Thermodynamics: Enthalpy of Reaction and Hess's Law

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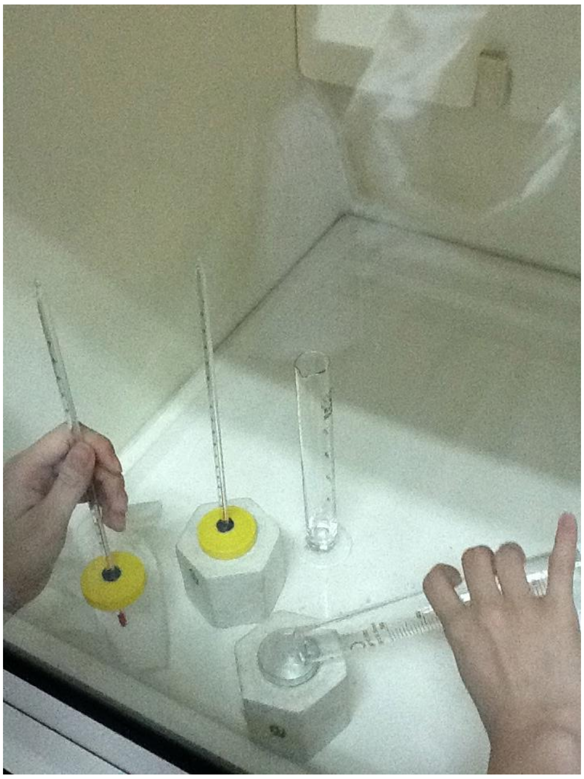
Purpose: The purpose of this lab is verify Hess's law by finding the enthalpies of the reactions; NaOH and HCl, NH_2Cl and NaOH, and NH_3 and HCl. The overall enthalpy should equals to the sum of enthalpy of the three reactions in order to verify Hess's law. Understanding Hess's law would be important when scientist tries to determine the overall reaction when only parts of the reaction are given.

Hypothesis: The hypothesis of this experiment is that the enthalpy of the reaction could be determined by using Hess's law and calorimetry because the enthalpy of the entire reaction is the sum of the enthalpies for each step and using calorimetry the transfer of heat could be determined. After such procedure is done stoichiometry could be applied to solve for the energy that was absorbed or released during the experiment and the combination of reactions 1 and 2 should be the same as reaction 3.

Equipment:

2M Ammonia Solution; 25mL
2M Ammonium Chloride solution; 25mL
2M Sodium Hydroxide solution; 25mL
2M Hydrochloric Acid solution; 50mL
Distilled Water; more than 500mL
250mL Beaker; 1
50mL Graduated Cylinder; 4
Bunsen burner; 2
50mL Calorimeter with lid; 2
Thermometer, 2
Glycerol, few drops
Stopwatch; 1
Fume hood; 1
Dropper; 4
Wire gauzes, 2
Ring stand; 2



Procedure:

Part1 - Determining the Heat Capacity of the Calorimeter

1. Set up a calorimeter with a thermometer placed in the lid (add few drops of glycerol if lubrication is needed)
2. Measure 25mL of distilled water using a graduated cylinder
3. Close the lid of the calorimeter and swirl it
4. Measure and record the temperature of the water
5. Heat approximately 25mL of distilled water to 70° C in a 250mL beaker
6. Add the heated distilled water into the calorimeter.
7. Close the lid of the calorimeter with thermometer
8. using a stopwatch, measure the temperature every 20 seconds until 180 seconds
9. repeat procedure #1~8 for another trial

Part 2 – Determine the Heat of Reaction

Reaction 1

$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

1. Measure 25mL of a 2.0M HCl solution using a graduated cylinder
2. Transfer the HCl solution into a calorimeter
3. Measure and record the initial temperature of HCl
4. Rinse the graduated cylinder with distilled water
5. Measure 25mL of a 2.0M NaOH solution using a graduated cylinder
6. Measure and record the initial temperature of NaOH
7. Add the NaOH solution into the calorimeter as soon as possible (because NaOH absorbs water from the surroundings)
8. Close the lid of the calorimeter with thermometer in it
9. Swirl the calorimeter as soon a the stop watch sets to start
10. Record the temperature every 20 seconds
11. Repeat procedure #1~10 for another trial

