration. This is illustrated in Figure 2.

Figure 2a. Enthalpy of dissolution of Ammonium Chloride ($NH_4Cl_{(s)}$)

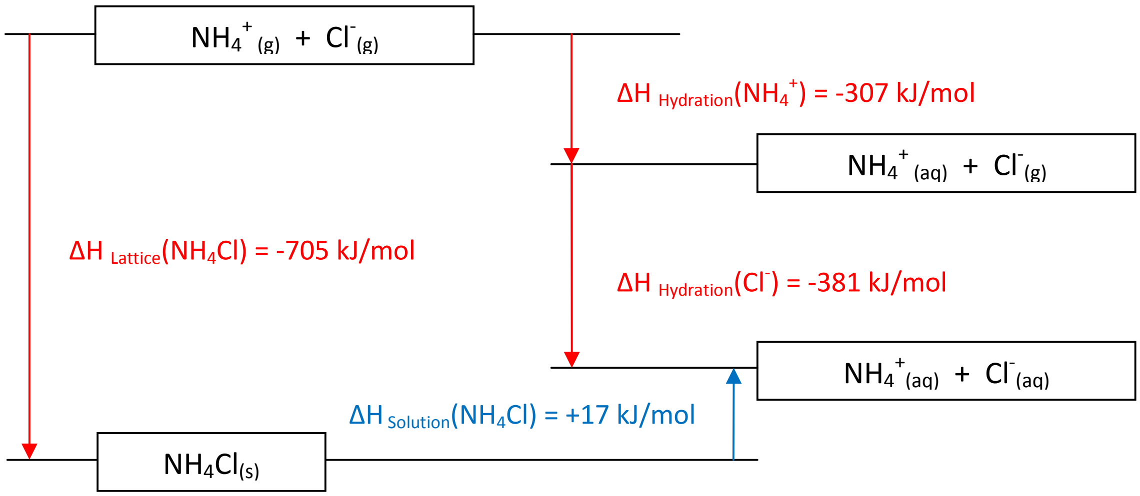
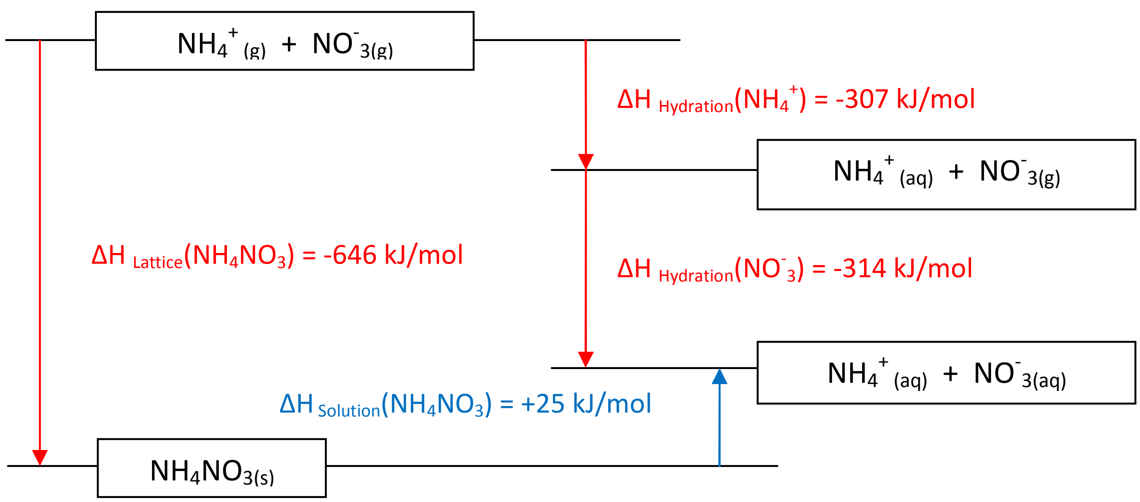


Figure 2b. Enthalpy of dissolution of Ammonium Nitrate ($NH_4NO_{3\,(s)}$)



The following analysis determines if the dissolution of NH_4Cl and NH_4NO_3 in water is endothermic or exothermic.

