

# Experiment 20D:

## Hydrolysis - The Reaction of Ions with Water

### 1 Purpose

To identify the whether a salt has undergone hydrolysis by measuring its pH and to explain whether hydrolysis has occurred in terms of relative strengths of acids / bases from which a given salt is made. Also, to deduce which is greater for some amphiprotic anions, the  $K_a$  for the further ionisation of the ion, or the  $K_b$  for the hydrolysis of the ion.

### 2 Procedure

See experiment 20D procedure for chemistry 12. The only change in procedure is that this experiment is not actually performed, as we dont have access to the necessary equipment. This lab is performed in theory and all resulting data is given.

### 3 Data & Observations

Table 1:

Solution	Colour of Universal Indicator	pH	Type of Hydrolysis (Anionic, Cationic, Both, or Neither)
NaCH <sub>3</sub> COO	green-turquoise	8	Anionic
NaCl	yellow	6	Neither
NH <sub>4</sub> Cl	orange-yellow	5.5	Cationic
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	orange-yellow	5.5	Both
AlCl <sub>3</sub>	red	4	Cationic
Ca(NO <sub>3</sub> ) <sub>3</sub>	yellow	6	Neither
Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	red	≤4	Both
Na <sub>2</sub> CO <sub>3</sub>	deep blue	≥10	Anionic
Na <sub>2</sub> PO <sub>4</sub>	deep blue	≥10	Anionic
K <sub>2</sub> SO <sub>4</sub>	green	7	Anionic
KBr	yellow	6	Neither
(NH <sub>4</sub> ) <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	yellow-green	6	Both
NH <sub>4</sub> CH <sub>3</sub> COO	yellow-green	6.5	Both
(NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub>	turquoise	8.5	Both

**Table 2:**

Solution	Colour of Universal Indicator	pH	Type of Reaction (Anionic Hydrolysis or Further Ionization)
K <sub>2</sub> HPO <sub>4</sub>	blue	9	Hydrolysis
KH <sub>2</sub> PO <sub>4</sub>	red	>4	Ionisation
NaHCO <sub>3</sub>	blue	9	Hydrolysis
KHCO <sub>4</sub>	red	4	Ionisation
NaHSO <sub>3</sub>	orange-yellow	5.5	Ionisation

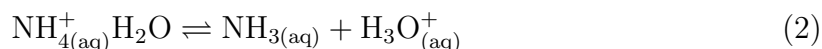
## 4 Questions & Calculations

1. NaCH<sub>3</sub>COO; CH<sub>3</sub>COO<sup>-</sup>, CH<sub>3</sub>COOH; Weak Base

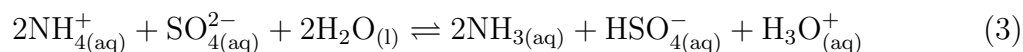


NaCl; N/A; No Acid or Base

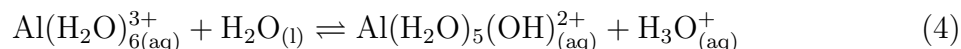
NH<sub>4</sub>Cl; NH<sub>4</sub><sup>+</sup>, NH<sub>3</sub> Weak Acid



(NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>; NH<sub>4</sub><sup>+</sup>, NH<sub>3</sub>, SO<sub>4</sub><sup>2-</sup>, HSO<sub>4</sub><sup>-</sup> Weak Acid & Base

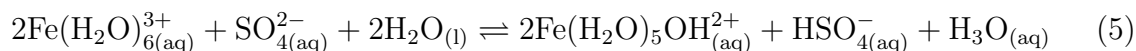


AlCl<sub>3</sub>; Al(H<sub>2</sub>O)<sub>6</sub><sup>3+</sup>, Al(H<sub>2</sub>O)<sub>5</sub>OH<sup>2+</sup>; Weak Acid

