7.8: Acid-Base Properties of Salts

Salts, when placed in water, will often react with the water to produce H_3O^+ or OH^-. This is known as a hydrolysis reaction. Based on how strong the ion acts as an acid or base, it will produce varying pH levels. When water and salts react, there are many possibilities due to the varying structures of salts. A salt can be made of either a weak acid and strong base, strong acid and weak base, a strong acid and strong base, or a weak acid and weak base. The reactants are composed of the salt and the water and the products side is composed of the conjugate base (from the acid of the reaction side) or the conjugate acid (from the base of the reaction side). In this section of chemistry, we discuss the pH values of salts based on several conditions.

When is a salt solution basic or acidic?

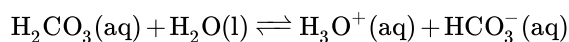There are several guiding principles that summarize the outcome:

1. **Salts that are from strong bases and strong acids do not hydrolyze.** The pH will remain neutral at 7. Halides and alkaline metals dissociate and do not affect the H^+ as the cation does not alter the H^+ and the anion does not attract the H^+ from water. This is why NaCl is a neutral salt. **In General:** Salts containing halides (except F^-) and an alkaline metal (except Be^{2+}) will dissociate into spectator ions.
2. **Salts that are from strong bases and weak acids do hydrolyze, which gives it a pH greater than 7.** The anion in the salt is derived from a weak acid, most likely organic, and **will *accept* the proton from the water in the reaction. This will have the water act as an acid that will, in this case, leaving a hydroxide ion (OH^-)**. The cation will be from a strong base, meaning from either the alkaline or alkaline earth metals and, like before, it will dissociate into an ion and not affect the H^+.
3. **Salts of weak bases and strong acids do hydrolyze, which gives it a pH less than 7**. This is due to the fact that the anion will become a spectator ion and fail to attract the H^+, while the cation from the weak base will donate a *proton* to the water forming a hydronium ion.
4. **Salts from a weak base and weak acid also hydrolyze as the others, but a bit more complex and will require the K_a and K_b to be taken into account.** Whichever is the stronger acid will be the dominate factor in determining whether it is acidic or basic. The cation will be the acid, and the anion will be the base and will form either form a hydronium ion or a hydroxide ion depending on which ion reacts more readily with the water.
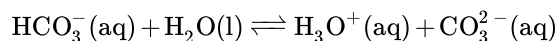
Salts of Polyprotic Acids

Do not be intimidated by the salts of polyprotic acids. Yes, they're bigger and "badder" then most other salts. But they can be handled the exact same way as other salts, just with a bit more math. First of all, we know a few things:

- It's still just a salt. All of the rules from above still apply. Luckily, since we're dealing with acids, the pH of a salt of polyprotic acid will always be greater than 7.
- The same way that polyprotic acids lose H^+ stepwise, salts of polyprotic acids gain H^+ in the same manner, but in reverse order of the polyprotic acid.

Take for example dissociation of H_2CO_3, carbonic acid.

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$$

with $K_{a1} = 2.5 \times 10^{-4}$

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$$

with $K_{a2} = 5.61 \times 10^{-11}$.

This means that when calculating the values for K_b of CO_3^{2-}, the K_b of the first hydrolysis reaction will be $K_{b1} = \dfrac{K_w}{K_{a2}}$ since it will go in the reverse order.

Summary of Acid Base Properties of Salts

Type of Solution	Cations	Anions	pH
Acidic	From weak bases NH_4^+, Al^{3+}, Fe^{3+}	From strong acids: Cl^-, Br^-, I^-, NO_3^-, ClO_4^-	< 7

| Type of Solution	Cations	Anions	pH
Basic	From strong bases: Group 1 and Group 2, but not Be^{2+}	From weak acids: F^-, NO_2^-, CN^-, CH_3COO^-	> 7
Neutral	From strong bases: Group 1 and Group 2, but not Be^{2+}.	From strong acids: Cl^-, Br^-, I^-, NO_3^-, ClO_4^-	= 7

Questions

1. Predict whether the pH of each of the following salts placed into water is acidic, basic, or neutral.

    a. $NaOCl_{(s)}$
    b. $KCN_{(s)}$
    c. $NH_4NO_{3(s)}$

2. Find the pH of a solution of .200 M NH_4NO_3 where ($K_a = 1.8 * 10^{-5}$).
3. Find the pH of a solution of .200 M Na_3PO_4 where ($K_{a1} = 7.25 * 10^{-5}$, $K_{a2} = 6.31 * 10^{-8}$, $K_{a3} = 3.98 * 10^{-3}$).
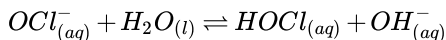
Answers