From Figure 2a, we have:

$$\Delta H_{\text{Solution}}\,(NH_4Cl) = \Delta H_{\text{Lattice}}\,(NH_4Cl) + \Delta H_{\text{Hydration}}\,(NH^+_4) + \Delta H_{\text{Hydration}}\,(Cl^-)$$

$$= (705\text{ kJ/mol}) + (-307\text{ kJ/mol}) + (-381\text{ kJ/mol})$$

$$= 17\text{ kJ/mol}$$

From Figure 2b, we have:

$\Delta H_{Solution} (NH_4NO_3) = \Delta H_{Lattice} (NH_4NO_3) + \Delta H_{Hydration} (NH^+_4) + \Delta H_{Hydration} (NO^-_3)$

$= (646 \text{ kJ/mol}) + (-307 \text{ kJ/mol}) + (-314 \text{ kJ/mol})$

$= 25 \text{ kJ/mol}$

The enthalpy of dissolution of ammonium chloride and ammonium nitrate are +17 kJ/mol and +25 kJ/mol respectively. This means both chemical changes are endothermic and can be used to cool the liquid drink of water. Health & Safety factors and ease of handling were taken into account before deciding on the chemical of choice. NH_4Cl and NH_4NO_3 have similar acute hazards/symptoms with the exception of symptoms and hazards regarding fire, explosion, and exposure. NH_4Cl is not combustible and does not enhance combustion of other materials. It has no explosion and exposure hazards. (CDC, 2001). NH_4NO_3 is not combustible but it does enhance combustion of other substances and requires very careful and professional handling. There is also the risk of fire and explosion under confinement and high temperatures. (CDC, 2001). NH_4Cl was chosen to be used in the experiment as our cooler because it does not enhance combustion of other substance and does not require careful and professional handling. At this point, the cost ceased to be a factor of consideration.

100mL of water was chosen to be the minimum amount of water to dissolve the NH_4Cl in. This was done through observation. That is, 100mL is the minimum volume of water that was able to cover about 90% of the surface area of the aluminum can containing the drinkable water. This is important because the greater surface area that is covered will allow quicker and efficient heat transfer.

The thermal energy required to cool $100cm^3$ of water by 5^oC is calculated below. When the salt dissolves in 100mL of water, it will absorb energy from the drinkable water in the aluminum can, the can itself, and the water in which the salt is dissolved. The energy required to change the temperature of a substance can be calculated using the equation:

$Q = mc\Delta T$ where

Q is the thermal energy measured in Joules (J).
m is the mass of the substance in grams (g).
c is the specific heat capacity of the substance measured in J/kgK or J/k^oC.
ΔT is the change in temperature undergone by the substance.

$\rho_{water} = 1 g/cm^3$ (density of water)
$c_{water} = 4.18$ J/gK
$c_{Aluminum} = 0.9$ J/gK
$\Delta T = 5K$
$m_{water} = (100\ cm^3 + 100 cm^3) * (1g/\ cm^3) = 200g$
$m_{Aluminum} = 8.30g$