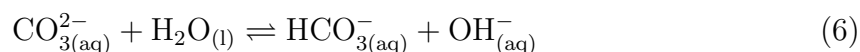


Ca(NO<sub>3</sub>)<sub>3</sub>; N/A; No Acid or Base

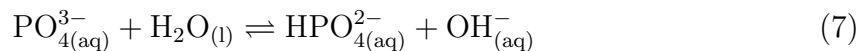
Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>; Fe(H<sub>2</sub>O)<sub>6</sub><sup>3+</sup>, Fe(H<sub>2</sub>O)<sub>5</sub>(OH)<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, HSO<sub>4</sub><sup>-</sup>; Weak Acid & Base



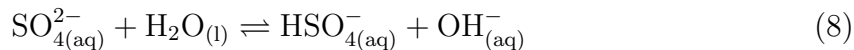
Na<sub>2</sub>CO<sub>3</sub>; HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>; Weak Base



Na<sub>2</sub>PO<sub>4</sub>; HPO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>; Weak Base

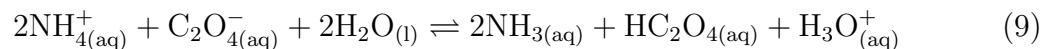


K<sub>2</sub>SO<sub>4</sub>; HSO<sub>4</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>; Weak Base

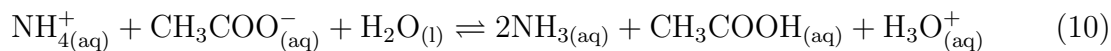


KBr; N/A

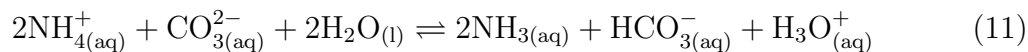
(NH<sub>4</sub>)<sub>2</sub>C<sub>2</sub>O<sub>4</sub>; NH<sub>4</sub><sup>+</sup>, NH<sub>3</sub>, HC<sub>2</sub>O<sub>4</sub><sup>-</sup>, C<sub>2</sub>O<sub>4</sub><sup>2-</sup>; Weak Acid & Base



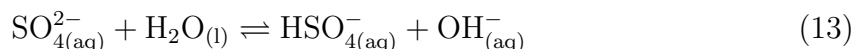
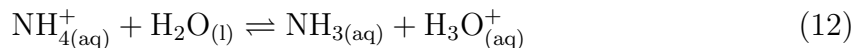
NH<sub>4</sub>CH<sub>3</sub>COO; NH<sub>4</sub><sup>+</sup>, NH<sub>3</sub>, CH<sub>3</sub>COO<sup>-</sup>, CH<sub>3</sub>COOH; Weak Acid & Base



(NH<sub>4</sub>)<sub>2</sub>CO<sub>3</sub>; NH<sub>4</sub><sup>+</sup>, NH<sub>3</sub>, HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>; Weak Acid & Base



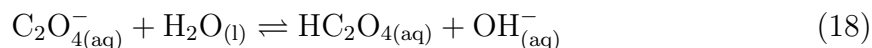
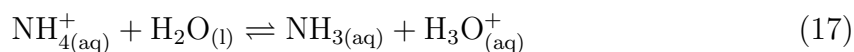
2.



$$K_a(\text{NH}_4^+) = 5.6 \times 10^{-10} \quad (14)$$

$$K_b(\text{SO}_4^{2-}) = \frac{K_w}{K_a(\text{HSO}_4^-)} = \frac{1.0 \times 10^{-14}}{1.2 \times 10^{-2}} = 8.3 \times 10^{-13} \quad (15)$$

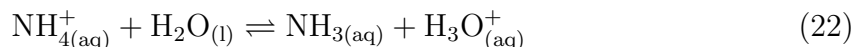
$$K_a(\text{NH}_4^+) > K_b(\text{SO}_4^{2-}) \quad (16)$$



$$K_a(\text{NH}_4^+) = 5.6 \times 10^{-10} \quad (19)$$

$$K_b(\text{C}_2\text{O}_4^{2-}) = \frac{K_w}{K_a(\text{HC}_2\text{O}_4^-)} = \frac{1.0 \times 10^{-14}}{6.4 \times 10^{-5}} = 1.6 \times 10^{-10} \quad (20)$$

