GENERAL CHEMISTRY

LAB COMPONENT CHE101L

CONTENT: LAB 3

Dissolution Reactions: Heats of Dissociation

NAME Masroor Mofiz Arman SECTION 15

STUDENT ID 1921079642

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NAME OF THE INSTRUCTOR Dr. Mohammed Kabir Uddin (MKUN)

SIGNATURE & DATE ....

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EXPERIMENT 3

SESSION 1 (QUALITATIVE)

DISSOLUTION REACTIONS: HEATS OF DISSOCIATION

Heats (exothermic or endothermic) are associated with chemical reactions. Quantity of heat evolved or absorbed is directly proportional to the amount reacted. Consider the reactions below:

$$MgSO4(s) + H_2O\,(l) \longrightarrow Mg^{2+}(aq.) + SO_4^{2-}(aq.) \pm \text{heat}$$

$$NaNO_3(s) + H_2O\,(l) \longrightarrow Na^{+}(aq.) + NO_3^{-}(aq.) \pm \text{heat}$$

Heat could be generated or absorbed in this reaction. When heat is generated/released from a chemical reaction it is called exothermic reaction (you can feel it by touching the reaction container (warmer) and when heat is absorbed the reaction is called endothermic (colder). When reactions occur in a reaction vessel (*e.g.*, Beaker) in aqueous condition, formation and dissociation of chemical bonds occur simultaneously. Bond formation and dissociation involves heat energy of the system which is expressed by the term Q which is called enthalpy.

Problem statement: **Is heat energy related to chemical reactions, how?**

This experiment is subdivided into two parts:

I. Qualitative
II. Quantitative

Part I. Qualitative

Data Collection:

Place about 30 mL of distilled water into a 50 mL beaker. Suspend a thermometer (having 0.1^{0}C division mark) into the beaker using thermometer clamp and ring stand. Please make sure that the thermometer is not touching the bottom of the beaker, as any movement of the beaker could break the thermometer. Record the temperature of water in the beaker in every 30 seconds for 180 seconds.

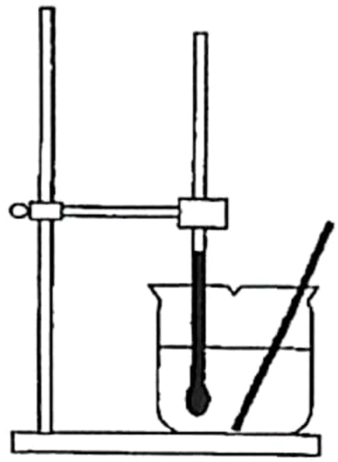


Figure 1: Experimental setup for dissolution reaction

Place a moderate amount (which would be 1 to 3 cm^3) of supplied anhydrous magnesium sulfate ($MgSO_4$) to the beaker. Mix vigorously with the glass rod for 2 minutes. Record your observations. **(2 points)**

Repeat this procedure with each of the following compounds with two different amounts (roughly 1:2): **(2 points)**

a. Sodium Nitrate, $NaNO_3$

Initial Temp: 26°C, Final Temp: 19.75°C. So, Endothermic.

b. Sodium Chloride, NaCl

Initial Temp: 26°C, Final Temp: 25.75°C. So, Endothermic

c. Hydrated Calcium Chloride, $CaCl_2.2H_2O$

Initial Temp: 26°C, Final Temp: 29.75°C. So, Exothermic.

d. Ammonium Nitrate, NH_4NO_3

Initial Temp: 25°C, Final Temp: 19.75°C. So, Endothermic

e. Magnesium Sulfate, $MgSO_4$

Initial Temp: 26°C, Final Temp: 29.75°C. So, Exothermic

DATA ANALYSIS:

Compare and contrast the behaviors of these compounds. Identify any generalizations that can be made about the chemical reactions observed. What conclusions can be drawn from the data? (4 points)

$NaNO_3$, NaCl and NH_4NO_3 exhibit endothermic reactions, meaning they absorb heat from the surroundings, resulting in a temperature decrease. $CaCl_2 . 2H_2O$ and $MgSO_4$ are undergo exothermic reactions, releasing heat into the surroundings and causing a temperature rise. In endothermic reactions $NaNO_3$ and NH_4NO_3 show significant cooling, while NaCl has a minimal temperature decrease, implying a weaker endothermic effect. In exothermic reactions $CaCl_2 . 2H_2O$ and $MgSO_4$ both release heat, causing a temperature increase of exactly 3.75° in both cases that suggests these compounds might release similar amounts of energy. Sodium-based salts generally exhibit endothermic behavior. On the other hand, Calcium and Magnesium salts are exothermic, indicating that metal ions are likely to drive reactions that release heat. In conclusion, the degree of temperature change gives insight into the strength of the endothermic or exothermic reaction. Larger changes indicate stronger heat absorption or releasing during dissolution or reaction.