$Q_{Total} = Q_{water} + Q_{Aluminum\ can}$

$Q_{Total} = [\ (200g) * (\ 4.18\ J/gK) + (8.30g) * (0.9\ J/gK)]*5K$

$Q_{Total} = 4217.35\ J = 4.21735\ kJ$

<u>Moles of NH_4Cl needed:</u>

$n\ (NH_4Cl) = Q_{Total} \div \Delta H_{Solution}\ (NH_4Cl)$

$n\ (NH_4Cl) = (4.21735\ kJ) \div (17\ kJ/mol)$

$n\ (NH_4Cl) = 0.24879$ moles

<u>Minimum mass of NH_4Cl needed:</u>

$M\ (NH_4Cl) = 53.4916$ g/mol

$m\ (NH_4Cl) = (0.24879\ moles) * (53.4916\ g/mol) = 13.27g$

In order to determine the mass of NH_4Cl required to cool 100mL of water by 5K in 5 minutes, 3 trials of experimentation was conducted. In each trial an amount of NH_4Cl in grams was used in the experiment as outlined in the procedure and temperature was recorded every 30 seconds. Amount of NH_4Cl in grams is the independent variable and temperature is the dependent variable. The temperature change after 5 minutes will be calculated for each trial and these values will be graphed against the mass of NH_4Cl used in that trial. Although a temperature change of -5^oC was not attained in the laboratory during any of the 3 trials, a graph of temperature change after 5 minutes vs. mass of NH_4Cl used will enable us to determine the mass of salt required to cool 100ml of drinkable water by 5^oC.

PROCEDURE

Materials:

- ~150g NH_4Cl
- Styrofoam calorimeter
- Thermometer probe connected to LabQuest2
- 100mL measuring cylinder
- Mass balance
- Spatula/Spoon
- 100mL Aluminum can

Steps:

1. Measure 100mL of water and pour into Styrofoam cup.
2. Measure 100mL of water and pour into aluminum can.
3. Place can containing water into the Styrofoam cup.
4. Cover Styrofoam cup with its lid.
5. Place thermometer probe through hole in lid into the aluminum can containing the drinkable water.
6. Measure the temperature. This is temperature at time t = 0.
7. Measure ~13.27g of NH_4Cl using mass balance and pour into water in the Styrofoam cup.
8. Cover Styrofoam cup with its lid.
9. Record temperature every 30 second while swirling the calorimeter to facilitate salt dissolution.
10. Remove thermometer probe.
11. Discard solution and water in aluminum can.
12. Repeat steps 1 to 11 for 16g and 22g of NH_4Cl.

OBSERVATIONS

Trial 1: All the NH_4Cl failed to dissolve. There was complete dissolution approximately 2 minutes past the 5 minute mark. Salt solution was noticeably colder than the water in aluminum can. The temperature of the water in aluminum can decreased gradually from time t = 0 to t = 4.5 minutes. At 5.0 minutes, the temperature went from 21.5 ^oC at t = 4.5 minutes to 21.7 ^oC.

Trial 2: All the NH_4Cl failed to dissolve. There was complete dissolution approximately 2 minutes past the 5 minute mark. Salt solution was noticeably colder than the water in aluminum can. The temperature of the water in aluminum can decreased gradually from time t = 0 to t = 4.5 minutes. At 5.0 minutes, the temperature went from 21.4 ^oC at t = 4.5 minutes to 22.6 ^oC.

Trial 3: All the NH_4Cl failed to dissolve. There was complete dissolution approximately 2 minutes past the 5 minute mark. Salt solution was noticeably colder than the water in aluminum can. The temperature of the water in aluminum can decreased gradually from time t = 0 to t = 5.0 minutes.

