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Acid and Base Thermochemistry Lab

The heats of reaction were calculated for a set of four acid/base reactions. Hydrochloric

acid (0.10M) was used as the strong acid and acetic acid (0.10M) was used as the weak acid.

Sodium hydroxide (0.13M) was used as the strong base and aqueous ammonia (0.13M) was used

as the weak base. The overall and net ionic equations for the four reactions are shown below in

Table 1.

Strong Acid/Strong Base
1) Hydrochloric acid and sodium hydroxide
Overall Equation: $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O$
Net Ionic Equation: $H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O$
Strong Acid/Weak Base
2) Hydrochloric acid and aqueous ammonia
Overall Equation: $HCl_{(aq)} + NH_{3(aq)} \rightarrow NH_4Cl_{(aq)}$
Net Ionic Equation: $H^+_{(aq)} + NH_{3(aq)} \rightarrow NH_4^+_{(aq)}$
Weak Acid/Strong Base
3) Acetic acid and sodium hydroxide
Overall Equation: $HC_2H_3O_{2(aq)} + NaOH_{(aq)} \rightarrow NaC_2H_3O_{2(aq)} + H_2O$
Net Ionic Equation: $HC_2H_3O_{2(aq)} + OH^-_{(aq)} \rightarrow C_2H_3O_2^- + H_2O$
Weak Acid/Weak Base
4) Acetic acid and aqueous ammonia
Overall Equation: $HC_2H_3O_{2(aq)} + NH_{3(aq)} \rightarrow NH_4C_2H_3O_{2(aq)}$
Net Ionic Equation: $HC_2H_3O_{2(aq)} + NH_{3(aq)} \rightarrow NH_4^+_{(aq)} + C_2H_3O_2^-_{(aq)}$

Table 1: The overall and net ionic equations for the four acid/base reactions

The change of temperature for the acid/base reaction was monitored using TI-84 graphing calculators and thermometer probes. The initial and final acid and base temperatures were obtained using the tangent-method on the temperature curves. The temperature data for the four reactions is shown below in Table 2.

Reaction	$T_{initial\ base}$ (°C)	$T_{final\ base}$ (°C)	ΔT_{base} (°C)	$T_{initial\ acid}$ (°C)	$T_{final\ acid}$ (°C)	ΔT_{acid} (°C)
1) Hydrochloric acid and sodium hydroxide	23.36	23.91	0.55	23.50	24.04	0.54
2) Hydrochloric acid and aqueous ammonia	22.65	23.68	1.03	23.69	23.82	0.13
3) Acetic acid and sodium hydroxide	23.33	23.36	0.03	22.80	23.47	0.67
4) Acetic acid and aqueous ammonia	23.29	23.47	0.18	22.80	23.41	0.61

Table 2: Temperature values for each of the acid/base reactions

The heat of reaction (ΔH_{rxn}) was calculated using Equations 1 and 2, as shown below. The mass of acid and base, ΔT's, and ΔH_{rxn} are shown for each reaction in Table 3 below.

$$\Delta H_{rxn} = -(q_{acid} + q_{base} + q_{calorimeter)} \qquad (1)$$

$$\Delta H_{rxn} = -(4.184J/g^oC \text{ x } mass_{acid} \text{ x } \Delta T_{acid} + 4.184J/g^oC \text{ x } mass_{base} \text{ x } \Delta T_{base} + 32.0J/^oC \text{ x } \Delta T_{acid} \ (2)$$

Reaction	$Mass_{base}$ (g)	$Mass_{acid}$ (g)	ΔT_{base} (°C)	ΔT_{acid} (°C)	ΔH_{rxn} (J)	ΔH_{rxn} (kJ/mole L.R.)
1) Hydrochloric acid and sodium hydroxide	27.23 L.R.	52.88	0.55	0.54	2Ō0	-56
2) Hydrochloric acid and aqueous ammonia	26.67 L.R.	55.72	1.03	0.13	-149	-43
3) Acetic acid and sodium hydroxide	25.13 L.R.	57.82	-0.03	0.67	-187	-55
4) Acetic acid and aqueous ammonia	25.39	56.69	0.18	0.61	180	-44