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a. The ions present are Na^+ and OCl^- as shown by the following reaction:

$$NaOCl_{(s)} \rightarrow Na^+_{(aq)} + OCl^-_{(aq)}$$
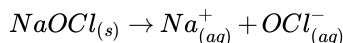
While Na^+ will not hydrolyze, OCl^- will (remember that it is the conjugate base of HOCl). It acts as a base, accepting a proton from water.

$$OCl^-_{(aq)} + H_2O_{(l)} \rightleftharpoons HOCl_{(aq)} + OH^-_{(aq)}$$

Na^+ is excluded from this reaction since it is a spectator ion.
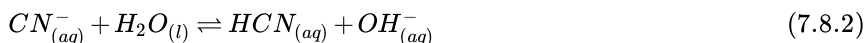
Therefore, with the production of OH^-, it will cause a basic solution and raise the pH above 7.

$$pH > 7$$

b. The $KCN_{(s)}$ will dissociate into $K^+_{(aq)}$ and $CN^-_{(aq)}$ by the following reaction:

$$KCN_{(s)} \rightarrow K^+_{(aq)} + CN^-_{(aq)} \tag{7.8.1}$$

K^+ will not hydrolyze, but the CN^- anion will attract an H^+ away from the water:

$$CN^-_{(aq)} + H_2O_{(l)} \rightleftharpoons HCN_{(aq)} + OH^-_{(aq)} \tag{7.8.2}$$

Because this reaction produces OH^-, the resulting solution will be basic and cause a pH>7.

$$pH > 7$$

c. The $NH_4NO_{3\,(s)}$ will dissociate into NH_4^+ and NO_3^- by the following reaction:

$$NH_4NO_{3(s)} \rightarrow NH^+_{4(aq)} + NO^-_{3(aq)} \tag{7.8.3}$$
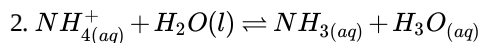
Now, NO_3^- won't attract an H^+ because it is usually from a strong acid. This means the K_b will be very small. However, NH_4^+ will lose an electron and act as an acid (NH_4^+ is the conjugate acid of NH_3) by the following reaction:

$$NH^+_{4(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + H_3O^+_{(aq)} \tag{7.8.4}$$
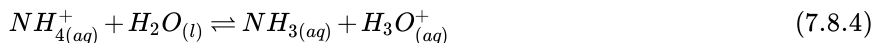
This reaction produces a hydronium ion, making the solution acidic, lowering the pH below 7.

$$pH < 7$$

2. $NH^+_{4(aq)} + H_2O(l) \rightleftharpoons NH_{3(aq)} + H_3O_{(aq)}$
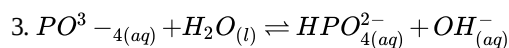
$$\frac{x^2}{0.2 - x} = \frac{1 * 10^{-14}}{1.8 \times 10^{-5}}$$

$$x = 1.05 * 10^-5 M = [H_3O^+]$$

$$pH = 4.98$$

3. $PO^3{}-_{4(aq)} + H_2O_{(l)} \rightleftharpoons HPO^{2-}_{4(aq)} + OH^-_{(aq)}$

The majority of the hydroxide ion will come from this first step. So only the first step will be completed here. To complete the other steps, follow the same manner of this calculation.

$$\frac{x^2}{0.2 - x} = \frac{1 * 10^-14}{3.98 \times 10{-13}} \tag{7.8.5}$$

$$x = 0.0594 = [OH^-] \tag{7.8.6}$$

$$pH = 12.77 \tag{7.8.7}$$

Practice Questions

1. Why does a salt containing a cation from a strong base and an anion from a weak acid form a basic solution?
2. Why does a salt containing a cation from a weak base and an anion from a strong acid form an acidic solution?
3. How do the K_a or K_b values help determine whether a weak acid or weak base will be the dominant driving force of a reaction?

The answers to these questions can be found in the attached files section at the bottom of the page.

References

1. Petrucci, Ralph H., William S. Harwood, F G. Herring, and Jeffry D. Madura. General Chemistry: Principles and Modern Applications. 9th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.
2. Timberlake, Karen C. Chemistry 101 Introductory Chemistry. 2nd ed. San Francisco: Pearson Education, 2007. Print.

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