RESULTS

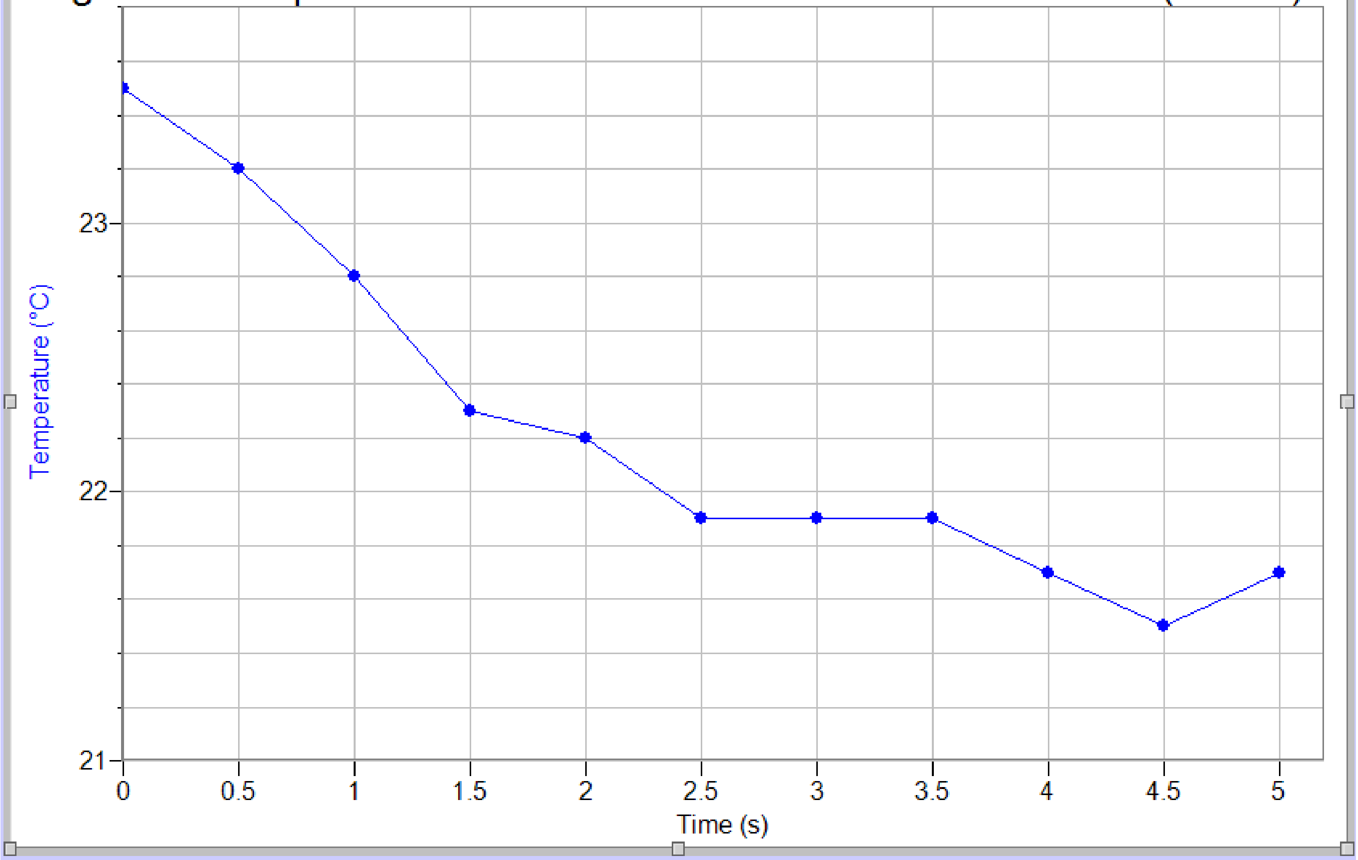
Table 1. Temperature of water in Aluminum can during the cooling process.

Time, t (minutes)	Temperature, T (^{o}C)		
	Trial 1 (13.27g NH_4Cl)	Trial 2 (16g NH_4Cl)	Trial 3 (22g NH_4Cl)
0.0	23.5	22.6	22.1
0.5	23.2	22.5	21.8
1.0	22.8	22.2	21.8
1.5	22.3	22.1	20.9
2.0	22.2	22.0	19.6
2.5	21.9	21.9	19.5
3.0	21.9	21.8	19.1
3.5	21.9	22.0	19.0
4.0	21.7	21.9	18.9
4.5	21.5	21.4	18.8
5.0	21.7	21.4	18.6

Table 2. Temperature change of water in Aluminum can after 5 minutes.