SESSION 2(QUANTITATIVE)

PART II. QUANTITATIVE

DATA COLLECTION:

a. Accurately weigh a 3 to 5 gm sample of $MgSO_4$ on the analytical balance. Record the exact mass here. For 4 different trials below measure four different weight samples (e.g., 1,2, 4 & 5 grams respectively).
b. Suspend the thermometer into a polystyrene cup/coffee cup. Make sure of the thermometer is not touching the bottom of the cup. Measure 20 mL of distilled water by a volumetric cylinder into the cup and stir for 240 second. Record the temperature in every 20 seconds. After 240 seconds add $MgSO_4$ with vigorous mixing while continuing to record data for 5 minutes.
c. Determine the temperature change, ΔT, for the reaction. This can be done from the difference of the highest temperature minus the slope of the line go through the points from first 240 seconds of data.
d. Draw a temperature vs. time graph. Draw the best curve through the points and point out what is happing in each part of the curve.
e. Repeat the whole procedure with $NaNO_3$.

DATA TABLE 1:

TRAILS

(I) Mass of $MgSO_4$_0.5 gm			(II) Mass of $MgSO_4$_1.0 gm	
Time (s)	Temp(^{0}C)		Time(s)	Temp(^{0}C)
20	25		20	25
40	25		40	25
60	25		60	25
80	26		80	26
100	26		100	26
120	26		120	26
140	26		140	26
160	26.25		160	26.5
180	26.25		180	26.5
200	26.25		200	26.5
220	26.25		220	26.5
240	26.25		240	26.5
260	26.25		260	26.5
280	26.25		280	26.5
300	26.25		300	26.5

$\Delta T = 26.25°C - 25°C$
$= 1.25°C$

$\Delta T = 26.5°C - 25°C$
$= 1.5°C.$

(III) Mass of $MgSO_4$_1.5 gm			(IV) Mass of $MgSO_4$_2.0 gm	
Time (s)	Temp(^{0}C)		Time(s)	Temp(^{0}C)
20	25.8		20	27
40	25.8		40	27
60	25.8		60	27
80	26		80	28.5
100	26		100	28.5
120	26.2		120	28.5
140	26.5		140	28.5
160	26.5		160	28.5
180	26.5		180	29
200	27		200	29
220	27.5		220	29
240	27		240	29
260	26.8		260	29
280	27		280	29
300	27		300	29

$\Delta T = 27.5°C - 25.8°C$
$= 1.7°C.$

$\Delta T = 29°C - 27°C$
$= 2°C.$

DATA TABLE 2:

TRAILS

(I) Mass of $NaNO_3$_0.5 gm			(II) Mass of $NaNO_3$_1.00 gm	
Time (s)	Temp(^{0}C)		Time(s)	Temp(^{0}C)
20	25		20	25
40	25		40	25
60	25		60	25
80	24		80	23
100	23.75		100	23
120	23.75		120	22
140	23.75		140	22
160	23.75		160	22
180	24.25		180	22
200	24.50		200	22
220	24.75		220	22
240	24.75		240	22
260	24.75		260	22
280	24.75		280	22
300	24.75		300	22

$\Delta T = 23.75°C - 25°C$
$= -1.25°C$

$\Delta T = 22°C - 25°C$
$= -3°C.$

(III) Mass of $NaNO_3$ _1.5 gm			(IV) Mass of $NaNO_3$ _2.0 gm	
Time (s)	Temp(°C)		Time(s)	Temp(°C)
20	26		20	25.5
40	26		40	25.5
60	26		60	25.5
80	25		80	25
100	24		100	25
120	24		120	25
140	24		140	25
160	24		160	24.5
180	23.8		180	24.5
200	23.5		200	24.5
220	23.5		220	24
240	23		240	24
260	23		260	24
280	23		280	24
300	23		300	24

