Lesson 34 Describing Acid-Base Solutions

Key Words

related acid-base pair: acid and base that differ by one proton

K_a: ionization constant of an acid; it shows the relative strength of acids

pH: scale that shows the concentration of H_3O^+

KEY IDEAS

In acid-base reactions, protons—H^+—move from one substance to another. Not all acids and bases lose or gain protons to the same degree. The extent of proton transfer determines acid or base strength. A pH number describes the concentration of hydrogen ions—H^+—or hydronium ions—H_3O^+.

Human blood is a slightly basic solution with a pH of about 7.4. Changes in the pH of the blood may occur when the body does not function properly. If the pH rises to near 8.0 or drops to below 6.8, the result can be fatal.

Proton Transfer. Recall that an acid is a proton donor. The proton, or H^+, is accepted by a base, which is a proton acceptor. For example, in a reaction between H_2SO_4 and H_2O, a proton moves from the H_2SO_4 to the H_2O, forming H_3O^+ and HSO_4^-.

Equation 1 $$\underset{\text{acid}}{H_2SO_4} + \underset{\text{base}}{H_2O} \longrightarrow H_3O^+ + HSO_4^-$$

The H_2SO_4 is the acid because it donates a proton—H^+. The H_2O is the base because it gains a proton—H^+. As a result of the H_2O gaining a proton, H_3O^+ is formed.

The reverse of this reaction can also occur. In this case, a proton moves from the H_3O^+ to the HSO_4^-, forming H_2O and H_2SO_4.

Equation 2 $$\underset{\text{acid}}{H_3O^+} + \underset{\text{base}}{HSO_4^-} \longrightarrow H_2SO_4 + H_2O$$

The H_3O^+ is an acid because it donates a proton—H^+—to the HSO_4^-. The HSO_4^- is the base because it gains a proton—H^+—from the H_3O^+.

When the products of a chemical reaction react to reform the reactants, the reaction is called a reversible reaction. Equation 3 combines Equation 1 with Equation 2 as one equation, showing a reversible reaction.

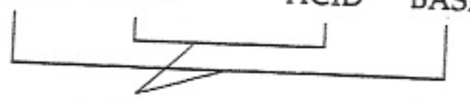
Equation 3 $$\underset{\text{acid}}{H_2SO_4} + \underset{\text{base}}{H_2O} \rightleftharpoons \underset{\text{acid}}{H_3O^+} + \underset{\text{base}}{HSO_4^-}$$

Acid-base Pairs. The H_2SO_4 became HSO_4^- when it lost, or donated, a proton. After an acid has donated a proton, the substance remaining is a base. This base forms a related pair with that acid. So H_2SO_4 and HSO_4^- are a **related acid-base pair.** The acid and base in this pair differ by only one proton.

The H_2O became H_3O^+ when it gained, or accepted, a proton. After a base has accepted a proton, the substance remaining is an acid. This acid forms a related pair with that base. So H_3O^+ and H_2O are a related acid-base pair. The acid and base in this pair differ by only one proton. Study Fig. 34-1, which shows acid-base pairs for the reaction in Equation 3.

Fig. 34-1

$$\underset{\text{ACID}}{H_2SO_4} + \underset{\text{BASE}}{H_2O} \rightleftharpoons \underset{\text{ACID}}{H_3O^+}\quad \underset{\text{BASE}}{HSO_4^-}$$



acid/base pairs

1. On the lines under each substance in the equation, write the word *acid* or *base* to identify the substance.

$$HCl \quad + \quad H_2O \quad \rightleftharpoons \quad H_3O^+ \quad + \quad Cl^-$$

(a) _____ (b) _____ (c) _____ (d) _____

2. The related acid-base pairs in Equation 2 are

(a) ____________________ and (b) ____________________.

Substances That Act As Acids or Bases. Some substances can act as either an acid or a base. When in the presence of an acid, such a substance acts as a base. When in the presence of a strong base, however, the same substance acts as an acid.

Water is an example of such a substance. When water donates a proton to NH_3, which is a strong base, the water is an acid.

Equation 4 $$\underset{\text{acid}}{H_2O} + \underset{\text{base}}{NH_3} \longrightarrow NH_4^+ + OH^-$$

When water accepts a proton from HCl, which is an acid, the water is a base.

Equation 5 $$\underset{\text{acid}}{HCl} + \underset{\text{base}}{H_2O} \longrightarrow H_3O^+ + Cl^-$$

Water ionizes only slightly. When this happens, one water molecule donates a proton to another water molecule. Water, therefore, acts as both acid and base.