Mass of NH_4Cl, m (g)	Temperature Change, ΔT (^{o}C)
13.27	-1.8
16	-1.2
22	-3.5

Figure 3. Temperature of Water in Can as a Function of Time (Trial 1)



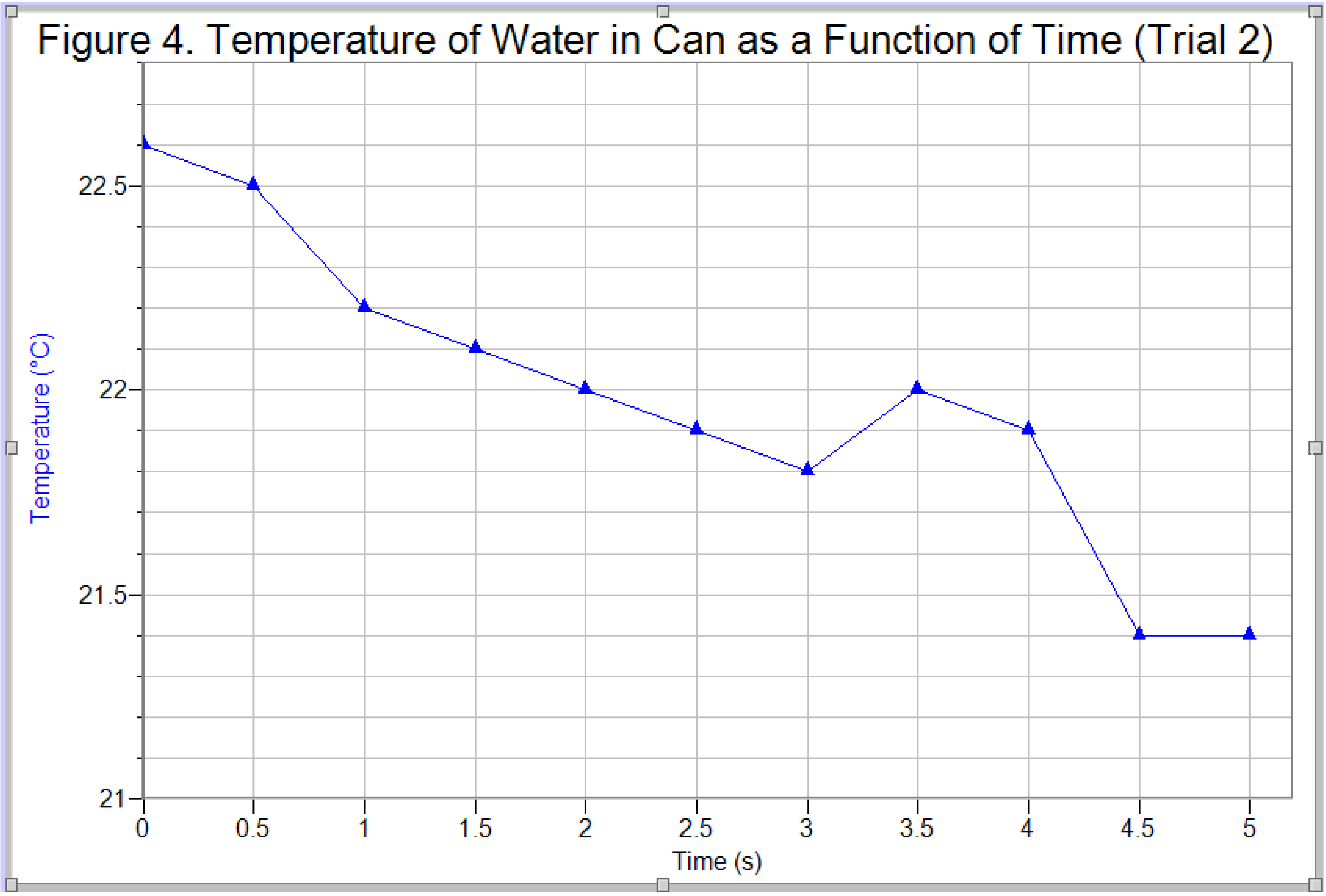


Figure 4. Temperature of Water in Can as a Function of Time (Trial 2)
Temperature (°C)
22.5
22
21.5
21
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (s)