$\Delta T = 23°C - 26°C$
$= -3°C.$

$\Delta T = 24°C - 25.5°C.$
$= -1.5°C.$

DATA ANALYSIS

1. What do you understand form both data sets you recorded and from the other trials? **(4 points)**

$MgSO_4$ is exothermic, so temperature rises as more $MgSO_4$ is added, indicating heat release during dissolution. $NaNO_3$ is endothermic, so temperature drops as $NaNO_3$ dislves, absorbing heat from the surroundings. In both compounds, increasing the mass leads to a more pronounced thermal effect, but in opposite directions (ie. rise for $MgSO_4$, fall for $NaNO_3$). $MgSO_4$ shows a stronger exothermic response at higher concentrations, while $NaNO_3$ shows a stronger endothermic effect as the mass increases. The rate of temperature change of $MgSO_4$ is relatively quick, peaking early and then stabilizing but the rate of temperature change of $NaNO_3$ occurs more gradually, especially with higher masses, indicating that the endothermic process takes longer to reach equilibrium. $MgSO_4$ dissolves and releases heat quickly, reaching thermal equilibrium in less time. $NaNO_3$ dissolution absorbs heat slowly, with cooling effect stabilizing over a longer period. Therefore, both compounds stabilize after a period, completion of dissolution and heat transfer.

2. Calculate the heat, Q & moles, n, of the reaction both data sets. Take help from the equitation Q = C x M x ΔT. Assume C = 4.18 Joules/gram ^{0}C and M is the mass of water (take the water density as 1.00 grams/cm^3). **(4 points)**

Mass of water, $M = \rho . V = 1 \times 20 = 20$ gram
$[\rho = 1 \text{ gram/cm}^3, V = 20 \text{ mL}]$

Molar mass of $MgSO_4 = (24+32+(4\times16)) = 120 g/mol$

$0.5\ MgSO_4$: $\Delta T = 26.25°C - 25°C = 1.25°C$.

$Q = (4.18 J/g°C) \times 20g \times 1.25°C = 104.5 J$

$1\ MgSO_4$: $\Delta T = 26.5°C - 25°C = 1.5°C$.

$Q = (4.18 J/g°C) \times 20g \times 1.5°C = 125.4 J$

$1.5\ MgSO_4$: $\Delta T = 27.5°C - 25.8°C = 1.7°C$.

$Q = (4.18 J/g°C) \times 20g \times 1.7°C = 142.12 J$

$2\ MgSO_4$: $\Delta T = 29°C - 27°C = 2°C$.

$Q = (4.18 J/g°C) \times 20g \times 2°C = 167.2 J$

$\therefore n_1 = \frac{0.5g}{120g/mol} = 0.0042$ mol

$\therefore n_2 = \frac{1g}{120g/mol} = 0.0083$ mol

$\therefore n_3 = \frac{1.5g}{120g/mol} = 0.0125$ mol

$\therefore n_4 = \frac{2g}{120g/mol} = 0.0167$ mol

$n = \frac{\text{Given Mass}}{\text{Molar Mass}}$

Molar mass of $NaNO_3 = (23+14+(3\times16)) = 85 g/mol$

$0.5\ NaNO_3$: $\Delta T = 23.75° - 25°C = -1.25°C$

$Q = (4.18 J/g°C) \times 20g \times -1.25°C = -104.5 J$

$1\ Mg\ NaNO_3$: $\Delta T = 22°C - 25°C = -3°C$.

$Q = (4.18 J/g°C) \times 20g \times -3°C = -250.8 J$

$1.5\ NaNO_3$: $\Delta T = 23°C - 26°C = -3°C$

$Q = (4.18 J/g°C) \times 20g \times -3°C = -250.8 J$

$2\ MgSO_4$: $\Delta T = 24°C - 25.5°C = -1.5°C$.

$Q = (4.18 J/g°C) \times 20g \times -1.5°C = -125.4 J$

$\therefore n_1 = \frac{0.5g}{85g/mol} = 0.0059$ mol

$\therefore n_2 = \frac{1g}{85g/mol} = 0.0118$ mol

$\therefore n_3 = \frac{1.5g}{85g/mol} = 0.0176$ mol

$\therefore n_4 = \frac{2g}{85g/mol} = 0.0235$ mol

$n = \frac{\text{Given Mass}}{\text{Molar Mass}}$

3. Plot the collected data as moles, n vs. Q both sets of data. Number of moles can be calculated as n = (mass of sample in gram) / (molecular weight in grams/mole). Try to find algebraic equations. **(4 points)**