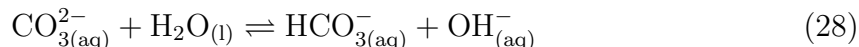
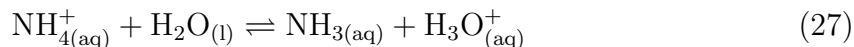
$$K_a(\text{NH}_4^+) > K_b(\text{C}_2\text{O}_4^{2-}) \quad (21)$$



$$K_a(\text{NH}_4^+) = 5.6 \times 10^{-10} \quad (24)$$

$$K_b(\text{CH}_3\text{COO}^-) = \frac{K_w}{K_a(\text{CH}_3\text{COOH})} = \frac{1.0 \times 10^{-14}}{6.5 \times 10^{-5}} = 1.5 \times 10^{-10} \quad (25)$$

$$K_a(\text{NH}_4^+) > K_b(\text{CH}_3\text{COO}^-) \quad (26)$$

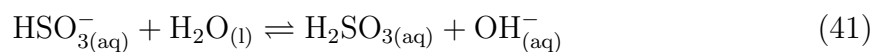
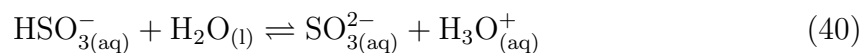
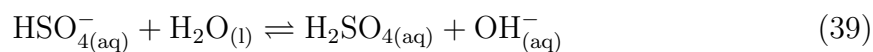
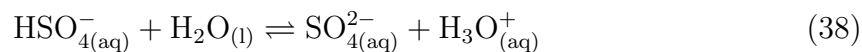
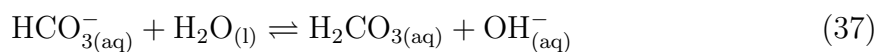
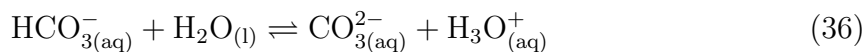
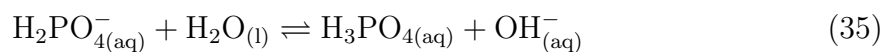
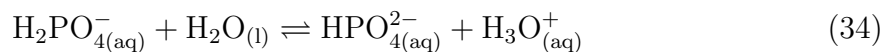
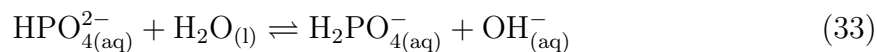
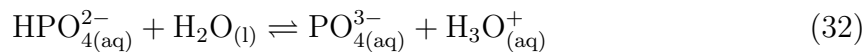


$$K_a(\text{NH}_4^+) = 5.6 \times 10^{-10} \quad (29)$$

$$K_b(\text{CO}_3^{2-}) = \frac{K_w}{K_a(\text{HCO}_3^-)} = \frac{1.0 \times 10^{-14}}{5.6 \times 10^{-11}} = 1.8 \times 10^{-4} \quad (30)$$

$$K_a(\text{NH}_4^+) < K_b(\text{CO}_3^{2-}) \quad (31)$$

3.



4. For  $K_2HPO_4$ , according to the experimental results, the reaction  $HPO_4^{2-} + H_2O_{(l)} \rightleftharpoons H_2PO_4^- + OH_{(aq)}^-$  occurred to a greater extent, producing a basic solution.

$$K_a(HPO_4^{2-}) = 2.2 \times 10^{-13} \quad (42)$$

$$K_a(H_2PO_4^-) = 6.2 \times 10^{-8} \quad (43)$$

$$K_b(PO_4^{3-}) = \frac{K_w}{K_a(HPO_4^{2-})} = \frac{1.0 \times 10^{-14}}{2.2 \times 10^{-13}} = 4.5 \times 10^{-2} \quad (44)$$

$$K_b(HPO_4^{2-}) = \frac{K_w}{K_a(H_2PO_4^-)} = \frac{1.0 \times 10^{-14}}{6.2 \times 10^{-8}} = 1.6 \times 10^{-7} \quad (45)$$

$K_b(HPO_4^{2-})$  turns out to be the strongest of all acids and bases, this is why the solution is basic.