Reaction 2 *needs to be done in a fume hood

$NH_4Cl_{(aq)} + NaOH_{(aq)} \rightarrow NH_{3(aq)} + NaCl_{(aq)}\ H_2O_{(l)}$

1. Rinse the graduated cylinder and the calorimeter form the previous reaction
2. repeat procedure #1~11 from reaction 1 using NH_4Cl instead of HCl
3. repeat Procedure 1 and 2 from this reaction for another trial

Reaction 3 *needs to be done in a fume hood

$NH_{3\ (aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)}$

1. Rinse the graduated cylinder and the calorimeter form the previous reaction
2. repeat procedure #1~11 from reaction 1 using NH_3 instead of HaOH
3. repeat Procedure 1 and 2 from this reaction for another trial

Results:

Part1 - Determining the Heat Capacity of the Calorimeter		
	Trial 1	**Trial 2**
25mL H_2O – room temperature (° C)	26	26
25mL H_2O – heated (° C)	70	70
Temperature of the solutions after 20 seconds. (° C)	47	48
Temperature of the solutions after 40 seconds. (° C)	48	50
Temperature of the solutions after 60 seconds. (° C)	49	52
Temperature of the solutions after 80 seconds. (° C)	49	52
Temperature of the solutions after 100 seconds. (° C)	49	52
Temperature of the solutions after 120 seconds. (° C)	49	52
Temperature of the solutions after 140 seconds. (° C)	49	52
Temperature of the solutions after 160 seconds. (° C)	49	52
Temperature of the solutions after 180 seconds. (° C)	49	52
T_{mix} (° C)	49.5	47.75
T_{ave} (° C)	48	48
q_{cal} (J)	– 313.8	– 52.3
C_{cal} (J/° C)	– 13.3532	– 2.4046
Specific heat of water (J/g*° C)	4.184	4.184

Part2 – reaction 1 – Determining the Heat of Reaction		
$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$	**Trial 1**	**Trial 2**
Temperature of 25mL 2.0M HCl (° C)	27	26
Temperature of 25mL 2.0M NaOH (° C)	30	30
Temperature of the solutions after 20 seconds. (° C)	37	35
Temperature of the solutions after 40 seconds. (° C)	38	37
Temperature of the solutions after 60 seconds. (° C)	40	38
Temperature of the solutions after 80 seconds. (° C)	40	38
Temperature of the solutions after 100 seconds. (° C)	40	38
Temperature of the solutions after 120 seconds. (° C)	40	38
Temperature of the solutions after 140 seconds. (° C)	40	38
Temperature of the solutions after 160 seconds. (° C)	40	38
Temperature of the solutions after 180 seconds. (° C)	40	38
T_{mix} (°C)	37.94	36.31
T_{ave} (° C)	28.7	28
q_{rxn} (J)	–966.504	1303.83
∆H (kJ/mol)	–18.2	30.2
Specific heat of solution (J/g * ˚C)	4.184	4.184
Solution(g)	51.5	51.5
Density of Solution (g/mL)	1.03	1.03
Amount of solutions (mL)	50	50