For $MgSO_4$, $m = \frac{138 - 125.4}{0.0125 - 0.0083} = 3\times10^3$

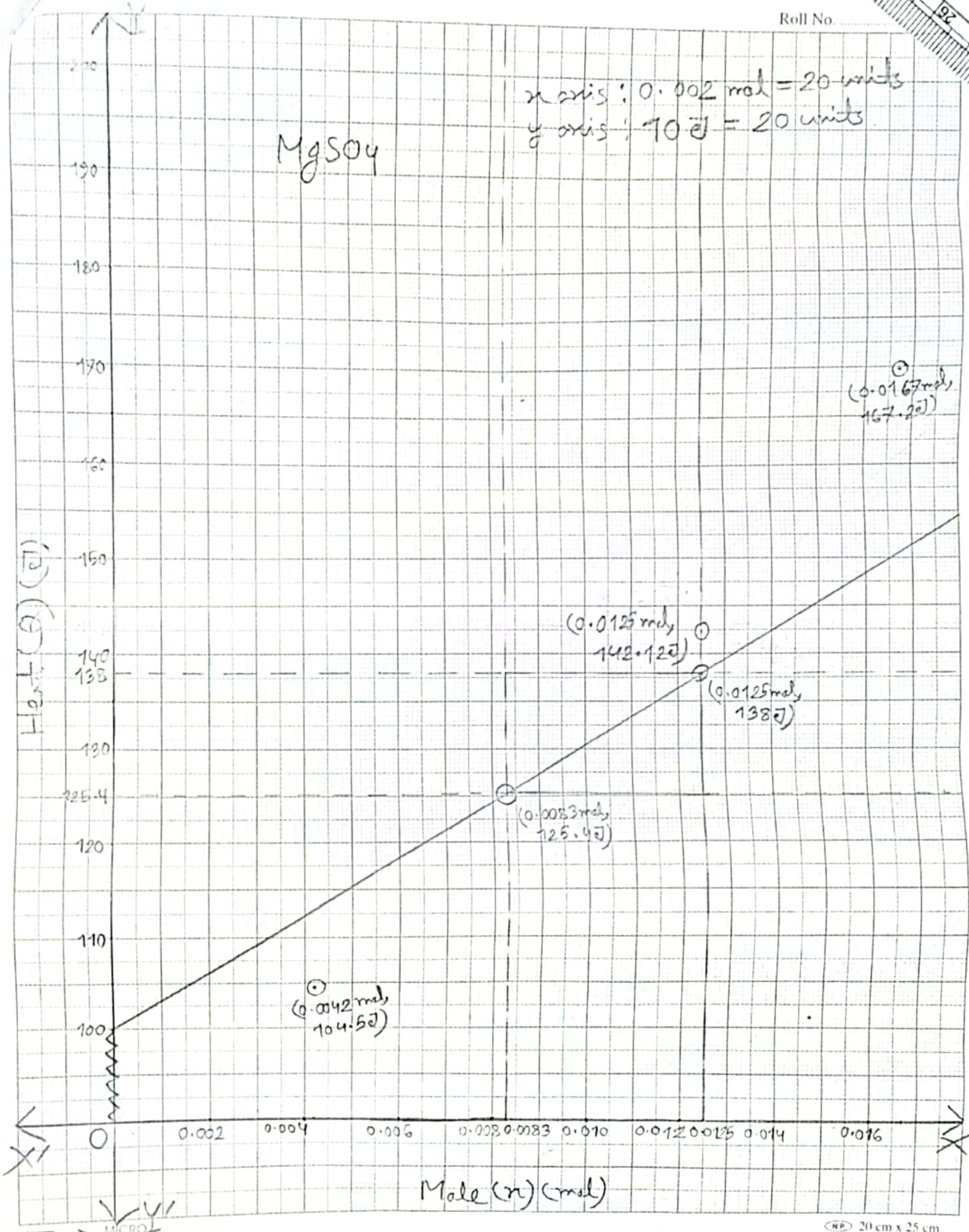
So, the linear equation is: $y = mx + c. = (3\times10^3)x + 100$ (Ans).

For $NaNO_3$, $m = \frac{-250.8 + 195}{0.0176 - 0.0118} = -9.6\times10^3$

So, the linear equation is: $y = mx + c = (-9.6\times10^3)x + 100$ (Ans).