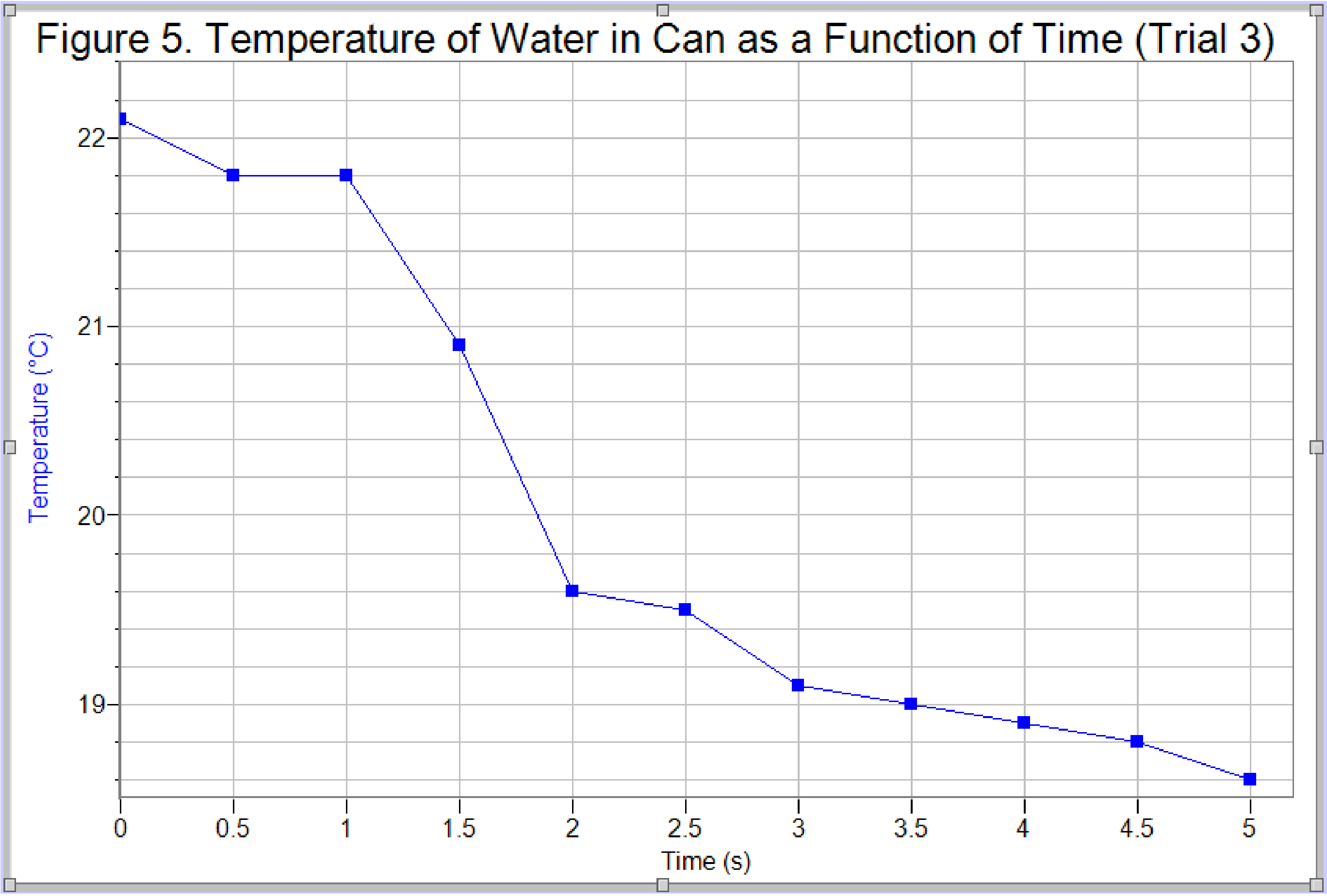