For  $KH_2PO_4$ , according to the experimental results, the reaction  $H_2PO_4^- + H_2O_{(l)} \rightleftharpoons HPO_4^{2-} + H_3O_{(aq)}^+$  occurred to a greater extent, producing an acidic solution.

$$K_a(H_2PO_4^-) = 6.2 \times 10^{-8} \quad (46)$$

$$K_a(H_3PO_4) = 7.5 \times 10^{-3} \quad (47)$$

$$K_b(HPO_4^{2-}) = \frac{K_w}{K_a(H_2PO_4^-)} = \frac{1.0 \times 10^{-14}}{6.2 \times 10^{-8}} = 1.6 \times 10^{-7} \quad (48)$$

$$K_b(H_2PO_4^-) = \frac{K_w}{K_a(H_3PO_4)} = \frac{1.0 \times 10^{-14}}{7.5 \times 10^{-3}} = 1.3 \times 10^{-12} \quad (49)$$

$K_a(H_3PO_4)$  turns out to be the strongest of all acids and bases, this is why the solution is acidic.

For  $NaHCO_3$ , according to the experimental results, the reaction  $HCO_3^- + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} + OH_{(aq)}^-$  occurred to a greater extent, producing a basic solution.

$$K_a(HCO_3^-) = 5.6 \times 10^{-11} \quad (50)$$

$$K_a(H_2CO_3) = 4.3 \times 10^{-7} \quad (51)$$

$$K_b(CO_3^{2-}) = \frac{K_w}{K_a(HCO_3^-)} = \frac{1.0 \times 10^{-14}}{5.6 \times 10^{-11}} = 1.8 \times 10^{-4} \quad (52)$$

$$K_b(HCO_3^-) = \frac{K_w}{K_a(H_2CO_3)} = \frac{1.0 \times 10^{-14}}{4.3 \times 10^{-7}} = 2.3 \times 10^{-8} \quad (53)$$

$K_b(CO_3^{2-})$  turns out to be the strongest of all acids and bases, this is why the solution is basic.

For  $\text{KHSO}_4$ , according to the experimental results, the reaction  $\text{HSO}_{4(\text{aq})}^- + \text{H}_2\text{O}_{(\text{l})} \rightleftharpoons \text{SO}_{4(\text{aq})}^{2-} + \text{H}_3\text{O}_{(\text{aq})}^+$  occurred to a greater extent, producing an acidic solution.

$$K_a(\text{HSO}_4^-) = 1.2 \times 10^{-2} \quad (54)$$

$$K_a(\text{H}_2\text{SO}_4) = \text{Strong Acid} \quad (55)$$

$$K_b(\text{SO}_4^{2-}) = \frac{K_w}{K_a(\text{HSO}_4^-)} = \frac{1.0 \times 10^{-14}}{1.2 \times 10^{-2}} = 8.3 \times 10^{-13} \quad (56)$$

$K_a(\text{H}_2\text{SO}_4)$  is undefined because  $\text{H}_2\text{SO}_4$  is a strong acid, as a result the solution becomes very acidic.

For  $\text{NaHSO}_3$ , according to the experimental results, the reaction  $\text{HSO}_{3(\text{aq})}^- + \text{H}_2\text{O}_{(\text{l})} \rightleftharpoons \text{SO}_{3(\text{aq})}^{2-} + \text{H}_3\text{O}_{(\text{aq})}^+$  occurred to a greater extent, producing a basic solution.

$$K_a(\text{HSO}_3^-) = 1.0 \times 10^{-7} \quad (57)$$

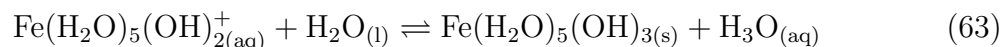
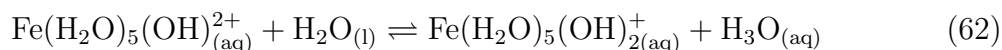
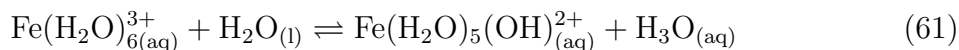
$$K_a(\text{H}_2\text{SO}_3) = 1.5 \times 10^{-2} \quad (58)$$

$$K_b(\text{SO}_3^{2-}) = \frac{K_w}{K_a(\text{HSO}_3^-)} = \frac{1.0 \times 10^{-14}}{1.0 \times 10^{-7}} = 1.0 \times 10^{-7} \quad (59)$$