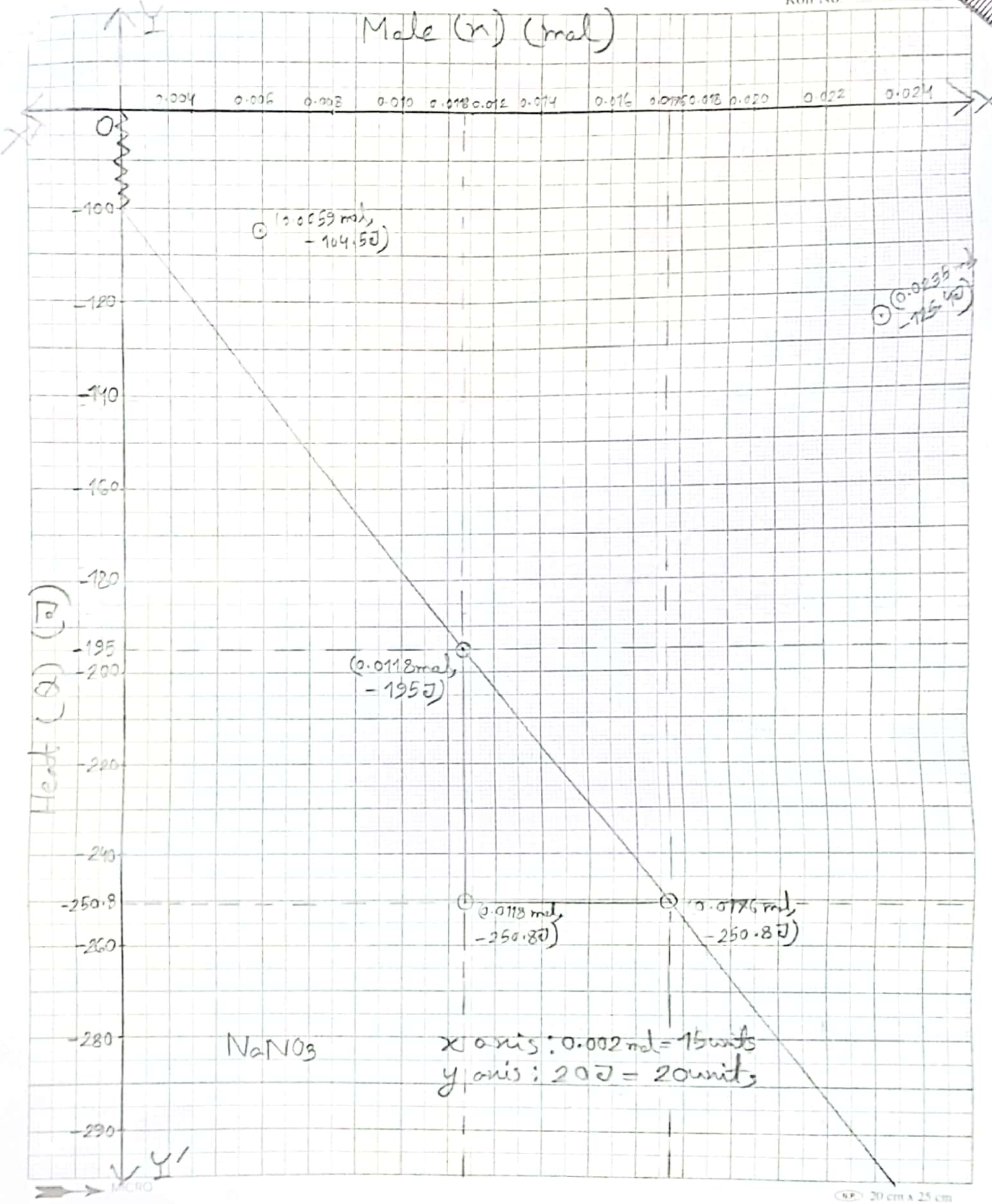
FIGURE: plot here

Roll No. ....



MICRO

20 cm x 25 cm

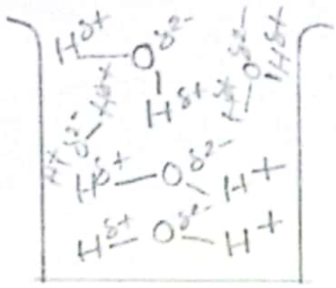

Mole (n) (mol)
Heat (Q) (J)
0.004
0.006
0.008
0.010
0.0118
0.012
0.014
0.016
0.0176
0.018
0.020
0.022
0.024
-100
-120
-140
-160
-180
-195
-200
-220
-240
-250.8
-260
-280
-290
(0.0059 mol, -104.5J)
(0.0235 mol, -126 J)
(0.0118mol, -195J)
(0.0118 mol, -250.8J)
(0.0176 mol, -250.8J)
NaNO3
x axis : 0.002 mol = 15units
y axis : 20J = 20units