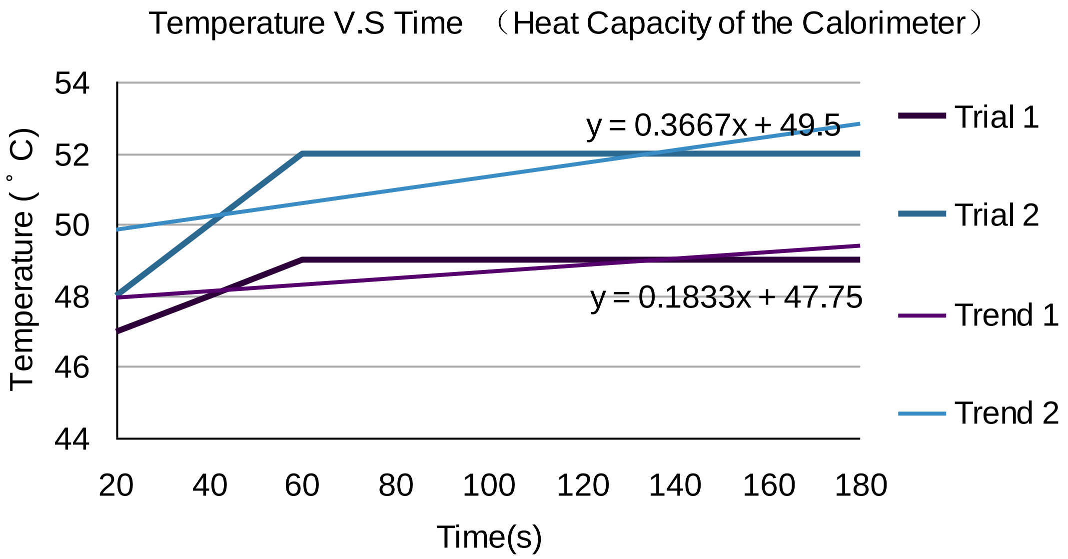
Part 2 – Reaction 2 – Determining the Heat of Reaction		
$NH_4Cl_{(aq)}$ + $NaOH_{(aq)}$ → $NH_{3(aq)}$ + $NaCl_{(aq)}$ $H_2O_{(l)}$	**Trial 1**	**Trial 2**
Temperature of 25mL 2.0M NaOH (° C)	30	31
Temperature of 25mL 2.0M NH_4Cl (° C)	25	25
Temperature of the solutions after 20 seconds. (° C)	25	29
Temperature of the solutions after 40 seconds. (° C)	27	30
Temperature of the solutions after 60 seconds. (° C)	29	30
Temperature of the solutions after 80 seconds. (° C)	29	30
Temperature of the solutions after 100 seconds. (° C)	29	30
Temperature of the solutions after 120 seconds. (° C)	29	30
Temperature of the solutions after 140 seconds. (° C)	29	30
Temperature of the solutions after 160 seconds. (° C)	29	30
Temperature of the solutions after 180 seconds. (° C)	29	30
T_{mix} (° C)	29.56	26.5
T_{ave}(° C)	27.5	28
q_{rxn} (J)	–215.476	–235.35
ΔH (kJ/mol)	–4	6.8
Specific heat of solution (J/g * ˚C)	4.184	4.184
Solution(g)	51.5	51.5
Density of Solution (g/mL)	1.03	1.03
Amount of solutions (mL)	50	50

Part 2 – Reaction 3 – Determining the Heat of Reaction		
$NH_{3\,(aq)}$ + $HCl_{(aq)}$ → $NH_4Cl_{(aq)}$	**Trial 1**	**Trial 2**
Temperature of 25mL 2.0M HCl (° C)	26	26
Temperature of 25mL 2.0M NH_3 (° C)	25	25
Temperature of the solutions after 20 seconds. (° C)	30	31
Temperature of the solutions after 40 seconds. (° C)	32	32
Temperature of the solutions after 60 seconds. (° C)	32	33
Temperature of the solutions after 80 seconds. (° C)	32	33
Temperature of the solutions after 100 seconds. (° C)	32	33
Temperature of the solutions after 120 seconds. (° C)	32	33
Temperature of the solutions after 140 seconds. (° C)	32	33
Temperature of the solutions after 160 seconds. (° C)	32	33
Temperature of the solutions after 180 seconds. (° C)	32	33
T_{mix} (° C)	31.75	31.11
T_{ave}	25.5	25.5
q_{rxn} (J)	–653.75	880.209
ΔH (kJ/mol)	–12.2	20.4
Specific heat of solution (J/g * ˚C)	4.184	4.184
Solution(g)	51.5	51.5
Density of Solution (g/mL)	1.03	1.03
Amount of solutions (mL)	50	50

Analysis:

Part1 - Determining the Heat Capacity of the Calorimeter

Graph:



T_{ave} = [(25mL H_2O – room temperature + 25mL H_2O – heated temperature)] / 2

Trial 1: [(26) + (70)] / 2 = 48 ˚C

Trial 2: [(26) + (70)] / 2 = 48 ˚C

q_{cal} = – [(Grams of Water) × (Specific heat of Water) × (T_{mix} – T_{ave})]

