Chemistry 132 NT

It is the mark of an instructed mind to rest satisfied with the degree of precision that the nature of a subject permits, and not to seek exactness where only an approximation of the truth is possible.

Aristotle

1

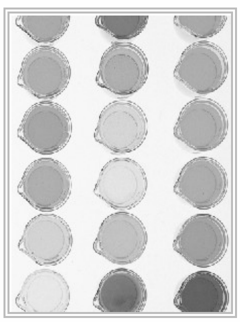
Chem 132 NT

Acids and Bases

Module 3

Self-Ionization of Water and pH

- **Self-Ionization of Water**
- **Solutions of Strong Acid or Base**
- **The pH of a Solution**



Acid-base indicator dye.

2

3

Review

- Conjugate acid-base pairs
- Acidic strength related to molecular structure

Self-ionization of Water

- **Self-ionization** is a reaction in which two like molecules react to give ions.
  - In the case of water, the following equilibrium is established.

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

  - The equilibrium-constant expression for this system is:

$$K_c = \frac{[H_3O^+][OH^-]}{[H_2O]^2}$$

Self-ionization of Water

- **Self-ionization** is a reaction in which two like molecules react to give ions.
  - The concentration of ions is extremely small, consequently the concentration of H_2O remains essentially constant. This gives:

$$\underbrace{[H_2O]^2 K_c}_{\text{constant}} = [H_3O^+][OH^-]$$

Self-ionization of Water

- **Self-ionization** is a reaction in which two like molecules react to give ions.
  - We call the equilibrium value for the ion product $[H_3O^+][OH^-]$ the **ion-product constant for water** which is written $\mathbf{K_w}$.

$$K_w = [H_3O^+][OH^-]$$

  - At 25 °C, the **value of K_w is 1.0×10^{-14}.**
  - Like any equilibrium constant, K_w varies with temperature.

7

Self-ionization of Water

- **Self-ionization** is a reaction in which two like molecules react to give ions.
  - Because we often write H_3O^+ as H^+, the ion-product constant expression for water can be written:

$$K_w = [H^+][OH^-]$$

  - Using K_w you can calculate the concentrations of H^+ and OH^- ions in pure water.

8

Self-ionization of Water

- These ions are produced in equal numbers in pure water, so if we let $x = [H^+] = [OH^-]$

$$1.0 \times 10^{-14} = (x)(x) \qquad \text{at } 25\,^{o}C$$

$$x = \sqrt{1.0 \times 10^{-14}} = 1.0 \times 10^{-7}$$

  - Thus, the concentrations of H+ and OH^- in pure water are both 1.0×10^{-7} M.
  - If you add acid or base to water they are no longer equal but the K_w expression still holds.

9

Solutions of Strong Acid or Base

- In a solution of a strong acid you can normally ignore the self-ionization of water as a source of H^+(aq).
  - The H^+(aq) concentration is usually determined by the strong acid concentration.
  - However, the self-ionization still exists and is responsible for a small concentration of OH^- ion.

10

Solutions of Strong Acid or Base

- As an example, calculate the concentration of OH^- ion in 0.10 M HCl.

  Because you started with 0.10 M HCl (a strong acid) the reaction will produce 0.10 M H^+(aq)

  HCl (aq) ® H^+ (aq) + Cl^- (aq)

  - Substituting $[H^+]$=0.10 into the ion-product expression, we get:

$$1.0 ´ 10^{-14} = (0.10)[OH^-]$$

11

Solutions of Strong Acid or Base

- As an example, calculate the concentration of OH^- ion in 0.10 M HCl.

  Because you started with 0.10 M HCl (a strong acid) the reaction will produce 0.10 M H^+(aq)

  HCl (aq) ® H^+ (aq) + Cl^- (aq)

  - Substituting $[H^+]$=0.10 into the ion-product expression, we get:

$$[OH^-] = \frac{1 ´ 10^{-14}}{0.10} = 1 ´ 10^{-13} M$$

Very very small

12

Solutions of Strong Acid or Base

- Similarly, in a solution of a strong base you can normally ignore the self-ionization of water as a source of $OH^-(aq)$.
  - The $OH^-(aq)$ concentration is usually determined by the strong base concentration.
  - However, the self-ionization still exists and is responsible for a small concentration of H^+ ion.

13

Solutions of Strong Acid or Base

- As an example, calculate the concentration of H^+ ion in 0.010 M NaOH.

  Because you started with 0.010 M NaOH (a strong base) the reaction will produce 0.010 M $OH^-(aq)$

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

  - Substituting $[OH^-]$=0.010 into the ion-product expression, we get:

$$1.0 \times 10^{-14} = [H^+](0.010)$$

14

Solutions of Strong Acid or Base

- As an example, calculate the concentration of H^+ ion in 0.010 M NaOH.

  Because you started with 0.010 M NaOH (a strong base) the reaction will produce 0.010 M $OH^-(aq)$

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

  - Substituting $[OH^-]$=0.010 into the ion-product expression, we get:

$$[H^+] = \frac{1 \times 10^{-14}}{0.010} = 1 \times 10^{-12} M$$

Very very small

15

Solutions of Strong Acid or Base

- By dissolving substances in water, you can alter the concentrations of $H^+(aq)$ and $OH^-(aq)$.
  - In a **neutral solution**, the concentrations of $H^+(aq)$ and $OH^-(aq)$ are **equal**, as they are in pure water.
  - In an **acidic** solution, the concentration of $H^+(aq)$ is far greater than that of $OH^-(aq)$.
  - In a **basic** solution, the concentration of $OH^-(aq)$ is far greater than that of $H^+(aq)$.