Equation 6 $$\underset{\text{acid}}{H_2O} + \underset{\text{base}}{H_2O} \rightleftharpoons H_3O^+ + OH^-$$

3. What is one substance with which water acts as an acid? What is a substance with which water acts as a base?

(a) ________________ and (b) ________________.

Ionization Constants. An ionization constant, K_a, is used to compare the relative strengths of acids. To compute K_a for an acid, the concentration of the ions is divided by the concentration of the acid. A strong acid yields a large concentration of ions. A weak acid produces few ions in comparison to the number of acid molecules. So the K_a values of strong acids are larger than the K_a values of weak acids.

The chart in Fig. 34-2 lists some acids, the bases with which they form related pairs, and K_a values. The strong acids are at the top of the chart. Compare phosphoric acid—H_3PO_4—with acetic acid CH_3COOH. Phosphoric acid is the stronger acid and is higher on the chart. Also compare the K_a values of the two acids. The K_a of H_3PO_4 is 7.5×10^{-3}. This K_a is larger than the 1.8×10^{-5} value for CH_3COOH. A larger K_a means more ions and a stronger acid.

Fig. 34-2

Strengths of Acids

Related acid-based pairs: ACID				BASE	K_a
HCl	=	H^+	+	Cl^-	large
HNO_3	=	H^+	+	NO_3^-	large
H_2SO_4	=	H^+	+	HSO_4^-	large
HSO_4^-	=	H^+	+	SO_4^{2-}	1.2×10^{-2}
H_3PO_4	=	H^+	+	$H_2PO_4^-$	7.5×10^{-3}
HNO_2	=	H^+	+	NO_2^-	4.6×10^{-4}
HF	=	H^+	+	F^-	3.5×10^{-4}
CH_3COOH	=	H^+	+	CH_3COO^-	1.8×10^{-5}
H_2CO_3	=	H^+	+	HCO_3^-	4.3×10^{-7}
HSO_3^-	=	H^+	+	SO_3^{2-}	1.1×10^{-7}
H_2S	=	H^+	+	HS^-	9.5×10^{-8}
$H_2PO_4^-$	=	H^+	+	HPO_4^{2-}	6.2×10^{-8}
NH_4^+	=	H^+	+	NH_3	5.7×10^{-10}
HCO_3^-	=	H^+	+	CO_3^{2-}	5.6×10^{-11}
HPO_4^{2-}	=	H^+	+	PO_4^{3-}	2.2×10^{-13}
HS^-	=	H^+	+	S^{2-}	1.3×10^{-14}
H_2O	=	H^+	+	OH^-	1.0×10^{-14}

4. **Compare HF with H_2S. Which acid is stronger? _________________.**

Acidity as pH. The acidity of solutions can be stated in terms of **pH.** Neutral solutions have a pH value of 7. Acidic solutions have pH values less than 7. Basic solutions have values greater than 7.

pH < 7 Acidic Solution
pH = 7 Neutral Solution
pH > 7 Basic Solution

Mathematically pH is the negative logarithm, to the base 10, of the concentration of the hydronium ion—H_3O^+. Brackets [ ] around a formula mean concentration in moles/liter.

Equation 7

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

When water ionizes, hydronium—H_3O^+—and hydroxide—OH^-—ions are formed. K_w stands for the ionization constant of water. It has a value of 1.0×10^{-14}.

Equation 8

$$K_w = [H_3O^+]\,[OH^-] = 1.0 \times 10^{-14}$$

In pure water, $[H_3O^+] = [OH^-] = 1.0 \times 10^{-14}$. Therefore, the $[H_3O^+]$ and the $[OH^-]$ must both be 1×10^{-7} because $(1 \times 10^{-7})(1 \times 10^{-7}) = (1 \times 10^{-14})$.

Substituting the concentration of 1×10^{-7} into Equation 7, you can calculate the pH of water as 7.00.

The pH of a solution can be easily found with a calculator. Use your calculator and the following procedure shown in Fig. 34-3.

Fig. 34-3

1. Enter 1.0 Exp -7 2. Then push (1/x) 3. Then push (Log)

Repeat the procedure to find the pH of a 0.1 M HCl solution. See Fig 34-4.

Fig. 34-4

1. Enter 0.1 2. Then push (1/x) 3. Then push (Log) Answer is pH = 1.00

You can estimate pH using the system shown in Fig 34-5.