Table 3: The mass and temperature data needed to calculate ΔH_{rxn}

The actual values for ΔH_{rxn} were calculated using Hess's Law (Equation 3). The actual ΔH_{rxn} values are shown in Table 4 below.

$$\Delta H_{rxn} = \Delta H_{products} - \Delta H_{reactants} \tag{3}$$

Strong Acid/Strong Base
1) Hydrochloric acid and sodium hydroxide
Complete Ionic: $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
Net Ionic Equation: $H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$
ΔH_{rxn} = -285.83kJ/mol H_2O - [0kJ/mol H^+ + -299.99kJ/mol OH^-] ΔH_{rxn} = -55.85kJ/mol
Strong Acid/Weak Base
2) Hydrochloric acid and aqueous ammonia
Complete Ionic: $HCl_{(aq)} + NH_{3(aq)} \rightarrow NH_4Cl_{(aq)}$
Net Ionic Equation: $H^+_{(aq)} + NH_{3(aq)} \rightarrow NH_4^+_{(aq)}$
ΔH_{rxn} = -132.51kJ/mol NH_4^+ - [0kJ/mol H^+ + -80.29kJ/mol NH_3] ΔH_{rxn} = -52.22kJ/mol
Weak Acid/Strong Base
3) Acetic acid and sodium hydroxide
Complete Ionic: $HC_2H_3O_{2(aq)} + NaOH_{(aq)} \rightarrow NaC_2H_3O_{2(aq)} + H_2O_{(l)}$
Net Ionic Equation: $HC_2H_3O_{2(aq)} + OH^-_{(aq)} \rightarrow C_2H_3O_{2(aq)}^- + H_2O_{(l)}$
ΔH_{rxn} = [-488.87kJ/mol $C_2H_3O_2^-$ + -285.83kJ/mol H_2O] - [-485.76kJ/mol $HC_2H_3O_2$ + -229.99kJ/mol OH^-] ΔH_{rxn} = -58.95kJ/mol
Weak Acid/Weak Base
4) Acetic acid and aqueous ammonia
Complete Ionic: $HC_2H_3O_{2(aq)} + NH_{3(aq)} \rightarrow NH_4C_2H_3O_{2(aq)}$
Net Ionic Equation: $HC_2H_3O_{2(aq)} + NH_{3(aq)} \rightarrow NH_4^+_{(aq)} + C_2H_3O_2^-_{(aq)}$
ΔH_{rxn} = [-488.87kJ/mol $C_2H_3O_2^-$ + -132.51kJ/mol NH_4^+] - [-485.76kJ/mol $HC_2H_3O_2$ + -80.29kJ/mol NH_3] ΔH_{rxn} = -55.33kJ/mol

Table 4: Actual ΔH_{rxn}'s calculated using $\Delta H_{formation}$'s

The experimental values were compared to the actual values using % error (Table 5). Statistical analysis using the t-test could not be used to test for significant differences among classmates' data because classmates did not report their data.

Reaction	Experimental ΔH_{rxn} (kJ/mole L.R.)	Actual ΔH_{rxn} (kJ/mole L.R.)	% error
1) Hydrochloric acid and sodium hydroxide	-56	-55.84	0%
2) Hydrochloric acid and aqueous ammonia	-43	-52.22	-20%
3) Acetic acid and sodium hydroxide	-55	-58.95	-7%
4) Acetic acid and aqueous ammonia	-44	-55.33	-21%

Table 5: Percent error values for the experimental and actual ΔH_{rxn}'s.

Questions:

5) Explain why the values for the heats of reaction are similar for all four reactions.

The heats of reaction are similar for the four reactions because very similar bonds are being broken and formed. In the first reaction, a bond is being formed between an oxygen and a hydrogen. In the third reaction, a bond is also being formed between an oxygen and a hydrogen. In addition an acidic H—O bond is being broken. Since the third reaction's ΔH_{rxn} is 3.11kJ/mole more negative, the dissociation of the acetic acid is exothermic.