Trial 1: – [(25 + 25) × (4.184) × (49.50 – 48)] = – 313.8 J

Trial 2: – [(25 + 25) × (4.184) × (47.75 – 48)] = – 52.3 J

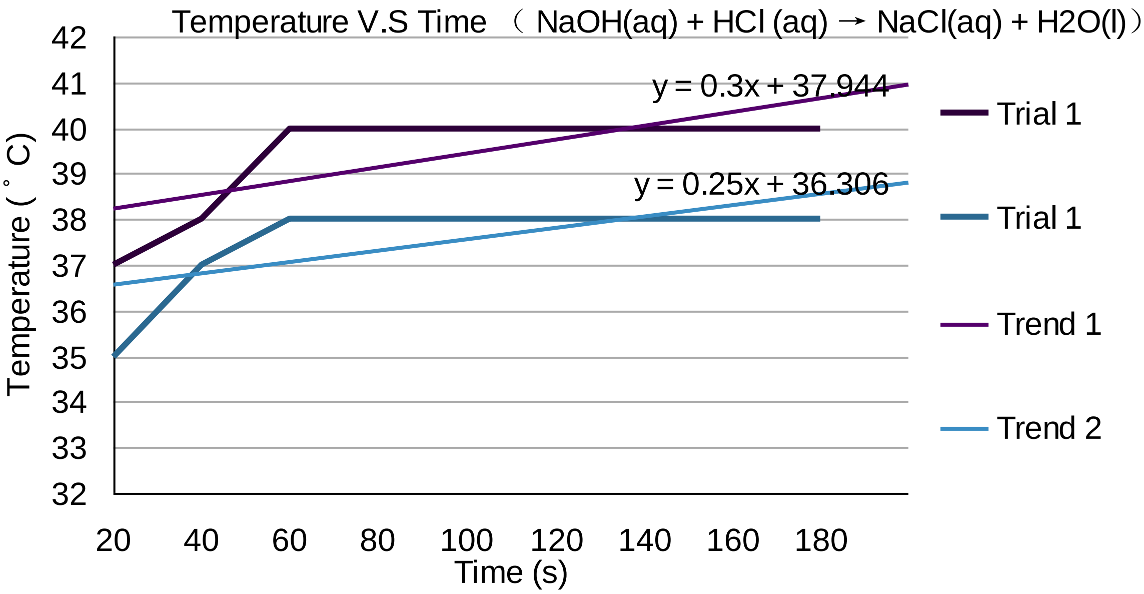
C_{cal} = [(q_{cal}) / (T_{mix} – Room temperature of unheated water)]

Trial 1: [(– 418.4) / (49.50 – 26)] = – 13.3532 J/^{o}C

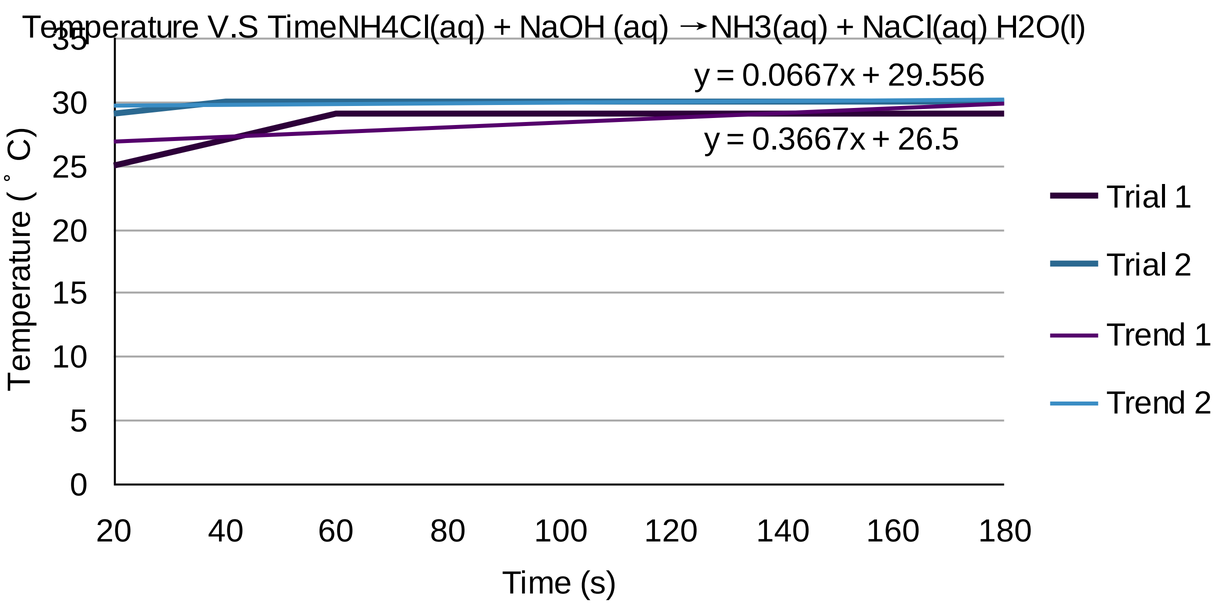
Trial 2: [(– 52.3) / (47.75 – 26)] = – 2.4046 J/^{o}C