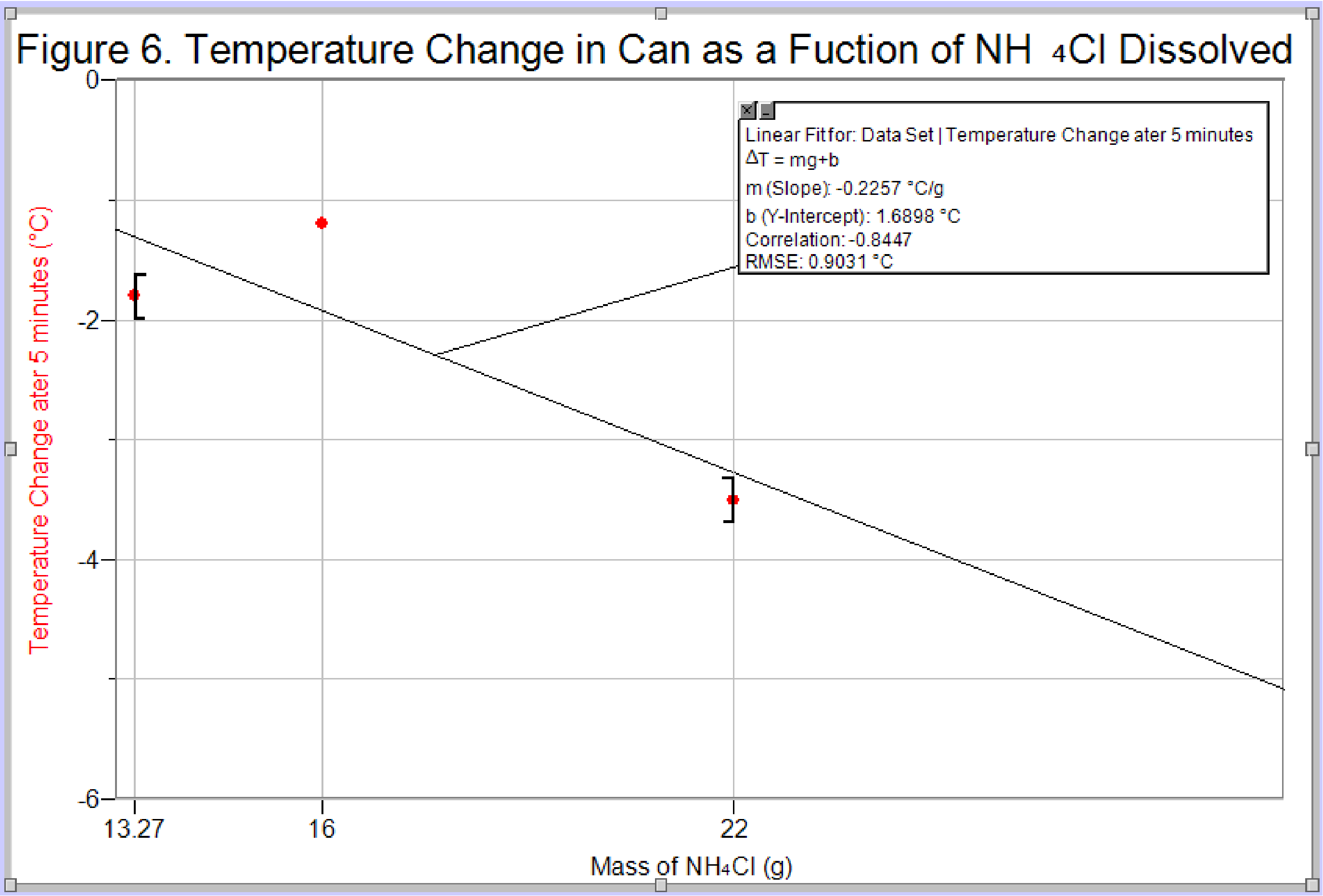