16

Solutions of Strong Acid or Base

- At 25 °C, you observe the following conditions.
  - In an acidic solution, $[H^+] > 1.0 \times 10^{-7}$ M.
  - In a neutral solution, $[H^+] = 1.0 \times 10^{-7}$ M.
  - In a basic solution, $[H^+] < 1.0 \times 10^{-7}$ M.

17

The pH of a Solution

- Although you can quantitatively describe the acidity of a solution by its $[H^+]$, it is often more convenient to give acidity in terms of pH.
  - The **pH** of a solution is defined as the negative logarithm of the molar hydrogen-ion concentration.

$$pH = -\log[H^+]$$

18

The pH of a Solution

- For a solution in which the hydrogen-ion concentration is 1.0×10^{-3}, the pH is:

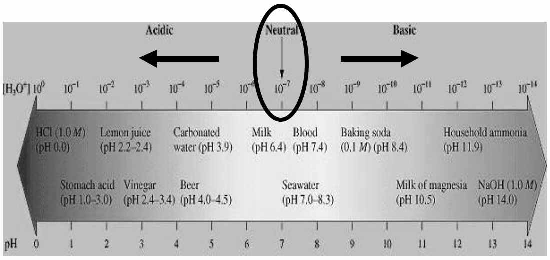
$$\mathrm{pH} = -\log(1.0 \times 10^{-3}) = 3.00$$

  - Note that the number of decimal places in the pH equals the number of significant figures in the hydrogen-ion concentration.

The pH of a Solution

- In a **neutral solution**, whose hydrogen-ion concentration is 1.0×10^{-7}, the **pH = 7.00.**
- For **acidic solutions**, the hydrogen-ion concentration is greater than 1.0×10^{-7}, so the **pH is less than 7.00.**
- Similarly, a **basic solution** has a **pH greater than 7.00.**
- The next slide shows a diagram of the pH scale and the pH values of some common solutions.

The pH Scale



A Problem To Consider

- A sample of orange juice has a hydrogen-ion concentration of 2.9×10^{-4} M. What is the pH?

$$pH = -\log[H^+]$$

$$pH = -\log(2.9 \times 10^{-4})$$

$$pH = 3.54$$

22

A Problem To Consider

- The pH of human arterial blood is 7.40. What is the hydrogen-ion concentration?

$$[H^+] = \text{anti}\log(-pH)$$

$$[H^+] = \text{anti}\log(-7.40)$$

$$[H^+] = 10^{-7.40} = 4.0 \times 10^{-8}\,M$$

23

The pH of a Solution

- A measurement of the hydroxide ion concentration, similar to pH, is the pOH.
  - The **pOH** of a solution is defined as the negative logarithm of the molar hydroxide-ion concentration.

$$pOH = -\log[OH^-]$$

24

The pH of a Solution

- A measurement of the hydroxide ion concentration, similar to pH, is the pOH.
  - Then because $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25 ^oC, you can show that

$$pH + pOH = 14.00$$

25

A Problem To Consider

- An ammonia solution of has a hydroxide-ion concentration of 1.9×10^{-3} M. What is the pH of the solution?

You first calculate the pOH

$$pOH = -\log(1.9 \times 10^{-3}) = 2.72$$

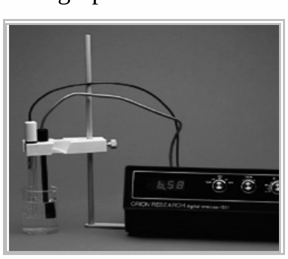
Then the pH is:

$$pH = 14.00 - 2.72 = 11.28$$

26

The pH of a Solution

- The pH of a solution can accurately be measured using a pH meter

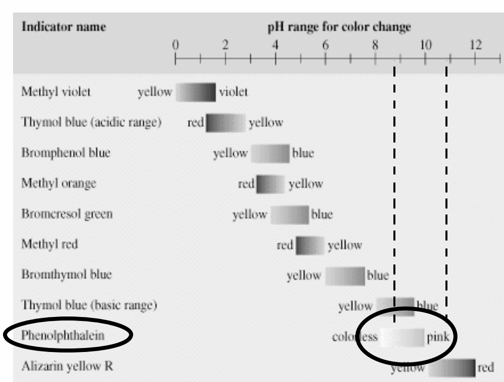


27

The pH of a Solution

- Although less precise, acid-base indicators are often used to measure pH because they usually change color with in a narrow pH range.
  - The next slide shows the color changes of various acid-base indicators.

28



29

Operational Skills

- Identifying acid and base species
- Identifying Lewis acid and base species
- Deciding whether reactants or products are favored in an acid-base reaction
- Calculating the concentration of H^+ and OH^- in solutions of strong acid or base
- Calculating the pH from the hydrogen-ion concentration, or vice versa.

30

Key Equations

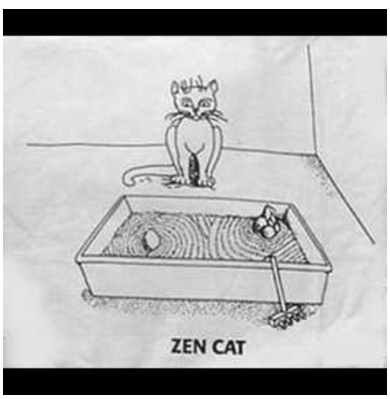
$K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ at 25°C

$pH = -\log[H_3O^+]$

$pH + pOH = 14.00$

Time for a few review questions.

31



32