Part 2

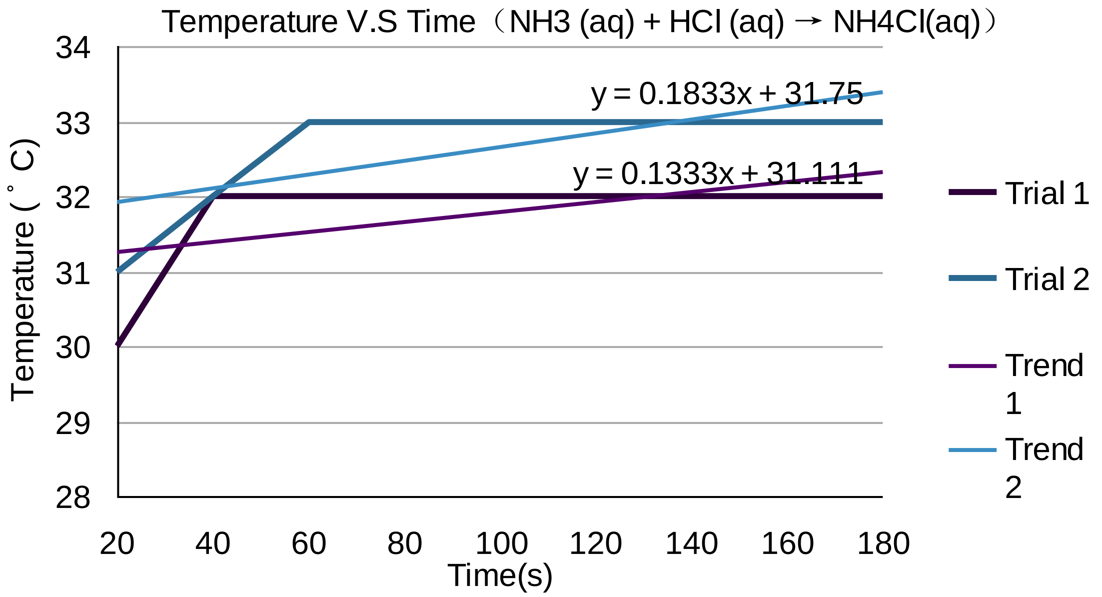
Graph of Reaction 1: $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$



Graph of Reaction 2: $NH_4Cl_{(aq)} + NaOH_{(aq)} \rightarrow NH_{3(aq)} + NaCl_{(aq)}\ H_2O_{(l)}$



Graph of Reaction 3: $NH_{3\,(aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)6}$



q_{rxn} = – [(Grams of Solution × Specific heat of Water × (T_{mix} – T_{ave}))] + (C_{cal} × (T_{mix} – T_{ave}))

Reaction 1:
Trial 1:
[(50×1.03) × (4.184) × (37.94 – 28.7)] + [(– 313.8) ×(37.94 – 28.7)]
= –908.514J = –0.91kJ
Trial 2: =
[(50×1.03) × (4.184) × (36.31 – 28)] + [(– 52.3) ×(36.31 – 28)]
= 1507.75 J = 1.51kJ

Reaction 2:
Trial 1:
[(50×1.03) × (4.184) × (29.56 – 27.5)] + [(– 313.8) ×(29.56 – 27.5)]
= –202.547J = –0.20 kJ
Trial 2:
[(50×1.03) × (4.184) × (26.5 –28)] + [(– 52.3) ×(26.5 –28)]
= 336.143 J = 0.34kJ