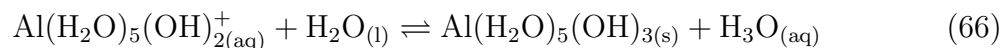
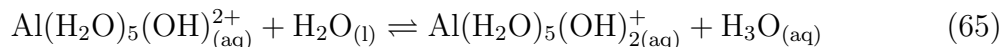
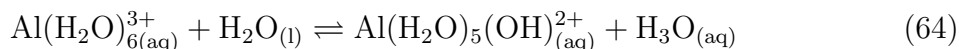
$$K_b(\text{HSO}_3^-) = \frac{K_w}{K_a(\text{H}_2\text{SO}_3)} = \frac{1.5 \times 10^{-2}}{4.3 \times 10^{-7}} = 6.7 \times 10^{-13} \quad (60)$$

$K_a(\text{H}_2\text{SO}_3)$  turns out to be the strongest of all acids and bases, this is why the solution is acidic.

5. The precipitate observed in solutions containing  $\text{Fe}^{3+}$  occurs because of the following reaction, where, in the last step, the product formed precipitates out of the solution.



6. The precipitate observed in solutions containing  $\text{Al}^{3+}$  occurs because of the following reaction, where, in the last step, the product formed precipitates out of the solution.



## 5 Followup Questions

1. If the farmer used  $(\text{NH}_4)_2\text{SO}_4$  the soil would become more acidic as a result of the hydrolysis of the  $\text{NH}_4$  contained in the salt. As a result,  $\text{KNO}_3$  would be a far better choice for keeping the soil from becoming too acidic.
2.  $\text{Na}_3\text{PO}_4$  is a very strong basic solvent, as a result it can be quite useful as a detergent. The phosphate in the salt will readily react with earth metals such as calcium and magnesium. TSP is especially useful for stainless steel, which a chlorinated cleanser could corrode.
3. Baking powder reacts with the acid-forming ingredient to produce carbon dioxide, which helps baking products to rise. The acid forming ingredient in this case is  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ , which reacts with the  $\text{HCO}_3^-$  to form carbon dioxide gas. Bubbles of carbon dioxide become trapped in the flour mixture. The bubbles expand when they are heated and make the mixture rise.
4. In order to stress the right side of the reaction, one could add some  $\text{HCl}$  to the solution, thereby causing more  $\text{H}_3\text{O}^+$  ions to form, these ions, when in excess, would then react with the iron compound, causing the equation to shift to the left again. As a result we would end up with more iron in the solution.
5. Since the solution is basic, we have  $\text{HCO}_3^-$  ions, and  $\text{NH}_3$  ions in the resulting solution. These two ions could react with each other to produce  $\text{NH}_4\text{HCO}_3$ . As a result of the new product forming, the equation will shift to the right in order to regain equilibrium.
6. I would assume that when a vial containing ammonium carbonate is crushed, some of the ammonium ions could escape as gas into the air. Ammonia has quite a strong odour, and is quite a shock to the system when inhaled, as a result, ammonia is quite good at reviving unconscious patients. The patient wakes up because of a built in response that is part of the sympathetic nervous system, which controls the “fight or flight” response.



## 6 Conclusion

From the results of this experiment, we have been able to show that salts, which contain an acid or base, will undergo hydrolysis. The resulting solution depends on whether the salt contains an acid or base ion. When the salt contains an acid ions, such as  $\text{NH}_4\text{Cl}$ , the the dissolution of this compound will result in an ammonium ions, which will then react with water (hydrolysis) to produce an acidic solution; the same is true for bases. In some cases we have salts that are made up from both an acid an a base, in these cases we need to calculate which of the two is stronger, the acid or the base. If the acid is stronger, we will end up with an acid solution, and conversely if the base is stronger, we will end up with a basic solution.