Fig. 34-5

1.0×10^{-3}

If this number is exactly 1, then this number is the pH

5. (a) What is the pH of a solution with $[H_3O^+] = 1.0 \times 10^{-12}$? ____________
   (b) Is this solution an acid or a base? ____________

TAKE ANOTHER LOOK

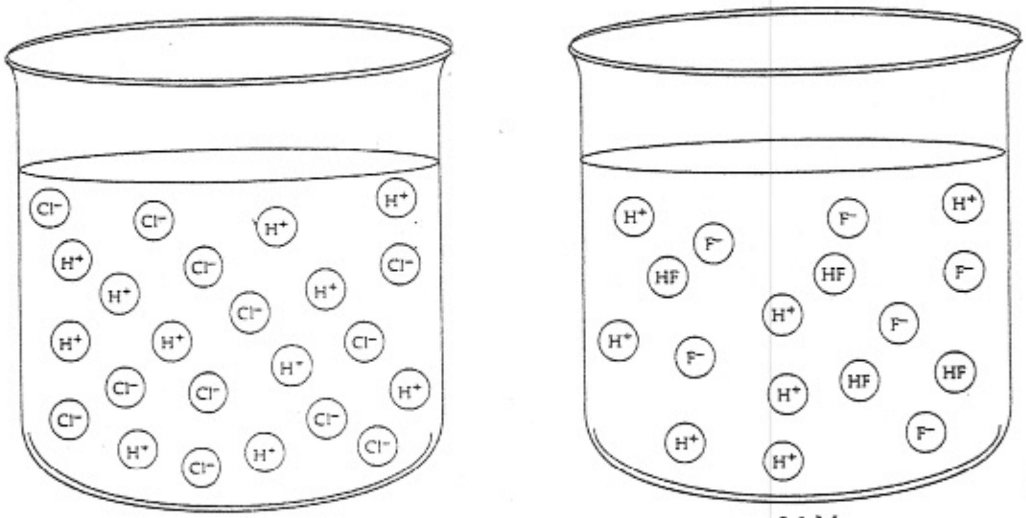
The scale in Fig. 34-6 shows $[H_3O^+]$ and pH. On this scale, you can see that a solution with $[H_3O^+] = 1 \times 10^{-7}$ has a pH of 7 and is neutral. Acidic solutions have a pH less than 7. Basic solutions have a pH greater than 7.

Fig. 34-6

$[H_3O^+]$	1×10^{0}	1×10^{-1}	1×10^{-2}	1×10^{-3}	1×10^{-4}	1×10^{-5}	1×10^{-6}	1×10^{-7}	1×10^{-8}	1×10^{-9}	1×10^{-10}	1×10^{-11}	1×10^{-12}	1×10^{-13}	1×10^{-14}
pH	0	1	2	3	4	5	6	7 Neutral	8	9	10	11	12	13	14

Fig. 34-7 compares a strong acid and a weaker acid. The strong acid—HCl— produces many ions in solution. The weaker acid— HF—produces fewer ions.

Fig. 34-7



0.1 M HCl

0.1 M HF

Remember that pH is based upon the concentration of the hydronium (or hydrogen) ion. Low pH numbers mean a high hydronium (or hydrogen) ion concentration and a solution that is acidic. High pH numbers mean that many hydroxide ions are present and the solution is basic.

Check Your Understanding

Use the key terms from the beginning of this lesson to fill in the blanks.

6. An acid and a base that differ by only one proton are called ________.

7. Relative strengths of acids are compared using ________.

8. The concentration of H_3O^+ in solution is expressed in terms of ________.

What Do You Know?

Circle the correct term.

9. The ionization constant, K_a, for acetic acid—CH_3COOH—is
   a. 1.2×10^{-2}.   b. 3.5×10^{-4}.   c. 1.8×10^{-5}.   d. 5.6×10^{-11}.

10. A sample of water contains
    a. equal concentrations of H_3O^+ and OH^-.
    b. greater concentrations of H_3O^+ than OH^-.
    c. lower concentrations of H_3O^+ than OH^-.
    d. no H_3O+ or OH^-.

11. In the reaction $H_2O + H_2O \rightarrow H_3O^+ + OH^-$, the water is acting as
    a. both an electron receiver and an electron donor.
    b. neither an electron receiver nor an electron donor.
    c. neither a proton donor nor a proton accepter.
    d. both a proton donor and a proton acceptor.

12. In the reaction $H_2S + H_2O \rightarrow H_3O^+ + HS^-$, a related acid base pair is
    a. H_2S and H_2O.
    b. H_2O and H_3O^+.
    c. H_3O^+ and HS^-.
    d. H_2O and HS^-.

13. What is the pH of a solution if the $[H_3O^+]$ is 1×10^{-8}?
    a. 1   b. 6   c. 8   d. 14

14. Pure water has a pH of
    a. 1×10^{-7}.   b. 7.   c. 1.   d. 1×10^{-14}.