In the second reaction, a bond is being formed between a nitrogen and a hydrogen. In the fourth reaction, a bond is also being formed between a nitrogen and a hydrogen. In addition an acidic H—O bond is being broken in acetic acid. It so happens that the fourth reaction has a ΔH_{rxn} 3.11kJ/mole lower than the second reaction because the same acetic acid H—O bond is being broken as was the case in the third reaction.

6a) If all of the base was not transferred to the calorimeter, how would this affect the % error?

The base is needed to accept the proton from the acid. The process is exothermic, so heat is released as the conjugate acid forms. If not all of the base is transferred, there will be less heat produced. This will lower the ΔT and the calculated ΔH_{rxn}. Since the same number of moles of base is being used to calculate the ΔH_{rxn}, the molar ΔH_{rxn} will be less. This will make the % error more negative, since the ΔH_{rxn} is below the actual value.

6b) If the temperature sensor for the acid read lower than the temperature sensor for the base and this were not corrected for, how would this affect the experimental ΔH_{rxn}? If the acid probe read lower, the ΔT_{base} would be lower than it should be. This would reduce the q_{base} in the calculation. Overall, the ΔH_{rxn} would be lower than it should be. Since the base is the limiting reactant, the effect of the error would not be as drastic. A change in temperature of the same magnitude would be much more drastic for the acid, since its mass is greater in calculating q_{acid}. In addition, it is the acid's ΔT that is used in calculating the $q_{calorimeter}$. Since the base probe was transferred, a final temperature was able to be calculated for the base and the acid, independently This eliminates the need to correct for any difference in probe temperature readings.

Conclusion/Reflection: This lab left me with some unanswered questions. I was told not to write the formula for ammonium hydroxide. It was written on the chemical solution's bottle in the lab, but supposedly it does not exist. I guess I need some explanation as to why it does not exist before I feel satisfied. If it does not exist, I probably should not have my students name that compound on any future tests, quizzes, or worksheets.

Secondly, when first writing ionic and net ionic equations for the lab, I started to break apart any aqueous solution, not thinking about strong acids or weak acids. Once I figured that

out, I did not have too much trouble because I was familiar with the difference between strong and weak acids. I was a little less familiar with the dissociation properties of bases. I guess I am still a little confused when to dissociate an ionic substance. When does an ionic substance form an aqueous solution and when does it dissociate? The first topic deals with solubility, but I do not remember learning about a dissociation equilibrium constant in AP chemistry or college.

Lastly, I was asked to look at the statistical significance of my data using the t-test. I did not have my classmates' data, so I was unsure what I was supposed to compare my data to. To calculate a t-test, you need at least two sets of data with multiple trials, because you need to be able to calculate an average and a standard deviation. I am really confused as to what the t-test would tell me about just my own data.

After the next class meeting, data was exchanged so t-tests could calculated. The data was analyzed for a significant difference between the hydroxide data and the ammonia data. A significant difference (p=.031 class) was noted between the ΔH of the HCl/NaOH reaction and the ΔH of the HCl/NaH_3 reaction. A significant difference (p=.92) was not noted for the ΔH of the $HC_2H_3O_2/NaOH$ reaction and the ΔH of the $HC_2H_3O_2/NH_3$ reaction. The fact that three students got -98kJ/mole for the $HC_2H_3O_2/NH_3$ reaction may have had something to do with the lack of significance. Using only my data, there was a significant difference (p = .003) between the hydroxide and ammonia reactions.

When comparing my data to the rest of the class, I found a significant difference (p=.000018) in the HCl/NH_3 data. The p value for the $HC_2H_3O_2/NH_3$ was close to being significant at .056.

It was interesting that both hydroxide reactions had less than -7% error, whereas both ammonia reactions had less than -21% error. I presume ammonia had more error because some

of the ammonia came out of solution while the temperature probes were calibrating. This would

have caused less moles of ammonia to be in solution and therefore would have given off less

heat.