Figure 5. Temperature of Water in Can as a Function of Time (Trial 3)
Temperature (°C)
22
21
20
19
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (s)



CALCULATIONS

<u>Change in Temperature for Trial 3:</u>

$\Delta T = T_f - T_i$

$\Delta T = 18.6\ ^oC - 22.1\ ^oC = -3.5\ ^oC$

From Figure 6, we have:

$\Delta T = mg + b$ where
m is slope in $^oC/g$
g is mass in grams
b is y intercept in ^oC

$\Delta T = (-0.2257\ ^oC/g)\ g\ -\ 1.6898\ ^oC$

For $\Delta T = -5\ ^oC$, we have

$-5\ ^oC = (-0.2257\ ^oC/g)\ g\ -\ 1.6898\ ^oC$

g = 29.64 grams

DISCUSSION

For 13.27g, 16.0g, and 22.0g of NH_4Cl, a temperature change of -1.8 ^oC, -1.2 ^oC, and -3.5 ^oC was attained respectively. Assuming a linear relationship between temperature after 5 minutes and amount of NH_4Cl used, it would theoretically require 29.64g of NH_4Cl to achieve a temperature change of -5.0 ^oC. The design did not work as expected. The experiment has to be repeated with better design that would allow complete dissolution of NH_4Cl. Such a design would require less than 29.64 grams of NH_4Cl to cool 100mL of water by 5 ^oC. Swirling the system in an attempt to dissolve the salt did little to achieve that. A bigger styrofoam cup would allow more room for movement which would help to dissolve the salt. A container with a lower specific heat capacity than aluminum can be used. Silver (0.240 J/gK) or Tin (0.21 J/gK) are good candidates. In this case more heat will be lost from the drinkable water than from the container the water is contained in.

In designing the experiment it was assumed that the calorimeter is perfect and does not exchange heat with its surroundings. This is an ideal situation and in reality calorimeters, even bomb calorimeters exchange thermal energy with their surroundings. In our experiment, there must have been some heat transfer from the hands to the system because the system was held throughout the duration of the each reaction. This heat exchange cannot be completely eradicated. After each trial, there was some NH_4Cl left in the styrofoam cup that did not dissolve. Uneven heat exchange occurs when reactants are not properly mixed.

CONCLUSION

There was a temperature change of -3.5 ^oC after 5 minutes when 22 grams of NH_4Cl was used. From graphical extrapolation, it would theoretically require 29.64 grams of NH_4Cl to achieve a temperature change of -5 ^oC.

REFERENCES

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https://www.cdc.gov/niosh/ipcsneng/neng1051.html. Centers for Disease Control and Prevention.

http://www2.ucdsb.on.ca/tiss/stretton/database/specific_heat_capacity_table.html. Stretton, T. Tom Stretton's Chemistry Pages

RAW DATA

Time (s)	T_1 (13.27g)	T_2 (16 g)	T_3 (22 g)
0	23.5	22.6	22.4
0.5	23.2	22.5	21.8
1	22.8	22.2	21.8
1.5	22.3	22.1	20.9
2	22.2	22.0	19.6
2.5	21.9	21.9	19.5
3	21.9	21.8	19.1
3.5	21.9	22.0	19.0
4	21.7	21.9	18.9
4.5	21.5	21.4	18.8
5	21.7	~~22.6~~ 21.4	18.6

Assessment Criteria for Planning A Tall Cold Drink of Water

TA Name: YOUSEF	FATMA	**Names of Students in Group:**	**a.** PRINCE
			b.
		Date: 12/10/2017	
Criteria:	**Marks Possible**	**Assessment** Self	**Assessment** TA
1. Identify the problem and state it clearly in a way that can be tested.	1	1	
2. Use proper apparatus, techniques and safety precautions.	1	1	
3. Materials are easily available.	1	1	
4. Plan to vary only one independent variable at a time.	1	1	
5. Controls on other variables are clearly stated.	1	1	
6. Measurement errors are minimized by appropriate procedures or apparatus.	1	1	
7. The methods are clear enough to be followed by other students.	1	1	
8. No invalid assumptions are made.	1	1	
9. Reagents that need accurate measurement are identified.	1	1	
10. Lab trials are stated.	1	1	
11. Repeats are stated.	1	1	
12. Chemistry vocabulary is used correctly.	1	1	
13. Limitations of the experimental design are described.	1	1	
TOTAL:	13	13	