Mental Model: Use the chemical equation given above to represent the dissolution reaction in this experiment. Draw a picture(s) which describes what is happening in atomic or in molecular level for either $MgSO_4$ or $NaNO_3$ system. How heat release or absorbed can be described from these pictures? **(5 points)**

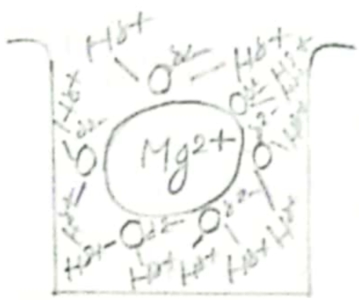
$MgSO_4$:

Chemical equation: $MgSO_4(s) \xrightarrow{water(H_2O)} Mg^{2+}(aq) + SO_4^{2-}(aq)$

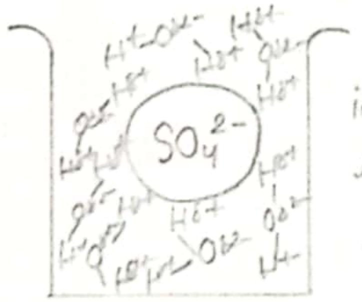
When magnesium sulfat ($MgSO_4$) is dissolved in water, it dissociates into Mg^{2+} (magnesium ions) and SO_4^{2-} (sulfate ions).



Water molecules have hydrogen bonds to hold them together. When the hydrogen bonds breakdown inside water it requires energy. So it is an endothermic process.



When $MgSO_4$ is added the negative dipole oxygen get surrounded to the positive ion and this ordered arrangement of water releases energy called hydration enthalpy and this process is exothermic process.



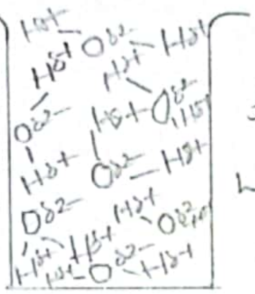
The positive dipole of hydrogen surrounds the negative ions and release energy. In this case, hydration enthalpy is greater than latice energy. So, the solid structure energy is used up to increase the temperature.

Therefore, the energy is released when water molecules from hydration shells around the dissociated ions. The attraction between water molecules and the ions results in the release of energy, which is observed as heat in the solution. The overall is exothermic, meaning the energy released from hydration of ions exceeds the energy required to break the ionic bonds. This causes the temperature of the water to rise.

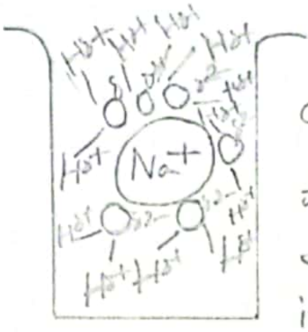
NaNO$_3$:

chemical equation : $NaNO_3(s) \xrightarrow{\text{water}(H_2O)} Na^+(aq) + NO_3^-(aq)$

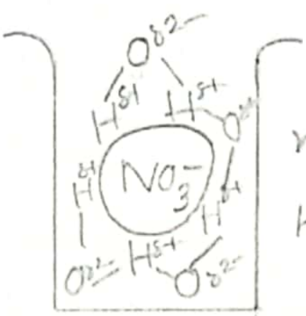
when sodium nitrate ($NaNO_3$) is dissolved in water, it dissociates into Na^+ (sodium ions) and NO_3^- (nitrate ions).



Water molecules have the hydrogen bonds to hold them together. When hydrogen bonds breakdown inside water it requires energy. So, it is an endothermic process.



When $NaNO_3$ is added the negative dipole oxygen get surrounded to the positive ion and this ordered arrangement of water releases less energy required to break the ionic bonds, resulting in net energy absorption. This process is called endothermic process.



The positive dipole of hydrogen surrounds the negative ion and absorbed energy. In this case, hydration enthalpy is less than the latice energy.

Therefore, water molecules from hydration shells around the dissociated ions. However the energy released during this hydration process is less than the energy required to break the ionic bonds, resulting in net energy absorption, making the solution feel cooler. As $NaNO_3$ dissolves, more energy is absorbed than is released, leading to a drop in temperature. Thus this reaction is an endothermic reaction.