Reaction 3
Trial 1:
[(50×1.03) × (4.184) × (31.75 – 25.5)] + [(– 313.8) ×(31.75 – 25.5)]
= –614.525J = –0.61kJ
Trial 2:
[(50×1.03) × (4.184) × (31.11 – 25.5)] + [(– 52.3) ×(31.11 – 25.5)]
= 1019.85 J = 1.02kJ
Moles per reactant = Molarities × volume

The moles per reactant is the same for all 3 reactions
Reaction 1:
Trial 1: 2M * 0.025 mL = 0.05 mol
Trial 2: 2M * 0.025 mL = 0.05 mol

$\triangle H_{rxn}$ = [(q_{rxn}) / Moles per reactant]
Reaction 1
Trial 1: (–0.91) / 0.05 = –18.2kJ
Trial 2: (1.51) / 0.05 = 30.2kJ
Reaction 2
Trial 1: (–0.20) / 0.05 = –4kJ
Trial 2: (0.34) / 0.05 = 6.8kJ
Reaction 3
Trial 1: (–0.61) / 0.05 = –12.2kJ
Trial 2: (1.02) / 0.05 = 20.4kJ

Hess's Law
Trial 1
Reaction 1: HCl + NaOH → NaCl + H_2O $\triangle$H: -18.2 kJ
Reaction 2: NaOH + NH_4Cl → NH_4OH + NaCl $\triangle$H: -4 kJ

HCl + ~~NaOH~~ → ~~NaCl~~ + H_2O $\triangle$H: -18.2kJ
NH_4OH + ~~NaCl~~ → ~~NaOH~~ + NH_4Cl $\triangle$H:4kJ

=HCl + NH_4OH → NH_4Cl + H_2O (reaction 3) $\triangle$H: -14.2 kJ
The $\triangle$H: 14.2 kJ is very close to –12.2kJ so the hypothesis has been generally proven correct

Trial 2
Reaction 1: HCl + NaOH → NaCl + H_2O $\triangle$H: 30.2 kJ
Reaction 2: NaOH + NH_4Cl → NH_4OH + NaCl $\triangle$H: 6.8 kJ

HCl + ~~NaOH~~ → ~~NaCl~~ + H_2O $\triangle$H: 30.2kJ
NH_4OH + ~~NaCl~~ → ~~NaOH~~ + NH_4Cl $\triangle$H: -6.8kJ

=HCl + NH_4OH → NH_4Cl + H_2O (reaction 3) $\triangle$H: 23.4 kJ
The $\triangle$H: 23.4 kJ is very close to 20.4kJ so the hypothesis has been generally proven correct

Percent Error: [(difference between calculated $\triangle$H and $\triangle$H from combined reaction 1 + reaction 2) / (calculated $\triangle$H)] × 100
Trial 1: (2 / 12.2) × 100 = 16.4%
Trial 2: (3 / 20.4) × 100 = 14.7%
Average percent error: [Trial 1 error +trial 2 error] / 2

(16.4 + 14.7) / 2= 15.55%

According to the analysis, the hypothesis has generally been proven correct; however there is 15.55% average error between the two results. Meaning the results had a 84.45% accuracy. The graph also presented the accuracy of the lab because the difference of the temperature in the reaction was shown. In order to find the temperature mix the graph is needed because the equation could only be found when there is graph. In the equation given in the graph it also shows the slope of the equation. This is significant to when finding the temperature mix

Conclusion:

The hypothesis was generally proven correct with a 15.55% percent error. Even though the results were mostly accurate however there must be some possible errors which contaminated the results. One of the possible error was the thermometer itself was not accurate as it not provide any decimal places. This might cause the data to be inaccurate. In the future there are ways to prevent certain inaccuracies, such as using a digital thermometer with 0.01 precision instead of a normal thermometer. The other error is that the rubber stopper wasn't placed back right away on to the flask that contains NaOH after each reaction and trials were done. This might dilute the 2M NaOH and reduce the amount of reaction that occurred because NaOH absorbs the water in the air causing the solution to be more diluted. In the future we should always close the flask that contains NaOH as soon as we have done using it.